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Table of contents

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LIST OF ABBREVIATIONS

AGC	Automatic Generation Control
AS	Ancillary Services
BS	Black Start
CR	Contingency Reserve
DS	Distribution system
DSO	Distribution System Operator
ENTSO-E	European Network of Transmission System Operators for Electricity
FCR	Frequency Containment Reserve
FFR	Fast Frequency Response
FoR studies	The All Island TSO Facilitation of Renewable Studies (Eirgrid and SONI)
FRR	Frequency Restoration Reserve
FRT	Fault Ride-through
HV	High Voltage
HVDC	High Voltage Direct Current
LFSM	Limited Frequency sensitive mode
MV	Medium Voltage
NC	Network Code, also may be called as grid code
NC RfG	ENTSO-E Network Code for Requirements for Grid Connection Applicable to all Generators
RoCoF	Rate of Change of Frequency
RR	Replacement Reserve
SS	System Services
TS	Transmission system
TSO	Transmission System Operator

SUMMARY

Ancillary services are grid support services required by the power systems (transmission or distribution system operators TSOs or DSOs) to maintain integrity, stability and power quality or the power system (transmission or distribution system). Ancillary services can be provided by connected generators, controllable loads and/or network devices. Some services are set as requirements in Grid Codes and some services are procured as needed by TSOs and DSOs to keep the frequency and voltage of the power system within operational limits or to recover the system in case of disturbance or failure.

There are different procurement and remuneration practices for Ancillary services, and these practices are evolving. There are already markets for some services. Some services are mandatory (not necessarily paid for) and some services are subject to payments according to regulated (tariff) pricing or tendering process and competitive pricing.

It is foreseeable that also variable renewable generators, like wind and solar, will provide ancillary services. This is needed from power system point of view in times of high wind and solar production when conventional generators are at low level. From renewable generators point of view providing ancillary services may add to their incomes in future.

In this report, different ancillary services are described and a table listing main services is presented. While Chapter 2 is describing the services from (renewable) generators point of view, Chapter 3 is considering future system needs for services with increased wind and solar penetration. The table will be used as a starting point in the REServiceS project to see how much these services would cost when provided from wind/PV (WP3/4), and how often these services would be used in systems with higher penetrations of wind and solar (WP5/6).

The main categories of frequency support, voltage support and restoration services were selected as starting point for the table.

Main impacts of non-dispatchable renewables are due to increased variability and uncertainty that will result in more balancing needs and impact frequency and voltage control. Another important aspect is that during high wind and sunny hours, less conventional units will be online to provide frequency support and inertia (as well as voltage support and congestion management). Experience and study results so far show that the electrical impacts of variable renewables are depending on local power system characteristics and on network voltage levels. Solutions for frequency control and in particular cases also for voltage management are very often of cross border nature. There is experience from significant wind penetration levels from Denmark since year 2000 when wind power exceeded 10 % share of domestic electricity consumption, and since several years from Spain, Portugal, Ireland and Germany. The first experiences from PV integration emerge from Germany and Italy. However, there have been other changes in frequency and voltage control also, making it difficult to get direct information about how much the needs for frequency and voltage support have actually increased due to additions of wind and solar power.

The main services in use today are voltage control and frequency control with different time scales (the division proposed by ENTSO-E has been chosen) and black start for system restoration. New services to reflect future needs are fast frequency response and ramping margin for frequency support; fast reactive current injection during voltage dips and for post fault voltage control; and islanding services related to restoration (Table). The report lists current procurement practices and prices for several European countries, as well as more detailed technical description of services reflecting the recently proposed

ENTSO-E Network Code NC RfG as well as some illustrative examples from Grid Codes in countries.

Frequency support	Voltage support	System restoration
Frequency Containment Reserve FCR (<5, 10 or 30 sec) Frequency Restoration Reserve FRR (<15 min) Replacement Reserve RR (15 min to hours)	Normal Operation: control of power factor, reactive power or voltage	Black start
Fast frequency response (synthetic inertia) (< 2s) Ramping margin (1, 3, 8 hours ahead)	Fast reactive current injection	Islanding

The cost structure for ancillary services chosen lists the possible costs in three categories: cost for ability/capability (investment), readiness (cost for capacity reserved, opportunity cost loosing energy that cannot be sold) and utilisation (actual provision of the services). (Table below)

Ability / capability	Readiness / holding / availability	Utilisation / response
• investment cost related to providing the capability	• cost for capacity reserved, opportunity cost loosing energy that cannot be sold • link to other markets	• actual provision of the service, like energy as used with fuel cost • increased maintenance costs (wear and tear)

There can be additional costs from offering a service, related to compliance and testing of the service quality, as well as from communication costs to monitor responses. TSOs and DSOs will evaluate the performance of Ancillary service providers in relation to declared availability and contracted provisioning.

The findings are based on surveying different ancillary services, their procurement and pricing, and the system needs of services in future with higher levels of renewables. Especially regarding quantified results on how renewables impact system needs for ancillary services and costs for services from conventional generators, the information we could obtain from literature and from system operators is still limited. Findings from on-going work in Ireland regarding costs for services from different generators are not yet included in this report and will be considered in the project as soon as the results become available. Regarding wind and solar PV, and especially their combined impacts on system needs, the task of making a full estimate is challenging. System services are there for the whole power system and quantified impacts from specifically selected types of generation are difficult to extract. This report summarises the findings so far in tables, for different penetration levels of wind and solar, that can be used as a starting point in WP5/6 when estimating the impacts.

1. INTRODUCTION

Transmission system operators (TSOs) and distribution system operators (DSOs) need a variety of system services for a secure and reliable operation of the electrical power system (system needs). Generators (and flexible loads, and in some cases network connected devices) can provide these, so called, ancillary services (AS). Some services are set as requirements in Grid Codes and some services are procured as needed by TSOs and DSOs to keep the frequency and voltage of the power system within operational limits or to recover the system in case of disturbance or failure.

Variable generation (predominantly wind and solar power generation) will impact the system needs, but can also provide ancillary services. The variability and uncertainty in power systems will increase with increasing levels of variable generation. This will increase some system needs. As variable generation replaces conventional generation from the system, at some point they should also take part in providing ancillary services for operational, economic and security reasons. Moreover supply of ancillary services may provide an additional revenue stream for renewable generators – and may in the future result in penalties for those not delivering. This will apply to both high voltage transmission system level connected larger renewable power plants, and distributed generation connected in distribution networks.

This report is a compilation of Work Package 2 (WP2) findings, looking at the different ancillary services. It provides an overview of system needs for ancillary services as well as the general impacts that variable renewables will have on these needs, based on a literature study. The various cost elements for ancillary services (for example, operation and capacity reservation) are listed for different types of services. Differences in the current practices in different countries are presented. Existing integration studies (mostly wind) are reviewed to build an overview of needs for services for different RES penetration levels, for different systems and for different ancillary services. This report covers all ancillary services from the generator point of view that are critical in systems with high share of variable renewables: voltage, frequency, and restoration services, both at transmission and distribution system level. The analysis of the costs for providing AS from conventional generation will be a separate document.

This report sets the framework for common approaches and definitions in the REserviceS project, more specifically for the analyses of wind power and solar PV and their capabilities and costs for providing services in future EU transmission and distribution systems. The separate deliverable D2.1 pulls together the results from this report to form the basis for the work in the REserviceS WPs 3 and 4.

1.1. Objectives

WP2 provides structure to the analysis part of the REserviceS project providing three main outcomes:

In particular we may expect that:

- <u>A set of uniform definitions (types of reserves, services and costs).</u> Power systems all have different terminology for ancillary services. Each power system is unique with its particular aspects that set the boundaries for requirements of system services. There is currently collaboration between TSOs within ENTSO-E and efforts to convert to similar terminology. However, there are still varying practices in different member countries, and the different synchronous systems in Europe. This report adopts a uniform terminology for the project partners and WPs in

REserviceS. Current practices (generic options) are listed based on the approaches developed for different grid codes and ancillary services practices in Europe and specific issues at pan-European level are highlighted (for example related to cross-border trading of the service such as capacity allocation for cross-border primary reserve etc.). Approaches for quantification and modelling of ancillary services were also studied (physical and cost). Cost models include costs for ability, readiness and actual provision of the services. Market prices for ancillary services were collected. This was performed where possible in consultation with the European system operators (mainly through the ENTSO-E WG on Ancillary Services).

- Definition of the most relevant ancillary services for different RES penetration levels. There is no existing publication or study that gives the whole picture regarding the need for system services from the power system point of view for all different services, different systems, and different RES penetration levels. In WP2 existing information was gathered, and a consensus was formed on which services will become important at low, medium and high penetration levels of wind and solar PV, for different systems in Europe.

- Cost data for conventional generators for providing the ancillary services in the study. To be able to compare the ancillary services from conventional and renewable generators and to study their use in different system operational states, this report presents an overview of the ancillary service provision costs from different conventional generators, based on existing data, including prices from ancillary service markets.

Outcomes of WP2 are basic approaches for assessing costs for ancillary services (D2.1, for input to WP3 and 4) and costs from conventional generation ancillary services (D2.3, for input to WP5 and 6).

2. ANCILLARY SERVICES

This chapter presents introduction and definitions of ancillary services and existing categorisation of services by EURELECTRIC, ENTSO-E and CIGRE. Based on these, the selected ancillary service classes for this project are chosen.

2.1. Background and definitions

Controlling both frequency and voltage has always been a critical task in operating an electrical power system. Following the liberalisation of the electricity sector, the System Operator (SO) obtains these grid support services from other participants in the power system. Since the liberalisation process has progressed independently in different regions and each power system has its own specific characteristics, technical definitions for these services vary considerably. Ancillary services have been defined differently, depending on the electrical system and on the regulatory framework in which they are implemented.

Definition for ancillary and system services: We use here the definitions from (EURELECTRIC, 2004):

- Ancillary services are all grid support services required by the transmission or distribution system operator to maintain the integrity and stability of the transmission or distribution system as well as the power quality. These needs can be fulfilled by connected generators, controllable loads and/or network devices.
- System services contain all services provided by a system (or a network) operator to users connected to the system.
- Ancillary services are provided from users to system operators, and system services from operators to all users.

The system operator (SO) manages the ancillary services by obtaining contributions ("elementary" ancillary services) from service producers (some of which follow from regulatory or contract obligations); carrying out the technical management of the system, while making sure there is a suitable level of security; adding its own share (implementation of controls, load dispatching function) and thus elaborates the final system services.

Ancillary services are related to capabilities of generators and loads to deliver specific performances (responses etc.) in the point of connection to the network. Under the different groups of ancillary services (like frequency, voltage, etc.) there are different ancillary service products that generators can deliver to network operators to assist network operation and management. In this report we use the term ancillary services in a generic way; the detailed products will be dealt with in the next stages of the REserviceS project.

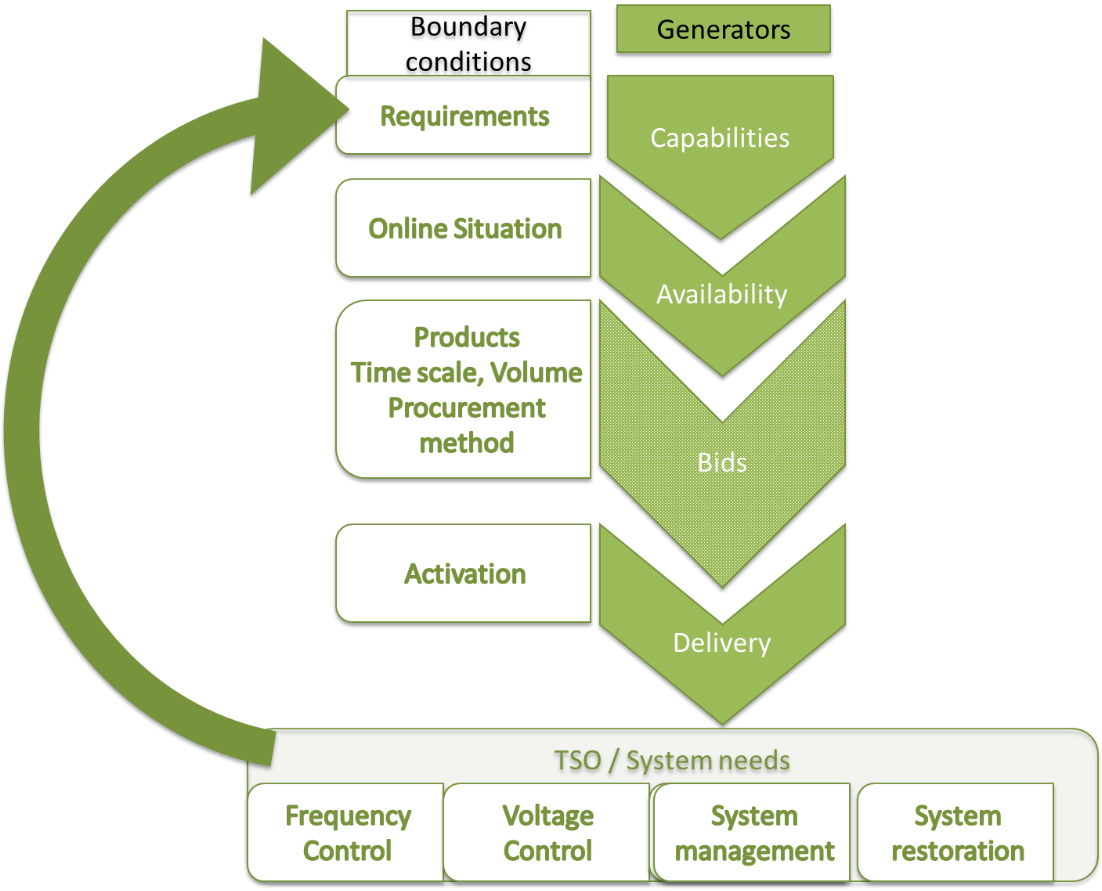

Figure 1: Delivering ancillary services from generators. The requirements from system operator (TSO) define the capabilities that generator must have. This is the basis for providing services. The online situation will determine whether the generator is available to provide a service. A specific ancillary service product will define how and when the service can be offered in practice. Depending on the situation, or when the bid is accepted, TSOs will ask to activate the service.

<u>Payments for services</u>: Ancillary services include both mandatory services (not necessarily paid for) and services subject to payments according to regulated (tariff) pricing or tendering process and competitive pricing. For example providing voltage support and (reactive) power in Fault-Ride-Through circumstances, is not remunerated but required as mandatory from generators when connecting to the grid (Grid Code). Some services, like voltage control and automatic frequency control, are often paid for as negotiated or tendered contracts, or according to regulated prices (EURELECTRIC, 2000; Cigre, 2010). Also mandatory services can be paid according to a tariff. Payments can have a fixed part and a part that is only paid when the service is called for and used. Some services, like balancing energy activated in 10-15 minutes, can be procured and paid through markets. Markets for ancillary services are relatively new. In future more services could be procured on the market, or remunerated when called even if they are now requirements provided without payments. Generators bear a cost from providing a service depending on the generator type. Usually the costs consist of a capital cost component as well as a component related to the operation (provision of the service). Furthermore it can entail an opportunity cost of energy not being sold to energy markets. The price paid for the service should cover any extra cost incurred. In order to allow these services to be delivered also by other sources than conventional power production units, the contracting procedures might need adaptation.

Ancillary services at TSO/DSO level: Services can be procured by TSO or DSO and delivered by generators at transmission level (to a TSO) or distribution level (to a DSO or TSO). Some services available at transmission level are not currently used at distribution level. Not all services are even relevant to be delivered from generation connected at distribution level. However, it is possible that these will be required or offered in future, due to increased system needs, increasing share of decentralised generation (also reducing the possibility to rely exclusively on large generation) and possible connection and reinforcement cost optimisation at distribution level. The means and costs for the ancillary services at distribution and transmission level can also vary.

Services currently used and need for new ones: In addition to new ways of contracting services, in future new services might be required. A list of currently available and proven ancillary services is the starting point for the categories proposed in this report, but potential future services are also listed where relevant.

Cross-border: Frequency management has the most significant and clear cross-border character, as frequency is a global measure of the synchronous power system. However, the frequency associated services are not always procured cross-border. For instance, the need for automatic primary frequency reserve is determined at European level and the responsibility to procure it is then allocated at national level, whereas the secondary reserves are managed at national level and coordinated through control zone exchange balance. Voltage management services are not by nature cross-border. However, they become cross-border for example as a part of defence plan against large voltage collapse managed by system operators. Services related to voltage control are always tradable against network development and/or relocation of generation/consumption.

Ancillary services and requirements in Grid Codes: Requirements for capabilities for generators, and demand appliances are presented in grid codes, or network codes as they are called at ENTSO-E. These capabilities can be used to provide a service and are regarded as essential for enabling delivery of sufficient services for the system. The capabilities are usually not available all the time but depend on whether the generator is on-line and generating at a level where a service can be provided. The services are usually only called upon when needed – some services are used during normal operation (continuous) and some services are provided for abnormal/emergency situations (event driven). Network Codes only deal with constructive capabilities of generators/appliances, with no prejudice for future actual use. The cost of the capabilities is a potentially important driver in the development of the market for AS.

Grid codes also specify the conditions (voltage and frequency ranges) when the generator needs to stay connected. In the ENTSO-E Network Code (NC) Requirements for Grid Connection Applicable to all Generators (RfG), like in national codes, not all generators (called Power Generating Modules or PGM) are required to have all the capabilities. The requirements in NC RfG are distinguished into:

- General requirements (for all types of PGM): also including requirements relevant for wind and solar PV;
- Specific requirements for Power Park Modules (PPM): specifically relevant for wind and solar PV;
- Specific requirements for AC connected offshore PPM: (requirements for HVDC connected offshore PPM still to be drafted in a different NC document);
- Specific requirements for synchronous PGM (in general not relevant for wind and solar PV);

Furthermore, the ENTSO-E NC RfG applies a classification system for generators according to their impact on the system and classifies the generators as Type A, B, C and D. This classification looks both to the size (capacity) of the PGM and to the voltage level of connection (below or above 110 kV). The requirements in the NC are classified according to these types. The capacity thresholds for categorising the generators differ for the synchronous areas in Europe. In general, the requirements for capabilities are increasing with the type of generator.

Table 1: Types of generators from ENTSO-E NC RfG.

	Type A	Type B	Type C	Type D
Connection point	< 110 kV	< 110 kV	< 110 kV	>110 kV
Lower capacity threshold*	0.8 kW	0.1 – 1.5 MW	5 – 50 MW	15 – 75 MW
Upper capacity threshold*	0.1 – 1.5 MW	5 – 50 MW	15 – 75 MW	No limit
General functionality required for system operation (ref Entso-E NC RfG).	Logic interface for disconnecting. Remote operation requirement by the network operator.	Controllable in steps smaller than 20% of capacity. Remote operation requirement by the network operator. TSO decides about reconnecting after a network disturbance.	Automatic set-point control (plus manually if needed). May be required to provide inertia — also equivalent performance if not inherent.	Specific for higher voltage connected generation to allow stable operation of the interconnected network.

*Range for capacity depends on synchronous area in Europe (see ref. NC RfG)

2.2. Ancillary service categories

From studying the literature and discussions with system operators, it appears that there is no uniform or “standardised” categorisation of ancillary services. This paragraph gives a brief overview of some sources (EURELECTRIC, CIGRE, ENTSO-E). From there, it proposes a categorisation that can be further used in the project, with the aim of keeping the categories clear and simple, but to cover the most important ancillary services from the point of renewable generators.

The categories are mainly looked at from the Transmission system point of view. Currently, distribution systems mainly take part in voltage control. In the future, however, there will be more possibilities, and needs, for the distribution system connected generators to provide ancillary services, too.

2.2.1. Ancillary service categories according to EURELECTRIC

EURELECTRIC divides ancillary services in categories for maintaining frequency, voltage, stability, and restarting the system. In this approach, the services that are used for stability and frequency purposes overlap as can be seen in Figure 2. However for a simpler categorisation purpose the additional 'stability' category does not seem to be useful.

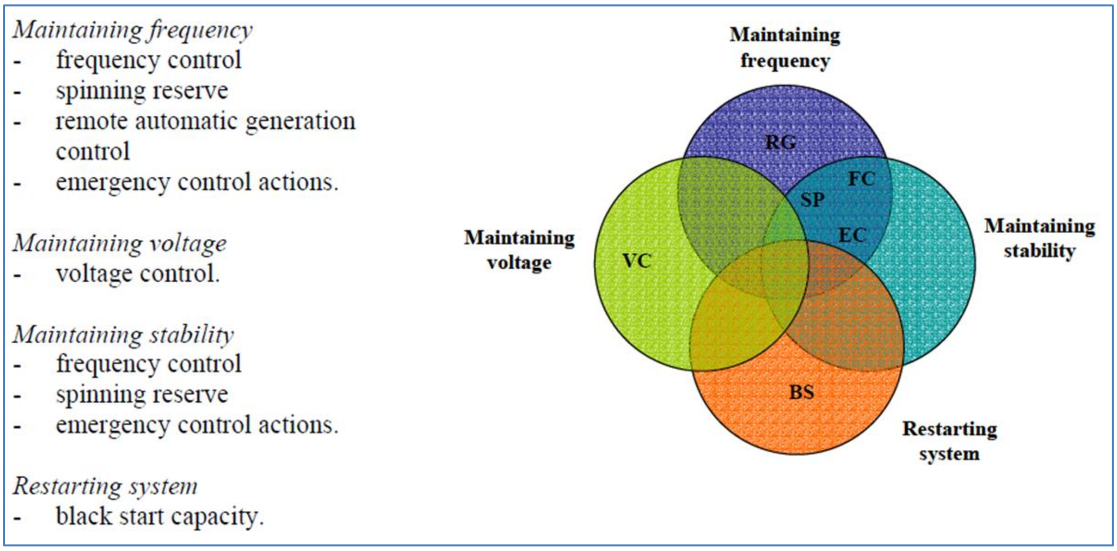

Figure 2: Ancillary services categories from EURELECTRIC, 2004

Ancillary services can also be grouped based on their relation to the system state in which they are used. Under Normal operation we find frequency and voltage control, remote automatic generation control and grid loss compensation. Failure prevention includes spinning reserve, standing reserve and emergency control action. System restoration means using black start capability.

EURELECTRIC did not look into the distribution level. Voltage control is partially directed by DSOs and they manage the sources connected to their network.

2.2.2. Other ancillary services categorization

The CIGRE report on international practices on Ancillary services has categories for Frequency control, Network control (containing also parts that are not ancillary services), Voltage control and Black Start. There is further classification into instantaneous, continuous and event driven services.

Table 2: Ancillary services categories from CIGRE, 2010

Primary Freq Control	**Secondary Frequency Control**			**Secondary Network Control**		**Tertiary Network Control**	**Voltage Control**	**Black Start**
	Load Freq Control (regu-lation)	Contin-gency Reserves Spinning	Contin-gency Reserves Non spinning	Load Following (Energy dispatch)	Conges-tion Mana-gement	Repla-cement Reserves		
Not directed by TSO	Directed by TSO			Directed by TSO		Directed by TSO		
Instanta-neous & Continu-ous Control	Conti-nuous	Event-driven		Conti-nuous	Event-driven	Event-driven	Event-driven	Event-driven
AS-1	**AS-2**	**AS-3**	**AS-4**	Basic task – **Not an AS**		**AS-5**	**AS-6**	**AS-7**

Like EURELECTRIC, CIGRE also did not look into the Distribution level.

An ILEX report for the British DTI (Department of Trade and Industry) has listed ancillary services as Frequency, Reserve, Reactive Power, Network support and Black start, when comparing the possibilities of different generators for providing these services (ILEX 2004). This classification includes a Reserves category that some other classifications group under Frequency control. A summary of the British system can be seen in Table 3. The British system often mixes mandatory provision of services with an option to provide the same service under a commercial contract. For example in the (automatic) frequency response, under firm contract the generator is committed to provide the service upon request and is paid according to the holding payments (€/MWh). Under optional contract the generator has discretion whether to deliver the service and is paid according to response energy payments (€/MWh). Often the service is procured through a balancing mechanism (BM), which pools offers together and gives the TSO the freedom to choose the least-cost options that fulfil the requirements for the specific service required.

Table 3: Summary of the main ancillary services produced by the NGC in England and Wales (adopted from Mutale and Strbac 2005)

Ancillary services	Product types	Service providers	Loading & control	Contract types and payments	Market value (per annum)
Frequency response (automatic)	Mandatory: • Primary (seconds) • Secondary (30 seconds to minutes) • High (downward reserve)	• Large generators • Demand side • Through BM or without it	• Part loaded generators • Dynamic control arrangements (e.g. AGC) • Automatic initiation	Mandatory: • Firm (holding payments)	€28 million
	Commercial: • Same, but for offers beyond the grid code requirements			Commercial: • Firm (holding payments) • Optional (response energy payments)	€39 million
Reserves (manual)	• Regulating (spinning) • Fast (2 min and 25 MW/min) • Standing (20 min) • Warming & Hot standby (for steam plants)	• Large and small generators • Demand side • Through BM or without it	Regulating: • Part loaded units from BM	Regulating: Through BM	No estimate
				Standing: through BM or without it	€61 million
			Others: • Non-spinning with different requirements	Fast: tenders and bilateral contracts	€31 million
				Warming & Hot standby: Through BM	€31 million
Reactive power	Default mandatory requirements for units rated over 100 MW	• Generators through BM or without it • TSOs static voltage compensation equipment	• Part loaded • Fully loaded	Default: on a €/MVArh basis	€24 million
	Market-based option: tender			Tender: renumeration for both availability (€/MVAr/h) and utilisation (€/MVArh)	€25 million
Fast start (5-7 mins)	Remote controlled (TSO) fast start	OCGT	Off load	Bilateral: based on availability (€/h)	€4.5 million
Black start	Black start service	Usually OCGTs	Off load	Bilateral: based on availability (€/h)	€14.9 million

ENTSO-E has not yet compiled a full-scope definition of AS. They have a classification for frequency support that is divided into three categories (NC OS operational reserves report, 2012)

- **Frequency Containment Reserves (FCR)** – constant containment of frequency deviations (fluctuations) from nominal value. Frequency containment aims at the operational reliability of the synchronous area by stabilizing the system frequency in the time-frame of seconds at an acceptable stationary value after a disturbance or incident; it does not restore the system frequency to the set point.

- **Frequency Restoration Reserves (FRR)** – to restore frequency to the nominal value after sudden system imbalance occurrence. Frequency restoration aims to restore the system frequency in the time frame defined within the synchronous area by releasing system wide activated frequency containment reserves. For large interconnected systems, where a decentralised frequency restoration control is implemented, frequency restoration also aims to restore the balance between generation and load for each TSO, and consequently restore power exchanges between TSOs to their set point.
- **Replacement Reserves (RR)** – to restore the level of operating reserves. Replacement reserves are activated manually and centrally at the TSO control centre in case of observed or expected sustained activation of FRR and in the absence of a market response. TSO can also use RR to anticipate on expected imbalances.

These categories are processes, named after the purpose of the services, each including several Ancillary services products. Balancing markets, operated by TSOs, are operated during the delivery hour, as they have bids that can be activated in 10-15 minutes. This is an example of already existing ancillary service market, for the manually activated part of Frequency Restoration.

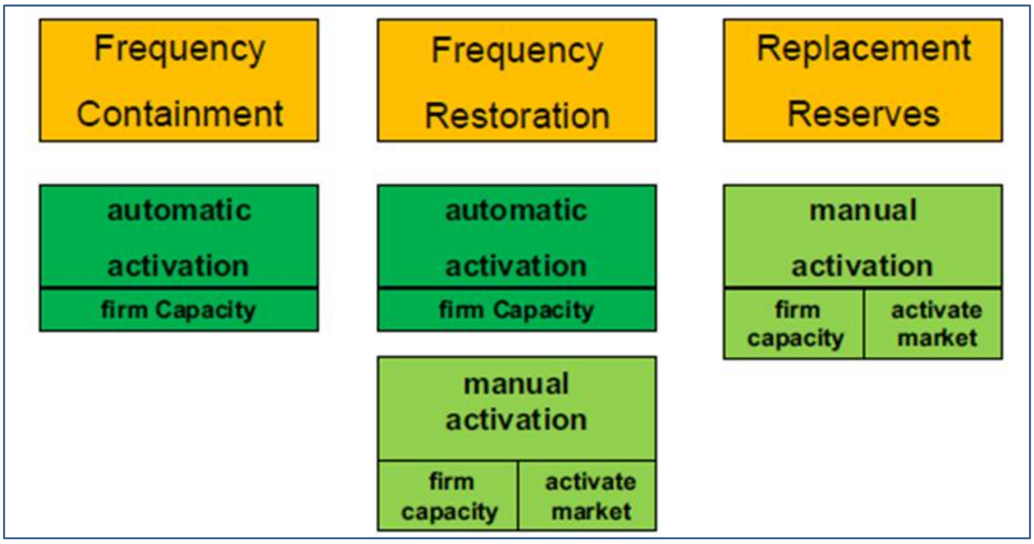

Figure 3: Classification of frequency control services by ENTSO-E (Operational reserve report June 2012).

2.2.3. Summary: Ancillary service categories adapted for REserviceS

Looking at the different definitions for which services can be included in under ancillary services from (EURELECTRIC, 2004; Cigre, 2010; ILEX, 2004), three main groups of services appear in all lists:

- **Frequency control** – services related to the short-term balance of energy and frequency of the power system; it includes automatic (primary/secondary) and manual (tertiary) frequency regulation and operational reserves. This is the main service provided by generators (online for automatic services and online or offline for longer term activated services). It can also be provided from flexible loads, and storage units.
- **Voltage control** – services required for maintaining the power system voltage within the prescribed bounds during normal operation and during

disturbances by keeping the balance of generation and consumption of reactive power. Voltage control includes reactive power supply (injection or absorption) and can be provided by the dynamic sources (generators, synchronous compensators) and static sources (capacitor banks, static voltage controllers and FACTS devices, including, Unified Power Flow Controller as well as network equipment like tap-changing transformers in the substations and loads. In the event of a disturbance to the system, dynamic reactive power response is required to maintain system stability. Network reinforcements and reconfiguration will impact on the voltage control needed.

- **System restoration** – services required to return electrical power system to normal operation after a blackout; from the generator point of view it includes mainly black start), and can in future also include islanding operation.

The subdivision of frequency control contains different terminology in the approaches of EURELECTRIC, Cigre and the ILEX report. We adopt the division proposed by ENTSO-E with Frequency Containment Reserves (automatic and local), Restoration Reserves (automatic and manual) and Replacement Reserves (manual) (ENTSO-E LFC&R NC). Some literature has Reserves as a separate category (like the ILEX report). We consider that the ENTSO-E list of frequency control services will cover also frequency reserves. While EURELECTRIC has stability as a different category, Eirgrid/SONI have in their DS3 Programme included Stability under Frequency and Voltage control. Following the system needs analysis through several operating scenarios with high penetration renewables, the Irish TSOs propose new system service products within three categories frequency control, ramping and voltage control. These main categories are further explained in Sections 2.3…2.5, where the services belonging to each of these categories are described.

The technical specifications related to ancillary services are to a large extent based on the requirements for capabilities, described in Grid Codes, or Network Codes as they are called at ENTSO-E. In the present situation there is a high divergence amongst Grid Codes in Europe. Consequently, requirements and their applicability are different in almost every country. There is an on-going formal process (Third Package) of creation of Network Codes that is intended to streamline the requirements in Europe. In the light of the progressed stage of the first network code issued by ENTSO-E, REserviceS takes the ENTSO-E Network Code for Requirements for Grid Connection Applicable to all Generators (NC RfG) as a reference document, rather than taking requirements from all present Grid Codes in Europe. The ENTSO-E NC intends to bring more consistency primarily for the requirements relevant for cross-border system management. For REserviceS, this is most useful for the frequency response capabilities, where the NC RfG contains quite detailed specifications. However, the NC RfG leaves many of the requirements open for detailed specification at national level. Sometimes the document gives some guidance for those national specifications, but in many cases it leaves requirements open for specification by the local TSO. This is particularly relevant for the reactive power capabilities. Therefore in REserviceS we have to regard how these requirements are specified in national codes. Finally, it should be remarked that the specifications in the ENTSO-E NC RfG have to be regarded as preliminary before they reach the status of European law.

2.3. Services related to maintaining frequency

Frequency control maintains the frequency within the given margins by (continuous) modulation of active power. It has several time scales of operation that differ in their response times in different systems. In the report we adopt the ENTSO-E classification:

- **Frequency Containment Reserve (FCR) or Primary Response**: The automatic response to frequency changes released increasingly with time over a period of some seconds. As a generation resource it is a fast-action, automatic and decentralised function e.g. of the turbine governor, that adjusts the power output as a consequence of the system frequency deviation. With an instant response and a full activation time of up to typically 30 s, it is activated automatically and locally. In UK and Ireland the full activation time is faster than for Central European system, 5-10 s. The response has to be maintained for up to 15 minutes before it is released. The need is assessed collectively at synchronous area level and the procurement duty is split amongst TSOs.
- **Frequency Restoration Reserve (FRR) or Secondary Response**: Activation of Frequency Restoration Reserve (FRR) modifies the active power set points/adjustments of reserve providing units in the time-frame of seconds up to typically 15 minutes after an incident. Activated centrally and has automatically activated and manually activated parts. It is managed by each TSO and coordinated through the control of transits between TSO's area of responsibility.
- **Replacement Reserve (RR) by Tertiary response**: Manually activated, activation time from 15 minutes to hours. Replacement reserves are activated manually and centrally at the TSO control centre in case of observed or expected sustained activation of FRR and in the absence of a market response.

This division of services (reserves) also applies in cases of disturbances such as contingencies (tripping off of a large generator or transmission line). After a disturbance in the balance between generation and demand the following steps are performed:

1. Automatic procedures: Frequency Containment (0 – 30 sec) and automatic Frequency Restoration (30 sec – 15 min).
2. Manual Procedures: manual Frequency Restoration and Replacement of Frequency Restoration. Also balancing energy from market parties can be used for longer term.

The time frame of frequency support is usually within the delivery hour. The energy markets, day-ahead and intra-day can be used for balancing the supply and demand in the time scales of hours and day ahead.

The automatic reserve will be delivered from spinning reserve and the manual reserve can be either from spinning or from standing reserves. Spinning reserve means an increase or decrease of generation or reduction in consumption that can be provided at short notice, carried out by partially loaded generating units and interruptible consumers (loads). Standing reserve involves increase in generation or a reduction in consumption by those generating units that are not synchronously on-line, or by interruptible consumers (loads).

System inertia is an important part of the power system response to frequency events, its magnitude being proportional to the system's resilience to sudden change. It depends on the physical characteristics of the power system, namely the types of generators in operation and their own rotating masses that provide energy during the momentary frequency dips. The more inertia a system can exhibit, the more resilient to events is its frequency. With an increasing penetration of non-synchronous generation in the system (e.g. through HVDC connectors and through increasing converter connected generation like wind and PV) there will be an increasing need for capabilities from generators to supply very fast frequency response. This is already included in several present national Grid Codes as well as in the ENTSO-E NC RfG. The network code requires additional Active Power capability to limit the rate of change of frequency (RoCoF) in the system; this ability could constitute a new ancillary service. Intelligent algorithms can be used to provide synthetic inertia from wind generators (Mullane & O'Malley, 2005; Ruttledge et al., 2012) and industry is offering technical solutions. PV can provide synthetic inertia when it is run below maximum available power generation or in combination with a storage unit e.g. a battery (van Wesenbeeck et al, 2009). A new service has been added under Frequency control to account for this:

- Fast Frequency Reserve: additional increase in active power (MW) output from a generator (and/or reduction in demand) following a frequency event that is available within 2 seconds of the start of the event and is sustained for at least 15 seconds. Potential providers of these services include conventional generators, demand customers with static under-frequency relays, synchronous generators, and synchronous storage units. Also HVDC interconnectors and some DFIG (Double-fed Induction Generator) and full-converter type wind turbines with advanced control mechanisms (e.g. providing an emulated inertial response) as well as PV systems that are run below the maximum available electricity generation. (Option 2 of FFR in Eirgrid and SONI 2012a)

As an additional category, for future needs we add:

- Ramping service/Ramping margin: Imbalances between generation and demand in both directions (upwards and downwards) are managed using frequency response services (e.g. operating reserves) over very short timeframes (seconds and minutes). Over longer timeframes, additional factors can cause an imbalance which, if not managed, would result in unacceptable frequency excursions. These factors include changes in demand, wind generation, interconnector flows and generator availability. *Potential providers of these services include conventional generators that are not dispatched to their maximum output, storage devices, demand side providers, solar PV and wind power plants that have been dispatched down. In the future with the potential for implicit continuous gate closures, interconnector participants with excess capacity for importing may also be able to provide this service. (EirGrid and SONI, 2012a)*

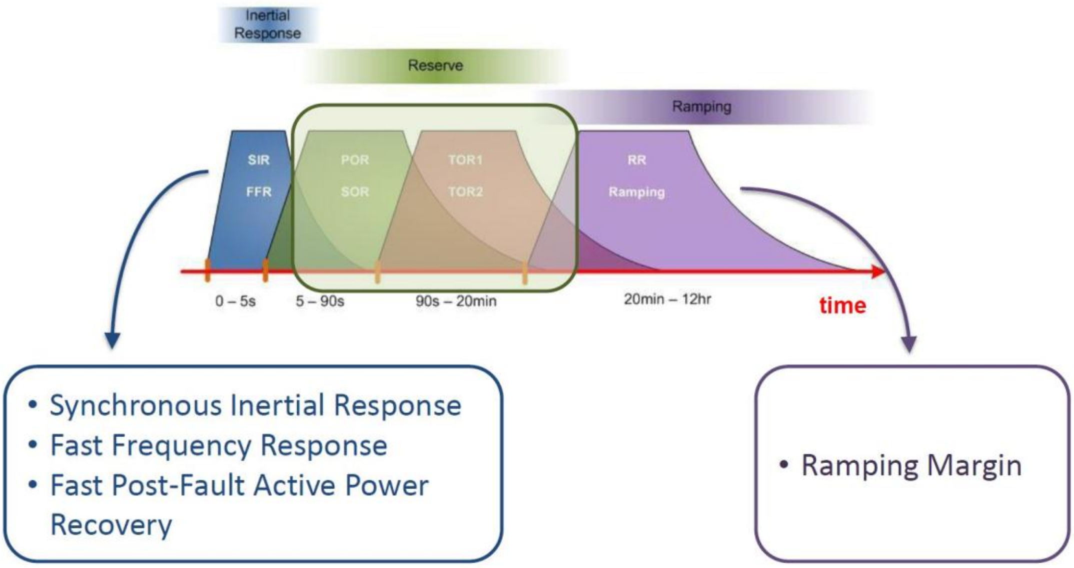

Figure 4: Characteristic time scales of frequency control and the proposed new AS products (Source: EirGrid and SONI, 2012b)

For interconnected power systems, different balancing areas and system operators can share some of the reserves (Figure 5). This relates to cross-border delivery of the reserve AS.

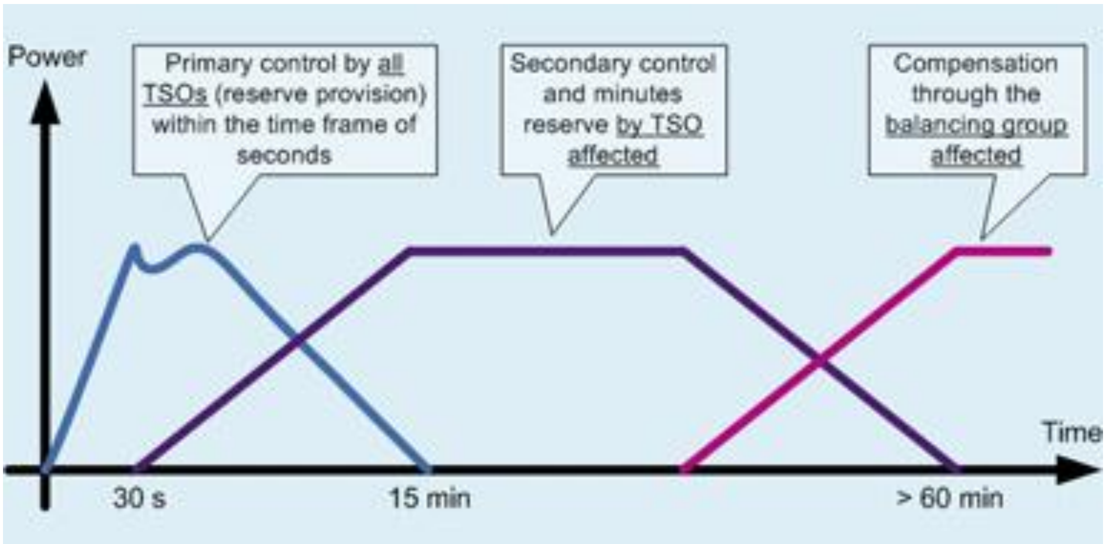

Figure 5: Frequency control and reserve sharing amongst the interconnected systems (Source: Amprion)

While the generators in distribution systems do not currently take part in frequency control services, this is foreseen in the future. Today, the system operator (TSO) can impose load shedding on the DSO in the presence of energy shortages in order to control the frequency.

2.4. Services related to maintaining voltage

2.4.1. Overview

System voltage is another key performance metric of the power system. Voltage is a local measure, which differs in every power system node, both on transmission and distribution level. Voltage is influenced by reactive power. Reactive power transmission causes losses, and as reactive power can be more easily generated at the site where it is needed, in general reactive power transmission is tried to be avoided.

The voltage levels of the power system nodes constitute the voltage profile of the power system. The voltage profile must be maintained within prescribed ranges at every node on the power system to maintain power quality, avoid damages to components (either networks' or customers') in case of excessively high voltage and prevent malfunctions in case of excessively low voltage, as well as maintain power system voltage stability.

This is achieved by a combination of three tools:

1. Preventing unnecessary transits of reactive power (mainly through requirements for customers and pricing of reactive power transits);
2. Adding new network assets to support the active and reactive transits;
3. Balancing (dynamically) the generation and consumption of reactive power (i.e. capacitive and inductive reactive power) in the voltage controlled nodes of the system.

Control of voltage is tightly connected to reactive power control. Voltage can be controlled through voltage control, reactive power control, power factor control or by a combination of two of these, so they are often referred to as voltage/reactive power control.

The need for reactive power varies as demand varies and as the sources of generation vary. As reactive power is not viable to be transmitted over long distances in transmission network, its production is distributed across the system, usually closer to the locations where it is needed. In some power system locations there may not be a strong link between the need for active power and reactive power from the same sources (locations). Reactive power support provision procurement rules should therefore incentivise reactive capability across the widest possible active power range (Eirgrid and SONI 2012a).

As regards TSOs real time operations and operational planning, Voltage control has two targets:

1. **Voltage profile management and reactive power dispatch (steady state)**: The aim is to keep the voltage profile close to the desired profile and within the tolerance band margins with time frame of hours. This entails minimisation of the system active power losses while keeping steady-state system security in the face of possible contingencies.
2. **Maintaining voltage stability (dynamic)**: This service controls the network voltages in a dynamic time frame (seconds to minutes). The aim is to prevent a slow voltage collapse event or limit its depth and extension in case of an incident (loss of main, loss of generation unit).

Voltage stability is the ability of a power system to maintain steady acceptable voltages at all network nodes in the system under normal operating conditions and after being subjected to a disturbance (Kundur, 1994). Voltage stability is compromised when a disturbance (e.g. network fault), variation in load or generation – including changes in wind power – or change in other system conditions cause an unacceptable, progressive, and uncontrollable decrease in voltage. The main factor causing voltage instability is the inability of the power system to locally meet the demand, especially for the reactive power at certain load bus in a certain moment. The reason may be that the reactive source is too far or of insufficient capacity.

While voltage instability is essentially a local phenomenon, its consequences may have a widespread impact in case of voltage collapse. Voltage and transient stability issues are interrelated and same mitigation measures apply (EirGgrid & SONI, 2012). The remedies for improvement of voltage stability at the affected bus include: additional injection of reactive power at or near of the identified bus; blocking of the distribution under load tap changer feeding the affected bus; and reduction of load, which is the least desired means. Therefore, additional reactive power sources will be needed at heavily loaded buses in case of high penetration of RES in the power network, especially at the distribution level.

To achieve the above control strategies, the following voltage control services are needed to ensure that adequate voltage support is maintained in normal operation:

- **Steady-state Reactive Power/Voltage Control**: Controlling voltage node profile to a target value or within a target range. This control is commonly achieved by injecting or absorbing reactive power at a voltage controlled node by means of synchronous sources, static compensation, tap changing transformers in the substations, transmission lines' switching, virtual power plants including demand facilities and if necessary load shedding. The system operator dispatches the reactive power using the active and passive reactive power sources that belong to different levels: generation, transmission and distribution, using Optimal Power Flow methods. This type of services has a similarity with the active power economic dispatch related to the implementation of the hourly pool-based energy market.
- **Fast reactive current injection** : Oriented towards system dynamic security and voltage quality, it can be provided by spinning generators and synchronous compensators, reactors and capacitors, Static VAR Compensators (SVCs), HVDC (implemented with technology VSC) substations and other FACTS devices, or other equipment capable of fast regulation. This type of service can be considered analogous to active power reserve and frequency-control services (primary and secondary AGC frequency regulation).
- It is defined as the capability of a generator to deliver a reactive response that shall be proportionate to the magnitude of the Voltage dip. Presently, there are no examples of system services based on this capability, but services based upon this capability may be needed much more often in the future, when there will be more need for local voltage support from distributed generators. In Figure 6 fast reactive current injection is called dynamic reactive power.

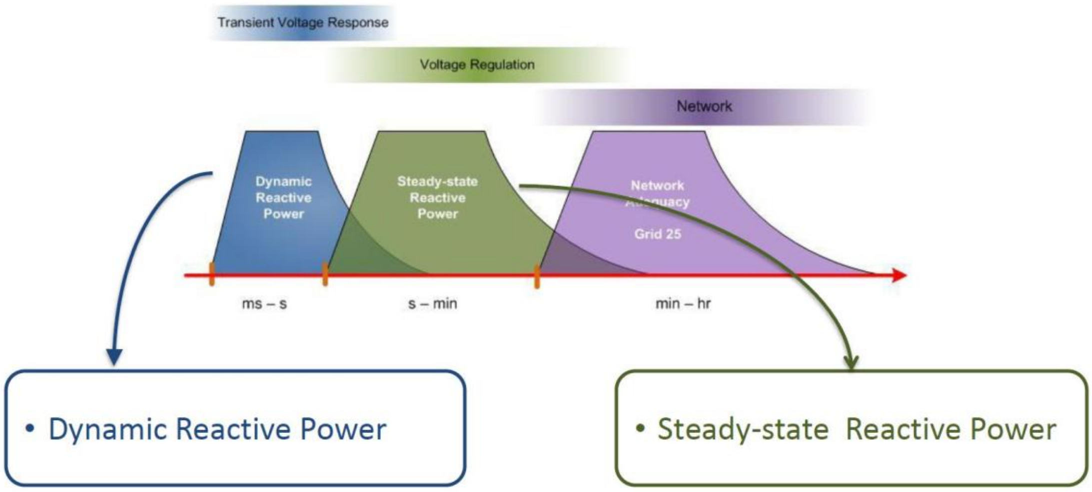

Figure 6: Characteristic time scales of voltage control and the proposed new AS (Source: EirGrid and SONI, 2012b)

Achieving an acceptable voltage profile as regards standards on contractual obligations, in normal and often N-1 situation is directly determining the structure and cost of the connection scheme for a customer.

When considering the case of a generator with possible reactive power management capability, these capabilities can be used, and according to regulation very often must be used, to reduce the cost of the connection. Thus the entire capability of the generating units is not necessarily available to provide AS, but only the part that is not actually used because of the very structure of the connection. In addition to the services, network adequacy through regular reinforcements is important to be able to manage the voltages.

2.4.2. Voltage control in Distribution networks

In the power system, TSO monitors transmission system elements, transmission connected generators and consumptions, as well as DSO connection points. System users (Generator, Consumer, DSO) shall maintain voltage and/ or reactive power within limits at the connection point in the range required by the TSO or DSO (subject to e.g. grid connection rules). DSOs shall support TSOs in voltage control (blocking of automatic voltage control of transformers and directing users to follow other voltage control instructions, as well as implement the Low Voltage Demand Disconnection scheme), also by giving available reactive power reserve information to TSOs (real-time and forecast) (ENTSO-E OS NC).

Both the voltage regulation practice in distribution networks and the grid design itself is based on radial power flows from the substation to the loads. Generation that is distribution network connected, like PV and a portion of wind power plants, introduces power flows that interfere with the effectiveness of conventional voltage regulation practice. Wind and PV can provide reactive power compensation (for example by predefined power factor), and this has direct influence on voltage control and power transmission losses. Sufficient amounts of reactive power in voltage controlled nodes help maintain the voltage levels of the system nodes within the expected intervals and provide capacity for the network capacity exploitation.

Efficient reactive power compensation on the DSO network can be provided by on-load tap changer (OLTC) transformers at substations, supplementary line regulators on feeders, switched capacitor banks installed on HV/MV substations and coordinated reactive power injection from generation connected to distribution level. Besides the services, network adequacy through regular reinforcements is important to be able to manage the voltages.

As wind and solar penetrations increase, the question of their contribution to the provisions of reactive power support at a local level is raised. Especially in countries with very high penetration of these renewable energy sources as they may remove traditional regulating generation units from merit order.

However the question of the target of these provisions is still unresolved. Shall they contribute mainly to the optimisation of connection costs, usually to the sole benefits of the generator? Shall they contribute to the overall optimisation of Distribution Network usually to the benefits of the consumers supporting most of the costs through grid access tariffs? Shall they contribute to the needs of the TSO in optimizing its network development costs and system security management? And in any case how shall it be operated and what procurement strategy should be followed, including the pricing?

- **DSO voltage and power flow management services** – wind and PV may provide important services (e.g. voltage support or flow control; for PV see EPIA, 2012) especially in stressed conditions, where wind and PV would be suitable for such applications. Opportunities may improve with increased wind and PV penetrations due to the higher collective availability. However it is very dependent on the regulatory framework for connection scheme design. The actually available capability for network optimisation is only what is left after what has been used in minimizing the cost of the connection scheme. Furthermore it must be noted that the situation is very asymmetrical concerning the consumption and injection of reactive power on Distribution Network. If DSO can deploy and operate without notable difficulties compensation devices on their network, the deployment of reactors is not presently industrially solved. Considering this reactive power absorption by DG could be a real technical opportunity.

- **TSO reactive power** – Following the increasing emphasis on distributed renewable energy sources, high penetration levels of variable, asynchronous generation will displace synchronous plant and may cause a challenging scarcity of traditional ancillary service providers, notably in the area of reactive power provision. Renewable generators must therefore increasingly provide the reactive support necessary to operate the power system. It is important to remember that it is inefficient to transfer reactive power across large electrical distances, including across the transformation between voltage levels. The effectiveness of distribution reactive power resources to provide support at transmission level will thus not be possible in all instances. It is highly dependent on the network impedance, and on the generation resource and technology employed (Cuffe, Smith Keane, IEEE TSTE 2012). Reactive power compensation at lower distribution voltages may diminish the need for reactive power from transmission-connected generation. DG connected at these levels can make a significant impact on the amount of reactive power exchanged between the transmission and distribution systems.

The ENTSO-E NC RfG described in section 2.4 are applicable to Type C generators (as specified in Table 1), and thus are also applicable in some distribution networks.

A consideration of the interaction between the local distribution priorities and system level transmission issues is vital in the effective resolution of the provision of services from distributed renewable resources.

In future, reactive power control for voltage management issues could be dealt with through optimizing overall costs of distribution network, taking into account losses and operational costs in addition to optimising connection costs. Last but not least DSOs and TSOs are not used to addressing the same amount of connection points. TSOs are used to directly monitor and control a limited number of facilities, and tend to favour remote control solution that gives a strong control to operator, sometimes mitigating the solution with local automatism when fast reaction is needed. DSOs are used to operate the system with no or little monitoring and control of (very) numerous connected facilities, they tend to prefer local automatism sometimes mitigated with simple monitor/control interface for larger units.

Reactive power provision requirement by distributed generators to the DSO is not state-of-the-art. However, there are several research and pilot projects carried out in order to evaluate the benefits of reactive power control by distributed generation, in particular PV (e.g. MetaPV, VSync, DG DemoNet-Validation, MorePV2Grid, DERri, and 7 MW-WEC-by-11). The main objective of these projects is to evaluate whether reactive power supply on distribution grid level can reduce the need for grid reinforcements and further increase the hosting capacity for further generators.

2.5. System restoration services

There are two services that are considered under system restoration services: Black start (BS) and Islanding operation.

2.5.1. Black start

Black start is used in the power system restoration phase, defined as "a set of actions implemented after a disturbance with large-scale consequences to bring the system from emergency or blackout system state back to normal state. Actions of restoration are launched once the system is stabilised. Restoration of the system consists of a very complex sequence of coordinated actions whose framework is studied and, as far as possible, prepared in advance" (ENTSO-E OH, Policy 5, Appendix)

The restoration process has several stages: re-energisation from blackout, frequency management and resynchronisation.

The re-energisation process can be implemented using two strategies. I) Top-down re-energisation using external voltage sources when the grid is reenergised from a neighbouring TSO, starting from the tie-lines. II) Bottom-up re-energisation based on internal sources capabilities is done using units that provide the capability of controlling voltage and speed/frequency during supplied isolated operation and stable operation in an islanded network. Those units are referred to as having black start capabilities.

In general, all power stations need an electrical supply to start up: under normal operation this supply would come from the transmission or distribution system; under emergency conditions black start stations receive this electrical supply from small auxiliary generating plant located on-site or in the case of pumped storage plants the power can be supplied from a smaller "auxiliary" turbine (commonly a Francis turbine). In this context, black start capability of a generator is defined as: The capability of a generating unit to start up without an external power supply, called on as a means of restoring supplies following a major failure on all or part of the network. Black start capability is usually considered at plant design. In power systems not all power stations have, or are required to have, this black start capability.

Presently, wind and solar PV are not providing this service, and it is included in REserviceS for a possible future service. In practice it has to be noted that during the restoration process TSOs have even higher demands for reliability and will avoid any components adding uncertainty. This means that for wind and solar, uncertainty and variability should be limited during this time in order to be suitable/ eligible for this service provision.

2.5.2. Islanding operation

The foremost prerequisite for island operation is defining the (potential) island operation area, where the power balance (i.e. consumption and generation) could be possible to realise during the whole period of island operation. Only when this feasibility is clear, other island operation issues can be discussed.

Most of the current generators are not designed to perform in islanding conditions, as separated from the main grid. This could be a future service from generators, especially connected to distribution networks. The ability of islanded operation of distributed generation would improve the reliability of the grid. For future islanding operation existing regulatory, also technical and safety framework has to be carefully addressed (EConnect 2005).

In practice islanding operation can be realised by defining suitable sub-networks, called cells (Figure 7), where power supply would depend entirely on distributed generators in the cell. These cells would guarantee availability of electric power to a certain level. The generators would need to have measures installed that could be activated in case of islanding, being able to maintain stable frequency and voltage during islanding, also keeping network impedance within range and phase symmetry, and capability to handle fault currents. They would also need to be able to re-connect to main grid when in synchronism.

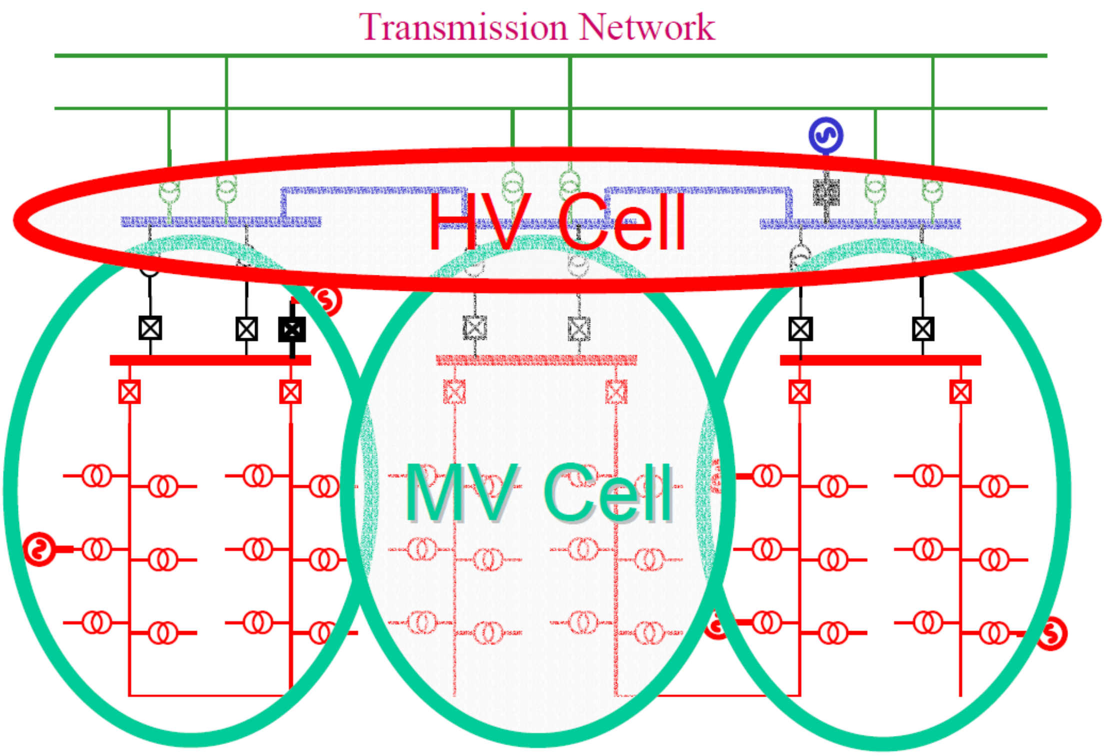

Figure 7. Example of cells in medium voltage network. (Overbeeke and Roberts, 2002)

The cells would need to provide several services to the system and/or to each other:

- **Reactive power (supply/absorption)**: In many cases it is more cost-effective to ensure reactive power balance locally in the distribution grid, provided by the DSO as a service.
- **Voltage control**: every island should have an adequate source that provides voltage support.
- **Negotiated power exchange**: A capability to exchange power with neighbouring cells; suitable actuators control the exchange; managed operation of connections with adjacent cells (Overbeeke and Roberts, 2002)
- **Fault management:** Faults are managed and isolated within a cell; effect will not propagate to other cells (Overbeeke and Roberts, 2002)
- **Phase symmetry**: Symmetry between phases may become an issue when networks are operated at higher impedance levels. The optimal value of network impedance will be determined by a trade-off between requirements of voltage stability and absorption of flicker phenomena on one hand, and limitations on fault level on the other hand.
- Network impedance range, defined as:

- High enough to limit fault level.
- Low enough at harmonic frequencies and to supply starting currents, absorb load variations and secure generator stability.

- **Security of supply/ connectivity**: While the medium and low voltage networks are constructed as meshed, they are operated in a radial fashion. To increase security of supply during islanding, cells can be interconnected using connections open in normal operation, resulting in a meshed low or medium voltage network. Power balance is primarily achieved on cell level, which requires control of local generators/loads. If this is not possible, power is transferred between cells on the same level. The next step is to involve cells with larger geographic coverage on higher voltage levels, and failing that, they make use of the top-level, transmission level cell. If required, cells on higher level can co-ordinate efforts on lower levels using extensive systems for monitoring and control.

- **Reconnection of DG**: As small DGs are designed to connect automatically to the network, small DG should be required to reconnect under the provision of a progressive gradient of power over a reasonable amount of time. Namely, while establishing power balance in an island, an important amount of intentionally disconnected DG could automatically reconnect upon reconnection of load a few minutes later, potentially unbalancing the system in a critical phase.

The re-synchronising phase is very important, as has also been described in the black start recovering process.

2.6. Other services

The ancillary services that we focus on in REServiceS project are the ones provided by generators. This section lists services that have been left out.

Because we have focused on time frames close to power system operation and electricity market daily developments, we have excluded long term reserves that are planned to ensure long term capacity adequacy. This is a part of power system planning with its timescale measured in years.

The ancillary services that are not further explored in REServiceS project because they are not services provided by generators are:

- **Coordination of operating procedures between DSO and TSO** (loss of mains protection settings; prevention of system to ride through high RoCoF events etc.).
- **Emergency control (EC) actions**: Maintenance and use of special equipment (e.g. power system stabilisers and dynamic braking resistors) to maintain a secure transmission system.
- **Dynamic Stability Management**: offline studies for voltage, rotor angle or frequency stability:

Some system services can be handled with already listed ancillary services, even if they are for different purpose:

- **Congestion management**: Re-dispatch to prevent violations of the power flow Operational Security Limits (ENTSO-E OS NC)
- From generator point of view this service is technically similar to manually activated frequency support services. Even if not for balancing but for load flow management, TSOs could take these from manually activated Frequency Restoration reserve, for example if wind and solar were bidding to balancing markets.

- **Grid loss compensation (GL)**: Compensating the transmission system losses. This is part of voltage control service.
-

2.7. Summary of REServiceS categories of ancillary services

The ancillary services categories, relevant for renewable generator point of view, are presented in Table 4.

Table 4: Ancillary services relevant from renewable generators.

Frequency support	Voltage support	System restoration
Frequency Containment Reserve FCR (<5, 10 or 30 sec) Frequency Restoration Reserve FRR (<15 min) Replacement Reserve RR (15 min to hours)	Normal Operation: control of power factor, reactive power or voltage	Black start
Fast frequency response (synthetic inertia) (< 2s) Ramping margin (1, 3, 8 hours ahead)	Fast reactive current injection	Islanding

* The first row in the table refers to existing ancillary services and the second row to new services.

A more detailed table with technical specifications and a comparison to existing ancillary services in some EU countries are presented in Chapter 5 and Appendix 1.

3. SYSTEM NEEDS FOR ANCILLARY SERVICES

This chapter presents a summary of findings regarding how renewables impact ancillary services at different penetration levels and in different systems, from literature and system operators. From this information, a consensus on what services will become important at low, medium and high penetration levels of wind and solar PV for different systems in Europe is made.

Renewables will also impact need for new grid infrastructure and the capacity adequacy of the power systems – these impacts can be large, but as they are not related to ancillary services in operation of the system, they are not discussed in this report. The experience from Portugal show that there are no impacts on congestions if the system operator has been able to implement grid reinforcements in time and limited the connection of wind power plants to reflect the grid capability (Ribeiro, 2012). The experience of Germany show that curtailments of wind are needed to manage congestions in case of delayed grid reinforcements (Söder et al, 2007).

Another important impact not discussed further is the increased need for coordination between TSOs and DSOs. Especially real-time monitoring and ability to control requires an effort for providing the communication to small renewables plants. This is relevant also for congestion management. Data exchange will be greatly expanded, and DSOs will also be more involved.

This section aims at conclusions towards the needs for the identified categories of services. How wind and PV impact the need of frequency and voltage support in the system – how much frequency and voltage support is required without wind and PV and with different levels of penetration? Impact on black start capability is briefly mentioned as this has not been an issue so far. Information about the costs is presented when available. The main impacts are summarised in tables. This gives information needed to model how the needs of the system change in the systems with increasing non synchronous system penetration in following work packages of REServiceS WP5/6, when searching for more detailed information based on simulation results on how frequently the services are needed regarding RES.

3.1. Services related to maintaining frequency

Main impacts of variable renewables are due to more variability and uncertainty that will result in more balancing needs and can impact frequency control. Other important aspect is that during high wind and sunny hours, less conventional units will be online to provide frequency support and inertia (as well as voltage support and congestion management). This is one reason for variable generation to participate in ancillary services, to avoid curtailments due to keeping other generation online to provide services (unless loads or network components can do it with smaller costs).

Experience and study results so far show that the impacts of variable renewables are power system specific. For example the location of variable renewables versus load centres and the existing network will influence required grid measures and operational practices whereas existing flexibility of conventional generators will influence impacts on balancing and frequency support. Using flexibility of neighbouring countries or regions has been found as one major assumption influencing results of wind integration studies because larger balancing areas have less impacts from renewables (Holttinen et al, 2009), For this reason, variable renewables impact the need for cross border trade of ancillary services, obviously for the frequency related services and to a less extent for voltage related services.

There is experience from significant wind penetration levels from Denmark since year 2000 when wind power exceeded 10 % share of domestic electricity consumption, and since several years from Spain, Portugal, Ireland and Germany. However, there have been other changes in frequency control or balancing schemes also, making it difficult to get direct information about how much the balancing needs have actually increased due to additions of wind power. There is also experience of solar power (PV), mainly from distribution networks but also some first transmission level impacts when the shares of PV have exceeded 1-2 % in recent years in Germany, Italy and Spain. Experience from the rapid PV additions show that the setting parameters can have impact on system needs: initial parameters making PVs to trip at > 50.2 and < 49.7 Hz frequency could have led to tens of GWs tripping at those frequencies and thus impacting the frequency reserves (EPIA, 2012). The retrofitting of the about 315 000 PV systems in Germany is currently in underway and will be finished within less than three years.

In the following the impact of variable RES on the need for reserves. The discussion will almost exclusively discuss the impact of wind energy. This is due to the fact that PV only recently reached levels that impact reserve design. Therefore most literature and in particular investigation of the impact over a longer term are only elaborated for wind energy.

One reason for operating reserves is to cover for the largest unit that can trip off. This is usually more than 1000 MW and wind power plants would not directly impact that design criteria for reserves. However, wind power will impact the reserve that is operating to cover for load and generation unbalances. Experience of wind integration shows that when reaching penetration levels of 5-10 %, an increase in the use of short term reserves is observed, especially for reserves activated on a 10-15 minute, or longer time scale (IPCC, 2011; Ribeiro, 2012). In Spain, the frequency control activating in 30 seconds has not been impacted by wind power with about 15 % penetration level (Gil et al, 2000). The same experience is from the other highest wind penetration countries Denmark and Portugal: no significant frequency impacts have been observed that are the result of wind power variation (Eto et al., 2010). So far, no new reserve capacity has been built specifically for wind power (Söder et al., 2007). In Portugal and Spain, new pumped hydro is planned to be built to increase the flexibility of the power system, mainly to avoid curtailment of wind power (Estanqueiro et al., 2010; Ribeiro, 2012).

Impact of inadequate system services have mainly been seen as curtailments: In Spain, curtailments of wind power due to inability to maintain power balancing have occurred since 2008 (when penetration exceeded 10 %) and they have slowly been increasing (0.5 % of total wind generation curtailed due to insufficient operating reserve in 2010, with >16 % penetration) (Holttinen et al, 2011). In Portugal, wind power has been providing close to all load during some hours without the need of curtailments, due to access to flexible hydro power (Ribeiro, 2012). In Denmark, the curtailments were reduced in 2005 after combined heat and power plants started flexible operation. In Denmark also the minimum production levels used in thermal plants were lowered (Holttinen et al, 2009). In Denmark, must run commitments of thermal power plants are related to stability and voltage control. Options for further decrease must run units are currently investigated, to reduce curtailment needs in the future without compromising system stability. In Spain, too, there needs to be a minimum of manageable generation (mainly conventional) presently that assures a sufficient level of provision of ancillary services.

Challenging situations seen in system operation so far are from high wind power generation during low load situations, when instantaneous wind power penetration levels exceed 50 %, as well as high wind power ramps during rare storm events. In Ireland some curtailments have been due to concerns about low inertia (Dudurych, 2010) and consequently susceptibility to instability in the system due to high instantaneous wind penetration and low system load. Currently, the issue of low inertia is unique to small systems like Ireland and possible solutions are being investigated (EirGrid and SONI, 2010), including wind power plants providing ancillary services and flexible balancing plants that can operate at low output levels and deliver stabilizing services. The reduction of inertia leading to more pronounced frequency excursions has been studied for the large UCTE system in de Haan et al, 2012.

In wind integration studies, impacts of wind power as well as possible mitigation methods are presented. These studies are available from several European countries, as well as some Europe wide studies (Tradewind: van Hulle 2009, EWIS: Winter 2011, Offshore Grid: De Decker and Kreutzkamp 2011). The aspects studied, as well as the methodologies and ways to present results vary. The studies often concentrate on the mitigation methods needed to manage larger wind penetrations: improving exchange to neighbouring countries (also in shorter time scales sharing balancing resources), improving TSO tools to forecast wind generation and to manage variability closer to real-time, improving flexibility of conventional generation and demand. Also the participation of variable renewables to ancillary services is one option.

Integration studies have aimed to quantify the increase in short term reserves (usually the ones activated in 10-15 minutes so manual FRR). Summary of estimates from several integration study results on increases in operating reserve requirements (MW) are shown from IEA Wind Task 25 in Figure 9. In Germany there are several studies showing estimates of increase in reserve requirements (dena, 2005 Figure 9, Dobschinski, 2010 Figure 8 and Figure 9, Haubrich, 2008).

Summary of estimates from several integration study results from IEA Wind Task 25 on increases in balancing costs (€/MWh), are presented in Figure 10. Estimated increase in balancing costs at wind penetrations of up to 20 % amounted to roughly 1–5 €/MWh of wind power produced (Holttinen et al, 2012) ILEX 2004 study for Ireland provided estimate of additional fuel costs in addition to costs of reserve provision required at varying wind penetration (O'Malley, 2004).

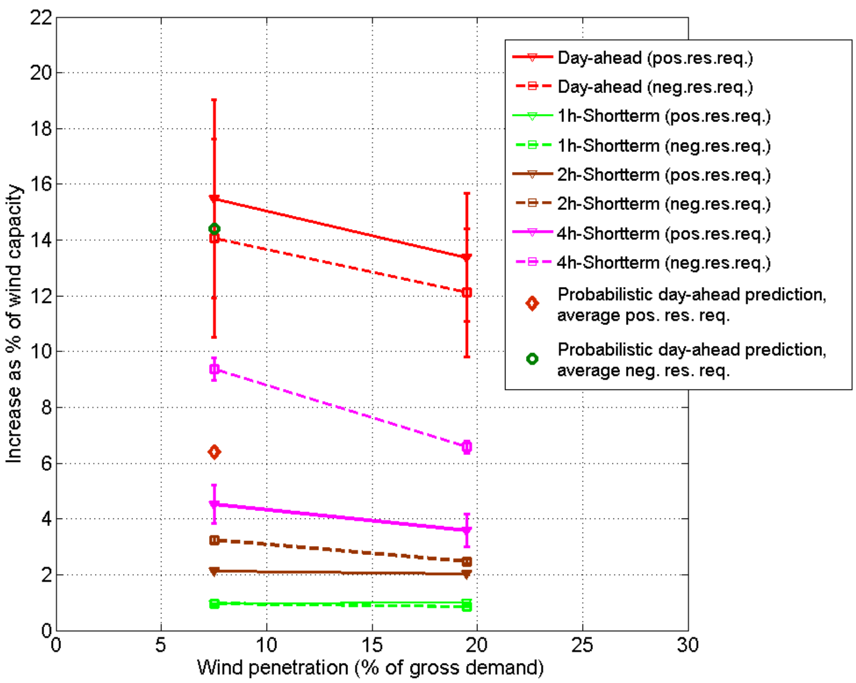

Figure 8: Estimated increase of up and down operating reserve requirement in Germany due to wind power (Dobschinski et al, 2010), assuming different forecast/uncertainty time horizon for the reserve allocation.

The improvements assumed for wind forecasting accuracy will outweigh the increases in reserve requirement due to higher penetration level.

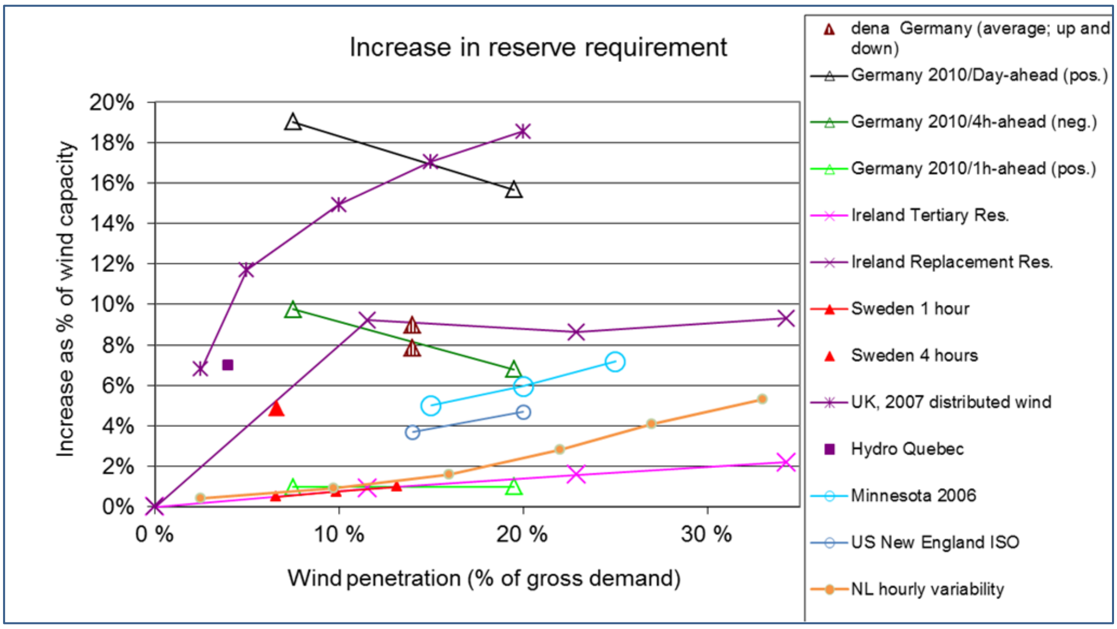

Figure 9; Summary of increased operating reserve (frequency control) requirements due to wind power, for different wind penetration levels (Source Holttinen et al, 2012)

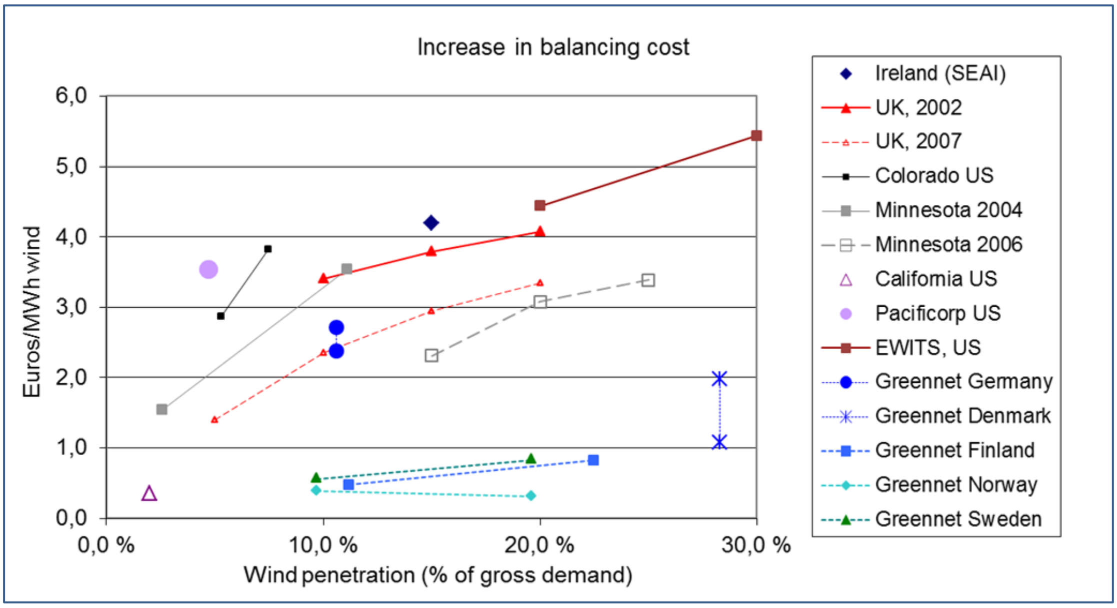

Figure 10: Summary of increased balancing cost (frequency control) due to wind power, for different wind penetration levels (Source Holttinen et al, 2012)

EWIS results pointed out that significant changes are needed in dispatch and interconnectors will be used more extensively. Large-scale storage and demand side management were not found to bring significant benefits. The costs for additional deployment of reserves were estimated at 3.6 USD/MWh) (EWIS, 2010).

Managing the short-term variability of solar PV will be somewhat similar to that of wind power. The variability of solar PV systems can be considerable in partly cloudy weather and also with fog or snow (Lorenz et al., 2009; Mills et al., 2011). The ramping up and down during morning and evening of solar output, even if highly predictable and sometimes coinciding with load ramping, can also impose a large variation for electrical power systems with large amounts of solar PV energy (Denholm et al., 2009).

At increasingly high penetrations of solar PV and Concentrated Solar Power (CSP) without thermal storage (>10% annual energy production), the net demand, that means demand less solar production, will become increasingly low during the middle of the day when the sun is shining, while the night time net demand will not be reduced by these solar resources.

3.2. Services related to maintaining voltage

The impacts of wind and PV on voltage control differ for different grids. There are multiple voltage levels in a distribution network and each will often have different characteristics. Also the urban and rural grids are different. In a densely populated urban areas, load is spatially concentrated and often supplied from several locations with adequate reactive power sources, however much of the distribution lines are cabled. On the other hand, rural demand is spatially dispersed, weakly connected and chronically underfed with reactive power, leading to poor voltage profile.

3.2.1. Voltage setting of the reactive power sources in the network

With increasing the penetration of renewables, changes in voltage profiles will appear in the power system. To maintain the voltage profiles close to the optimal profiles, the voltage settings of the reactive power sources including large generators will need to be recalculated. Their settings are determined by their influence in the network voltage profile, dependent on the configuration of the network, position of the reactive power source in the power system, and their capacity. Using extensive power flow calculations and statistical analysis, the setting and the ranges for a particular reactive source can be obtained to collectively bring about the optimal network voltage profile (Gubina and Gubina, 1999).

3.2.2. Influence of distribution-connected renewable generation on the voltage profile

In the distribution network, the volatility of renewable sources power generation leads to varying of the voltage profile. This influence should be studied beforehand in the planning phase of renewable source penetration and the mitigation measures should be employed. In the radial line, typical in a distribution network, a reactive power source could be installed to mitigate variations in voltage profile.

Due to its radial nature, the voltage level in a distribution network is generally decreasing proportionally with the distance from the substation. With the connection of distributed generation, various situations may be encountered regarding the voltage profile influence. The voltage might be raised at the beginning or at the end of a distribution line. In case or failure of an element of a distribution line, the customers would be reconnected to another line, which may considerably change the voltage profile of a reconnected line. With the connection of distributed generation on a radial line, power would flow in the direction opposite to the normal flow, causing problems with protection and changes in voltage profiles (e.g. voltage rise along the line instead of the expected voltage drop).

Voltage rise in distribution grids is an issue for PV integration (Widén et al., 2009). Thomson and Infield (2007), however, show that in a typical urban UK network with a very high PV penetration level (2,160 Wpeak on half of all houses), only small increases in average network voltages occur.

RES as distributed generation can also improve voltages in certain places of the network, especially at the end of a long radial line or far away from other reactive power sources, thus supporting traditional voltage control means. Most units are connected to the distribution grid with a power electronic inverter. Both the voltage-current relationship and the power exchange are determined by the choice of the topology and control strategy. A suitable choice of the hardware in combination with the implementation of a smart control strategy could allow grid-connected inverters to offer a wide range of grid supporting services. The improvement of the power quality is nowadays mainly taken care of by so-called power quality conditioners (PCQ). These systems have the sole purpose of improving the power quality in electrical grids. Distributed generators are extremely fit to improve the power quality because they are connected to the grid via a voltage-source inverter and are able to improve the power quality by injecting active and/or reactive power in the grid. In contrast to the dedicated PQC-solutions, distributed generators do not require energy storage since the energy delivered by the primary energy source can be used for this purpose.

The reactive power sources may be remotely controlled by the DSO or be programmed to act automatically. They might be embedded in the renewable source as well. Moreover, the under-load tap changer's voltage control should be adjusted to the changed situation of active power load and lack of reactive power and to voltage stability problems.

Even though in particular in regard to reactive power provision PV can be a cost-effective source, most studies and investigation where so far carried out for wind energy. Therefore the following discussion of the role and impact of RES in voltage support provision will almost exclusively focus on wind energy.

Following the integration of significant number of wind power plants onto the system the online reactive power, both static and dynamic, available to the system operator to manage voltage will fundamentally alter. The main three reasons are:

- The wind power plants are located further from load centres than traditional conventional plant. An analysis of the applications for wind power plant connections in Ireland and Northern Ireland shows that over half the expected 6000 MW will connect to the distribution network (the system up to 2005 had all the significant active and reactive power sources directly connected to the transmission network).
- The reactive power capability from wind power plant as defined in the All Island Grid Code and typically to be found in globally available wind power plants has a reactive power capability of 0.95 p.u. leading/lagging power factor at wind power outputs greater than 50 %. This compares to conventional plants that are required to meet wider ranges of 0.93 leading to 0.85 p.u. lagging (0.8 p.u. for some units in Northern Ireland) power factor at their maximum MW output level and they can give even more MVAr outputs at lower setpoints. Therefore, even if all generators on the system are compliant with the required standards there is a potential reduction in aggregate MVAr control capability with the addition of 6000 MW of wind power plants there is a potential reduction in aggregate MVAr control capability.
- With the increasing penetration of distributed RES, such as wind generation, the nature of the reactive support will change. Instead of being predominantly provided by synchronous generators, which have fast acting excitation systems and the ability to provide constant reactive current during voltage disturbances, more and more will

be provided by doubly fed induction generators, static compensators or static var compensators depending on the nature of the wind power plant. This has implications for the transient stability of the power system, for managing voltage collapse phenomena especially at high load and low wind levels, and ultimately for network design.

A review of the actual available reactive power on the Ireland and Northern Ireland power system using the actual hour-to-hour dispatched output of each unit on the system combined with their known reactive power capability curve shows that the available lagging MVAr ranges between 2500 MVAr to just over 5000 MVAr. Comparing the 2010 with the 2020 model (Figure 11) using an annual duration curve, there is a noticeable reduction in online synchronous reactive power available all through the year. When transmission connected wind power plants are included there is an increase in the available reactive power on the 2020 level, but it still does not meet the levels in 2010. There is less capability to manage voltage in the 2020 power system with high penetrations of wind power plant.

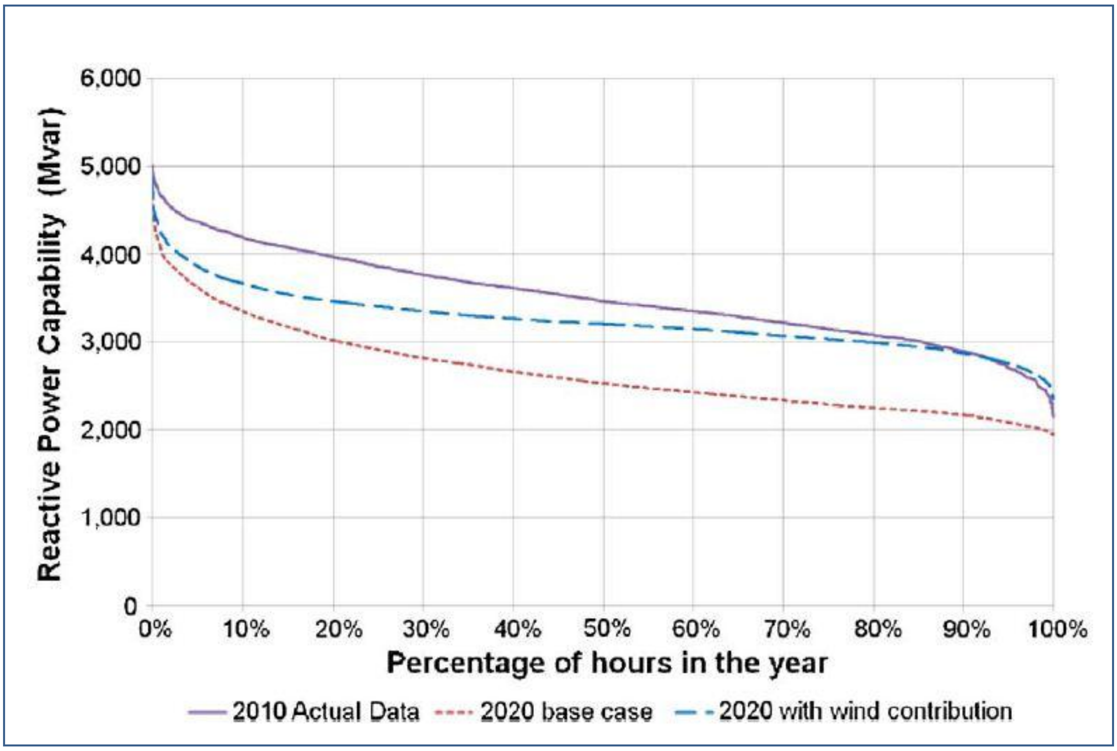

Figure 11: Duration curve for lagging MVAr capability curve for 2010 against 2020

Although it is difficult to quantify the full impact of the reduced and changing nature of reactive power control on the management of voltage, the estimated levels will present significant operational issues in the future. Systematic practices, tools and policies are needed clearly reflecting the issues involved.

Potential challenges mirror in the reactive power duration curve for Dublin. As the largest load centre in Ireland and Northern Ireland it has a ring network of seven 220 kV cables supported by a meshed 110 kV overhead network. Traditionally, this network has high voltage issues during low load periods when the cables are operated below their surge impedance loading and the excess capacitive support needs to be actively managed. Solutions used the combined use of leading MVAr from local transmission connected generators and the switching out of some cables to reduce the charging are solutions used. However, comparing the duration curve for available leading MVAr in 2010 and

2020 (Fig. 9) shows that there will be on average a 400 MVAr reduction in leading MVAr with the subsequent reduced capability to manage high voltage. Some of this will be partly accounted for by increased load due to demand growth but this is unlikely to be sufficient to fully compensate for this level of change.

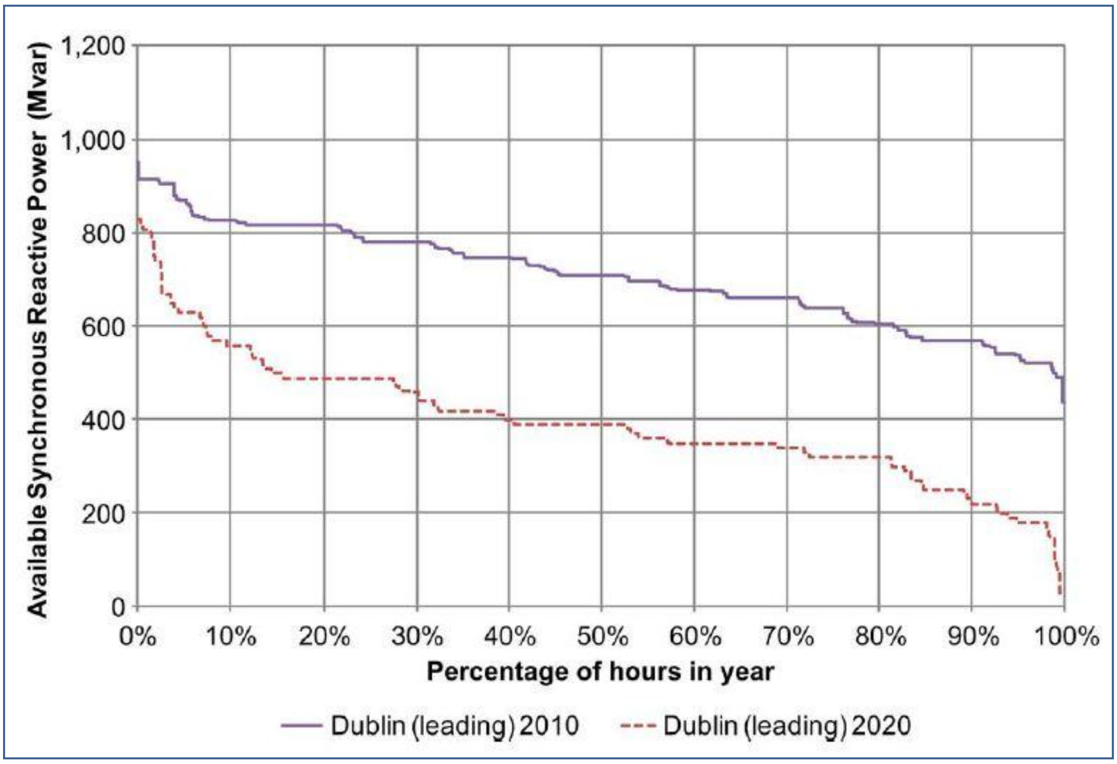

Figure 12: Available leading MVAr in Dublin as measured in 2010 and as projected in 2020. (Source: O'Sullivan et al, 2012)

3.2.3. Reactive power: projected portfolio capability and system characteristics

The Irish study has assumed that as the generation portfolio evolves, the new synchronous generation that is commissioned will provide the reactive power capability. This means that existing generation, which has slightly better than Grid Code capabilities in terms of lagging reactive power but poorer than Grid Code capabilities in terms of leading reactive power, will be replaced with Grid Code compliant generation. In addition, the level of installed synchronous generation is expected to fall by approximately 700 MW. Thus, as illustrated in Figure 13, the system capability for lagging reactive power is expected to fall while the level of leading reactive power is expected to rise.

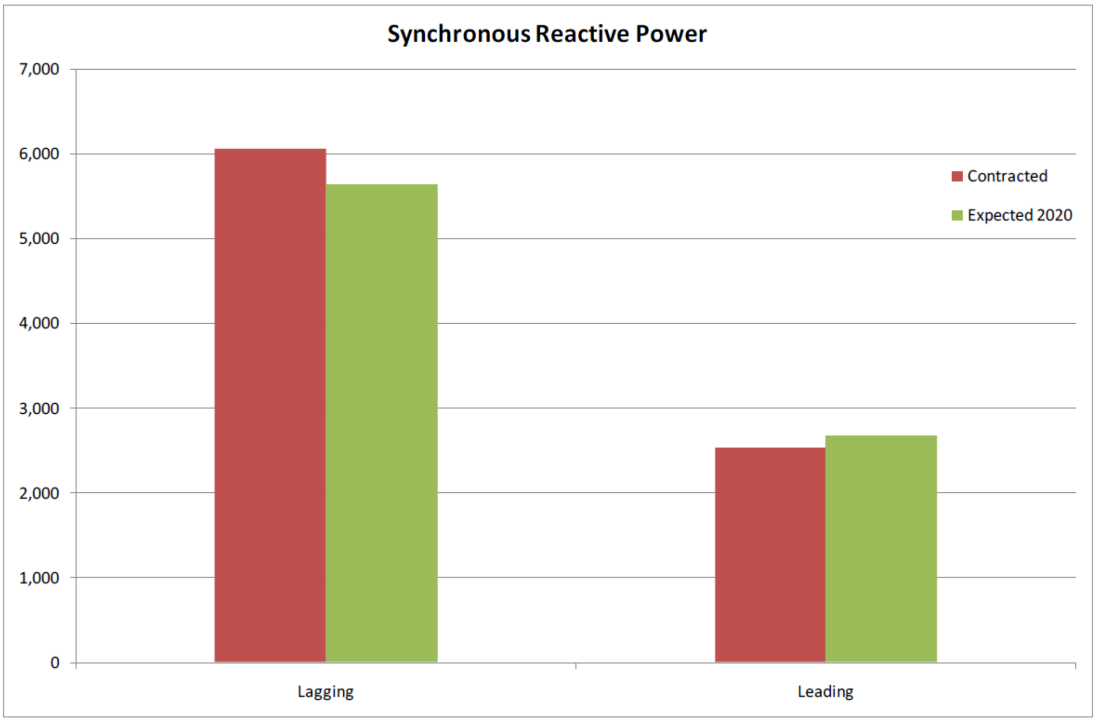

Figure 13: Expected 2020 portfolio synchronous Reactive Power capability (MVAr) (Source: EirGrid and SONI, 2011)

Table 5 shows average available reactive power (i.e. from on-line generation) in 2010 and 2020 (with percentage increase/ decrease). Also shown are two wind cases, one where it is assumed that only Transmission-connected wind (approximately 50%) provides the Grid Code required levels of reactive power, and a second where it is assumed that all wind provides the capability set out in Figure 13.

Table 5: System Reactive Power with different 2020 portfolio and windfarm capabilities (Source: EirGrid and SONI, 2011)

	Lagging Mvar	Leading Mvar
2010	3510	1570
2020 (conventional only)	2650 **(-24%)**	1310 **(-16%)**
2020 (Transmission wind)	3240 **(-8%)**	2000 **(+21%)**
2020 (all wind)	3830 **(+9%)**	2480 **(+58%)**

According to average values and to the reactive power duration curves, Figure 14, the level of available synchronous reactive power is expected to fall by 2020. If the wind generation that displacing the synchronous generation provides an equivalent reactive power service, this reduction can be somewhat offset.

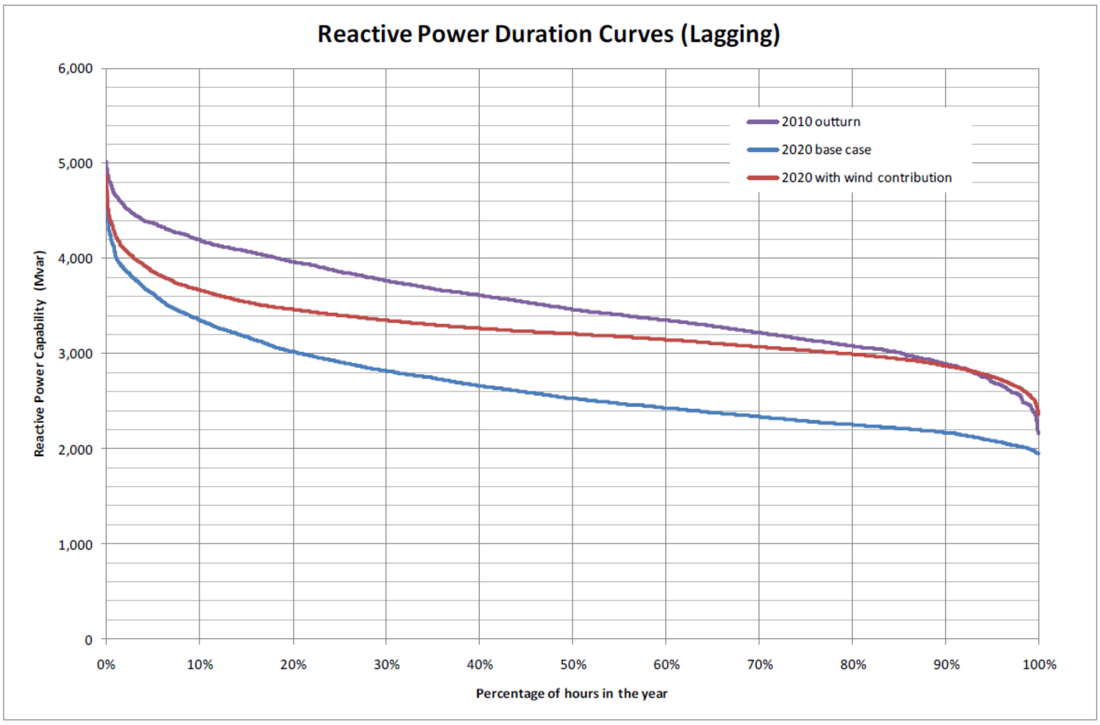

Figure 14: Reactive Power duration curve – evaluated from 2010 actual data and two modeled scenarios in 2020 (graph). (Source: EirGrid and SONI, 2011)

The European wide EWIS study listed additional measures needed to maintain system security as faster protection schemes, more reactive power compensation devices, faster ramping of other plants, and additional protection measures when using dynamic line rating for increasing network capacity. Future wind plants need to be equipped with state-of-the art FRT capability. The joint operation of the European network needs to be better coordinated, and dedicated control centres for renewable sources should be implemented similar to those in Spain (Morales et al., 2008; J. Rodriguez et al., 2008).

3.2.4. Dynamic Reactive Power Considerations

The All Island TSO Facilitation of Renewable Studies (a.k.a. FoR studies, EirGrid and SONI, 2010) indicated that at high system non synchronous penetration levels the transient stability of the system will be significantly compromised (Figure 15). This arises since with fewer on-line synchronous generating units there is a reduction in synchronising torque – the forces that keep generators operating in unison. As the instantaneous penetration of wind increases relative to system demand (and exports), the percentage of contingencies with a critical clearance time (CCT) less than 200ms increases. Since critical clearance time is a measure of the transient stability of the system (with higher critical clearance time denoting greater stability), this means that the system becomes less transiently stable at high wind penetrations relative to system demand.

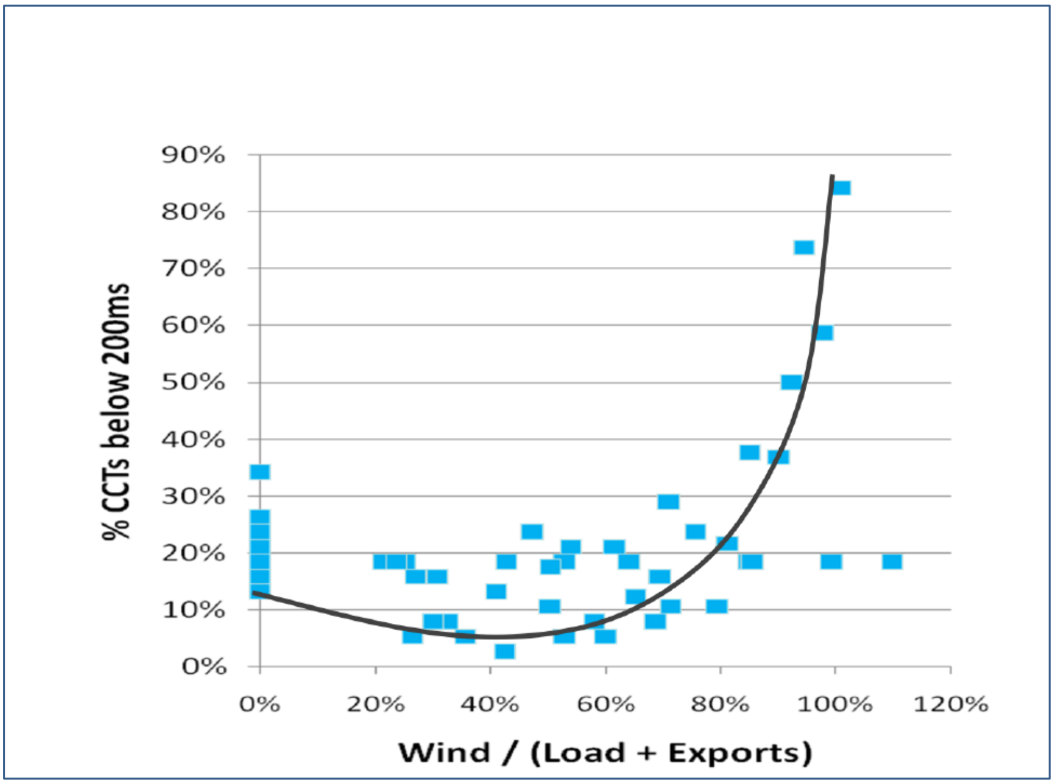

Figure 15: Percentage of contingencies causing Critical Clearance Times (CCT) lower than 200ms vs SNSP (Source: EirGrid and SONI 2011)

However, the FoR studies also indicated that the provision of dynamic reactive power in a measured fashion from network devices (e.g. synchronous compensators or wind farms) during voltage disturbances could be used to mitigate many, if not all, of these issues (Figure 16). The figure shows the impact of the mitigation strategies on the critical clearance times of the contingencies studied. These results suggest that application of the mitigation strategies substantially improves transient stability by increasing the critical clearance time of the most onerous faults.

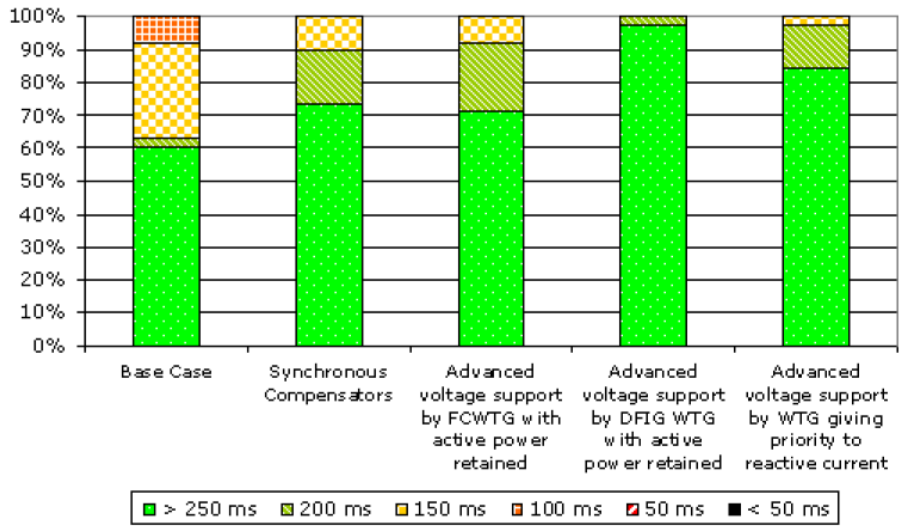

Figure 16: Impact of mitigation strategies for improving transient stability issues on Critical Clearance Times (Source: EirGrid and SONI 2011)

In 2010, the studies determined that the TSOs of Ireland and Northern Ireland can achieve the renewable energy targets securely and effectively by 2020 and can securely manage the system provided that the System Non-Synchronous Penetration (SNSP) level in real-time operations remains below 50 %. SNSP is a measure of the non-synchronous generation on the system in an instant. It is a ratio of the real-time MW generation from wind and HVDC imports to demand plus HVDC exports.

It is expected that by 2020 with the development of enhanced system operational policies, tools and practices, the investment in the required transmission and distribution infrastructure, and the evolution of the appropriate complementary portfolio, the studies indicate that SNSP level of up to 75 % is achievable, Figure 17.

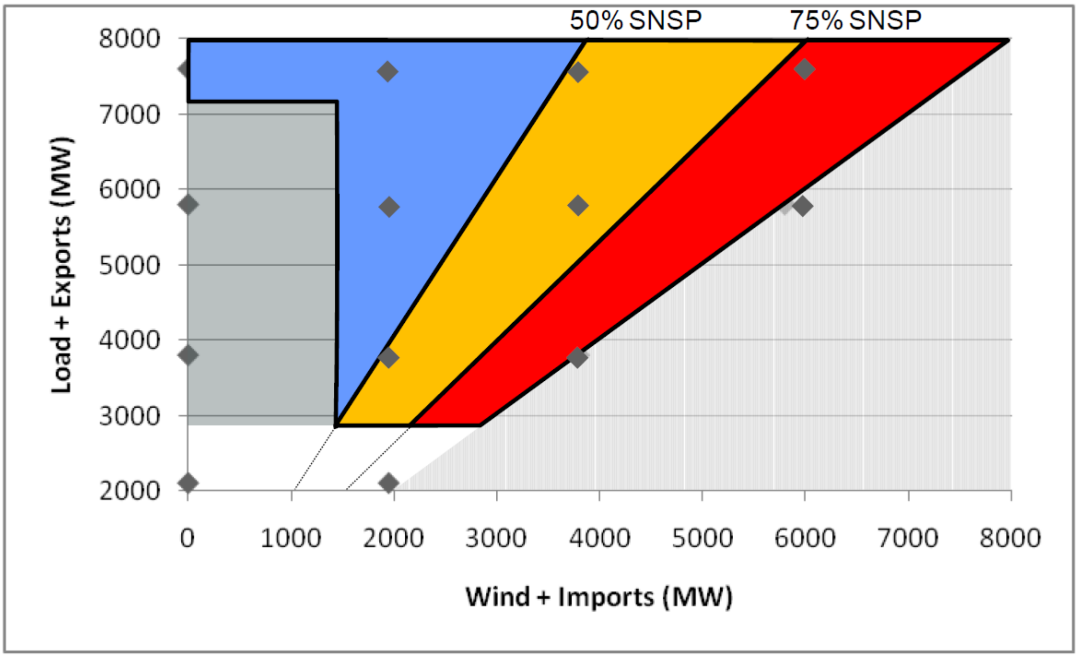

Figure 17: System operability Regions load and HVDC exports vs. Wind generation and HVDC imports (Blue – operable, Amber – need actions to be achieved, Red – unlikely to be feasible even with significant mitigation actions), (Source: FoR Studies EirGrid/SONI, 2010)

The operational SNSP limit set by TSO has a direct impact on the running levels on all generators (both conventional and renewable) and in particular on the level of energy utilisable (on an annual basis) from windfarms. The impact the operational SNSP limit has for a projected Ireland and Northern Ireland system with 6000 MW of installed windfarms and 8370 MW of conventional generation. If actions are taken to allow an increasing operational SNSP limit from 60 % to 75 % the level of annual curtailment on windfarms falls from over 13% to 4%. This has a resultant benefit of increasing the annual amount for energy coming from windfarms from 34 % to 39 %.

[Ensuring a Secure, Reliable and Efficient Power System in a Changing Environment, EirGrid 2011]Results from a GB study are shown in Table 6 (peak load 63 GW so penetration levels are below 20 %).

Table 6 – The total DNO reactive import (MVAr) from the transmission network in MVAr at peak for different level penetration of DG and various power factors (p.f.).

	Aggregate Peak DNO Reactive Imports (MVArs)		
Penetration of DG [GW]	p.f. = 0.975 (lagging)	p.f. = 1	p.f. = 0.975 (leading)
0	19,981	19,981	19,981
2.5	18,107	18,790	19,477
5	16,325	17,671	19,033
7.5	14,629	16,620	18,647
10	13,013	15,635	18,319

*(Source Mutale and Strbac (2005)

3.3. Other services

1. Black start capability

So far there is neither experience nor studies on how wind/PV would impact system restoration, a black start. Wind and solar may pose a potential threat to the system thus risking a black out, but no evidence of this has been produced.

Retirement of conventional power plants will impact the ability of the system to restore. In Spain for instance, black-start is performed by autonomous hydro power plants, which are not considered as retiring due to additions of variable renewables.

2. Islanding

In case of disturbance, a power system section may suffer lack of active power. If in island operation the survival of the island could be secured by activation of a conventional or less conventional power unit equipped with voltage controller. High penetration of RES in the grid considerably changes the islanding scheme. Due to transient stability problem after islanding, a certain balance should be achieved between conventional units and renewable sources in the island. That may be a difficult task in the realm of high RES penetrations and, as a result, larger islands will be sought.

A reduced number of conventional units in the system due to increased RES generation may make it challenging to find a suitable island. Additional measures including fast acting controllers will be needed. A careful transient stability study should be conducted for each new area with considerably increased RES penetration. The results may lead to differently formed islands. There might be no island found and consequently a conventional plant should be planned or fast reacting compensating devices should be installed accordingly. The island should be provided by load rejection and even generating sources rejection to maintain the equilibrium of production and consumption and to maintain the frequency and voltage levels within the required tolerances.

3.4. Summary of system needs at different penetration levels

The impacts of wind/PV to system needs of frequency and voltage support are summarised here for different penetration levels of wind/ solar. Table 7 shows the penetration levels as average over the year (wind/ solar generation relative to total electricity consumption).

Table 8 shows penetration levels as during one hour (instant penetration level).

Studies show that combining different variable renewable sources will be beneficial in smoothing the variability and decreasing overall uncertainty (Lund, 2006; Kavanagh et al 2011).

Table 7: Frequency and voltage control related impacts from wind power, estimated for different European countries at 10 –20 – 30 – 40 % penetration levels from yearly electrical energy (gross demand) based on experience (orange background) and studies (olive background)

	5-15 %	15-25 %	25-35 %	35-45 %
ALL	No significant frequency impacts have been observed that are the result of wind power variation (in some countries curtailments of wind in critical moments to ensure adequacy of frequency control/operating reserves)			
Ireland	Increase in operating reserve requirements estimated to be 2 % of installed wind capacity for hourly variability of wind and 4 % for 4-hourly variability of wind. Curtailments are used to limit non-synchronous (mainly wind) generation to max 50 % of the load (small system size), total 1.2 % of wind generation in 2010 (with 11 % wind penetration).			The percentage of contingencies with a critical clearance time (CCT) less than 200ms increases, and thus the transient stability of the system will be significantly compromised.[1] Enhanced sources of static and dynamic reactive power are needed – also from wind turbines. SNSP will be increased to 75 % to enable 40 % wind penetration with less than 10 % curtailment losses.
Denmark	Forecasting used to bid wind power to day-ahead Nordic electricity market, with imbalance settlement for wind power (2-3 €/MWh extra cost)	Curtailment of wind power is still very rare, due to good connections to neighbouring countries. Nordic balancing market is used for balancing.		

[1] Ensuring a Secure, Reliable and Efficient Power System in a Changing Environment, EirGrid and Soni 2011

Spain	Supervising and controlling wind power in real time (through control centres) has reduced the number of curtailments needed. Curtailments due to insufficient balancing/frequency control have started after >10 % wind penetration.	Curtailments due to insufficient balancing/frequency control have increased year by year, in 2010 this was 0.5 % of total wind power generation (with > 16 % wind penetration). Stronger interconnections with the rest of Europe needed to minimise these curtailments.	Curtailments due to balancing expected to increase. Stronger interconnections needed to minimise these curtailments. Voltage control by RES will help integration and reduce curtailments. More flexible thermal units and higher pumping capacity would also reduce them.	
Portugal	No curtailments of wind power. Operating reserve allocation has been increased to cover wind forecast errors. Reactive power consumption in transmission grid has experienced a decrease due to wind power installed in distribution grid. Static compensation devices have been added to the grid to enable managing high voltages.		New pumped hydro is planned to be built to increase the flexibility of the power system, mainly to avoid curtailment of wind power	
Germany	TSOs use intra-day markets to manage part of the wind power forecast errors from day-ahead markets.			

Table 8: Frequency and voltage control related impacts from wind power, estimated for different European countries at < 50 % ; 50 - 75% and 75 - 100% instant penetration level based on experience (orange background and studies (olive background)

	<50 %	50-75 %	75-100 %	>100 %
Ireland			75% is seen as the upper technical limit. Enhanced sources of static and dynamic reactive power are needed also from wind turbines. Increasing operational SNSP limit from 60 % to 75 % would result in annual curtailment on wind farms reduction from over 13 % to 4 %, increasing the annual amount of wind energy from 34 % to 39 % (in this case, RoCoF-related issues need to be resolved). With the development of enhanced system operational policies, tools and practices, the investment in the required transmission and distribution infrastructure, and the evolution of the appropriate complementary portfolio, the non-synchronous generation on the system in an instant (SNSP) level of up to 75 % is achievable.	
Denmark			Curtailment of wind power is still very rare, due to good connections to neighbouring countries. Nordic balancing market is used for balancing.	These situations have occurred in West Denmark several times per year, and all Denmark also. During high wind low load, always exporting.
Spain		Most RES generators shall comply with new grid code (PO 12.2/ Entso-e NC RfG). Interconnection compared to installed capacity at the level of central Europe. Higher pumping capacity significantly increased. Demand response and provision of ancillary services needed.		
Portugal		No curtailments of wind power.	No curtailments of wind power has occurred in the moments of 60-90 % of load from wind power. This has been managed with pumped hydro and exports to Spain.	

4. COST STRUCTURE AND PROCUREMENT OF ANCILLARY SERVICES

Provision of ancillary services will usually incur costs for the generators. These will vary for different generator types. This section aims for a common way of looking at costs for RES and conventional generation.

The costs of an individual service will also depend on how the service is procured, including eligibility to supply, and performance metric used to ensure the quality of the service procured. For variable renewables the timing and duration of offers will be critical as the forecast errors will increase with higher time horizons (like more than 6 hours ahead). For PV and wind a market to contract services in hourly level (like every 2-6 hours) would enable participation. Also possibility to only bid for certain hours is important – like PV cannot bid for night hours wind not during low wind hours.

Cost structure for a specific service can also imply how a service can be developed to a market in foreseeable future – if costs are not generator or time dependent, a market will give no benefits.

4.1. Examples for procuring the services

Examples of current approaches to contract frequency control services are presented in Table 9. Also Appendix 1 lists procurement of frequency control services in European countries, summarised from ENTSO-E questionnaire that was published as maps. Another survey can be found in Rebours et al (2007).

Table 9: Example of how frequency control offers work in Denmark, Finland, Germany, Spain and Ireland

Reserve Type and Key parameters[2]		Denmark	Finland	Germany	Spain	Ireland (All Island)
Frequency containment reserve (Primary control reserve)	Method of procurement	Auction	Partly yearly auctions and partly hourly market	Auction	Mandatory	Regulated services via bilateral contracts
	Gate closure and duration of the offer	Daily auction in 4 hour blocks, day before at 15:00	for the hours in the next calendar day until 20.00 o'clock	Weekly, 6 Days before	---	---
	Minimum Offer	0.1 MW	normal operation 0.1 MW and disturbance	Min 1 MW	±1.5% nominal power output	

[2] Irish GridCode, Operating Reserve is broken down into 4 time-scales: Primary Operating Reserve, Secondary Operating Reserve, Tertiary Operating Reserve 1 and 2. All the reserves except Primary are expressed as the additional MW output (and/or reduction in Demand) required compared to the pre-incident output (or Demand), fully available and sustainable over the indicated period following a frequency event (Eirgrid 2011).

			reserve 1 MW			
	Activation time and length (Full activation time, and how long needed to keep)	30 s	Normal operation: activated within 3 min (freq change of 0.1 Hz). Disturbance: Half to activate within 5 s, and the all within 30 s (freq change of -0.5 Hz)	30 s	30 s	between 5 and 15 seconds after an Event
	Paid for	Capacity and delivered energy	Capacity fee from hourly bid prices (largest bid taken). Energy fee from balance settlement prices.	Available power	Not remunerated	
Frequency restoration reserve (Secondary control reserve, Direct activated tertiary control reserve)	Method of procurement	Auction	Regulating Power Market of the Nordic TSOs	Auction	Optional service through auction	Regulated services via bilateral contracts
	Gate closure and duration of the offer	DK1: Prior to the delivery month, monthly offer DK2: common auction with SvK, hourly basis, D-2 and D-1 for the automatic FRR. Also Manual – activation time 15	45 min before delivery hour	5 Days before, Weekly	at 16:00, Daily	

		min				
	Minimum Offer		Min 10 MW	Min 5 MW[2]	10 MW	
	Activation time and length	DK1: 15 min DK2: 15 min	15 min, to keep until the end of the hour when called (can be asked to be stopped before the end of the hour)	15 min	Starts in 20 s, full deployment in 15 min	Secondary : 15 to 90 s Tertiary 1: 90 s to 5 min Tertiary 2: 5 min to 20 min
	Paid for	DK2 - Capacity and energy delivered for automatic and only energy delivered for manual	Energy produced, up/down regulation prices from the Regulating Power Market	Available power and energy produced	Availability (reserve) and usage (energy)	
Replacement reserve (Tertiary regulation)	Method of procurement	not existing	not existing	Auction	Optional service through auction	Regulated services via bilateral contracts
	Gate closure and duration of the offer			At 12:00, Daily	15 min before, Intraday	15 minutes notice before dispatch
	Offer			Min 5 MW	10 MW	
	Activation time				15 min and maintained for at least 2 consecutive hours	Replacement Reserve: 20 min to 4 h Substitute Reserve: 4 h to 24 h
	Paid for			Available power and energy produced	Usage (energy)	

* Source: Twenties project, Fingrid and Entso-e operational reserves document Annex A.

** Western Denmark (DK1) is part of the synchronous area of the former UCTE while Eastern Denmark (DK2) is part of Nordel. Due to the technical differences between these two synchronous zones they are handled separately.

*** The pooling of smaller units to reach this limit is permitted.

In addition to the procurement rules summarised in Table 9, there are procedures for verification of compliance and data flow. Regarding the automatic services, the regulation capacity of power plant equipment shall be verified by means of regulation tests, and generator is usually responsible for the costs of the tests. Regarding data flow, generator status information is required (e.g. in Finland every 3 minutes to TSO Fingrid, and history data shall have to be stored for at least four days). If the reserve capacity verified by means of measurements is lower than the bid, payment is only for the capacity delivered, and there can be a compensation payment for capacity not supplied (e.g. in Finland 30 per cent of the price for the hour for that bid) (Fingrid, 2012).

4.1.1. Examples of current approaches to contract voltage support

Examples of more detailed technical specifications and practices for the voltage control services from different countries are presented in the following:

- In Denmark, Germany and Spain, the provision of the reactive power for voltage control services by conventional generators is mandatory. Generators which provide reactive power in Germany and Denmark, do so via bilateral agreements with their respective TSOs. In Germany, wind generators (connected after January 2009) get a bonus for delivering reactive power, while this is not true for PV generators. In Denmark this service is not remunerated and for wind power, it became a requirement in the grid code of 2010. In Spain, special regime generators not involved in the active power market are allowed to trade on a tendering market for the provision of reactive power services. Over and above the basic remuneration there is bonus/penalty system based on producing within a particular power factor range depending on the load situation (Twenties, 2012).
- Spain: voltage control mandatory for all conventional generation and non-remunerated. In case of RES there is a power factor set-point of 1 that would imply receiving a bonus or a penalisation if this power factor is not maintained. TSO (REE) is able to send power factor set-points different than 1 to generators larger or equal to 10 MW. If this set-point is maintained, the generator will receive a bonus and if it is not maintained, it will be penalised. There is a proposal in the process of approval for allowing generators to have voltage control in a similar scheme to the conventional generation, but with bonuses and penalisations.
- Portugal, on the DSO network, has capacitor banks installed on HV/MV substations for grid loss compensation and voltage control. It has been recently imposed that most of Distributed Generation on the DSO network must have the possibility of injecting reactive power.
- Great Britain: NGC procures reactive power through both market-based tender processes and the default arrangements for all generators rated at over 100 MW and default arrangements procure reactive power accordingly.

The default arrangements remunerate generators for reactive power according to utilisation on a €/MVArh basis. (Mutale and Strbac 2005).

- Ireland: Eirgrid: Steady state reactive power is shaped as a product of Reactive Power Capability. It is defined as the reactive power range (in MVAr) that can be provided across the full range of active power output. Payment for Reactive Power Capability will be based on a rate that is scaled by the ratio of the active power output range (Maximum Generation – Minimum Generation) to the Registered Capacity of the generator. It is proposed that payment is based on the reactive capability, irrespective of the dispatched output of the generator. Synchronous and non-synchronous sources as well as synchronous compensators are eligible for this product. This re-structured product definition is illustrated in Figure 18 for a hypothetical 100 MW generator. Payment will be based on a rate that is scaled by the ratio of the active power output range (Maximum Generation – Minimum Generation) to the Registered Capacity of the generator. The difference is shown between what the plant can offer (red) and what TSO can use (blue). (Eirgrid and SONI, 2012a)

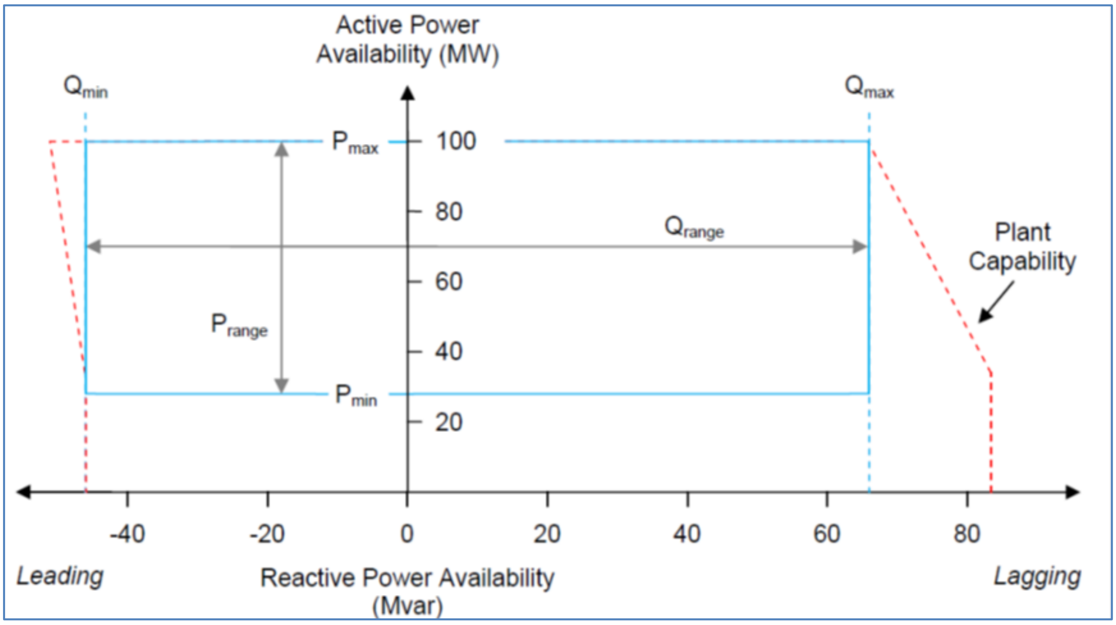

Figure 18: Reactive power capability: what a plant can offer and the TSO can use

- In France, three sources of reactive power management are manageable by Network Operators. Large generators connected to TSOs network are required to provide reactive power management capability, either absorption or injection according to their situation on the network. They can be used as synchronous compensators. Taking into account their proper constraints of stability the set points of operation are directly managed by the TSOs. The TSOs operate compensation devices and in some cases reactors on its own network and compensation devices are connected on the MV bus bars of primary substation. They are operated by DSO within an agreement with the TSO. Only the first one is considered an AS and is subject payment. Actual delivery of service is periodically checked.

4.2. Different ways of paying for services

The procurement and payments for the ancillary services are evolving and there are currently different ways of paying for the services (and some services are considered mandatory without payment). The ways of contracting and paying for the services can be listed as:

- Mandatory service with (or without) payment (mandatory offers or mandatory provision)
- Bilateral contracts
- Tendering – offers, auction
- Market-based

In Europe there are also hybrids of these ways (ENTSO-E, 2012a). Also packaging of services is possible.

For voltage control, payments are often based on long contracts (annual, or monthly), but some auctions are used (f.ex. England, where basic payment for capacity and operation with auction/ offer mechanism operated on a semester base) (Raineri et al, 2006). Some countries only pay for service that extends a mandatory range.

It should be noted that currently not all generators are able to bid/tender/offer all the services, due to pre-qualifications that are restricting or too heavy or costly to be realised by smaller producers.

There is already experience of cross border trade of services in the balancing market (FRR manual) from the Nordic Regulating Power market. In the Central Europe system the need for Frequency Containment Reserve is allocated between the countries.

CIGRE survey from 2010 lists some practices in use globally (Table 10). It can be seen that for (automatic) frequency control, the energy part is mostly unpaid. In some countries, the capacity part is not paid for the other ancillary services, but for most services payments are used.

Table 10: Ancillary Service Procurement Methods, Capacity/ Availability vs. Energy/ Utilisation. (CIGRE, 2010)

	AS-1 Frequency Control		AS-2 Regulation		AS-3 Reserves (Spinning)		AS-4 Reserves (Non-Spinning)		AS -5 Replacement Reserves	
	Capacity	Energy	Capa-city	Energy	Capa-city	Energy	Capa-city	Energy	Capa-city	Energy
Mandatory Unpaid	**BR, PT, SLO, ES**	**AR, BE, BR, NE, PT, SLO, ES**	**AR, BR**		**BE**		**BR**		**FR**	
Mandatory Paid	**E&W(2), FI (2)**	**JP**	**E&W, JP**	**AR, CZ, JP, SLO**	**FI**	**AR**		**AR, JP**		
Bilateral Contracting	**BE, E&W(2), FR**	**FR**	**BE, E&W, FR, PT, SLO**	**BE, FR, PT**	**BE, E&W, FR**	**BE, E&W, FR**	**E&W**	**E&W**	**BE (2), PT, SO (2)**	**PT, SO (2)**
Public Tendering	**BE, CZ, DE**		**BE, CZ (2), DE, NE, SLO, ES**	**BE, DE, SLO, ES**	**E&W, NE**	**E&W, ES**	**CZ**	**AR**	**BE (2), CZ, DE, SLO(2)**	**BE (2), DE, SLO(2), ES**
Real-Time Market	**AU (2)**	**AR**	**AU (2), USA**	**AR, BE, CZ, NE**	**AR, AU (2), ES, USA**	**AR, NE**	**AU (2)**	**AR, CZ**	**ES**	**BE (2), CZ, FR, NE, USA**

ENTSO-E has made a survey in 2012 (ENTSO-E, 2012a) on how the ancillary services for frequency support are currently procured in Europe. These are shown as maps – an example can be seen in Figure 19. For this report the information in the maps was collected in summary tables, which can be found in the Appendix 1.

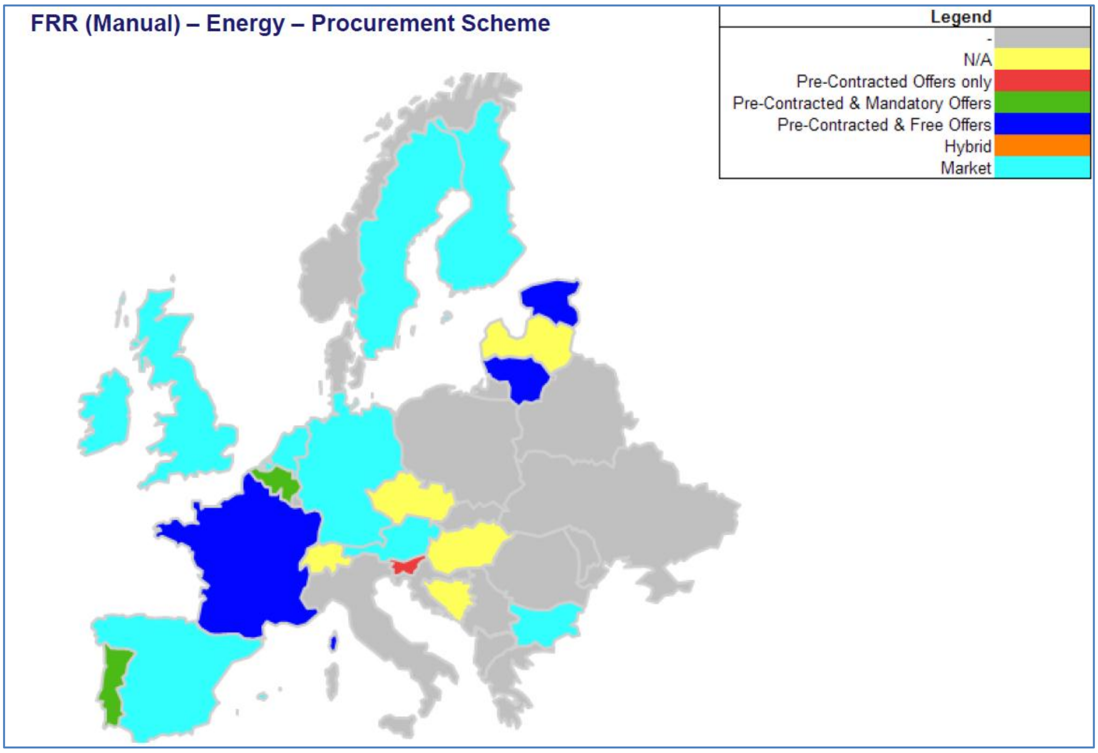

Figure 19: Procurement schemes for the manual frequency restoration reserve. (Source ENTSO-E Oct 2012)

4.3. Examples of existing prices

For active power, payments are made according to Holding (availability) and Response Energy Payments (delivered energy). Holding payments to generators are often based upon cost reflective €/MW/h payments. Response Energy Payments, flowing to and from generators, are remunerated on a €/MWh basis according to different practice (f.ex. a monthly average of system buy and sell prices obtained from the Balancing Mechanism (BM) under NETA, Mutale and Strbac 2005). Sometimes a service in paid for energy only, like for the Regulating Power Market of the Nordic TSOs for providing balancing that is activated in 15 minutes.

Primary frequency regulation (FCR), Raineri et al, Energy policy 2006 (using 0.9508 USD2005/ EUR2012):

- Great Britain 3.7 €/MWh
- California pays for capacity: upward 15.2 €/MW and down 19 €/MW
- Australia 0.02 €/MWh

Secondary frequency regulation (FRR automatic), Raineri et al, Energy policy 2006:

- Great Britain 4.1 €/MWh
- Spain for range 14.3 €/MW, for energy 21.9 €/MWh

- California pays for capacity: 2.2 €/MW plus operation payment for real-time dispatch
- Argentina 2.2 €/MW plus operation payment as a fraction of spot price
- Australia 0.03 €/MWh

Voltage control Raineri et al, Energy policy 2006:

- Great Britain has rates for capacity between 0–0.55 €/MVArh and use 1.25 €/MVArh
- Nordel only for use outside mandatory range (2.6 €/MVArh)
- Australia 0.2 €/MVArh

German prices for holding capacity are available in https://www.regelleistung.net/ip/. It contains tendering results for primary control, secondary control and minute reserve markets.

GB standing reserve services for 2004/2005 (inflation adjusted to 2012 with 1.1825) showed wide variations for both availability and utilisation. Availability prices ranged between 2.64–22.41 €/MWh, with an average price of approximately 6.39 €/MW/h. Similarly, wide ranges of utilisation prices were also witnessed of between 35–650 €/MWh with the largest grouping in the 123–264 €/MWh band (Mutale and Strbac 2005).

Regarding pricing, it is noteworthy that actual delivery of ancillary services is monitored and a penalty is imposed in case of non-delivery in most countries.

Some TSOs publish their balancing needs monthly, e.g. UK/National Grid (www.nationalgrid.com/uk/Electricity/Balancing/Summary/) and Finland/Fingrid (payment for the part of Freq control that is tendered day ahead) (www.fingrid.fi/portal/suomeksi/palvelut/jarjestelmapalvelut/taajuuden_yllapito/).

- Finland hourly prices for automatic Frequency containment reserve for the part of that is tendered day ahead (on average less than 10 MW/hour, max <100 MW/hour)
    - 2012 (1.1.-5.8.) normal operation average 34.5 €/MW (max 560 €/MW)
    - 2011 prices: normal operation average 14.9 €/MW (max 770 €/MW) and disturbance reserve average 16.9 €/MW (max 745 €/MW)
- Denmark (Jutland, DK1 Central European system) Primary frequency control:
    - Capacity upregulation: 32.5 €/MW; downregulation: 3.42 €/MW
    - Energy upregulation: 29.89 €/MWh; downregulation: 28.68 €/MWh
- Denmark (Själland, DK2, Nordic system)
    - Primary (FNR): Capacity upregulation 48.04€/MW; downregulation 32.19 €/MW. Energy upregulation 14.41 €/MW; downregulation 15.21 €/MW
    - Secondary (FDR): Capacity upregulation 22.73 €/MW, Energy upregulation 4.12 €/MWh.

- GB mandatory freq control July 2012: Average price primary 4.63£/MW/h secondary 1.38 £/MW/h, high (?) 5.77£/MW/h

- GB Short Term Operating Reserve July 2012: Average Contracted Availability Payment £7.49 /MW/h, Average Contracted Utilsation Payment £199.89 /MWh, for 3303.251 MWh

- Nordic balancing market (Regulating power market of the 4 TSOs for 15 min activated energy, bids one hour before delivery). Table 11 shows up- and down regulation price differences from the day-ahead price.

Table 11. Average prices in the day-ahead and balancing (regulating) power markets (see also Figure 20).

€/MWh	Elspot average price, Finland	Up regulation, average	Down regulation, average
2004	27,68	1,15	-1,65
2005	30,53	2,85	-1,76
2006	48,57	2,96	-3,00
2007	30,01	3,14	-2,54
2008	51,02	3,79	-5,28
2009	36,98	2,68	-3,66
2010	56,64	4,38	-7,40

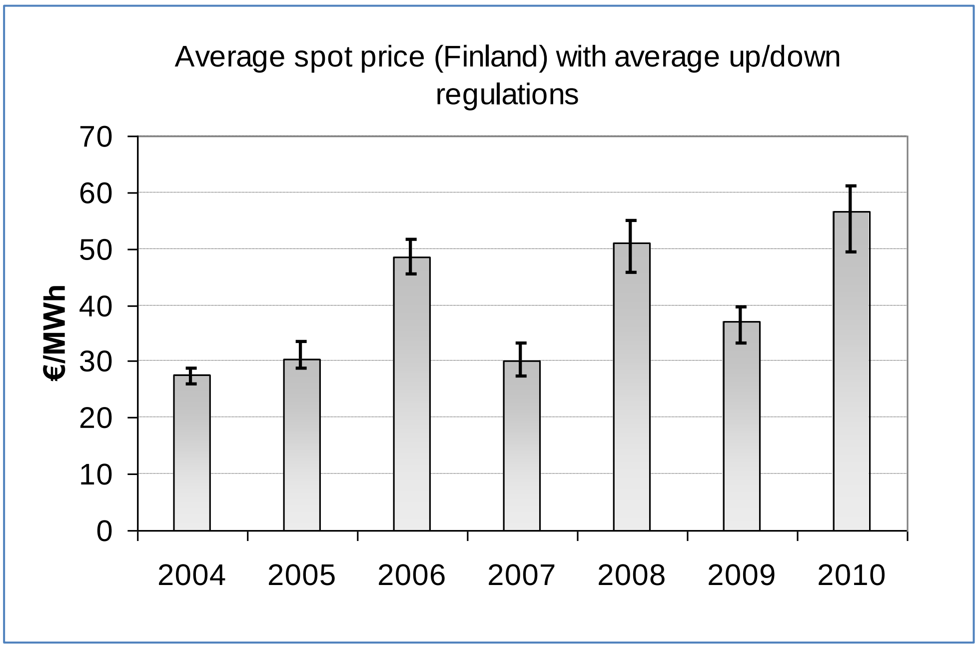

Figure 20: Average price difference of up and down regulation and spot price in the Nordic Regulating power market (spot price is day-ahead Elspot). Finland prices are for years 2004-2010 (Source: Holttinen & Stenberg, 2011)

Table 12: Ancillary Services Payment Rates in Spain

Ancillary services and market prices, year 2011	Detail 1	AVERAGE	MIN	MAX
Secondary Reserve [€/MW]	Marginal price	16.1	2.1	947.7
Secondary Reserve Energy [€/MWh]	UP	48.6	0	180.32
	DOWN	36.1	0	180
Intraday Market [€/MWh]	Session 1	48.7	0	81.65
Tertiary Reserve [€/MWh]	UP	55.4	0	180.3
	DOWN	29.1	0	73.6
Real Time Security Market [€/MWh]	UP	116.1	0	935.74
	DOWN	25.8	0	87.97
Imbalances Management [€/MWh]	UP	53.6	30	150
	DOWN	32.8	0	63.6
Energy Cost [€/MWh] (Final Average Cost)	Free contracting	57.7	2.23	110.11

Source for data: RED Electrica de Espana, MIBEL, http://www.esios.ree.es/web-publica/

Table 13: Ancillary Services Payment Rates in Ireland

Ancillary Services Payment Rates		
Payment Parameters and Rates	**EirGrid**	**SONI**
Primary Operating Reserve	€2.22 / MWh	£1.95/ MWh
Secondary Operating Reserve	€2.13 / MWh	£1.87/ MWh
Tertiary Operating Reserve 1	€1.76 / MWh	£1.55/ MWh
Tertiary Operating Reserve 2	€0.88 / MWh	£0.77/ MWh
Replacement Reserved (Synchronised)	€0.20 / MWh	£0.18/ MWh
Replacement Reserve (De-Synchronised)	€0.51 / MWh	£0.45/ MWh

* (Source: KEMA 2011)

4.4. Modelling cost structures for ancillary services

We have made a basic cost structure presented in Table 14. This lists the possible costs in three categories:

- Cost for ability/capability (investment),
- Readiness (cost for capacity reserved, opportunity cost loosing energy that cannot be sold) and,
- Utilisation (actual provision of the services).

Table 14: Cost structure that is used as basis for all ancillary services

Ability / capability	Readiness / holding / availability	Utilisation / response
• investment cost related to providing the capability	• cost for capacity reserved, opportunity cost loosing energy that cannot be sold • link to other markets	• actual provision of the service, like energy as used with fuel cost • increased maintenance costs (wear and tear)

There can be additional costs from offering a service, related to compliance and testing of the service quality, as well as from communication costs. TSOs and DSOs will evaluate the performance of ancillary service providers in relation to declared availability and contracted provisioning. Quality of the response from generating units to active and reactive power set points and the response to reserve calls will be monitored.

4.4.1. Cost for providing Frequency control services

For frequency control services there is usually payment for Capacity (fixed) and/or energy (as used). There is an opportunity cost of energy that cannot be sold to electricity markets.

Frequency control cost components for the automatic services are listed in (Raineri et al, 2006) as Capacity (investment), Operation/generation cost (fuel), Opportunity cost and Maintenance and lifetime reduction (based on survey from England, Spain, Nordel, California, and Australia).

4.4.2. Cost for providing Voltage control services

Voltage control cost components are listed in (Raineri et al., 2006) as Capacity (investment), Operation, Opportunity cost and Maintenance and lifetime reduction (based on survey from England, Spain, Nordel, California, and Australia).

In many cases there is no explicit commercial cost associated with the supply or absorption of reactive power. The cost of generating reactive power is mainly due to the active losses in the generator and in the step up transformer caused by the reactive power. These losses can be divided in Joule eddy, hysteresis and stray losses, and the losses of the excitation system (Gil et al., 2000). From the transmission network point of view the injected active and reactive power and the voltage in the high voltage bus characterise the generation plant. The generator operator tries to minimise the generation plant total losses while keeping the above constraints. The net result is that, for a given injected active power, high side voltage and transformer tap, the generation unit losses depends almost quadratically of the injected reactive power, with minimum losses for a slightly capacitive power factor (Barquin et al., 1998). Fixed part and variable part of cost: Fixed part requires investments. Variable part of cost is mainly due to active losses in generator and in step up transformer caused by reactive power.Different magnitude of its active power losses -> these losses should be valued to the active power cost, comparison between reference and injected P and Q power values, the service cost (Barquin et al., 1998).

Table 15: Comparison of voltage control costs between generators and other sources:

Equipment type	Speed of Response	Ability to support Voltage	Costs (in U.S. $)		
			Capital (per kVAr)	Operating	Opportunity
Capacitor	Slow, stepped	Poor, drops with V^2	$ 8-10	Very low	No
STATCOM	Fast	Fair, drops with V	$ 50-55	Moderate	No
SVC	Fast	Poor, above its rated value it drops with V^2	$ 45-50	Moderate	No
Synchronous condenser	Fast	Excellent, additional short-term capacity	$ 30-35	High	No
Distribution generation	Fast	Fair, drops with V	Difficult to separate	High	Yes
Generator	Fast	Excellent, additional short-term capacity	Difficult to separate	High	Yes

* Alvarado et al 2003 (taken from Pirbazari 2011).

REFERENCES

ENTSO-E Network codes and supporting documents:

- NC RfG: Network Code Requirements for Grid Connection (Submitted to ACER 13th July 2012), available at: https://www.entsoe.eu/resources/network-codes/requirements-for-generators/ (31.10.2012)
    - NC RfG Requirements in the context of present practices June, 2012 (input to comparison to practices in different EU countries)
- LFC&R NC: Load-Frequency-Control & Reserves Network Code. Draft 14.09.12, available at https://www.entsoe.eu/resources/network-codes/load-frequency-control-reserves/ (31.10.2012)
    - Ad Hoc team Operational Reserves Final Report 12.06.12
    - Survey on Ancillary services procurement & balancing market design, Oct 2012 (the information in maps has been presented in tables in the appendix of this document)
- OS NC: Operational Security Network Code (draft 3rd Sept 2012), available at: https://www.entsoe.eu/resources/network-codes/operational-security/ (31.10.2012)
- OH: Operational Handbook, available at: https://www.entsoe.eu/resources/publications/system-operations/operation-handbook/ (31.10.2012)
- Survey on Ancillary Services Procurement & Balancing market design, September 2012a, available at: https://www.entsoe.eu/fileadmin/user_upload/_library/resources/BAL/121022_Survey_on_AS_Procurement_and_EBM_design.pdf (6.11.2012)
-

Other references:

- Alvarado F., Borissov B., Kirsch L., "Reactive Power as an identifiable ancillary service", Laurits R. Christensen Associates Inc., March 18, 2003.
- Barquín J., Soler D., Largo O., Relaño G., and de la Fuente I., On the Cost of the Reactive Power Generation and Voltage Support Service, Proceedings of the Bulk Power System Dynamics and Control IV – Restructuring, Santorini, Greece, 24-28 August 1998.
- Braun et al., Is the distribution grid ready to accept large-scale photovoltaic deployment? State of the art, progress, and future prospects, Proc. of 26th EU PVSEC, Hamburg, Germany 2011.
- CIGRE, Ancillary Services: an overview of International Practices, CIGRE Working Group C5.06, Oct. 2010.
- Cuffe P., Smith P., Keane A., Transmission System Impact of Wind Energy Harvesting Networks. IEEE Transactions on Sustainable Energy, Vol. 3, No. 4, October 2012.
- Econnect Ltd, Islanded Operation of Distribution Networks, DTI DG/CG/00026/00/00, 2005, available at:

http://webarchive.nationalarchives.gov.uk/20100919181607/http:/www.ensg.gov.uk/assets/dgcg00026.pdf

- De Decker J. and Kreutzkamp P., et al., Offshore Electricity Grid Infrastructure in Europe A Techno-Economic Assessment, October 2011.
- Dudurych I.M., Statistical analysis of frequency response of island power system under increasing wind penetration, IEEE PES General Meeting 2010.
- EirGrid Grid Code v.4.0,8.12.2012, http://www.eirgrid.com/media/Grid%20Code%20Version%204.pdf
- EirGrid and SONI, DS3: System Services Consultation – New Products and Contractual Arrangements, EirGrid and SONI, June 2012a.
- EirGrid and SONI, "DS3 System Services Review, Consultation Paper–New Products", presentation, 4th July 2012b.
- EirGrid and SONI, Ensuring a Secure, Reliable and Efficient Power System in a Changing Environment, EirGrid and SONI, June 2011.
- EirGrid and SONI, All Island TSO Facilitation of Renewables Studies, EirGrid and Soni, June 2010.
- EPIA, Connecting the Sun – Solar photovoltaics on the road to large-scale grid integration, Full Report, September 2012.
- Eto J., J. Undrill, P. Mackin, R. Daschmans, B. Williams, B. Haney, R. Hunt, J. Ellis, H. Illian, C. Martinez, M. O'Malley, K. Coughlin, and K.H. LaCommare, Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation. Lawrence Berkeley National Laboratory, Berkeley, CA, USA, 141 pp, 2010.
- Estanqueiro A., Mateus C.B, and Pestana R., Operational experience of extreme wind penetrations. In: 9th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants, Quebec City, Canada, pp. 34-39, 18-19 October 2010.
- EURELECTRIC, Ancillary Services. Unbundling Electricity Products – an Emerging Market. EURELECTRIC Thermal Working Group, Ref: 2003-150-0007, Feb. 2004.
- Fingrid, 2012. Hourly market agreement and Application instructions, available at http://www.fingrid.fi/portal/in_english/services/system_services/maintenance_of_frequency/
- Gil A, de la Torre M, Dominguez T, Rivas R. Influence of wind energy forecast in deterministic and probabilistic sizing of reserves. Proceedings of the 9th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants. Québec City, 18-19.10.2010. pp 83-88
- Gubina F. and Gubina A.F. Investigation of voltage profiles in power system. V: International Colloquium and Meeting SC-39 CIGRÉ, 07-12 November 1999, Curitiba, Brazil.
- Haubrich H.J., Gutachten zur Höhe des Regelenergiebedarfs. Gutachten im Auftrag der Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post

und Eisen-bahnen, 2008 available at http://www.bundesnetzagentur.de/cae/servlet/contentblob/102556/publicationFile/5861/Gutachten%20zur%20H%C3%B6he%20des%20Regelenergiebedarfes.pdf

- van Hulle F, Integrating Wind – Developing Europe's power market for the large-scale integration of wind power, Final report of the Intelligent Energy Europe research program TradeWind, February 2009.
- Holttinen H., Meibom P., Orths A., van Hulle F., Lange B., O'Malley M., Pierik J., Ummels B., Tande J.O., Estanqueiro A., Matos M., Gomez E., Söder L., Strbac G., Shakoor A., Ricardo J., Smith J.C., Milligan M., Ela E., "Design and operation of power systems with large amounts of wind power" Final report, IEA WIND Task 25, Phase one 2006-2008. Espoo, VTT. 200 p. + app. 29 p. VTT Tiedotteita - Research Notes 2493. Available at http://www.vtt.fi/inf/pdf/tiedotteet/2009/T2493.pdf
- de Haan J.E.S, Aliano M., Frunt J., Kling W.L., Consideration of the load-frequency control and performance of the continental European power system during large imbalances. Proceedings of the 11th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants. Lisbon, 13-15.11.2012. pp 514-519.
- Holttinen H. Orths A.G., Eriksen P., et al., Currents of change, IEEE Power & Energy Magazine, IEEE, USA. Vol. 9, No. 6, pp. 47-59, 2011.
- Holttinen H. and Stenberg A., 2011. Wind power balancing costs for different size actors in the Nordic electricity market. Conference proceedings of the EWEA2011. EWEA. 2011, Brussels, Belgium, 14 - 17 March 2011
- ILEX Energy Consulting, Ancillary Service Provision from Distributed Generation, DTI Distributed Generation Programme, 2004.
- IPCC, 2011. Sims R., P. Mercado, W. Krewitt, G. Bhuyan, D. Flynn, H. Holttinen, G. Jannuzzi, S. Khennas, Y. Liu, M. O'Malley, L. J. Nilsson, J. Ogden, K. Ogimoto, H. Outhred, Ø. Ulleberg, F. van Hulle, 2011: Integration of Renewable Energy into Present and Future Energy Systems. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Kavanagh D., Keane A. and Flynn D., Challenges posed by the integration of wave power onto the Irish power system. Proceedings of the 9th European Wave and Tidal Energy Conference, Southampton, UK, 5–9th September, 2011.
- KEMA Inc., System Services International Review, Market Update, 16010876, London, November 24, 2011.
- Kundur P., Power System Stability and Control, McGraw-Hill, 1994.
- Kuzle I. and Sabolić D, Ancillary Services in the South East Europe, Presentation in the 8th International conference on the European Energy Market, 2011.

- Lund H., Large-scale integration of optimal combinations of PV, wind and wave power into the electricity supply, Renewable Energy, pp. 503-515, Vol. 31/4, April 2006.
- Miguélez E.L., Cortés I.E., Rodríguez L.R., Camino G.L., An overview of ancillary services in Spain, Electric Power Systems Research, pp. 515-523, Volume 78, Issue 3, 2008.
- Mullane A. and O'Malley M.J., The Inertial Response of Induction-Machine-Based Wind Turbines, IEEE TPWRS, Vol. 20, No. 3, August 2005.
- Mutale J. and Strbac G. DISPOWER project Task 5.5: Development of contract structures for ancillary services from distributed generation. University of Manchester (2005).
- O'Malley et al. Operating Reserve Requirements as Wind Power Penetration Increases in the Irish Electricity System, 2004 http://www.seai.ie/Archive1/Files_Misc/IlexWindReserrev2FSFinal.pdf
- O'Sullivan J., Coughlan Y., Rourke S., and Kamaluddin N., "Achieving the Highest Levels of Wind Integration— A System Operator Perspective", IEEE Transactions on Sustainable Energy, Vol. 3, No. 4, October 2012
- Van Overbeeke, F. and Roberts, V., "Active Networks as facilitators for embedded generation", IQPC Conferencia sobre "Embedded Generation within Distribution Networks", Londres. Enero. Y también el mismo trabajo se presentó en la conferencia "Cogeneration and On-Site Power Production" (COSPP), de Marzo-Abril, 2002. Available at: http://nu.eltra.dk/dok/NUdok92.pdf
- Pirbazari A.M., "Ancillary services definitions, markets and practices in the world", 2010 IEEE/PES Transmission and Distribution Conference and Exposition: Latin America, T and D-LA 2010, pp. 32, 2011.
- Raineri R., Ríos S. and Schiele D., Technical and economic aspects of ancillary services markets in the electric power industry: an international comparison, Energy Policy, vol. 34, pp.1540-1555, 2006.
- Rebours Y.G., Kirschen D.S., Trotignon M., Rossignol S., "A survey of frequency and voltage control ancillary services - Part I: Technical features", IEEE Transactions on Power Systems, vol. 22(1), pp. 350-357, 2007.
- RenewableUK, Position Paper on Inertia, 7th April 2011: http://www.bwea.com/pdf/publications/RenewableUK_Inertia_Position_Paper.pdf
- Ribeiro F., 2012. Impact of wind power in the Portuguese system operation. Proceedings of the 11th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants. Lisbon, 13-15.11.2012. pp 205-208.
- Ruttledge L., Miller N.W., O'Sullivan J., Flynn D., "Frequency Response of Power Systems With Variable Speed Wind Turbines," IEEE Transactions on Sustainable Energy, vol.3, no.4, pp.683-691, Oct. 2012
- SUPWIND project deliverable 8.1 – Assessment of market designs for energy and ancillary services

- Söder L., Hofmann L., Orths A., Holttinen H., Wan Y.H., and Tuohy A., Experience from wind integration in some high penetration areas. IEEE Transactions on Energy Conversion, 22(1), pp. 4-12, 2007.
- Thomson M., and D.G. Infield (2007). Impact of widespread photovoltaics generation on distribution systems. IET Renewable Power Generation, 1(1), pp. 33-40.
- vanWesenbeeck M. P. N, deHann S.W.H., Varela P., and Visscher K., Grid tied converter with virtual kinetic storage Proc. IEEE Power, Tech Conf., Bucharest, Romania, Jul. 2009
- Widén J., E. Wäckelgård, and P.D. Lund (2009). Options for improving the load matching capability of distributed photovoltaics: Methodology and application to high-latitude data. Solar Energy, 83(11), pp. 1953-1966.
- Winter W (ed.), European Wind Integration Study (EWIS) – Final Report. http://www.wind-integration.eu/downloads/library/EWIS_Final_Report.pdf, 10.8.2011.

APPENDIX 1. SUMMARY OF ENTSO-E SURVEY FOR RESERVES

Table 16. Summary of frequency control procurement procedures for Frequency containment reserve in European countries (Source: ENTSO-E, 2012a)

Country	Procurement Scheme: Hybrid		Organised Market		Bilateral Market		Mand. Provision, no Reservation		Mandatory Provision		Mandatory Offers		N/A		Minimum Bid Size: <= 5 MW		<= 1 MW		No minimum bid size		N/A	
	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E
Austria			X											X	X							X
Belgium			X											X			X					X
Bosnia and Herzegovina									X					X					X	X		
Bulgaria									X			X										
Czech Republic			X											X	X							
Denmark DK1			X											X			X	X				
Denmark DK2			X											X			X	X				
Estonia													X	X								
Finland			X											X			X	X				
France									X					X			X	X				
Germany			X											X			X					X
Hungary											X			X			X					
Ireland				X					X								X					X
Italy													X	X								
Latvia													X	X								
Lithuania													X	X								
Netherlands									X					X					X	X		
Norway	X													X			X	X				
Poland		X					X										X	X				
Portugal									X					X					X	X		
Slovakia			X											X			X	X				
Slovenia											X	X							X	X		
Spain									X					X					X			X
Sweden			X											X			X	X				
Switzerland			X											X			X					X
United Kingdom				X					X						X	X						
Total	1	1	10	2	0	0	1	0	8	0	2	2	4	21	3	1	13	8	5	4	0	6

Country	Timeframe for Product: 15 minutes	Hour(s)		Day(s)	Week(s)	Month(s)	Year or more	N/A		Timing for Offers / Gate Closure: D-1	> D-1	Day(s)	Week(s)	Month(s)	Year or more	N/A	
	E	C	E	C	C	C	C	C	E	E	E	C	C	C	C	C	E
Austria					X				X				X				X
Belgium							X		X						X		X
Bosnia and Herzegovina								X	X							X	X
Bulgaria								X	X							X	X
Czech Republic				X					X				X				X
Denmark DK1			X	X								X					X
Denmark DK2		X							X			X					X
Estonia																	
Finland		X							X			X					X
France	X							X								X	X
Germany					X				X				X				X
Hungary								X	X			X					X
Ireland			X				X								X		X
Italy								X	X							X	X
Latvia								X	X							X	X
Lithuania																X	X
Netherlands								X	X							X	X
Norway		X							X				X				X
Poland			X				X			X		X					
Portugal								X	X							X	X
Slovakia			X	X						X		X					
Slovenia								X	X							X	X
Spain		X							X						X		X
Sweden		X							X			X					X
Switzerland					X				X				X				X
United Kingdom			X	X									X				X
Total	1	5	5	4	3	0	3	9	18	2	0	7	6	0	3	9	23

Country	Settlement Rule: Hybrid	Regulated Price		Marginal Pricing		Pay as Bid		N/A		Capacity & Energy - Monitoring: Hybrid	Ex-Post Check	Real-Time Monitoring	N/A	Sec. Market for Res. Oblig.: Yes	No	N/A
	E	C	E	C	E	C	E	C	E	C,E	C,E	C,E	C,E	C	C	C
Austria						X			X		X				X	
Belgium						X			X		X				X	
Bosnia and Herzegovina								X	X			X			X	
Bulgaria	X	X									X				X	
Czech Republic						X			X		X				X	
Denmark DK1				X					X			X			X	
Denmark DK2				X					X			X			X	
Estonia																
Finland			X	X						X					X	
France		X	X							X				X		
Germany						X			X			X			X	
Hungary						X			X		X				X	
Ireland	X	X								X					X	
Italy								X	X			X			X	
Latvia								X	X				X			X
Lithuania								X	X				X			X
Netherlands								X	X		X				X	
Norway				X	X					X					X	
Poland		X			X					X					X	
Portugal								X	X				X			X
Slovakia		X			X							X			X	
Slovenia								X	X				X			X
Spain								X	X		X			X		
Sweden			X			X				X					X	
Switzerland						X			X	X					X	
United Kingdom						X	X			X					X	
Total	2	5	3	4	3	8	1	8	16	8	7	6	4	2	19	4

Table 17. Summary of frequency control procurement procedures for Frequency restoration (automatic) reserve in European countries (Source: ENTSO-E, 2012a)

Procurement Scheme											
Country	Hybrid C	Hybrid E	Market E	Organised Market C	Bilateral Market C	Mandatory Prov. without Reservation C	Mandatory Provision C	Mandatory Offers C	Mandatory Offers E	N/A C	N/A E
Austria			X	X							
Belgium			X	X							
Bosnia and Herzegovina									X		
Bulgaria					X				X		
Czech Republic				X							X
Denmark DK1				X							
Denmark DK2											
Estonia										X	X
Finland											
France								X			X
Germany			X	X							
Hungary								X			X
Ireland			X								
Italy									X	X	
Latvia										X	X
Lithuania										X	X
Netherlands			X		X						
Norway											
Poland		X				X					
Portugal								X			X
Slovakia				X							X
Slovenia					X						X
Spain		X		X							
Sweden											
Switzerland			X	X							
United Kingdom	X		X								
Total	1	2	7	8	3	1	0	3	3	4	9

Activ. Rule			
Country	Merit Order E	Pro-Rata (Parallel Activation) E	N/A E
Austria	X		
Belgium		X	
Bosnia and Herzegovina		X	
Bulgaria		X	
Czech Republic		X	
Denmark DK1			
Denmark DK2			
Estonia			
Finland			
France		X	
Germany	X		
Hungary	X		
Ireland		X	
Italy	X		
Latvia			X
Lithuania			X
Netherlands	X		
Norway			
Poland		X	
Portugal			X
Slovakia	X		
Slovenia		X	
Spain		X	
Sweden			
Switzerland		X	
United Kingdom	X		
Total	7	10	3

Minimum Bid Size										
Country	> 10 MW C	<= 10 MW C	<= 5 MW C	<= 5 MW E	<= 1 MW C	<= 1 MW E	No minimum bid size C	No minimum bid size E	N/A C	N/A E
Austria				X						
Belgium						X				
Bosnia and Herzegovina							X	X		
Bulgaria										
Czech Republic		X								
Denmark DK1					X					
Denmark DK2										
Estonia										
Finland										
France					X	X				
Germany				X						
Hungary		X								
Ireland					X					X
Italy						X				
Latvia										
Lithuania										
Netherlands				X						
Norway										
Poland					X	X				
Portugal	X							X		
Slovakia					X	X				
Slovenia							X	X		
Spain	X							X		
Sweden										
Switzerland				X						
United Kingdom				X						
Total	2	2	0	5	5	5	2	4	0	1

Timeframe for Product										
Country	15 minutes E	30 minutes E	Hour (or Blocks) E	Hour(s) C	Day(s) C	Week(s) C	Month(s) C	Year or more C	N/A C	N/A E
Austria			X			X				
Belgium	X							X		
Bosnia and Herzegovina							X			X
Bulgaria									X	X
Czech Republic			X		X					
Denmark DK1							X			
Denmark DK2										
Estonia										
Finland										
France		X							X	
Germany			X			X				
Hungary			X						X	
Ireland		X						X		
Italy			X						X	
Latvia									X	X
Lithuania										
Netherlands	X							X		
Norway										
Poland			X					X		
Portugal				X						X
Slovakia			X		X					
Slovenia			X					X		
Spain			X	X						
Sweden										
Switzerland			X			X				
United Kingdom			X		X					
Total	2	2	11	2	3	3	2	5	5	4

Timing for Offers / Gate Closure										
Country	Day(s) C	Week(s) C	Month(s) C	Year or more C	<= H-1 E	> H-1 E	D-1 E	> D-1 E	N/A C	N/A E
Austria		X					X			
Belgium				X			X			
Bosnia and Herzegovina									X	X
Bulgaria									X	X
Czech Republic		X								X
Denmark DK1			X							
Denmark DK2										
Estonia										
Finland										
France					X				X	
Germany		X						X		
Hungary	X						X			
Ireland				X		X				
Italy						X			X	
Latvia									X	X
Lithuania									X	X
Netherlands				X	X					
Norway										
Poland	X						X			
Portugal	X									X
Slovakia	X									X
Slovenia				X						X
Spain	X									X
Sweden										
Switzerland		X						X		
United Kingdom			X							X
Total	5	4	2	4	2	2	4	2	6	10

Settlement Rule									
Country	Hybrid E	Regulated Price C	Regulated Price E	Marginal Pricing C	Marginal Pricing E	Pay as Bid C	Pay as Bid E	N/A C	N/A E
Austria						X	X		
Belgium						X	X		
Bosnia and Herzegovina		X							X
Bulgaria	X	X							
Czech Republic			X			X			
Denmark DK1			X			X			
Denmark DK2									
Estonia									
Finland									
France		X	X						
Germany						X	X		
Hungary						X	X		
Ireland	X	X							
Italy							X	X	
Latvia								X	X
Lithuania								X	X
Netherlands					X	X			
Norway									
Poland		X			X				
Portugal				X					X
Slovakia		X			X				
Slovenia						X	X		
Spain				X	X				
Sweden									
Switzerland	X					X			
United Kingdom						X	X		
Total	3	6	3	2	4	10	7	3	4

Capacity & Energy - Monitoring				
Country	Hybrid C,E	Ex-Post Check C,E	Real-Time Monitoring C,E	N/A C,E
Austria	X			
Belgium		X		
Bosnia and Herzegovina	X			
Bulgaria		X		
Czech Republic			X	
Denmark DK1			X	
Denmark DK2				
Estonia				
Finland				
France	X			
Germany			X	
Hungary			X	
Ireland	X			
Italy			X	
Latvia				X
Lithuania				X
Netherlands		X		
Norway				
Poland	X			
Portugal		X		
Slovakia			X	
Slovenia	X			
Spain			X	
Sweden				
Switzerland	X			
United Kingdom	X			
Total	8	4	7	2

Table 18. Summary of frequency control procurement procedures for Frequency restoration (manual) reserve in European countries (Source: ENTSO-E, 2012a)

	Procurement Scheme									Activ. Rule			Minimum Bid Size												Timeframe for Product										Timing for Offers / Gate Closure										Settlement Rule									Capacity & Energy - Monitoring				Sec. Market for Res. Oblig.		
	Market	Organised Market	Bilateral Market	Mandatory Provision	Pre-Contr. & Free Offers	Pre-Contr. & Mand. Offers	Pre-Contracted Offers only	N/A		Merit Order	Pro-Rata (Parallel Activ.)	N/A	> 10 MW		<= 10 MW		<= 5 MW		<= 1 MW		No minimum bid size		N/A		15 minutes	30 minutes	Hour (or Blocks)	Hour(s)	Day(s)	Week(s)	Month(s)	Year or more	N/A		Day(s)	Week(s)	Month(s)	Year or more	<= H-1	> H-1	D-1	> D-1	N/A		Hybrid	Regulated Price		Marginal Pricing		Pay as Bid		N/A		Hybrid	Ex-Post Check	Real-Time Monitoring	N/A	Yes	No	N/A
Country	E	C	C	C	E	E	E	C	E	E	E	E	C	E	C	E	C	E	C	E	C	E	C	E	E	E	E	C	C	C	C	C	C	E	C	C	C	C	E	E	E	E	C	E	E	C	E	C	E	C	E	C	E	C,E	C,E	C,E	C,E	C	C	C
Austria	X	X								X					X	X											X			X						X					X							X		X	X				X				X	
Belgium		X				X				X									X	X					X							X						X		X								X		X	X				X				X	
Bosnia and Herzegovina								X	X			X									X	X											X	X									X	X				X				X	X				X			X
Bulgaria	X							X		X				X													X						X								X		X			X					X				X				X	
Czech Republic		X							X	X					X												X		X							X								X				X		X	X					X			X	
Denmark DK1		X													X														X						X													X	X							X			X	
Denmark DK2																																																												
Estonia				X	X					X											X	X					X				X						X			X								X		X	X					X				X
Finland	X		X							X					X	X											X					X						X	X									X	X	X				X					X	
France		X			X					X			X			X										X						X						X	X									X		X	X			X					X	
Germany	X	X								X							X	X									X	X							X						X							X		X	X					X			X	
Hungary								X	X			X																					X	X									X	X				X				X	X				X			X
Ireland	X			X						X									X					X		X						X						X		X					X	X								X					X	
Italy																																																X												
Latvia			X							X					X	X											X					X						X	X									X			X					X			X	
Lithuania			X		X				X	X							X	X									X		X						X					X						X					X			X					X	
Netherlands	X		X							X			X					X							X							X						X	X									X	X	X				X					X	
Norway																																																X												
Poland																																																X												
Portugal						X		X		X												X											X	X						X			X					X	X			X			X					X
Slovakia																																																X												
Slovenia			X				X				X										X	X					X					X						X						X				X		X	X				X			X		
Spain	X							X		X				X									X		X								X						X				X					X	X			X		X					X	
Sweden	X							X		X						X							X				X						X						X				X					X	X			X					X			X
Switzerland								X	X			X											X	X									X	X									X	X				X				X	X				X			X
United Kingdom	X	X								X							X	X									X						X										X	X						X	X			X					X	
Total	9	7	5	2	3	2	1	7	5	16	1	3	2	2	5	5	3	4	2	1	3	4	3	2	3	2	11	1	3	1	1	7	8	4	3	2	1	7	6	5	3	0	8	6	1	3	0	21	6	10	11	6	3	7	5	5	4	1	14	6

Table 19. Summary of frequency control procurement procedures for Replacement reserve in European countries. (Source: ENTSO-E, 2012a)

Country	Procurement Scheme								Activ. Rule			Minimum Bid Size											
	Mandatory Offers		Market	Organised Market	Bilateral Market	Mandatory Provision	N/A		Merit Order	Pro-Rata (Parallel Activation)	N/A	> 10 MW		<= 10 MW		<= 5 MW		<= 1 MW		No minimum bid size		N/A	
	C	E	E	C	C	C	C	E	E	E	E	C	E	C	E	C	E	C	E	C	E	C	E
Austria							X	X			X											X	X
Belgium			X				X												X				
Bosnia and Herzegovina		X				X				X										X	X		
Bulgaria		X				X			X				X										
Czech Republic			X	X					X					X					X				
Denmark DK1																							
Denmark DK2			X		X							X											
Estonia							X	X															
Finland																							
France			X			X			X					X	X								
Germany							X	X			X											X	X
Hungary	X	X							X					X			X						
Ireland			X		X				X									X					X
Italy		X					X		X										X				
Latvia					X			X	X			X	X										
Lithuania			X		X				X							X	X						
Netherlands			X				X		X								X			X			
Norway			X	X					X			X	X										
Poland				X														X					
Portugal		X					X		X												X		
Slovakia				X				X	X							X	X						
Slovenia			X				X			X										X	X		
Spain			X				X		X				X									X	
Sweden																							
Switzerland			X	X					X							X	X						
United Kingdom			X	X					X							X	X						
Total	1	5	12	6	4	3	9	5	15	2	2	3	4	3	1	4	6	2	3	3	3	3	3

Country	Timeframe for Product										Timing for Offers / Gate Closure									
	15 minutes	30 minutes	Hour (or Blocks)	Hour(s)	Day(s)	Week(s)	Month(s)	Year or more	N/A		Day(s)	Week(s)	Month(s)	Year or more	<= H-1	> H-1	D-1	> D-1	N/A	
	E	E	E	C	C	C	C	C	C	E	C	C	C	C	E	E	E	E	C	E
Austria									X	X									X	X
Belgium	X								X							X			X	
Bosnia and Herzegovina							X			X									X	X
Bulgaria									X	X							X		X	
Czech Republic			X		X							X				X				
Denmark DK1																				
Denmark DK2			X					X						X		X				
Estonia																				
Finland																				
France	X								X						X				X	
Germany									X	X									X	X
Hungary			X					X			X						X			
Ireland		X						X						X						X
Italy			X						X							X			X	
Latvia								X		X				X						X
Lithuania			X		X						X					X				
Netherlands			X						X										X	X
Norway			X			X						X				X				
Poland				X							X									
Portugal			X						X							X			X	
Slovakia			X		X						X									X
Slovenia			X						X							X			X	
Spain			X						X							X			X	
Sweden																				
Switzerland			X		X						X					X				
United Kingdom			X						X										X	X
Total	2	1	13	1	4	1	1	4	11	5	5	2	0	3	1	10	2	0	12	8

Country	Settlement Rule									Capacity & Energy - Monitoring				Sec. Market for Res. Oblig.	
	Hybrid	Regulated Price		Marginal Pricing		Pay as Bid		N/A		Hybrid	Ex-Post Check	Real-Time Monitoring	N/A	No	N/A
	E	C	E	C	E	C	E	C	E	C,E	C,E	C,E	C,E	C	C
Austria								X	X				X		X
Belgium							X	X					X		X
Bosnia and Herzegovina		X	X								X			X	
Bulgaria		X					X				X			X	
Czech Republic						X	X			X				X	
Denmark DK1															
Denmark DK2			X			X					X			X	
Estonia															
Finland															
France							X	X		X					X
Germany								X	X				X		X
Hungary						X	X				X			X	
Ireland	X	X								X				X	
Italy							X	X				X		X	
Latvia				X			X					X		X	
Lithuania		X					X			X				X	
Netherlands							X	X					X	X	
Norway				X	X					X				X	
Poland				X						X				X	
Portugal							X	X			X				X
Slovakia		X			X							X		X	
Slovenia								X					X		X
Spain					X			X			X				X
Sweden															
Switzerland						X	X			X				X	
United Kingdom						X	X			X				X	
Total	1	5	2	3	3	5	12	9	2	8	6	3	5	15	7