FREQUENCY SUPPORT MARKETS WITH WIND POWER PARTICIPATION

Master thesis, UPC Barcelona

Mentors: Dr. José Luis Domínguez-García, IREC

Ivanova, A.
anzelikaivanova@gmail.com
July 2016

Contents

1 Introduction ... 6

1.1 Methodology ... 6
1.2 Presentation of the materials ... 7

2 Ancillary services for frequency support and procurement practices in European Union countries ... 9

2.1 Definitions of ancillary services for frequency support ... 9

2.1.1 Definitions according to UCTE ... 9
2.1.2 Definitions according to ENTSO-E ... 10

2.2 Frequency Support Markets ... 11
2.3 Belgium ... 11

2.3.1 Ancillary services in Belgium ... 11
2.3.2 Procurement of ancillary services ... 13
2.3.3 Market data ... 15

2.4 Germany ... 16

2.4.1 Ancillary services in Germany ... 16
2.4.2 Procurement of ancillary services ... 17
2.4.3 Market data ... 17

2.5 France ... 18

2.5.1 Ancillary services in France ... 18
2.5.2 Procurement of ancillary services ... 18
2.5.3 Market data ... 19

2.6 Iberia ... 19

2.6.1 Portugal ... 19
2.6.2 Spain ... 23

2.7 Nordic Synchronous System ... 27

2.7.1 Ancillary services in the Nordic market ... 27
2.7.2 Procurement of ancillary services ... 30
2.7.3 Market data ... 35

2.8 Island of Ireland ... 36

2.8.1 Ancillary services in Ireland ... 36
2.8.2 Procurement of ancillary services ... 39
2.8.3 Market data ... 40

2.9 Great Britain ... 40

2.9.1 Ancillary services in Great Britain 40
2.9.2 Procurement of ancillary services 43
2.9.3 Market data 45

2.10 ENTSO-E classification and requirements important for wind operators 46
2.11 Balancing responsibility of wind power generators 51

3 Possible role of wind power in future balancing markets 53

3.1 Summary of volume and price data 53
3.2 Simple estimation of wind power participation in future balancing markets 54

4 Effects of the spot and balancing market practices to wind power participation in the balancing markets 56

4.1 Linear Programing model 56
4.2 Model implementation and analysis 58

4.2.1 Sensitivity analysis 59
4.2.2 Difference in income from day-ahead and balancing market for downward regulation 62

5 Main findings and discussion 63
6 Conclusions 66
7 References 67

Abbreviations and symbols

Abbreviations

AGC – Automatic Generation Control
AS – Ancillary Services
CREG – Commission for Regulation of Electricity and Gas
DR – Dynamic Reactive Response
DS – Distribution system
DSO – Distribution System Operator
ENTSO-E - European Network of Transmission System Operators for Electricity
EU - European Union
FCR – Frequency Containment Reserve
FFR – Fast Frequency Response
FPFAPR – Fast Post-fault Active Power Recovery
FRR – Frequency Restoration Reserve
FS – Frequency Support
LP – Linear Programming
RR – Replacement Reserve
SIR – Synchronous Inertial Response
TS – Transmission system
TSO – Transmission System Operator
UCTE - The Union for the Co-ordination of Transmission of Electricity

Symbols

λ_t^{DAM}	-	day-ahead market price at time t
λ_t^{BMU}	-	up regulation price at time t
λ_t^{BMD}	-	down regulation price at time t
$\bar{E}_{WPP}$	-	maximum energy that can be sold from the wind producer at time t
x_t	-	wind production mismatch at time t
η_t^{up}	-	probability that up regulation energy will be used at time t
η_t^{down}	-	probability that down regulation energy will be used at time t
E_t^{DAM}	-	energy that is used in the day-ahead market at time t
E_t^{BMU}	-	energy that is used for up regulation at time t
E_t^{BMD}	-	energy that is used for down regulation at time t
H_y	-	number of hours in one year

Tables

Table 1 - Contracted and activated volumes of R1, R2 and R3, in Belgium for 2015 16
Table 2 - Yearly prices of contracted volumes for R1, R2 and R3 reserves, in Belgium for 2015 16
Table 3 - Secondary and tertiary maximum activated capacities, in Germany for 2015 18
Table 4 - Primary and secondary reserve capacity and tertiary reserve energy, in France for 2015 19
Table 5 - Volumes and prices of secondary and tertiary reserve in Portugal, for 2015 23
Table 6 - Volumes and prices for secondary and tertiary reserve in Spain, for 2015 27
Table 7 - FCR-D reserve division 29
Table 8 - Fast active disturbance reserve requirements 29
Table 9 – FCR in Finland for 2015 32
Table 10 - FRR-M in Finland for 2015 33
Table 11 - Activated energy volumes and prices for FRR-M, in the Nordic Synchronous System for 2015 35
Table 12 - SIR 37
Table 13 - FPFAPR 38
Table 14 - FFR 38
Table 15 - RM 39
Table 16 - Ancillary services payment rates in Ireland for the period October 2015-October 2016 39
Table 17 - Operating reserve requirements- Ireland 40
Table 18 - Reserve payments for all types of reserves in the Island of Ireland, for the period 1st October 2014 - 31st September 2015 40
Table 19 - Ancillary services in the UK 41
Table 20 - Generators required to provide mandatory frequency response 41
Table 21 - Procurement of ancillary services in the UK 44
Table 22 - Reserves volumes in Great Britain for 2015 46
Table 23 - Summary of FCR services unified under ENTSO-E classification 48
Table 24 - Summary of FRR-a services unified under ENTSO-E classification 49
Table 25 - Summary of FRR-m and RR services unified under ENTSO-E classification 50
Table 26 - Balancing responsibility of wind power generators according to EWEA's survey 51
Table 27 - Summary of FRR-a services in EU countries for 2015 53
Table 28 - Summary of FRR-m and RR services in EU countries for 2015 53
Table 29 - Additional euros/MW annually for the wind producer from balancing market 59
Table 30 - Additional euros/MW annually from balancing market for different prices 60
Table 31 - Additional euros/MW annually from balancing market for different probabilities . 61

Figures

Figure 1 – Time frames of the activation of primary, secondary and tertiary reserve 10
Figure 2 - Timeframes of activation of reserves, ENTSO-E 11
Figure 3 - Ancillary services market in Spain 24
Figure 4 - Allocation process for secondary reserve in Spain 25
Figure 5 – Allocation process of tertiary reserve in Spain 26
Figure 6 - Deviation management process 26
Figure 7 - Time frames of MFR services 42
Figure 8 - Share of wind generation in balancing markets assuming market volumes of 2015 and double that, and 5- 20% share of wind power producers in the markets. 54
Figure 9 - Average spot price and average up/down regulation price for 2015 55
Figure 10 - Percentage of income for the wind producer from the balancing market in relation to the income from day-ahead market 58
Figure 11 - Percentage of income from the balancing market at different up/down regulation prices 60
Figure 12 - Percentage of income from balancing market for different values of the probability 61
Figure 13 - Difference in income from down regulation to income from day-ahead market for the amount of energy used for down regulation... 62
Figure 14 - Minimum system inertia including contribution from distributed generation 64

1 Introduction

The European Union (EU) aims to considerably reduce the emissions of harmful gases in the atmosphere, has resulted in drastic increase of power generation from renewable sources, especially wind. The nature of these sources is that it is difficult to predict their availability at certain moment of time. This increases the need to balance the generation side to the demand side and thus, the need for ancillary services (AS). In addition, the large integration of wind power on the power systems in EU imposes on markets and operators the unavoidability of wind power participation in the provision of these AS [1].

Most of the EU countries already have markets and other procurement methods for AS [2]. These procurement methods, however, are designed and based on conventional generation which limits or completely prevents the participation of wind power in the procurement of these services [3].

The challenge to reconsider the structure of current energy markets has been identified by the European Commission on the “Energy Roadmap 2050” [4]. This may contribute to provide an European common framework for the balancing markets (which is one form of a manually operated frequency control), allowing participation of wind power as well as simplified cross-border interaction. In addition, the participation in providing AS from wind power plants have been already analysed to be beneficial for both the system and the wind power producers [5].

A promising example of wind power participation on balancing markets is already happening to some extent in Denmark [6] and in Spain 3.5 GW of wind generation capacity is about to obtain the right to participate in the balancing market [7]. Also, for easing wind power participation, AS markets must be adapted for example reducing gate closure times of the markets, which will reduce wind power production uncertainty and enable offering larger capacity.

The aim of the thesis is to give the state of the art of AS for frequency support (FS), the important requirements that would encourage or discourage the participation of wind power generation in their provision and to analyse the potential economic benefits they would have from this provision.

1.1 Methodology

The methodology encompasses four steps: first, analysis of different AS for FS in terms of existing main classifications and different procurement practices in several countries; second, unification of the different AS for FS under the ENTSO-E classification; third, simple estimation of the size of future markets for manually activated reserves (balancing markets) in order to investigate the possible role of wind power in the future balancing markets; and fourth, determination of the optimal amounts of power a wind power producer should sell on the day-ahead and balancing markets in order to maximize its benefits.

For the first step, the analysis was made based on information collected from the Transmission System Operators' (TSOs) websites and the balancing rules of each considered country from the ENTSO-E Transparency Platform[1].

All countries have somewhat different classification and definitions of the AS for frequency support. Therefore, the second step was to unify these differences under the ENTSO-E classification, based on the overlapping of definitions for the particular country with the aforementioned ENTSO-E definitions. Such unification is of great relevance for further analysis of how neighbour countries behave under the same task. The tables that are a result of the unification of the services also include the parameters that are important from the viewpoint of wind power generators.

The third part includes a simple estimation of the size of future markets for manually activated reserves (balancing markets) to investigate the possible role of wind power in the future balancing markets. The estimation was done based on volumes and prices data available on the TSOs' websites, for 2015, namely for the Nordic, Spanish and Portuguese balancing market.

The fourth part withdraws the conclusions made from the analysis of the potential effects of the market practices on wind power participation in the balancing markets. This was done by solving a Linear Programming (LP) problem that investigates which are the optimal amounts of energy a wind power producer should sell on the day ahead and on the balancing market in order to maximize its income. The LP problem was solved using the GAMS program and the data for volumes and prices for manually activated reserves from 2015.

1.2 Presentation of the materials

Chapter 2 contains the overview of the different procurement practices in 11 EU countries, namely Belgium, Germany, France, Spain, Portugal, Denmark, Finland, Norway, Sweden, All-island Ireland and Great Britain. The unification of the different practices under the ENTSO-E classification is presented in three tables along with the parameters important from the wind power producer's point of view. In these tables, the results for each country were summarized including several parameters that are relevant for wind power operators – procurement arrangements, gate closing time and minimum offer. Additionally, a summary of the current balancing responsibility of wind power producers in the reviewed countries is shown.

[1] https://transparency.entsoe.eu/

In chapter 3 the results from the estimation of future volumes of the markets for manually activated reserves and the possible share of wind power in these markets in Portugal, Spain and the Nordic countries are presented. Moreover, this chapter contains the estimated income under the analysed conditions.

Chapter 4 gives the results from the solution of the LP problem-the optimal energy that should be used from day-ahead and the balancing market as well as the income a wind power producer would get in the case of Portugal, Spain and the Nordic countries. Based on the results of the analysis the main findings and recommendations are presented.

Finally, chapter 5 points out the main conclusions from this work.

2 Ancillary services for frequency support and procurement practices in European Union countries

2.1 Definitions of ancillary services for frequency support

Currently, a uniform classification and definition of AS does not exist. For the countries in ENTSO-E Continental Europe Regional Group, the UCTE classification is used and it is provided in the Continental Europe Operation Handbook [8] which also sets the requirements for the member countries.

The Nordic countries have different definitions and requirements for the AS which are given in the System Operation Agreement , so do UK and the Island of Ireland whose AS definitions and requirements are given in their national procurement guidelines.

A step to unify and standardize the different AS in European countries is the classification by ENTSO-E, which is somewhat an updated version of the UCTE classification. Therefore it is important to give the definitions according to both classifications. This classification has not been adopted by all European countries yet, and the UCTE is still the more frequently used one, especially in the countries of Continental Europe.

2.1.1 Definitions according to UCTE

The classification and definitions of AS for frequency support, according to UCTE, are given in [8]. The AS for FS primary, secondary and tertiary reserves. Primary reserves are activated within seconds after a disturbance and they bring the frequency to a quasi-stationary state. Secondary reserves are then activated within minutes to bring frequency back to the nominal value. Tertiary reserves are used to replace the secondary reserves. The reserves are used for primary, secondary and tertiary control:

- *Primary control*: It is started by the speed regulators of generating units before a frequency deviation higher than 20 mHz of the nominal frequency. The full activation of primary reserves starts at deviation of 200 mHz. The total primary reserve for the UCTE area is 3000 MW defined as the power deviation of the reference incident. The amount of primary reserve for each control area is calculated with (1), where $P_{prim,i}$ is the primary reserve for control area *i*, E_i is the total generated energy in control area *i*, E_{total} is the total generated energy in UCTE.

$$P_{prim,i} = \frac{E_i}{E_{total}} \cdot P_{prim,total} \qquad (1)$$

- *Secondary control*: It is started by the AGC of each control area to bring the frequency from the quasi-stationary value to it nominal value. The amount of secondary reserve needed in each control area is given by (2), where $P_{sec,i}$ is the secondary power reserve and $L_{max,i}$ is the peak load in area *i* and the coefficients *a* and *b* are set empirically at 10 MW and 150 MW.

$$P_{sec,i} = \sqrt{aL_{max,i} + b^2} - b \qquad (2)$$

- *Tertiary control*: Tertiary control should start 15 minutes after the incident. The amount of tertiary reserve should be enough to cover the loss of the largest amount of power in the control area.

The time frames of activation for each reserve are shown in Figure 1.

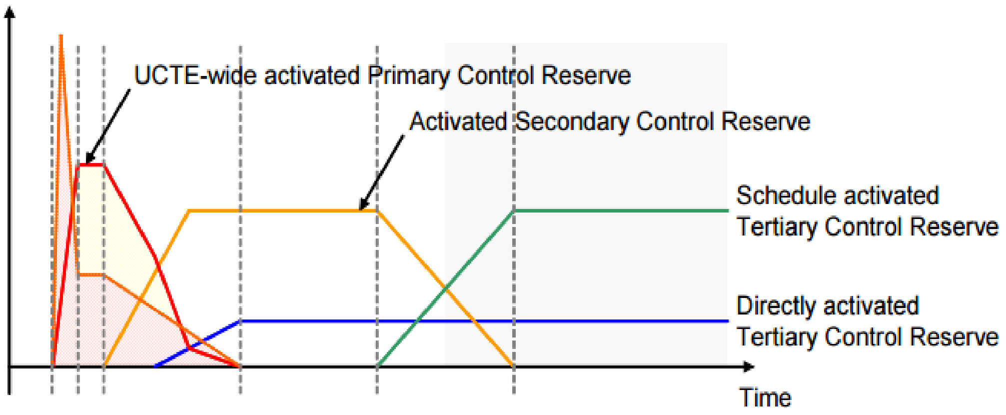

Figure 1 – Time frames of the activation of primary, secondary and tertiary reserve [8]

2.1.2 Definitions according to ENTSO-E

The classification and definitions of frequency support AS by ENTSO-E are given in [3]:

- *Frequency Containment Reserve (FCR) or Primary Response:* The automatic response to frequency changes released increasingly with time over a period of some seconds. 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 responsibility is split amongst TSOs.
- *Frequency Restoration Reserve (FRR) or Secondary Response:* Activation of FRR modifies the active power outputs of reserve providing units in the period 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.

- *Replacement Reserve (RR) by Tertiary response:* It is activated manually with activation time from 15 minutes to hours. Replacement reserves are activated manually at the TSO control centre in case of observed or expected sustained activation of FRR and in the absence of a market response.

The time frames of the activation processes are shown in Figure 2.

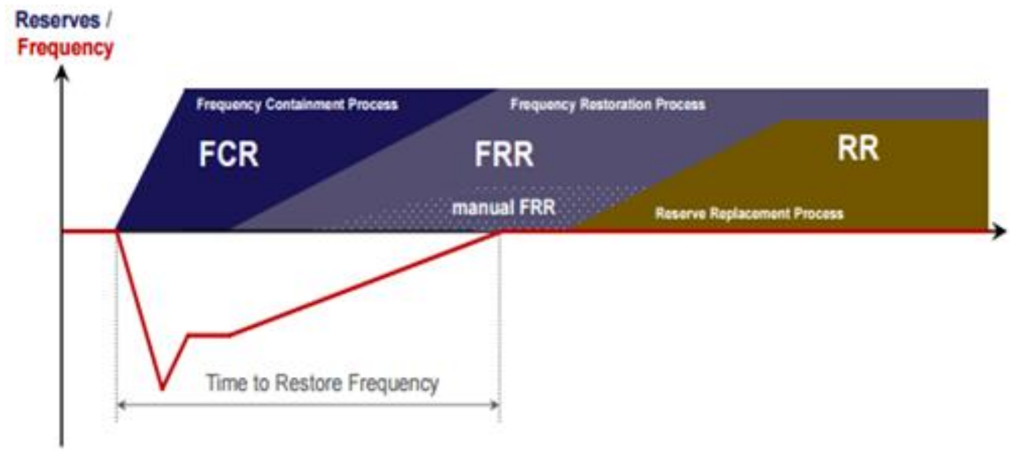

Figure 2 - Timeframes of activation of reserves, ENTSO-E [9]

2.2 Frequency Support Markets

Depending on the country's regulations, the AS for FS are either mandatory or they are procured through market arrangements. The procurement of these services is a task of the TSO.

In the following section, the different AS for frequency support are given for Belgium, Germany, France, Denmark, Finland, Norway, Sweden, Great Britain, All-island Ireland, Portugal and Spain. Furthermore, the method of procurement is presented for each country as well as the available market data for 2015 in terms of volumes and prices. The terms for AS for FS are presented as used in each country.

2.3 Belgium

2.3.1 Ancillary services in Belgium

The TSO in Belgium is Elia. It provides the following AS for frequency support [10]:

- Primary reserve (R1);
- Secondary reserve (R2);
- Tertiary reserve (R3).

2.3.1.1 Primary reserve

Based on the ENTSO-E regulations, the primary reserve must be symmetrical, with linear activation. The total activation should be at frequency deviation of +/- 200 mHz. Elia procures different types of products at different frequency deviations that constitute the product required by ENTSO-E [11]:

- R1 symmetrical 200mHz: this product is activated between -200mHz and + 200mHz, whereas the total contracted volume must be activated at the most extreme bands of the frequency interval.
- R1 symmetrical 100mHz: this product is activated between -100mHz and +100mHz, whereas the total contracted volume must be activated at the most extreme bands of the frequency interval. This maximum contracted volume must however also remain activated for frequency deviations between [-200mHz,-100mHz] and [100mHz, 200mHz].
- R1 upwards: this product is activated between [-200mHz, -100mHz], whereas the total contracted volume must be activated at -200mHz. This product is mainly supplied by industrial loads.
- R1 downwards: this product is activated between [100mHz, 200mHz], whereas the total contracted volume must be activated at 200mHz. This product is only supplied by base-load Elia-connected generation.

Some production units can automatically detect frequency variations and adjust production within 0 to 30 seconds. This reserve should be able to compensate two simultaneous serious incidents which is the equivalent of the loss of two 1500 MW production units. The volume which is required by Belgium in this share is approximately 100 MW [12]. The reserve it is to be delivered within 15 minutes of an incident.

Primary reserve from demand side has become available from April 2016 for the first delivery period of May 2016 [13].

2.3.1.2 Secondary reserve

The R2 is activated automatically by sending signals from Elia's dispatch centre to the supplier's dispatch centre. It can be activated in both upward and downward directions, R2+ and R2- respectively, and it should be available within 30 seconds and up to at least 15 minutes. These reserves are activated based on a set point that is sent continuously to the supplier [11]. The suppliers are generators located in Belgium.

Currently, Elia procures R2 with the same volume in both upward and downward direction, although it takes into account the possibility to procure upward and downward volumes separately [11].

Elia evaluates the volume of capacity in its secondary reserve based on its requirements and this volume must be approved by CREG[2] [14].

2.3.1.3 Tertiary reserve

Tertiary reserve (R3) is activated manually by Elia, which defers from primary and secondary reserve. Originally, it consist of two components, tertiary production reserve and tertiary offtake reserve [10]. Tertiary production reserve is the injection of extra capacity by producers who have signed contract for tertiary reserve. Tertiary offtake reserve is the reduction in the amount of power taken from the grid by the user who have signed interruptibility contract.

The interruptibility contract allows Elia to request that a specific volume of power is not taken from its grid [15].

2.3.1.4 Specific tertiary offtake reserve: Dynamic Profile

The 'Dynamic Profile' tertiary reserve (R3 DP) is a new type of reserve, established by Elia, allowing distributed energy sources to participate in the AS' provision.

The participation of distributed generation units is enabled by a contract with the relevant distribution grid operator, according to the technical requirements. The flexibility can also be aggregated from multiple energy sources and offered to Elia. The participants offering this resource are playing the new market role of dynamic profile provider and the number of activations and the duration of the activation are limited [16].

2.3.2 Procurement of ancillary services

Depending on the type of AS, there are two different procedures to procure it [13]:

- Via a general framework governing both the procurement and the provision of the service.
- Via a standard contract.

2.3.2.1 Via a general framework governing both the procurement and the provision of the reserve

This procedure is used to procure [13]:

- Primary reserve
  - Primary reserve by generators

[2] *CREG* is the federal regulator for electricity and gas markets in Belgium.

- Secondary control
  - Secondary reserve by generator
- Tertiary reserve
  - Tertiary reserve by generators
  - Tertiary reserve- dynamic profile

The procedure involves two steps. The first step is to become a qualified supplier and the second is to sign the General Framework.

By signing the General Framework, the qualified supplier can then participate in a short-term auction or a long-term tender. The framework should be signed the day before the start of the capacity bid submission, the latest. This refers to the short-term auction. For the long-term tenders, the signing happens at the date of the call for tender.

For 2015, tertiary reserves have been procured by long-term tenders and primary and secondary reserves by short-term tenders [17]. Short-term tenders are organized month-ahead on an online platform called Short-Term Auctioning of Reserves (STAR)[3] and the calendars for the auctions are available on the Elia website. The participants have to submit minimum offers of 5 MW for both secondary and tertiary reserves.

Elia remunerates grid users who provide primary reserve by generators with a set payment. The payment is done for both provision and activation of the primary reserve. In the case of insufficient primary reserve, Elia has the right to require additional primary reserve to the already contracted volume. This additional primary reserve is also remunerated.

Grid users who provide secondary reserve also receive payment for providing and activating the secondary reserve. The payment for provision of secondary reserve is based on the amount of reserve stated in the contract and it is expressed in €/MW/h. Elia pays for provision for the entire contractual term [14]. The payment for activation is based on the bids submitted by the provider on the day before delivery, selecting the bids by financial merit order. Activation payment is separate for upward and downward activation (R2+ and R2-). For R2+, Elia makes the payment to the grid user, based on the last bid. The maximum price for upward bid is given in €/MWh and is based on the fuel price and on the market reference price [14].

Tertiary reserve from production is also remunerated for provision and activation. The payment for provision is done for the entire contractual term and it is given in €/MW/h. The payment for activation has two components – payment for the energy supplied to Elia and payment to cover start-up costs [18]. The payment for energy supplied is calculated with a formula stated in the contract, considering the fuel used and the characteristics of the unit. The payment for

[3] *https://star.elia.be*

start-up is only made if the unit has been ordered to start-up, with the same formula and considering the fuel used, the characteristics of the unit and the management costs.

The remuneration process for tertiary reserve-dynamic profile is a payment in €/MW for each hour of availability, done by Elia to the dynamic profile provider providing the tertiary reserve. This payment, the size of which is specified in the contract, covers the entire contractual term. The fee is determined by the offer from the dynamic profile provider in the tendering process [16].

2.3.2.2 Via a standard contract

This procedure is used to procure [13]:

- Tertiary control
- Interruptibility service (tertiary offtake reserve)

This procedure is done by a call for tender. When it is initiated, a contract notice is published which specifies the needed volume for each service. The exact further procedure and the needed documents are given in the contract notice. The participants are selected based on three criteria: economic, financial and technical.

The interruptibility service is remunerated for provision and activation. Elia pays the gird users who have signed an interruptibility contract for provision of this service. This payment covers the period when this service is available [15]. The payment of activation is done according to the price for every quarter hour of the interruption time. The activation price is based on the bid prices for upward secondary reserve for the particular quarter hour, or for the tertiary reserve for the same quarter hour. The price is set at 110% of the highest upward bid selected by Elia. There is also a minimum payment set by Elia at 75 €/MWh [15].

2.3.3 Market data

The volumes for primary, secondary and tertiary reserves are evaluated and determined by Elia every year. The results of the long-term and short-term auctions are available on their website [17]. The evaluated results have to be presented to and approved by CREG prior to publishing.

Results are available for both contracted and activated capacity in MW, monthly, for every quarter hour. The energy values are not available.

The results presented in Table 1 show the monthly averages of both contracted volumes, in MW, of primary, secondary and tertiary reserves and the maximum value of the activated volumes, for secondary and tertiary reserves, in MW, for 2015. The values represent only the reserves procured by generating units in Belgium, without taking into account the cross-border exchanges.

Table 1 - Contracted and activated volumes of R1, R2 and R3, in Belgium for 2015

Reserve type	Contracted (MW)	Activated (MW)
Primary (R1)	20	-
Secondary (R2)	140	159
Tertiary (R3)	340	411

The weighted average prices of the contracted volumes for each month are given in €/MW/h. In Table 2, are shown the average of the monthly prices of 2015 for R1 and R2, and the weighted average price of 2015 for R3.

Table 2 - Yearly prices of contracted volumes for R1, R2 and R3 reserves, in Belgium for 2015

Reserve type	Average price (€/MW/h)
Primary (R1)	16.32
Secondary (R2)	11.77
Tertiary (R3)	4.66

2.4 Germany

The German transmission grid is managed by four TSOs - 50Hertz, Amprion, TenneT DE and TransnetBW. The AS are procured in close cooperation between the four TSOs, thus providing minimization of the overall needed amount. Since 2011, the German TSOs have procured their AS in an open, transparent and non-discriminatory control power market in accordance with the provisions of the Federal Cartel Office[4] [19].

2.4.1 Ancillary services in Germany

The AS in Germany, used for frequency support, consist of [20]:

- Primary control;
- Secondary control;
- Tertiary control.

The TSOs must provide enough power for primary, secondary and tertiary control to satisfy the UCTE requirements from [8].

[4] *Federal Cartel Office* or *Bundeskartellamt* is and independent competition authority based in Bonn. It is the national competition regulator in Germany.

The required volumes for primary secondary and tertiary control, are calculated by the German TSOs using a mathematical approach in such a way that the defined residual risk probability of a power surplus or deficit that cannot be balanced is not exceeded. This scientific approach was developed in cooperation with the University of Aachen to determine the necessary volume of secondary control power and minutes reserve on the basis of a probabilistic calculation [19].

2.4.2 Procurement of ancillary services

Primary control and secondary control power are procured though weekly tenders. The minutes reserve is procured through daily tenders. The tenders are organized through the shared IT-platform has been installed by the German TSOs [5] and the schedule for the tenders is given in the tendering calendar provided on the platform.

To be able to participate in the tenders, first the generating units or controllable loads must complete the prequalification procedure, in order to demonstrate that they can meet the requirements for providing the reserves.

In the primary control reserve tenders, there are other participants who can join the tender in addition to the German units. Swissgrid has participated in the joint call for tenders via the IT-platform, since 12th March 2012 and TenneT NL has participated in this tender since 7th January 2014 and currently procures 70% of the Dutch requirement for primary control reserve [21]. Since 7th April 2015 , this tender has been linked to the Austrian-Swiss tendering procedure. The tendering submission period for primary control reserves is one week before every Tuesday at 15:00. The minimum offer is +/-1 MW and there is no separate tendering for upward and downward primary control reserve [21].

The secondary control reserve tenders have tendering period of one week before every Wednesday. With the publication of the tenders, the TSOs also announce the total requirement and the needs for the four German control areas. The minimum offer for this reserve is set on 5 MW [22].

The tenders for minute reserve are organized daily and the products are offered in the positive or negative direction, with six four-hour time slices. The minimum offer is 10 MW.

2.4.3 Market data

The results of the tenders and the activated volumes of the reserves are published and available to download on the IT-platform [23].

[5] www.regelleistung.net

Through the common tender for primary reserves, a total of 793 MW was procured in January 2016, of which 173 MW for the four TSOs in Germany [21]. The volumes for secondary and minute reserves are given for upward and downward directions separately, for every quarter hour.

In Table 3, are presented the maximum activated capacities ,by all four TSOs for 2015, for both secondary and minute reserves, in MW.

Table 3 - Secondary and tertiary maximum activated capacities, in Germany for 2015

Direction	Secondary reserve(MW)	Tertiary reserve (MW)
Upward	2000	2200
Downward	1900	2200

2.5 France

The TSO that procures the AS in France is RTE. The description of these services can be found in [24], article 4.1 for frequency control[6] and the definitions are according to [8].

2.5.1 Ancillary services in France

The AS for frequency support in France consist of [25]:

- Primary reserve or FCR;
- Secondary reserve or FRR-a;
- Tertiary reserve or FRR-m and RR;

2.5.2 Procurement of ancillary services

The procedures for participation and also payment of the AS by RTE, are provided in the AS rules [26]. They are identical for all parties.

Generators concerned by the rules in the Grid Code[7], have an obligation to adhere to AS rules. All generator must participate in the provision of primary and secondary reserves. The remuneration process for these reserves is by a set tariff is done by RTE.

Since 1st January 2015 traders can also participate in the frequency regulation market [27]. They can exchange primary and secondary frequency reserves at a free price via mutually agreed transactions notified to RTE.

---

[6] Documentation is only available in French.

[7] Available online: *http://clients.rte-france.com/lang/an/clients_producteurs/mediatheque_client/dtr.jsp*

Tertiary reserves are procured through a tender each year. The contracted volumes make up for the FRR-m which can be adjusted in 13 minutes and the RR which can be adjusted in 30 minutes over a period running from 1st April to 31st March [25]. The providers of tertiary reserves receive an annual bonus on the offered volume and the activation time.

2.5.3 Market data

The data for the AS for frequency support can be downloaded from [28].

The average volumes for primary and secondary reserves are given in MW for every half-hour, for both upward and downward directions combined. For the tertiary reserves (balancing volumes), the used energy in GWh is given, also for every half-hour, in the two directions separately. The summarized data, for 2015, for the three types of reserves is presented in Table 4.

The payments for reserve capacities for primary and secondary reserves in 2015 have been made according to a fixed price of 9.16 €/MW/30 minutes.

Table 4 - Primary and secondary reserve capacity and tertiary reserve energy, in France for 2015

Direction	Primary reserve (MW)	Secondary reserve(MW)	Tertiary reserve (GWh)
Upward	577	660	2745
Downward	577	660	3702

2.6 Iberia

The Iberian region is formed by Portugal and Spain. In 2001, they signed a memorandum that set up the base for a Common Electricity Market, MIBEL. Its start was anticipated in 2003, but the start was postponed until 2007, when the Market Operator started operation as an extension of the existent one in Spain [29].

Even though Spain and Portugal have a common electricity market, the AS are procured on national level, by REE in Spain and REN in Portugal.

2.6.1 Portugal

2.6.1.1 Ancillary services in Portugal

The AS for frequency support in Portugal consist of:

- Primary reserve
- Secondary reserve

- Tertiary reserve[8]

The requirements for the frequency response reserves are based on [8].

2.6.1.2 Procurement of ancillary services

In Portugal, the primary reserve is a mandatory service provided by generators and it is not remunerated. The secondary and tertiary reserves are procured through market mechanisms.

Secondary reserve market

The market for secondary reserve provision takes place the day before delivery day (day-ahead) The upward and downward requirements for this reserve are published by REN the day before delivery day at 18:00 WET the latest [30]. The requirements are published for every market time unit[9] of the following day and they have to be matched with the offers from generators, for each market time unit. All physical units that are able to provide secondary reserve are obliged to participate in its procurement.

The offers have to be sent in the time period of 19:00 WET to 19:45 WET [30]. All participants have to offer upward and downward reserve concurrently, in proportion to the TSO's requirements, i.e. each participant is contracted for both upward and downward reserve concurrently.

The remuneration process involves payment for the procured secondary reserve in terms of capacity and payment for the secondary energy that has been used [30].

The procured capacity is paid based on marginal pricing. The secondary energy that has been used is paid based on the price of tertiary reserve in the same direction, upward or downward. In cases where the price of the tertiary reserve in certain direction does not exist, the secondary energy is paid by the price that would have been formed in the tertiary power market, if the amount used has been contracted on that market.

The participants who have been contracted for a certain hour, have to provide the needed reserve automatically in the hour they have been contracted for. If they cannot provide the contracted capacity, the penalty is 1.5 times the applied marginal price [30].

---

[8] The term used in Portugal is *regulation reserve.*

[9] One market time unit equals 1 hour of the following day.

The costs for reserved capacity are covered by the providers of secondary reserve according to the demand of their clients and the costs related to supplied energy are covered by the market participants that are imbalanced [30].

Tertiary reserve market

The tertiary reserve is procured at the day of delivery of the service (intraday). The requirements for tertiary reserve depend on the demand-supply situation for every hour and the amount that needs to be contracted is calculated by REN. If in real time the secondary reserve is does not suffice for the system's needs, REN uses tertiary reserve to compensate for the secondary reserve. All balancing areas with available reserve are obliged to present offers for the provision of this service [30].

The offers has to be sent 50 minutes before the beginning of the delivery period of the ongoing intraday session or 10 minutes after the publication of the Final Hourly Schedule (PHF[10]) schedule [30].

The needed reserve is assigned from a merit order list that is created based on the participants' offers. The payment is based on a marginal price for each market time unit, for both upward and downward directions separately. In case there is a reserve that has been contracted that does not follow the merit order list, the payment is done based on a pay-as-bid price and the offer is not considered in the marginal price formation of the tertiary reserve market [30].

Technical restrictions

Technical restrictions may happen after the day-ahead market, after the intraday market and in real time.

Technical restrictions after the day-ahead market

When the day-ahead market is concluded, REN has to make the technically feasible schedule based on the commercial from the market. In this process it is possible that the results lead to two different situations, which lead to the day-ahead market restrictions [30]:

- Production needed for the secure functioning of the electricity system was not matched in the day-ahead market.
- Production matched in the day-ahead market does not have technically adequate grid conditions to be injected in the grid.

[10] *PHF* is the abbreviation of the term Final Hourly Schedule in Portuguese *Programa Horário Final.*

When the first situation occurs, REN schedules the most economic offer that deals with the technical restriction. The technical restriction market is then used to determine which of the previously scheduled offers will be replaced by the offers that deal with the technical restriction. The participants whose offers have been replaced, place offers to buy back the energy they have sold in the day-ahead market, thus paying REN for the reduced energy [30].

In the second situation, if the generation from the matched offers cannot be injected, they are not included in the production schedule and REN replaces those offers with the most economic offers that deal with the technical restrictions [30].

The participants in the day-ahead restrictions market have to present their offers at 13:00 WET the latest or 30 minutes after REN publishes the Daily Base Operating Schedule (PDBF[11]) file which consists of the market and bilateral transactions [30].

The payments in this market are according to a pay-as-bid price [30].

Technical restrictions after intraday market

REN also has to validate if the transactions in the intraday market are technically feasible. Those transactions that are not technically feasible are called off [30].

Technical restrictions in real time

If in real time REN needs additional tertiary reserve to solve technical restrictions, it contracts offers not following the merit order list which are classified as Restrictions. The payments are according to the pay-as-bid price and the offers classified as Restrictions are not involved in the price formation for the tertiary reserve market. If there are additional costs due to restrictions, they are to be covered by the suppliers in proportion to their demand [30].

2.6.1.3 Market data

There is no available data for the primary reserves, as this is mandatory service in Portugal. The data for secondary and tertiary reserve, for 2015, is available in the Annual Market Report [31]. This data is presented in Table 5.

For the secondary reserve, the required and allocated reserves in GW, the average capacity in MW and the used energy in GWh for both upward and downward directions is presented. The volume of tertiary reserve represents the used energy in GWh.

[11] *PDBF* is the abbreviation of the term Daily Base Operating Schedule in Portuguese *Programa Diário Base de Contratação*

In addition, in the table are also given the weighted average prices for the secondary reserve capacity, in and for the used secondary and tertiary energy.

Table 5 - Volumes and prices of secondary and tertiary reserve in Portugal, for 2015

Reserve	Capacity - Required/Allocated; Average	Used Energy (GWh)		Price of capacity (€/MW)	Price of used energy (€/MWh)	
		Up	Down		Up	Down
Secondary	2265/2247 GW; 256 MW	424	67	20.2	68.2	29.0
Tertiary	-	691	1270	-		

2.6.2 Spain

2.6.2.1 Ancillary services in Spain

The AS in Spain are referred to as system adjustment services and follow the requirements in [8]. They AS for frequency support consist of [32]:

- Additional upward power reserve;
- Frequency-power regulation (primary, secondary and tertiary regulation);
- Resolution of the technical constraints identified in the PDBF (after physical bilateral contracts and day-ahead) and after intraday market sessions, as well as all those that may appear in real time during system operation.
- Deviation management.

2.6.2.2 Procurement of ancillary services

The procurement of the AS in Spain is done in the following time horizons [32]:

- Day-ahead scheduling horizon (solution of the technical constraints identified in the PDBF, additional upward power reserve and secondary regulation band allocation).
- Intraday and real time scheduling horizon (use of the following energies in real time: secondary regulation, tertiary regulation, deviation management, solution of intraday market and real time technical constraints, and voltage set-point variations in real time).

The structure of the markets is given in Figure 3 [32] .

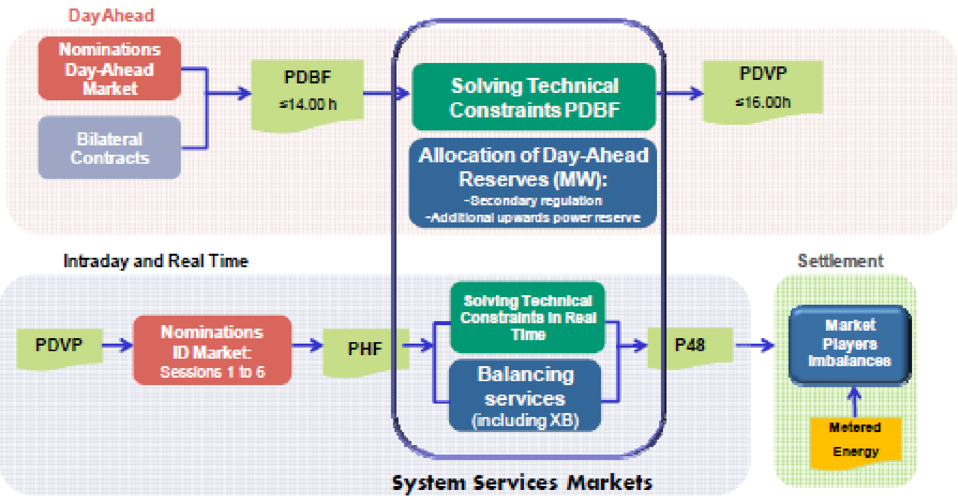

Figure 3 - Ancillary services market in Spain

Additional upward power reserve market

This system adjustment service is needed in addition to what is available in the provisional daily feasible schedule (PDVP[12]) to guarantee the security of the Spanish peninsular electrical system [32] .

The requirements for the additional upward power reserve are according to the available upward power reserve from the PDVP and the required amount for the grid. Bids are submitted by market agents that are responsible for the units enabled for this service. The payment is according to a marginal price set for every hour of assigned additional upward power. The units whose offers have been accepted for the service are obliged to participate in the next intraday session and in the deviation management market.

Regulation and balancing markets

In Spain, secondary and tertiary reserves for regulation of frequency are procured through markets.

Secondary regulation reserves

The requirements for secondary regulation reserves in both upward and downward direction, are published by REE every day for every hour of the next day. The units that are able to participate in this market submit bids for the secondary regulation band and REE assigns the

[12] *PDVP* is the abbreviation of the term Provisional Daily Feasible Schedule in Spanish *Programa Diário Viable Provisional*

bids until the requirements for upward and downward secondary regulation reserve are reached. The bids are assigned on the criteria of minimum cost and payed according to the marginal price of the secondary regulation band for every hour.

The allocation process for the secondary regulation reserve is shown in Figure 4 [32].

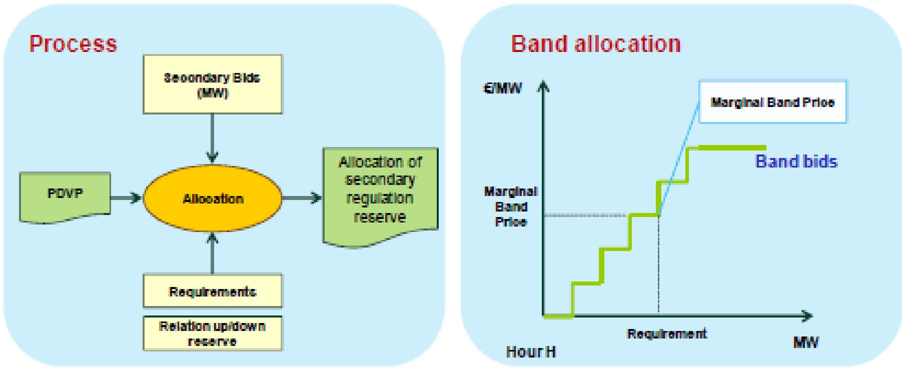

Figure 4 - Allocation process for secondary reserve in Spain

The remuneration process consists of two payments [32]:

- Availability (secondary reserve);
- Usage (secondary energy).

The activation of this service is automatic and distributed between the different control areas according to the market share obtained the previous day in this market. The used energy in real time is then remunerated at the marginal price of the tertiary regulation energy that would have been necessary to replace the net energy usage of secondary regulation energy, in both upward and downward directions [32].

Tertiary regulation reserves

The tertiary regulation reserve is an optional remunerated AS. The biding however, in both upward and downward direction, is mandatory for the units that are licensed for the provision of this service. The bids are selected based on minimum cost.

The tertiary regulation reserve is activated manually. The payments are done for used energy at marginal price for upward and downward direction separately.

The allocation process for this reserve is shown in Figure 5 [32].

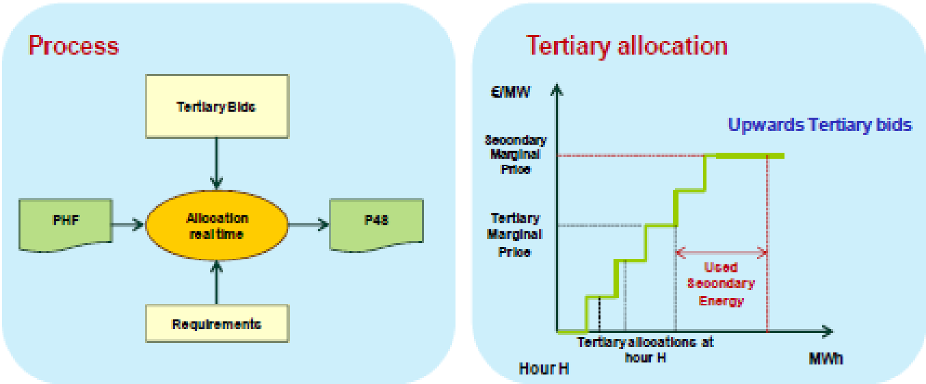

Figure 5 – Allocation process of tertiary reserve in Spain

Deviation management

Deviation management is used to deal with deviations between generation and demand that might occur between the end of one intraday market session and the beginning of the next intraday market horizon. This service enables a connection between intraday markets and tertiary regulation. Therefore, REE has more flexibility to resolve imbalances that may occur after the closure of the last intraday market session, without affecting the availability of the required secondary and tertiary reserves [32].

The deviation management market session is started by REE, if there is an expected deviation above 300 MWh after assessing the deviations before each hour.

The allocation is based on economic merit order and the remuneration is done at marginal price for each hour. The allocation process is shown in Figure 6 [32].

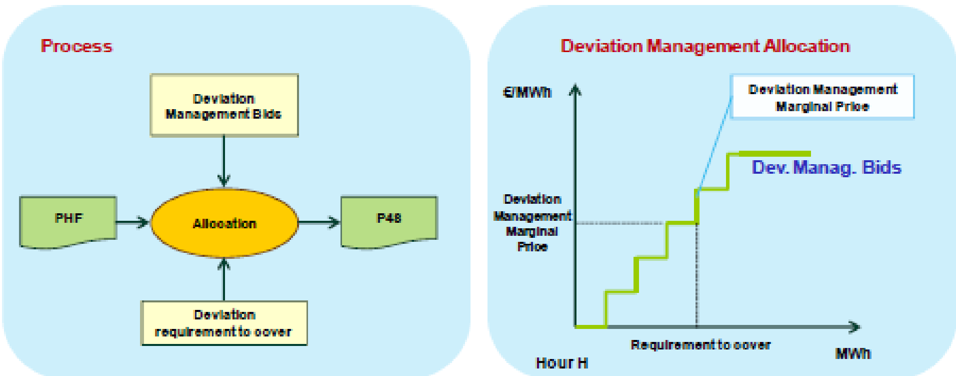

Figure 6 - Deviation management process

2.6.2.3 Market data

Primary regulation reserve is mandatory in Spain and data on the volumes is not available. The requirements however, are +/- 1.5 % of the nominal power output of the generating units [3].

The data for secondary and tertiary regulating reserves are available from [33]. In Table 6, are presented the volumes of used energy for secondary and tertiary reserves in GWh, for 2015. The volumes are given for upward and downward directions separately. In addition, the prices are also given for both directions in €/MWh.

Table 6 - Volumes and prices for secondary and tertiary reserve in Spain, for 2015

Reserve	Used Energy (GWh)		Price of used energy (€/MWh)	
	Up	Down	Up	Down
Secondary	1366	1193	58.87	31.95
Tertiary	3113	1625		

2.7 Nordic Synchronous System

Denmark, Finland, Norway and Sweden form the Nordic power system. The trading of AS in the Nordic region takes place on the Regulating Power Market, which is part of the Nord Pool Spot[13] electricity market.

The Nordic region consists of the synchronous system, composed of the subsystems of Norway, Sweden, Finland and East Denmark, and the subsystem of West Denmark. Western Denmark is part of the UCTE[14] system and is therefore submitted to the terms in the Continental Europe Operation Handbook [8]. All subsystems of the Nordic region must be in cooperation following the terms stated in the Nordic System Operation Agreement (SOA) [34].

An overview of the AS procured on the Regulating Power Market will be given in the following section, as well as the procedure of procurement and the volume of the market.

2.7.1 Ancillary services in the Nordic market

The AS for FS in the Nordic region are defined in [34]. They consist of:

- Frequency controlled normal operation reserve (FCR -N);

[13] *Nord Pool Spot* is the electricity market owned by the Nordic TSO's Statnett SF (Norway), Svenska Krafnät (Sweden), Fingrid Oyj (Finland), Energinet.dk (Denmark) and the Baltic TSO's Elering (Estonia) , Litgrid (Lithuania) and Augstspriemguma tikls (Latvia).

[14] *UCTE* - The Union for the Co-ordination of Transmission of Electricity of Continental Europe

- Frequency controlled disturbance reserve (FCR –D);
- Fast active disturbance reserve;
- Slow active disturbance reserve;
- Fast active forecast reserve;
- Fast active counter trading reserve.

These services have also been classified according to the ENTSO-E classification. This classification is provided in [34], as follows:

- FCR (Automatic active reserve or primary reserve) :
  - Frequency controlled normal operation reserve;
  - Frequency controlled disturbance reserve.
- FRR (Manual active reserve, balancing reserves, FRR-M or tertiary reserve):
  - Fast active disturbance reserve;
  - Slow active disturbance reserve;
  - Fast active forecast reserve;
  - Fast active counter trading reserve.

The SOA specifies the reserve capacity requirements per TSO, except the FRR-A (secondary reserve) requirements. The FRR-A requirements in the synchronous system have been introduced for evaluation in 2012 [35] [36] [37] [38], and for West Denmark they are specified according to [8].

Each type of reserve is described in the following sections.

2.7.1.1 Frequency controlled normal operation reserve

The FCR-N reserve has to be fully activated within 2-3 minutes if there is a frequency deviation of +/- 0.1 Hz. The required capacity of FCR-N is divided between the subsystems each year, based on the annual consumption of the previous year. A limit of cross-border trading is set in order to assure that each subsystem can provide the needed reserve in case of potential island operation. This limit is 1/3 of the total reserve of the subsystem.

2.7.1.2 Frequency controlled disturbance reserve

The FCR-D reserve has to be of such amount that would not allow a frequency drop below 49.5 Hz in the synchronous system, in the event of a dimensioning fault[15]. The total FCR-D

[15] A *dimensioning fault* on a subsystem must not bring about serious operational disturbances in other subsystems. This places demands on the frequency controlled disturbance reserve and the transmission capacity within and between the subsystems. This definition is provided in SOA.

reserve required is the amount of power equal to the dimensioning fault deducted by 200 MW and it has to be available until the fast active disturbance reserve is activated.

The division of this reserve between the subsystems is done in accordance to the dimensioning fault of the particular subsystem. The division has to be updated at least once a week.

An example of the FCR-D reserve division for week 15 of 2013 is presented in Table 7.

Table 7 - FCR-D reserve division

Subsystem	Dimensioning faults (MW)	FCR-D (MW)	FCR-D (%)
Denmark	600	176.5	14.7
Finland	880	258.8	21.6
Norway	1200	352.9	29.4
Sweden	1400	411.8	34.3
Total		1200	100

2.7.1.3 Fast and slow active disturbance reserve

The fast and slow disturbance reserves should be activated in order to replace the FCR-D reserve. The fast disturbance reserve has to be available within 15 minutes and the slow disturbance reserve should be available after 15 minutes.

The amount of fast disturbance reserve is determined in each subsystem separately, depending on local assessment of bottlenecks in the network, dimensioning faults and similar contingencies. Each TSO has to have the sufficient amount of this reserve, either owned or acquired with agreements, from gas, thermal, hydropower and load shedding. The rounded numbers of fast disturbance reserve for each subsystem are given in SOA [34] and are presented in Table 8.

Table 8 - Fast active disturbance reserve requirements

Subsystem	Fast disturbance reserve (MW)
Denmark	900
East	600*
West	700
Finland	880
Norway	1200
Sweden	1400

*300 MW of this amount is slow active disturbance reserve which can be made fast if needed.

The SOA does not specify the amounts of power needed for the slow active disturbance reserve.

2.7.1.4 Fast active forecast reserve

The fast active forecast reserve restores the FCR-N reserve. The requirements for this reserve are dependent on the national legislation of each subsystem. These reserves are technically similar to the fast active disturbance reserves and are acquired as contracted or voluntary regulation power. This service is comes from the Regulating Power Market.

2.7.1.5 Fast active counter trading reserve

The fast active counter trading reserve requirements also depend on the national legislation of each subsystem. This service can be acquired by particular purchases from producers, contracted regulating power or voluntary bids from the Regulating Power Market.

2.7.2 Procurement of ancillary services

2.7.2.1 East Denmark

FCR

Energinet.dk obtains the FCR in a common market with Svenska Krafnät. The bids are collected in a process consisting of two auctions. The first one runs two days before delivery day and the second one runs the day before delivery day.

The procurement of the FCR is then organized by each TSO before the delivery hour. The bids are capacity bids. The activation of these reserves is automatic, frequency response.

The remuneration of the FCR-N reserves involves two payments, the capacity payment (DKK/MW) based on the pay-as-bid price, and the activation payment (DKK/MWh) which is the payment for supplied energy with the regulating power price for upward (or downward) regulation [39].

The remuneration of the FCR-D reserves has only capacity payments based on the pay-as-bid price. The supplied energy volumes are settled as imbalances.

FRR - M

Energinet.dk obtains the upward and downward FRR-M with long-term contracts. If more FRR-M is needed, Eneginet.dk can also buy the FRR-M through the Regulating Power Market.

For the period of 2011-2015, the FRR-M are procured from only one supplier and in the period of 2016-2020 from five suppliers [35].

These reserves are activated manually, based on the lowest price. The remuneration of the balancing energy is done by marginal pricing, i.e. the price of the last bid that has been activated.

2.7.2.2 West Denmark

West Denmark as part of UCTE, has different requirements for the AS, set by the Continental Europe Operation Handbook. The requirements for every type of reserve are given in the following sections.

FCR (primary reserve)

The FCR reserve consists of and is requested as an upward and downward regulation reserve, depending on the system's need. Energinet.dk has the obligation to supply a share proportionate to the generation in West Denmark relative to the total generation in Continental Europe area. This share is determined once a year.

The FCR is obtained by every TSO from capacity bids from the market participants, before the hour of delivery. The FCR reserves in Denmark are acquire through daily auctions with the addition of a long-term contract of 10 MW on the Skagerrak line 4 (SK4) interconnection between Denmark and Norway [35].

The reserves are activated as automatic and local frequency response. The remuneration process consists of only capacity payment with marginal pricing in DKK/MW. The activated energy is settled as normal imbalance with the imbalance price.

FRR-A (secondary reserve)

West Denmark has requirements for the FRR-A reserve as part of UCTE. West Denmark is required to provide a minimum of 90 MW of FRR-A [35]. The FRR-A is procured monthly as a combined, symmetrical upward and downward regulation.

These reserves are also activated as local frequency response. The remuneration process is done according to a price agreed individually by the bidder and Energinet.dk based on the submitted bid.

In the period 2015-2020, 100 MW FRR-A will be delivered through SK4 and Energinet.dk will only procure more FRR-A if this amount is not enough or SK4 is out of function [35].

FRR-M (tertiary reserve)

The requirement for the FRR-M from [8] is an amount that will cover the dimensioning fault of the respective control area. For Denmark this amount equals 700 MW and it is procured through daily auction.

The FRR-M is activated manually, according to the lowest price. The balancing energy is remunerated according to the marginal price.

2.7.2.3 Finland

FCR

Fingrid obtains the FCR through yearly and hourly markets, the Russian and Estonian HVDC links and the other Nordic countries [40]. The maximum contracted capacities for 2015 are given in Table 9 [41].

Table 9 – FCR in Finland for 2015

Reserve	Procurement channel	Maximum contracted capacity (MW)
FCR-N	Yearly market	74
	Hourly market	91
	Other Nordic countries	-
	Vyborg DC link	90
	Estonia, Estlink 1&2	35
FCR-D	Yearly market	297
	Hourly market	307
	Other Nordic countries	40
	Disconnectable loads	-

The bidding competition for the yearly market is organised once a year in autumn. In order to re-enter the yearly market, the previous contractual period has to be finished. It is not possible to make a new yearly agreement in the middle of a contractual period. The amount in the reserve plans is bought in total. The price is fixed throughout the year and is set according to the most expensive bid that has been approved for the yearly market. The operator is obliged to maintain the reserve it sells to the yearly market within the framework of its free capacity after ELSPOT[16] market.

[16] *ELSPOT* is one part of the Nord Pool Sport where the power trade is done. The other part is *ELTREMIN* which is a marketplace for trading price hedging contracts.

In the hourly market, a reserve owner can participate by making a separate agreement with Fingrid but does not require making of a yearly agreement. This market is possible to enter in the middle of the year and the TSO buys only the required amount of reserve. The owners of reserves can submit daily offers for their reserve capacity. If the participant has a yearly agreement, it can only participate in the hourly market if it has supplied in full the amount of reserve specified in the yearly contract. The price according to which the payment is made is based on the most expensive bid used, separately for each hour.

FRR-A

From 2014, Fingrid procures the FRR-A in the hourly market and the bids can be submitted for upward and downward capacities separately. Based on the carried out regulation, the reserve owner receives energy compensation as well in addition to the capacity payment.

FRR-M

Fingrid obtains the needed FRR-M through its reserve power plants and through long-term bilateral agreements with the leasing power plants and disconnectable loads. Fingrid had contracts valid in the period 2005-2015, with wood processing, chemical and metal industries about loads that can be disconnected, in order to provide FRR-M and FCR-D reserves.

The maximum contracted FRR-M capacities in Finland for 2015 are given in Table 10 [41].

Table 10 - FRR-M in Finland for 2015

Reserve	Procurement channel	Maximum contracted capacity (MW)
FRR-M	Balancing power market	-
	Fingrid reserve power plants	935
	Leasing power plants	295
	Disconnectable loads	354

2.7.2.4 Norway (non-EU)

FCR

The FCR-N in Norway are procured through day-ahead and weekly auctions and the FCR-D only through day-ahead auctions [37]. The bids on the day-ahead auction are submitted for each individual hour of the following day. The weekly auctions are run separately for the weekdays and the weekend. Only the production side is allowed to participate.

The remuneration process involves capacity and activated energy payment. The procured capacities are normally payed at marginal price, except in special circumstances when due to the local grid conditions the resulting price is higher than the market price (marginal price). In these special circumstances the payment is done by the pay-as-bid price. The payment is done in NOK/MW for each hour. The payment of the activated energy is done based on the frequency measurements and by the market price for activated FRR-M.

In case of over- and under-delivery, the remuneration process is adjusted. This adjustment is done separately for FCR-N and FCR-D. For over-delivery adjustments, the price is fixed and for under-delivery is based on the highest of the market prices in the daily and weekly auctions for the particular delivery hour.

FRR-A

The FRR-A in Norway are acquired through weekly auctions where only production side is allowed to participate [37]. The weekly auctions are organized for the entire week and the timeslots for the products are announced in advance. The remuneration process includes payment for capacity at marginal price (NOK per MW per hour), except in special circumstances when the payment is done at pay-as-bid price, and payment for activated energy at the market price for activated FRR-M.

FRR-M

The FRR-M are procured through weekly and yearly auctions and both production and load side can participate [37]. The remuneration process includes capacity payment at marginal price (NOK per MW per hour) and in special circumstances at pay-as-bid price. The remuneration is adjusted based on the maximum duration of continuous activation and the rest periods between activations.

The requirement for FRR-M from Norway for the Nordic countries is 1200 MW. Norway procures 800 MW additional FRR-M in order to manage imbalances, congestion and other grid concerns.

2.7.2.5 Sweden

FCR

The FCR reserves in Sweden are procured through weekly and hourly auctions [42]. They are obtained based on the capacity bids from the market participants, before the operational hour. The participants are remunerated for their capacity at a pay-as-bid price and for the activated balancing energy at the price of activated FRR-M, based on the frequency measurements. The FCR reserves can also be traded bilaterally between the Nordic TSOs.

FRR-A

The FRR-A is procured by Svenska Krafnät before delivery hour. The procurement is based on the capacity bids from market participants and the remuneration consists of capacity payment and activated balancing energy payment. The capacity payment is at a pay-as-bid price and the activated energy payment is based on the frequency measurements and the price of activated FRR-M.

According to [43], Svenska Krafnät has decided not to procure FRR-A in 2016 until a permanent solution has been agreed between the Nordic TSOs.

FRR-M

In addition to the requirement for FRR-M stated in the SOA, Svenska Krafnät procures additional FRR-M needed for regulating imbalances, congestions and other grid issues.

The activation of FRR-M is based on the shared Nordic merit-order list of regulating reserves and the payment is done at marginal price.

2.7.3 Market data

The needed FCR volume for the Nordic countries is set with the SOA and for the entire synchronous system is a total of 600 MW.

According to [44], the Nordic TSOs had to contract FRR-a volume of 300 MW. The procurement of this reserve has been cancelled in the Nordic area until a Nordic FRR-a market design is developed [43].

The volumes and prices of the Regulating Power Market are available for download from the Nord Pool website [45]. The data is given for every hour of the year. The total volumes, in MWh, as well as the average prices, in €/MWh, for both downward and upward direction, for 2015 are presented in Table 11.

Table 11 - Activated energy volumes and prices for FRR-M, in the Nordic Synchronous System for 2015

Direction	Activated energy (MWh)	Average price (€/MWh)
Upward	1680792	27.18
Downward	2563958	20.49

2.8 Island of Ireland

The AS in Republic of Ireland and Northern Ireland are procured on the same market, run by SEMO which is the Single Electricity Market Operator for the island of Ireland. The TSO of Republic of Ireland is EirGrid and of Northern Ireland is SONI.

2.8.1 Ancillary services in Ireland

The definitions of each AS are provided in the Grid Codes of both Republic of Ireland and Northern Ireland [46] [47]. The AS for FS in Ireland are referred to as operating reserves and are given as:

- Primary operating reserve (POR);
- Secondary operating reserve (SOR);
- Tertiary operating reserve 1 (TOR 1);
- Tertiary operating reserve 2 (TOR 2);
- Replacement reserve (RR).

General definitions of the operating reserves are also provided in [48]:

- Primary Operating Reserve (POR): The additional MW output (or reduction in demand) at the frequency nadir compared to the pre-Incident output (or demand), where the nadir occurs between 5 and 15 seconds after the event. If the actual frequency, nadir is before 5 seconds or after 15 seconds after the event, then for the purposes of POR monitoring the nadir is deemed to be the lowest frequency which did occur between 5 and 15 seconds after the event.
- Secondary Operating Reserve (SOR): The additional MW output (or reduction in demand) compared to the pre-incident output (or demand), which is fully available and sustainable over the period 15 to 90 seconds following the event.
- Tertiary Operating Reserve 1 (TOR1): The additional MW output (or reduction in demand) compared to the pre-incident output (or demand), which is fully available and sustainable over the period 90 to 300 seconds following the event.
- Tertiary Operating Reserve 2 (TOR2): The additional MW output (or reduction in demand) compared to the pre-incident output (or demand), which is fully available and sustainable over the period 300 to 1200 seconds following the event.
- Replacement Reserve: The additional MW output (and/or reduction in demand) required compared to the pre-incident output (or demand) which is fully available and sustainable over the period from 20 minutes to 4 hours following an event. The purpose of this category of reserve is to restore primary reserve within 20 minutes including restoring any interruptible load shed.

2.8.1.1 DS3 System Services

The DS3 program was initiated in 2011 as a multiyear program in order to develop solutions to the challenges of operating the electricity system securely, while achieving the 2020 renewable electricity targets [49].

The DS3 program proposes new services refined definitions of some of the existing AS. They are presented in detail in [50] and their definitions are given in this section. The presented DS3 program AS take into account not only the FS AS, but also the voltage support AS.

The new proposed AS are:

- Synchronous Inertial Response (SIR);
- Fast Post-fault Active Power Recovery (FPFAPR);
- Dynamic Reactive Response (DR);
- Fast Frequency Response (FFR);
- Ramping Margin (RM).

Form the existing services, minor modifications are proposed for the replacement reserve and the steady-state reactive power.

SYNCHRONOUS INERTIAL RESPONSE

The proposed SIR product is defined as the kinetic energy (at nominal frequency) of a dispatchable synchronous generator, dispatchable synchronous condenser or dispatchable synchronous demand load multiplied by the SIR Factor (SIRF). The SIRF of a synchronous generator is the ratio of the kinetic energy (at nominal frequency) to the lowest sustainable MW output at which the unit can operate at while providing reactive power control. It will be based on the commissioned design capability of the plant as determined through appropriate testing procedures. The SIRF will need to exceed a threshold of 15 s for the provider to be eligible for payment and payment will be capped at a SIRF of 45 s. The SIRF for a synchronous condenser or a synchronous demand load that can provide reactive power control is 45 s. Payments for SIR will be based on the SIR Volume [50]:

$$\text{SIR Volume} = \text{Stored Kinetic Energy} \times (\text{SIRF} - 15) \times \text{Unit Status}$$

Table 12 - SIR

Product Volume	SIR Volume
Product Scalar	2 if the provider is capable of providing operating reserve at the lowest sustainable MW output at which the unit can operate at while providing reactive power control 1 otherwise

ETSEIB

FAST POST-FAULT ACTIVE POWER RECOVERY

Fast Post-fault Active Power Recovery is defined as having been provided when, for any fault disturbance that is cleared within 900 ms, a plant that is exporting active power to the system recovers its active power to at least 90% of its pre-fault value within 250 ms of the voltage recovering to at least 90% of its pre-fault value. The generator must remain connected to the system for at least 15 minutes following the fault [50].

Table 13 - FPFAPR

Product Volume	MW Output
Product Scalar	1

DYNAMIC REACTIVE RESPONSE

The Dynamic Reactive Response product is defined as the ability of a unit when connected to deliver a Reactive Current response for voltage dips in excess of 30% that would achieve at least a Reactive Power in Mvar of 31% of the registered capacity at nominal voltage. The Reactive Current response shall be supplied with a Rise Time no greater than 40 ms and a Settling Time no greater than 300 ms [50].

FAST FREQUENCY RESPONSE

Fast Frequency Response is defined as the additional increase in MW output from a generator 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 8 seconds. The extra energy provided in the 2 to 10 second timeframe by the increase in MW output must be greater than any loss of energy in the 10 to 20 second timeframe due to a reduction in MW output below the initial MW output [50].

Table 14 - FFR

Product Volume	Additional MW Output that can be provided when connected
Product Scalar	1

RAMPING MARGIN

Ramping Margin is defined as the guaranteed margin that a unit provides to the system operator at a point in time for a specific horizon and duration. The TSOs are proposing horizons of one, three and eight hours with associated durations of two, five and eight hours respectively. The Ramping Margin products are called RM1, RM3 and RM8 respectively. The Ramping Margin for a unit at the starting point is the ramp-up capability of the unit in the horizon time limited by the lowest availability in both the horizon and duration window (e.g. from 0 to 8 hours for RM3). Thus the Ramping Margin represents the increased MW output that can be delivered with a good degree of certainty by the product horizon time and sustained for the product duration window [50].

Table 15 - RM

Product Volume	**Ramping Margin**
Product Scalar	1

2.8.2 Procurement of ancillary services

The harmonised all-island arrangements have been brought into operation for AS on the 1st February 2010. The TSOs procure AS by means of contracts [51].

Service providers are paid for the different categories of reserve based on their stated availability. If during a frequency event the service provider does not provide the expected level of reserve then the TSOs levy a charge on the service provider for the first three categories of reserve [48].

Under Harmonised AS, service providers are paid for the provision of six categories of reserve, given in Table 16, and are exposed to charges for the first three categories of reserve (POR, SOR and TOR1). These charges are calculated based on the level of under provision and the hourly payment rate.

It is anticipated that the current AS agreements will terminate and the procurement of AS in future will be according to the DS3 System Services. Therefore, the policy [52] will be superseded by the 'TSO Procurement Strategy', as given in the SEM Committee decision on 19th December 2014 (SEM-14-108).

The remunerating process is done by a payment with set tariffs, determined for each following year. The prices for the period of 1st October 2015 to 31st September 2016, are provided in [53] and [54].

Table 16 - Ancillary services payment rates in Ireland for the period October 2015-October 2016

Ancillary Services Payment Rates		
Payment Parameters	Payment Rates- EirGrid (€/MWh)	Payment Rates- SONI (£/MWh)
POR	2.36	1.68
SOR	2.27	1.61
TOR 1	1.89	1.34
TOR 2	0.94	0.67
RR (Synchronised)	0.21	0.15
RR (De-Synchronised)	0.54	0.38

2.8.3 Market data

The minimum required volumes of operating reserves for both Republic of Ireland and Northern Ireland are stated in [55]. The higher value for Republic of Ireland is required for the day-time period and the lower value for night-time. They are shown in Table 17.

Table 17 - Operating reserve requirements- Ireland

Category	All Island Requirement % Largest In-Feed	Ireland Minimum[1] (MW)	Northern Ireland Minimum (MW)
POR[2]	75	110/75	50
SOR	75	110/75	50
TOR 1	100	110/75	50
TOR 2	100	110/75	50

1. Ireland Lower values apply from 00:00 - 07:00 inclusive
2. Minimum values of POR in each jurisdiction must be supplied by dynamic sources

Data for the activated reserve volumes is not available in the reports for procurement of the AS for FS . The available reports on the procurement only give the total costs for the services. The reserve payments, in €, for the period of 1st October 2015 to 31st September 2016, are available in [56] are presented in Table 18.

Table 18 - Reserve payments for all types of reserves in the Island of Ireland, for the period 1st October 2014 - 31st September 2015

Ancillary Services – Reserve Payments	
Payment Parameters	Payment Rates- EirGrid (€/MWh)
POR	2.36
SOR	2.27
TOR 1	1.89
TOR 2	0.94
RR	0.21

2.9 Great Britain

The AS in Great Britain are procured by National Grid Electricity Transmission (NGET) in accordance with [57]. The procurement guidelines for these services are given in [58].

The AS can be provided by both balancing mechanism (BM) providers, providers who have a contract with NGET and can participate in the balancing mechanism, and non-BM providers who do not have this contract.

2.9.1 Ancillary services in Great Britain

The AS are defined in the Connection Condition 8 of the Grid Code of UK [59]. They consist of AS that are mandatory and AS that are commercial. An overview of the different AS for FS is given in Table 19.

Table 19 - Ancillary services in the UK

Ancillary services	
Mandatory	Commercial
***Frequency response* - by means of frequency sensitive generation**	Firm frequency response Frequency control by Demand Management Fast reserve *Short -term operating reserve*

2.9.1.1 Mandatory frequency response

Mandatory frequency response (MFR) is an automatic change in active power output in response to a frequency change. This service is provided by all generators that are caught by the requirements in the Grid Code[17] depending on which TSO network they are connected to. The generators obliged to provide this service are the large generators as given in Table 20 [60]. The providers of this service must have 3-5% droop characteristic [61].

Table 20 - Generators required to provide mandatory frequency response

Size	National Grid	Scottish Power	Scottish Hydro Electricity Transmission
Small	<50 MW	<30 MW	<10 MW
Medium	>50 MW≤ 100 MW	N/A	N/A
Large	*≥100 MW*	*≥ 30 MW*	*≥ 10 MW*

There are three response services as parts of the MFR [60]:

- *Primary response* – provision of additional active power (or a decrease in demand) within 10 seconds after an event and can be sustained for additional 20 seconds.
- *Secondary response* – provision of additional power (or decrease in active power demand) within 30 seconds after an event and can be sustained for additional 30 minutes.
- *High frequency response* - the reduction in active power within 10 seconds after an event and sustained indefinitely.

The time frames of the different frequency response services is shown in Figure 7 [60].

[17] Available online: *http://www2.nationalgrid.com/uk/industry-information/electricity-codes/grid-code/the-grid-code/*

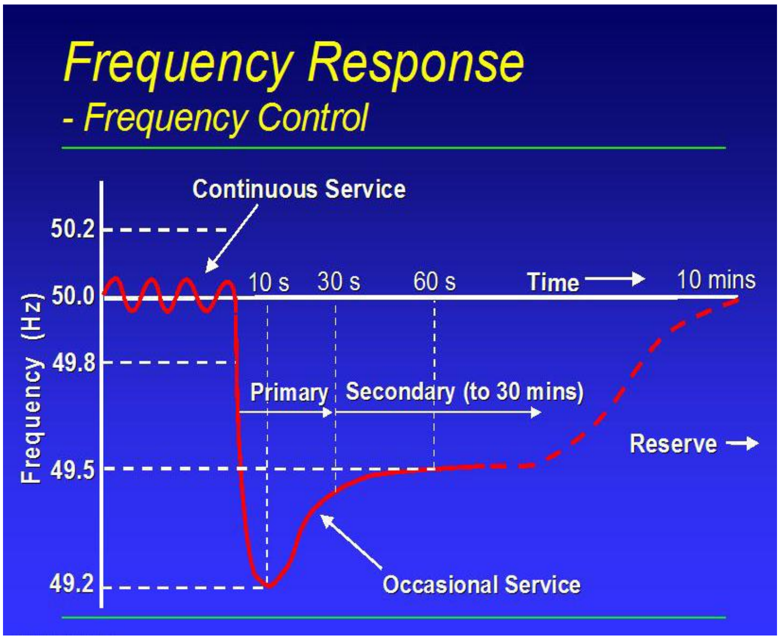

Figure 7 - Time frames of MFR services

2.9.1.2 Firm frequency response and frequency response by Demand Management

Firm frequency response (FFR) is used to meet the same needs as the MFR. The difference between the two is that in firm frequency response participation is allowed for any consuming or generating unit that meets the technical requirements.

The FFR can be either static or dynamic [62]. Dynamic FFR is the energy change in line with system frequency and static FFR is energy change that occurs at pre-set frequency and remain at a set level.

The frequency response by Demand Management (FRDM) is done by interrupting of customers. The interruption is automatic and the customers who provide this service have agreed to an interruption for 30 minutes. Statistically, these interruptions occur approximately ten to thirty times per year [63].

The technical requirements for the providers of FRDM are [63]:

- Provision of the service within 2 seconds of instruction.
- Delivery for minimum of 30 minutes.
- Delivery of minimum 3MW, also can be done by aggregation smaller loads at discretion of NGET.
- Have suitable operational metering.
- Provision of output signal into NGET’s monitoring equipment.

2.9.1.3 Fast reserve

Fast reserve (FR) provides rapid delivery of power through either an increased output from a generator or a reduction in consumption from demand sources, when National Grid sends electronic dispatch instruction [64]. FR as an additional service to the other AS for FS , in cases of sudden and unpredictable changes in generation or demand.

The delivery of active power has to start 2 minutes after the dispatch instruction, the latest. The minimum delivery rate is 25 MW/minute and it has to be able to deliver power for at least 15 minutes. The minimum delivery volume is 50 MW. These are the requirements that the providers of this service must have in order to pass the pre-qualification stage.

2.9.1.4 Short-term operating reserve

Short Term Operating Reserve (STOR) is a service which service providers can provide to National Grid to deliver a specific level of power from their generators or a reduction of demand [65]. This service is constrained in terms of the time period of provision, stated in the contract. This time period is referred to as the “Availability Window” which is the period where the provider is obliged to deliver the specified power [65].

The three types of STOR are [65]:

- *Committed* - a service provider must make the service available for all Availability Windows within the contract.
- *Flexible* - only open to non-BM service providers and allows greater flexibility on how many hours are made available and when that is offered.
- *Premium Flexible* – similar to the flexible STOR, with the difference that when a service provider offers availability in a ‘premium’ availability window, NGET guarantees to accept a large percentage of these.

The providers must offer the minimum of 3 MW generation or demand reduction and the response has to be within four hours after an instruction of NGET. The delivery should be sustained for at least two hours and the recovery period after the provision must not be more than 20 hours. The providers should be able to activate the STOR at least 3 times a week.

2.9.2 Procurement of ancillary services

The AS are procured either by market arrangements or via non-tendered bilateral contracts [66]. Which type of AS is procured by which method, is shown in Table 21.

Table 21 - Procurement of ancillary services in the UK

Services procured by non-tendering bilateral contracts	Services procured by market arrangements
• **Mandatory frequency response** • **Commercial frequency response** • **Fast reserve**	• Fast reserve • Short-term operating reserve

Procurement of MFR

If a generating unit has to provide MFR and meets the requirements, it has to sign the Mandatory Service Agreement with NGET. This allows NGET to instruct provision of the service when it is needed. The remuneration for MFR consists of two payments – holding and response energy payment. The holding payment, which is in £/h, is made for the capability of the unit to provide response when the unit has been instructed into frequency response mode; the response energy payment is in £/MWh and it is the cost for saving or changing the amount of delivered energy to the system or from the system [60]. The response energy payment can be either a payment or a charge which depends on whether the generator provides more or less energy during the response.

Procurement of FFR

The FFR is procured through monthly tender. The providers can tender for one or several months and the most economic offers are then chosen. The providers whose offers have been chosen are then bind by a contract to provide the service. The remuneration process consists of multiple payments, although most providers tender in only for availability and nomination [62]:

- Availability payment (£/h) – the number of hours of availability from a provider.
- Nomination payment (£/h) – for each hour utilised.
- Window initiation payment - for each FFR window that the provider has been instructed under.
- Tendered window revision payment (£/h) - NGET notifies providers of window nominations in advance and, if the provider allows, this payment is payable if NGET subsequently revises this nomination.
- Response energy payment (£/MWh) – this is for non-BM providers only and is based upon the actual response energy provided in the nominated window.

FCDM is procured only by means of bilateral negotiations with providers. The remuneration process involves only the availability payment.

Procurement of FR

The FR is procured by tender once the pre-qualification process is finished. There are optional FR and firm FR. For optional FR, there is a framework agreement that does not oblige the provider. Instead, the provider is allowed an optional dispatch whenever available. For firm FR, the providers can enter a framework agreement an then participated in a monthly tender.

The remuneration for optional FR involves Enhanced Rate Availability payment, in £/h. The providers receive this payment for the periods when they provide NGET with enhanced run-up and run-down rates of MW [64].

The payments for firm FR are all payments submitted by the provider as part of the tender [64]:

- Availability payment (£/h) - paid for each hour in a Tendered Service Period when the service is available.
- Window initiation - NGET will notify ‘windows’ during which it requires the service to be provided, for which a payment will be made.
- Positional payment - during a window, providers may also specify a positional payment (the cost of putting plant in a position where fast reserve may be provided).
- Utilisation payment (£/MW/h) payable for the energy delivered in both services.

Procurement of STOR

The STOR is procured through a competitive tender, three times a year. The providers that want to participate must first sign the STOR Framework Agreement.

The remuneration process involves two payments [65]:

- Availability payment – the provider is paid (£/MW/h) during the periods the service is available within the availability window.
- Utilisation payment– where energy is delivered in response to an instruction from NGET, payment is made on the volume delivered in £/MWh.

2.9.3 Market data

NGET publishes the volumes and costs for AS every month in the Monthly Balancing Services Summary, which is available on their website [67].

The aggregated values for 2015, for MFR, FFR, FR and STOR are shown in Table 22. The volumes of MFR and FFR are given for used energy in MWh. For FR, the total holding volume in MWh is given. The STOR values show the total utilized energy in MWh from both BM and non-BM units.

Table 22 - Reserves volumes in Great Britain for 2015

MFR (MWh)			FFR (MWh)			FR (MWh)	STOR (MWh)
Primary	Secondary	High frequency	Primary	Secondary	High frequency		
2596170	1536930	3693220	2835178	2908121	1677466	4939936	195111

2.10 ENTSO-E classification and requirements important for wind operators

The classification of the AS for FS of all countries according to the ENTSO-E classification has been done in separate tables for FCR, FRR-A (**Table 23** and Table 24) and the third table is for FRR-m and RR (Table 25). This classification was done by comparing the definitions of the services from each country with the definitions from ENTSO-E. In most of the countries, FRR-m and RR services are defined as one type of reserve, thus the third table includes both services.

The tables present several important parameters, namely which AS of the countries fall under the particular type according to ENTSO-E, the procurement arrangements, the gate closing times and the minimum offers.

These show some of the main critical requirements for wind power operators in order to be able to participate in the procurement of these services, as already analyzed in [5]:

- *Procurement rules and remuneration process:* The different AS for FS of the countries, in terms of activation time and how long the service is provided, show that TSOs must organize a cost-efficient way of procurement and remuneration of the services. A mandatory provision for all generators would mean that not all of the reserves can be used efficiently at all times.
- *Gate closing time:* As wind is an intermittent source of energy, the gate closing time is crucial for the cost-effective delivery of FS AS from wind. Short closing time from the point of submitting an offer to delivering the service, would mean better forecast of the wind conditions and the needed amount of reserves.
- *Minimum offer:* Small offers would improve the possibility of offering part of the foreseen power, as well as bidding also from smaller wind power plants.

Additional issues that would concern the wind power operators are the activation time and whether the offers can be submitted separately for upward and downward directions.

The activation time could be an issue, again due to the unpredictability of wind. If a certain service must be provided for prolonged period of time, wind generators may not be able to fulfill the needed reserves.

Regulating in upward direction might cause lower generation of wind power than what is available. The possibility to separate the offers for downward and upward regulation could enable a more economic provision of AS for the wind operators.

Table 23 - Summary of FCR services unified under ENTSO-E classification

Reserve type by ENTSO-E [68]	Parameters	Denmark	Finland	Norway	Sweden	Ireland	Great Britain	The Netherlands	Belgium	France	Germany	Spain	Portugal
Frequency containment reserve (FCR)	Reserve type by country	Frequency controlled normal operation reserve (FNR, now FCR-N), Frequency controlled disturbance operation reserve (FDR, now FCR-D)				Primary operating reserve, Secondary operating reserve	Mandatory frequency response, Firm Frequency Response (dynamic and static)	Primary reserve	Primary reserve	Primary system regulation	Primary control reserve	Primary control reserve	Primary control reserve
	Procurement arrangement	Two-day auctions	Yearly and hourly markets	Day-head and weekly auctions	Weekly and hourly auctions	Bilateral contracts	Firm Frequency Response – monthly tenders	Recently through tenders on the German platform	General framework : short-term auction or long-term tender	Mandatory , according to AS rules	Market auctions – weekly call for tender	Manda-tory	Manda-tory
	Gate closing time	Day before at 15:00 [3]	Yearly market – day before by 18:00; Hourly market-day before by 18:30	Day-ahead: by 19:00; Weekly: weekdays by Friday 13:00, weekend by Thursday 13:00 [37]	-	-	On business day 1 before of the month by 17:00	Every week by Tuesday at 15:00 [69], [21]	-	-	Every week by Tuesday at 15:00 [21]	-	-
	Minimum offer	DK1: 0.1 MW [3]	FCR-N 0.1 MW; FCR-D 1 MW [70]	Less than 1 MW [2]	Less than 1 MW [2]	-	-	1 MW [21]	1 MW [71]	-	1 MW [21]	1.5% of nominal power	-

Table 24 - Summary of FRR-a services unified under ENTSO-E classification

Reserve type by ENTSO-E [68]	Parameters	Denmark	Finland	Norway	Sweden	Ireland	Great Britain	The Netherlands	Belgium	France	Germany	Spain	Portugal
Automatic frequency restoration reserve (FRR-a)	Reserve type by country	Automatic FRR (still developing)				Tertiary operating reserve 1 Tertiary operating reserve 2	Fast reserve	Secondary reserve	Secondary reserve	Secondary regulation reserve	Secondary control reserve	Secondary control reserve	Secondary control reserve
	Procurement arrangement	Through market arrangements	Hourly market;	Weekly	Market	Bilateral contracts	Monthly tenders (single and multiple)	Day-ahead market	General framework : short-term auction or long-term tender	Mandatory, according to AS rules for FRR-a	Weekly auctions	Day-ahead market	Day-ahead market
	Gate closing time	DK2: two-day and day ahead auctions with Svenska Krafnat, two days and one day ahead	Hourly market, day before by 6:30 pm;	Weekly by Thursday 13:00 [37]	-	-	On business day 1 before the month by 17:00	Bids -day before delivery before 14:45, can be altered 1 hour before delivery [72]	Day before delivery day by 15:00 [14]	-	Before Wednesday every week [22]	At 16:00 daily [3]	In the period of 19:00-19:45 [30]
	Minimum offer	-	5 MW [73]	5 MW [74]	5 MW [75]	-	Minimum delivery volume 50 MW [76]	4 MW [72]	1 MW [71]	-	5 MW [22]	10 MW [3]	-

Table 25 - Summary of FRR-m and RR services unified under ENTSO-E classification

Reserve type by ENTSO-E [68]	Parameters	Denmark	Finland	Norway	Sweden	Ireland	Great Britain	The Netherlands	Belgium	France	Germany	Spain	Portugal
Manual frequency restoration reserve (FRR-m) and replacement reserve (RR)	Reserve type by country	FRR-m: Fast and slow active disturbance reserve (FADR and SADR) Fast active forecast reserve (FAFR) Fast active counter trading reserve (FACTR) RR : does not exist				Replacement reserve	Short Term Operating Reserve (STOR)	Tertiary reserve	Tertiary reserve	Tertiary reserve	Minute reserve	Tertiary control reserve	Tertiary control reserve
	Procurement arrangement	Through long-term contracts; Daily auctions if needed	Long-term bilateral arrangements and Nord Pool Regulating Power Market	Weekly and yearly auctions	Nord Pool Regulating Power Market	Bilateral contracts	Three tender rounds per year	Day-ahead market	General framework – short-term auction or long-term tender; Standard contracts (for interruptible loads)	Yearly tender	Daily auctions	Intraday market	Intraday market
	Gate closing time	DK1: Prior to delivery month for monthly offers	45 minutes before delivery hour	Weekly by Friday 14:00; Yearly – auctions are announced [37]	45 minutes	15 minutes notice before dispatch [3]	-	Bids must be delivered on the day before delivery before 14:45, can be altered 1 hour before delivery [72]	Day before delivery day by 14:00 [18]	-	At 12:00 daily [77]	25 minutes before delivery hour [78]	50 minutes before delivery hour [30]
	Minimum offer	10 MW [79]	10 MW [73]	10 MW [80]	10 MW [75]	-	3 MW [81]	4 MW [72]	1 MW [71]	-	5 MW [77]	10 MW [3]	-

2.11 Balancing responsibility of wind power generators

The provision of balancing energy is still mostly provided by conventional generators, as current balancing market arrangements are still in transition to accommodate wind generators. Some countries already have the conditions to allow wind generators to participate in the provision of energy on the balancing market, while other countries' balancing markets are still not developed to a stage where they can let wind power generators participate.

The European Wind Energy Association (EWEA) has conducted a survey to provide an overview of the balancing responsibility, including cost implications, of wind power generators in the EU countries [6]. The summary of this survey for the countries reviewed in this report is given in Table 26.

Table 26 - Balancing responsibility of wind power generators according to EWEA's survey

Country	Are wind generators balancing responsible?	Are they treated differently to other generators?	Is provision of balancing services allowed?
Belgium	Yes	No	Yes
Germany	Partly	N/A	Partly (Only RR)
France	No	N/A	No
Spain	Yes	No	Yes
Portugal	No*	N/A	N/A
Denmark	Yes	No	Yes
Finland	Yes	No	Yes
Norway	N/A	N/A	N/A
Sweden	Yes	No	Yes
Ireland	No	No	N/A
UK	Yes	No	Yes

In roughly half of the reviewed countries the wind generators are balancing responsible and they are not treated differently to other generators. The provision of balancing services is allowed for wind generators, but practically this is not the case due to the market conditions that are restricting their participation. Even when wind generators are allowed to provide balancing services it is mostly for RR.

However, steps to include wind generators in balancing markets are being made. The German TSO 50Hertz has allowed wind farms to participate in balancing market as of 17th February 2016 [82]. In Spain, the legislation that lays out the criteria for renewable generation to participate in AS has been implemented in February 2016, and 3.5 GW of wind generation capacity is about to obtain the right to participate in the balancing market [7]. Denmark has a promising example of wind power participation on balancing markets [6] and in Belgium there are successful results from the pilot project for delivery of balancing services by wind generators [83].

3 Possible role of wind power in future balancing markets

3.1 Summary of volume and price data

The market data collected for FRR-a and FRR-m and RR is summarized in Table 27 . The data was summarized only for those countries where consistent information was available. This was not the case for FCR, as this service is either mandatory or the data is unpublished.

Table 27 - Summary of FRR-a services in EU countries for 2015

<table>
<tr><th>FRR-a</th><th>Netherlands</th><th>Great Britain</th><th>Ireland</th><th>Portugal</th><th>Spain</th></tr>
<tr><td>Required power (MW)</td><td>300</td><td>600[18]</td><td>110[19]</td><td>256</td><td>600</td></tr>
<tr><td>Activated up (GWh)</td><td>252.4</td><td rowspan="2">4940</td><td rowspan="2">-</td><td>424.7</td><td>1366.3</td></tr>
<tr><td>Activated down (GWh)</td><td>-257.6</td><td>-67.7</td><td>-1193.0</td></tr>
<tr><td>Peak load (GW)</td><td>25.2</td><td>57.5</td><td>6.5</td><td>8.3</td><td>43.5</td></tr>
<tr><td>Gross demand (TWh)</td><td>120.9</td><td>335</td><td>28.2</td><td>50.3</td><td>243</td></tr>
<tr><td>Power to peak load (%)</td><td>1.19%</td><td>0.52 %</td><td>0.77 %</td><td>3.08 %</td><td>1.38 %</td></tr>
<tr><td>Energy to gross demand (%)</td><td>0.42 %</td><td>1.47 %</td><td>-</td><td>0.98 %</td><td>1.05 %</td></tr>
<tr><td>Average price up €/MWh</td><td>-</td><td rowspan="2">-</td><td rowspan="2">1.4</td><td>59.41</td><td>58.87</td></tr>
<tr><td>Average price down €/MWh</td><td>-</td><td>23.76</td><td>31.95</td></tr>
</table>

Table 28 - Summary of FRR-m and RR services in EU countries for 2015

FRR-m & RR	Nordic countries	Portugal	Spain
Activated up (GWh)	1680	691	3113
Activated down (GWh)	-2564	-1269	-1625
Gross demand (TWh)	388.9	50.3	243
Energy to gross demand (%)	1.09 %	3.90 %	1.95 %
Average price up €/MWh	29.5	59.4	58.9
Average price down €/MWh	19.6	23.8	32.0
Wind capacity in 2020 (GW)	15.6	5.5	24.5

[18] This amount required during summer season is 300 MW.

[19] The required MW is the minimum day-time requirement for Republic of Ireland. The price is an average of the prices for TOR1 and TOR2.

To compare the values, the amounts are presented also relative to peak load (for MW) and gross demand (for MWh).

For FRR-a required MW amounts, an average over the year is presented for Portugal and Spain, the minimum for Ireland and the maximum for Great Britain. The amounts of yearly MWh activated are also given. For FRR-m and RR the sums of activated MWh in both directions are presented. The sum of activated MWh for Great Britain was not available for both directions separately and it is presented as the total sum of activated MWh.

From the presented data, it can be seen that the share of energy used for balancing and FS is only a small fraction of the total demand served by generators. The differences for different countries is associated to the size of the system. For smaller synchronous systems like Ireland, GB and the Nordic system the share of energy used for FS is generally larger than for the large Central European system as it can be seen from the data for the Netherlands.

3.2 Simple estimation of wind power participation in future balancing markets

Based on the collected market data for 2015 and the low scenario of wind power capacity for 2020 as presented in [84], a rough estimation of the size of future balancing markets was made for three different markets, the Spanish the Nordic and the Portuguese. It is assumed that 25 % of the total wind power will participate in the balancing market, and produce on average 3000 MWh per MW. The estimation was done for two cases, a minimum and a maximum case. The results of both cases are presented in Figure 8.

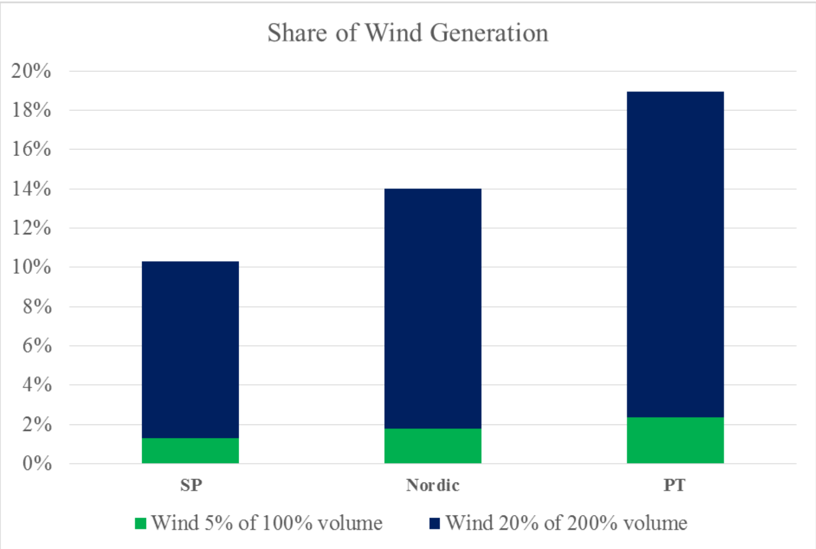

Figure 8 - Share of wind generation in balancing markets assuming market volumes of 2015 and double that, and 5- 20% share of wind power producers in the markets.

For the minimum case the assumptions are that the volume of the markets stays the same as in 2015 in the balancing markets, wind only takes part in downward regulation, and will get a 5% share of all bids accepted for the year. In this case, the wind power producers active in the balancing market would sell 1-2% of their yearly generation to balancing markets in the different countries: 1 % in Spain and 2% in Nordic countries and Portugal.

For the maximum case the assumptions are that the volume of the balancing markets is doubled and wind power producers would get a 20 % market share, selling both down and up-regulation. In this case the wind power producers active in the balancing market would sell 10-19% of their yearly generation to balancing markets in the different countries: 10 % in Spain, 14 % in Nordic countries and almost 19 % in Portugal.

Assuming a price range, decrease/increase of (80% / 120% of prices in 2015), possible future income for wind power producers from balancing market participation is estimated. For Nordic countries it would be between 1000 €/MW/a (down-regulation only, 5 % market share) and 12 000 €/MW/a (both up- and down-regulation, with higher market volume and market share), for Portugal twice as high and for Spain 1500 €/MW/a to 18 000 €/MW/a. This income would be associated with some less income from the spot market. The difference of spot price and up/down regulation is 3-10/3-7 €/MWh in Nordic countries and 6-14 / 12-19 €/MWh in Iberia, respectively. The spot and up/down regulation prices, and the difference between them, for the countries of the Nordic region as well as the total Nordic region, Spain and Portugal are given in Figure 9.

For down regulation you get paid less than spot price so this would not bring extra income for wind power producers, unless forced to operate in curtailed mode.

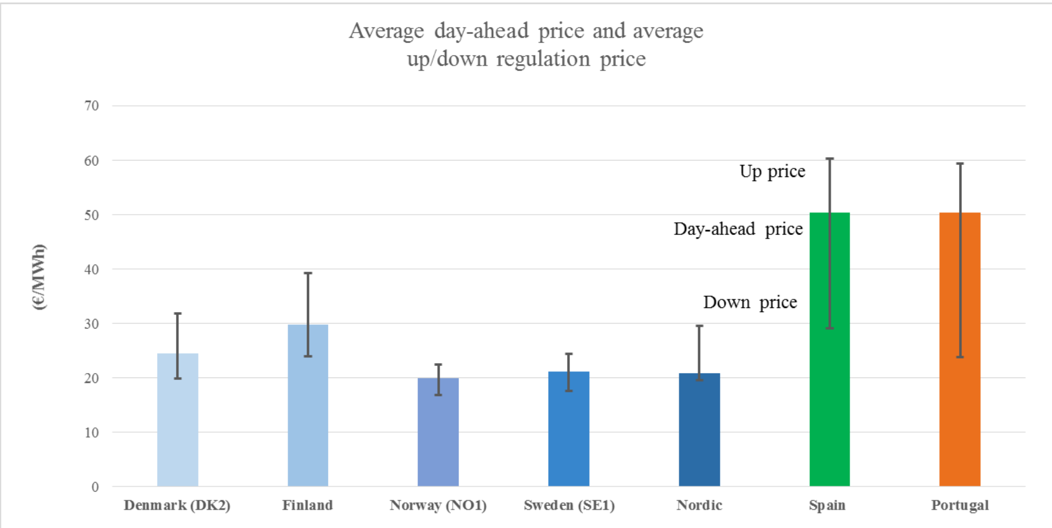

Figure 9 - Average spot price and average up/down regulation price for 2015

4 Effects of the spot and balancing market practices to wind power participation in the balancing markets

4.1 Linear Programing model

In order to perform a more detailed analysis of the possible benefits for wind generators participating in the balancing markets, a LP optimization problem was solved in order to see which parameters influence the maximization of the income for the wind generators from both day-ahead and balancing market. The programing was performed in GAMS software.

The objective function is the sum of all income that a wind producer would get from both day-ahead market and balancing market for up and down regulation. The problem aims to optimize the energy that should be sold on both markets from a wind power producer, by being subjected to several constraints. The complete model considers separate, asymmetrical upward and downward regulation, and is given as:

- Objective function:

$$\max \sum_{t=t_0}^{H_y} (\lambda_t^{DAM} \cdot E_t^{DAM} + \lambda_t^{BMU} \cdot E_t^{BMU} + \lambda_t^{BMD} \cdot E_t^{BMD})$$

- Constrains:

$E_t^{DAM} \geq 0$ t = 1, . . ., H_y (1)

$E_t^{BMU} \geq 0$ t = 1, . . ., H_y (2)

$E_t^{BMD} \geq 0$ t = 1, . . ., H_y (3)

$E_t^{DAM} \leq x_t * \bar{E}_{WPP}$ t = 1, . . ., H_y (4)

$E_t^{BMU} \leq \eta_t^{up} * (\bar{E}_{WPP} - E_t^{DAM})$ t = 1, . . ., H_y (5)

$E_t^{BMD} \leq \eta_t^{down} * E_t^{DAM}$ t = 1, . . ., H_y (6)

The time set is equal to the number of hours in a year, where one time unit equals one hour and H_y is the total number of hours.

In the considered model, the parameters are:

λ_t^{DAM} - day-ahead market price at time t

λ_t^{BMU} - up regulation price at time t

λ_t^{BMD} - down regulation price at time t

$\bar{E}_{WPP}$ - maximum energy that can be sold from the wind producer at time t

x_t - wind production mismatch at time t

η_t^{up} - probability that up regulation energy will be used at time t

η_t^{down} - probability that down regulation energy will be used at time t

The variables are:

E_t^{DAM} - energy that is used in the day-ahead market at time t

E_t^{BMU} - energy that is used for up regulation at time t

E_t^{BMD} - energy that is used for down regulation at time t

The maximum energy that can be sold from the wind power producer $\bar{E}_{WPP}$ is calculated based on the capacity factor for each time unit which is calculated as the ratio of the data for wind production for each time unit and the total available production in the considered country.

The mismatch parameter x_t represents the deviation of the actual wind production compared to the for every time unit, using the hourly data for actual and forecasted wind production for 2015.

The probability of whether up/ down regulation energy will be used $\eta_t^{up/down}$ is calculated based on the sold volumes at the day-ahead market and the volumes used for up/down regulation in 2015. The probability for each time unit is calculated as the ratio of up/down used regulation energy to the energy sold on the day-ahead market, at every time unit. The aim of this parameter was to take into account whether there is a possibility to have up/down regulation for each time unit.

In the objective function the first term $\lambda_t^{DAM} \cdot E_t^{DAM}$ refers to the income from the day-ahead market for every hour of the year. The second term, $\lambda_t^{BMU} \cdot E_t^{BMU}$ and the third term $\lambda_t^{BMD} \cdot E_t^{BMD}$ refer to the income from the used energy for up and down regulation respectively.

The constraints (1)-(3) are limiting the energy values to be larger or equal to zero.

Constraint (4) aims to restrict the value that can be sold to the day-ahead market, by being lower or equal to the maximum energy that the wind producer can give and downgraded by the mismatch between the forecasted and actual wind production at time t.

Constraint (5) puts a limit on the value of energy used for up regulation. This value is limited by the difference between the maximum available energy and the energy already sold to day-ahead market and the probability that energy for up regulation will be used at time t.

Constraint (6) restricts the value of energy used for down regulation. The maximum energy that can be offered for down regulation optimally would equal the total available energy already sold on the day-ahead market, but it is limited by the probability that energy for down regulation will be used at time t.

4.2 Model implementation and analysis

The model was implemented for three different balancing markets, the Portuguese, the Spanish and the Nordic. The wind power producer is assumed to have a maximum capacity of 60 MW in the analysis of the markets in all considered countries. This value has been taken to comply with the generator requirements for providing AS in the ENTSO-E Network Code on Requirements for Generators (NG RfG) [85].

In the case of the Nordic market, each country is analysed separately and for every bidding zone, as the prices are not always equal in all bidding zones. The Spanish and Portugal markets are analysed as a whole.

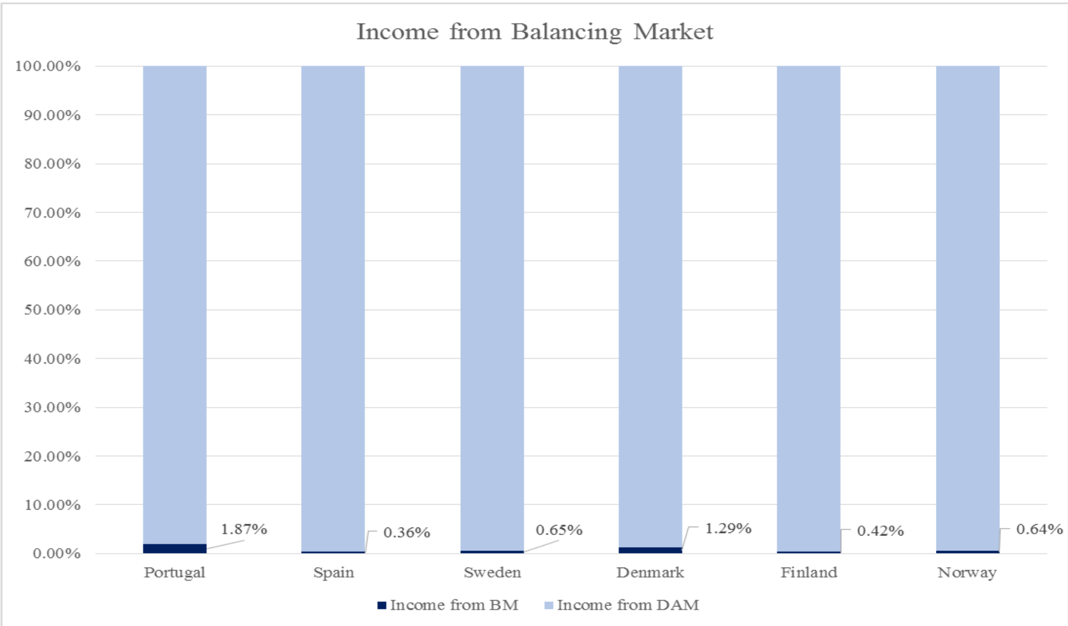

Figure 10 - Percentage of income for the wind producer from the balancing market in relation to the income from day-ahead market

The results give how much extra income the wind producer would receive from participating in the up/down regulation market compared to the income they get only from the day-ahead market. It also gives the additional euros/MW the wind producer would get annually from the participation in up/down regulation.

The percentage of the additional income from both up and down regulation, compared to the day-ahead market income, for each country is presented is presented in Figure 10.

The income from the balancing market is very modest compared to the income form the day-ahead, as it can be expected given the difference in the size of the markets. The additional income is varying from less than half percent in the case of Spain to almost 2% in the case of Portugal.

The percentage of income is slightly higher in the cases of Portugal and Denmark where the systems are smaller and the volume of energy used for regulation is higher.

From the obtained results, the additional euros a wind producer would get per MW annually can be calculated. For the Nordic countries, as every calculation was made separately for each zone, the additional euros are given as a range from the lowest to the highest amount of euros/MW a producer can get depending on the bidding zone. They are given in Table 29.

Table 29 - Additional euros/MW annually for the wind producer from balancing market

Portugal	Spain	Sweden	Denmark	Finland	Norway
1875	334	19-193	111-488	209	16-172

Looking at the additional euros/MW, only in the case of Portugal they are in the limits of the estimated values. A slightly higher value can be seen for Denmark. The country where the amount of additional euros per MW annually is lowest, is Norway.

4.2.1 Sensitivity analysis

In addition to the results from the model, a sensitivity analysis was done for two parameters that could influence the income from the balancing market. The two parameters are the prices (λ_t^{BMU} and λ_t^{BMD}) and the probability the energy for up/down regulation will be used ($\eta_t^{up}$and η_t^{down}) . The obtained results are shown in the following sections.

4.2.1.1 Price variations

The analysis for the price was done by increasing the prices for both up and down regulation for a factor 1.5 and for a factor 2, i.e. 150% of the prices in 2015 and 200% of the prices in 2015, for every time unit. The results are shown in Figure 11.

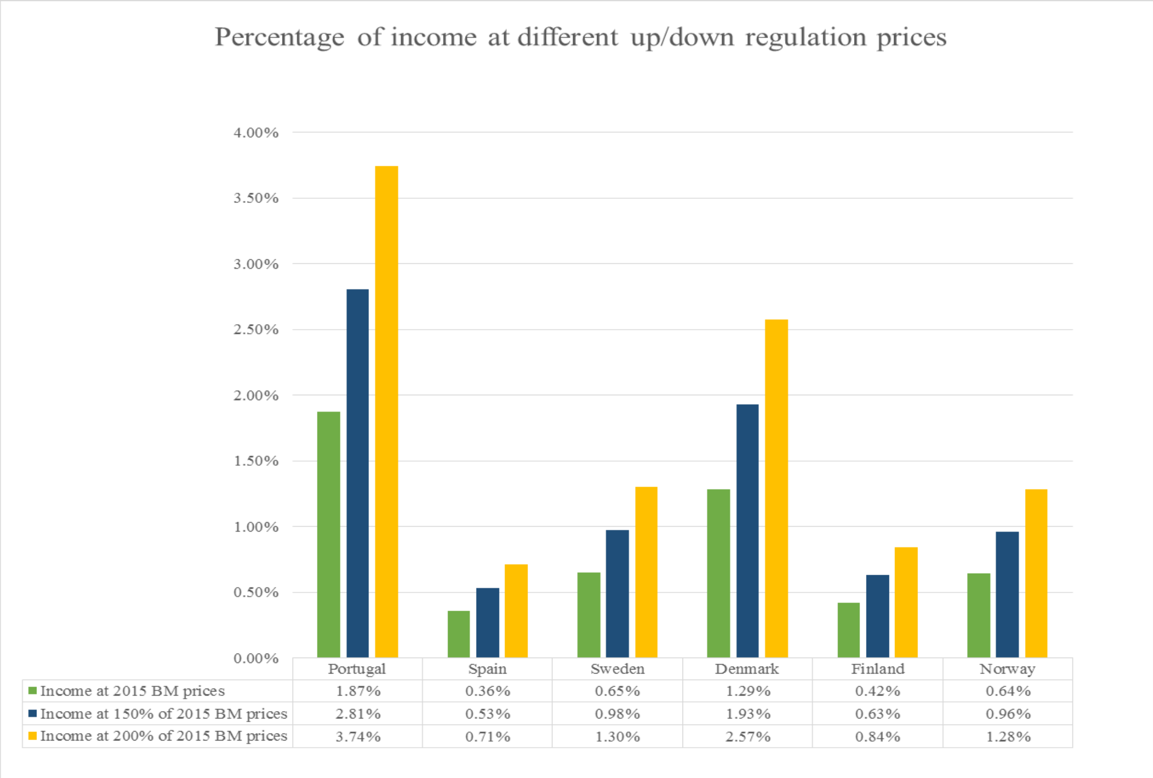

Figure 11 - Percentage of income from the balancing market at different up/down regulation prices

Several conclusions can be drawn from the results.

As expected, the income increases by the same factor as the prices. The income from the balancing market rises from the range of 0.4-2% to 0.7-4% in the case when the prices are doubled.

The same effect of the price variation is reflected in the additional euros/MW the wind producer would get. For both factors, the additional euros/MW are presented in Table 30.

Table 30 - Additional euros/MW annually from balancing market for different prices

Factor	Portugal	Spain	Sweden	Denmark	Finland	Norway
1.5	2812	500	28-289	266-732	314	24-258
2	3750	667	38-386	221-975	419	33-344

4.2.1.2 Probability variations

The effects of varying the probability that up/down regulation energy will be used were analysed by increasing the probabilities for both up and down regulation by factor 2, 5 and 10 for every time unit. The obtained results are shown in Figure 12.

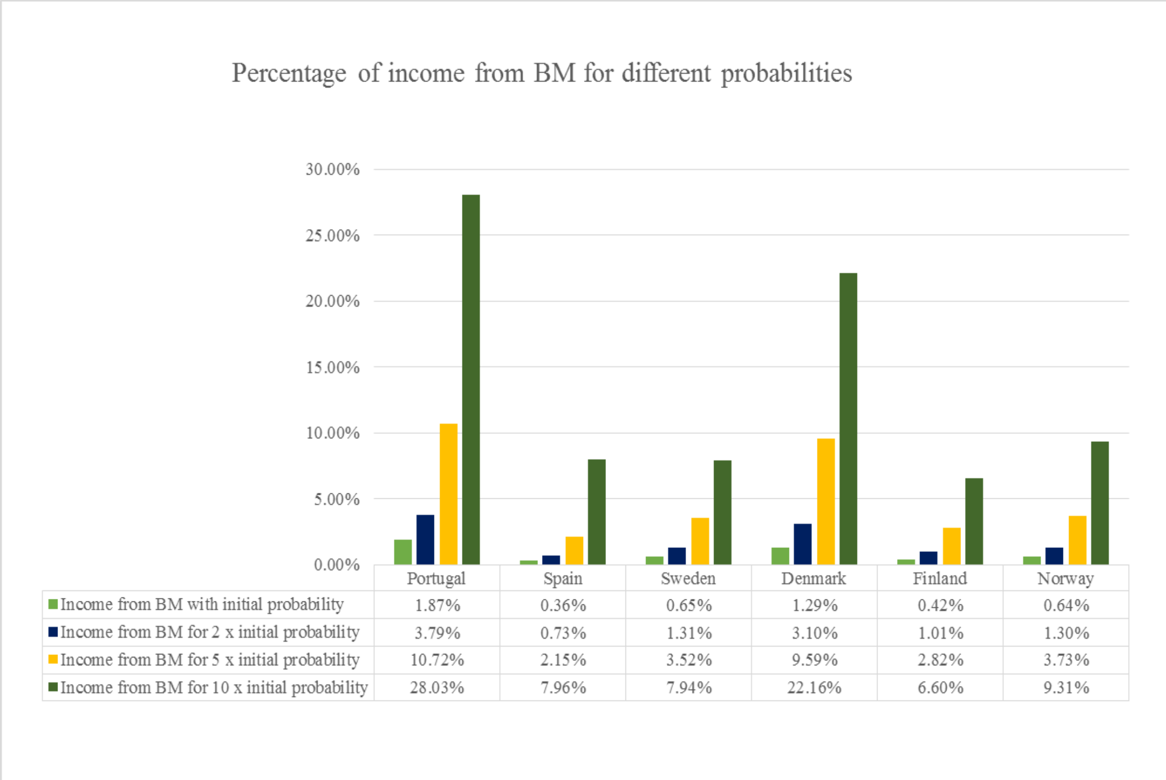

Figure 12 - Percentage of income from balancing market for different values of the probability

Starting from the increase by factor 2 and then following the other factor values, there is a non-linear change in percentage of income in relation to the factor value. The percentage of income increases from the range of 0.4-2% to the range of 0.7-3.8% for a probability twice as higher than the one calculated for 2015. For a probability 5 times higher, the percentage ranges between 2-11%, and for factor value of 10 in the range of 7-28%. From the results it can be seen that the percentage of income increases more than 10 times when the highest factor is used. This shows that the income from the balancing market is highly dependent on the probability that up/down regulation will be used.

The probability increase also resulted in increase in the additional euros/MW annually the wind power producer would get. For the three factors, the results are given in Table 31.

Table 31 - Additional euros/MW annually from balancing market for different probabilities

Factor	Portugal	Spain	Sweden	Denmark	Finland	Norway
2	3801	688	41-387	254-1184	503	33-352
5	10645	2005	116-1000	739-3652	1394	93-1068
10	26715	7238	320-2227	1640-8320	3243	240-2750

4.2.2 Difference in income from day-ahead and balancing market for downward regulation

It is important to take into account the difference in income that a wind power producer would get if the same energy that was used for downward regulation was actually sold at the day-ahead market. The reason for this is because prices for down regulation are always lower than prices at the day-ahead market, and as mentioned in the previous section, the income from downward regulation is associated with less income from the day-ahead market, unless the wind producer is forced to operate in curtailed mode.

This difference was calculated assuming the income for the energy used for down regulation a producer would get with the down regulation price and the income the producer would have gotten if the same amount of energy was actually used in the day-ahead market.

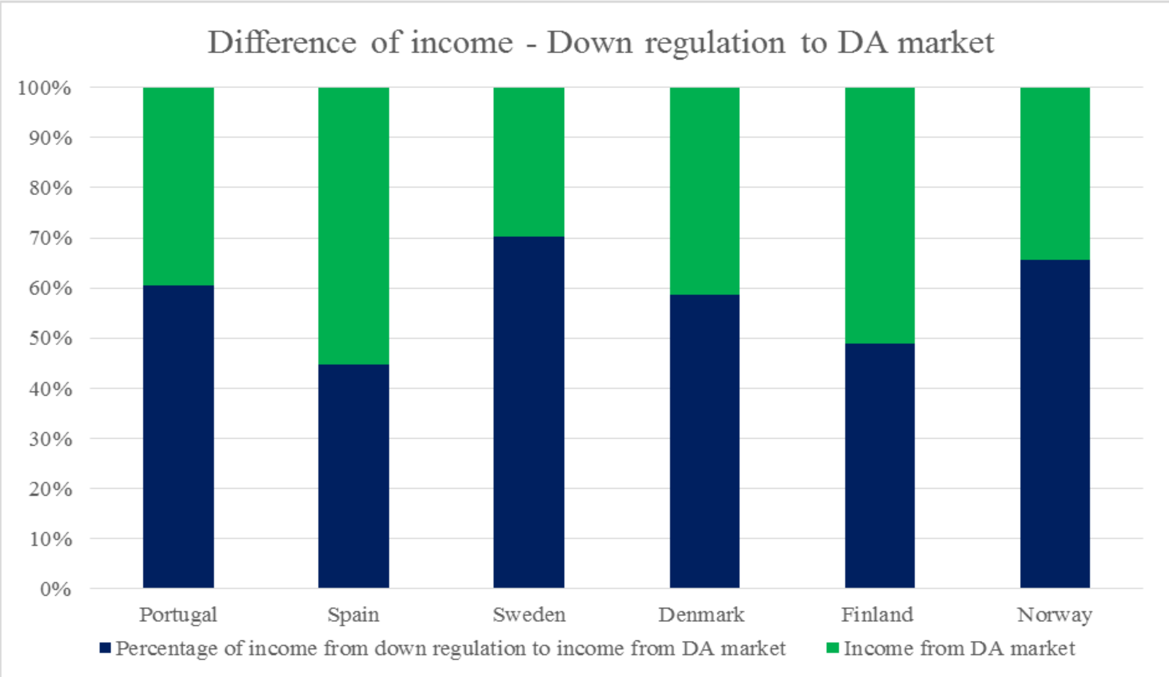

Figure 13 - Difference in income from down regulation to income from day-ahead market for the amount of energy used for down regulation

In the case of Portugal, the wind producer would get 39% less income from down regulation than it would have had if the same energy was used in the day-ahead market. In Spain, the wind producer would get 55% less and in the Nordic this difference is in the range of 30-50%.

5 Main findings and discussion

The Nordic countries are an excellent example of this, with the Regulating Power Market that has been operating for more than 10 years. In contrast, there are still cases where some of the AS are mandatory, such as the cases in Portugal and Spain for primary (FCR) reserves, or merely contracted, which is the practice in Ireland. Considering the market data, every country has its way of presenting it for the procured services and not all data is easily accessible. Also, it is not always available for all reserves.

The tables in which all practices are summarized under the ENTSO-E classification, by following the parameters important for wind power participation, show that some of the analysed countries, like Spain and the Nordic countries, have these parameters in favour of wind power producers providing manually activated reserves. Others still have to improve their market structures to accommodate wind power producers in providing these reserves. For the automatically activated reserves, most of the countries have to develop markets first, as some of these reserves are still mandatory.

The implementation of the model based on the data of 2015 has shown that with current market practices, the income from the balancing market would be very low compared to the income a wind power producer could get from the day-ahead market. Compared to the estimations done in the previous chapter, the results from the model implementation are lower.

The income from up/down regulation depends on two factors: price and probability the energy will be used for up/down regulation. The sensitivity analysis of the price and the probability tends toward the increase of these two parameters.

The increase in price has linearly increased the income for the producers and in the case of doubling the price from 2015, the income has doubled as well. In addition to this, a case where already the prices for up/down regulation have increased considerably due to the high penetration of solar and wind generation in the system, has been noted in California [86]. The requirements for frequency regulation increased considerably as a result of the high solar and wind generation, which tripled the prices for up/down regulation in the first quarter of 2016.

The increase in probability has shown much better results in increasing the income from the balancing market. Already, by only increasing with factor 5, the income has increased more than the factor value.

The probability that up/down regulation will be used can be associated with power system inertia [20]. By integrating more renewables in the system that substitutes conventional generators, the system inertia decreases.

This means that the system would be less capable of resisting the frequency changes and in higher need for FS reserves to maintain stability. Several future scenarios concerning this issue have been already studied, in [85] for the system in Great Britain and in [86] for the Nordic countries.

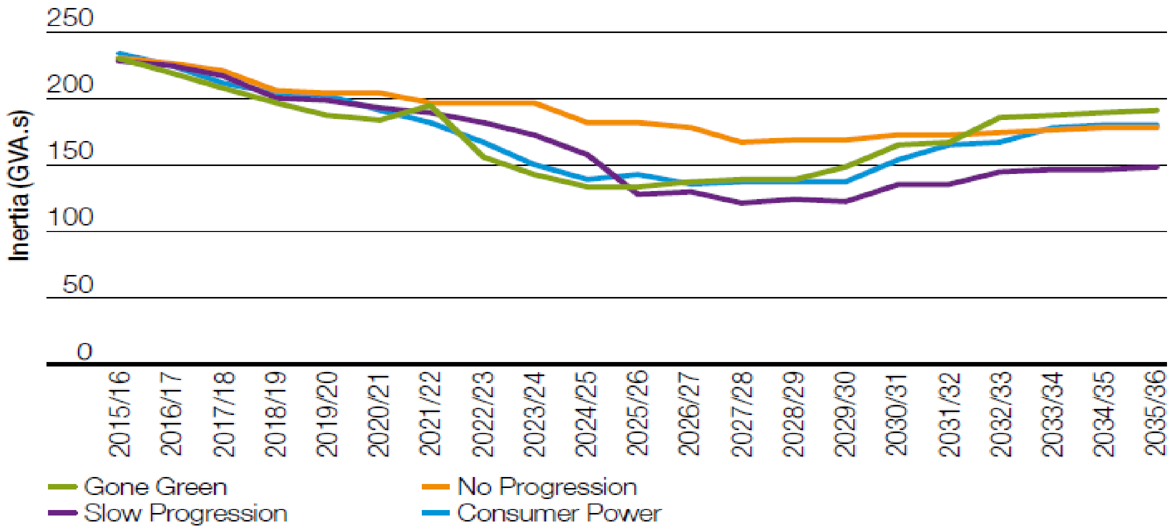

Figure 14 - Minimum system inertia including contribution from distributed generation [85]

Several scenarios from the system in Great Britain are shown in Figure 14. The Gone Green scenario is based on renewable, low-carbon generation. The No Progression and Slow Progression scenarios are considering that innovation in the energy sector is very low and very high, for both cases respectively. The Consumer Power scenario assumes high innovation focused on market and consumer needs. From all the considered scenarios, even though of highest relevance here is the Gone Green one, it can be seen that system inertia will drop in following years, even with the help of distributed generation. The results show that by 2030, for all scenarios the amount of FS that will be needed will increase by 3-4 times the current level.

[20] *Power system inertia* is the capability of the system to resist sudden changes of frequency as a result of the resistance of the rotating masses of synchronous generators.

In the model implementation the optimal amounts of already used energy were calculated to maximize the income, which is why in presentation of the results the income from downward regulation was taken as extra income. But when analysing this, it is important to note that income from down regulation is always associated with less income from the spot market due to the fact that prices for down regulation are always lower than day-ahead market prices. How much less would this be in the considered cases, was shown by calculating the difference in the income if the same energy that was used for down regulation was actually used in the day-ahead market.

Conclusions

The preformed analysis of AS for frequency response for 11 European countries, gives a clear overview of how distinct the definitions and procurement practices are, amongst the countries. The procurement methods visibly lean towards market-based procurement.

The distinction between the classifications of the services shows the need to unify these services within a common classification, because such unification is of great relevance for potentially analysing how neighbouring countries behave under the same task. The results of an attempt to unify the definitions under the ENTSO-E classification are presented in the three tables for FCR, FRR-A, and FRR-m with RR which also include the important parameters form the wind power producer’s point of view.

The simplified assessment of current market volumes for manually activated reserves gave cases with possible future market volumes and income. The results show that with current market volumes and assuming down-regulation participation only from wind power plants, the share of energy sold as well as extra income will probably be modest. With higher market volumes and shares of wind power, the volumes and income could become significant. Extra income would also come from automatically activated reserves.

A more detailed analysis was performed by solving a LP problem in order to maximize the income for the wind power producer, using the collected data for 2015. The results have shown that with current market practices the potential extra income a wind power producer could get from the balancing market is very low. Two parameters that can influence this are the prices in the balancing market and the probability that energy for up/down regulation will be used. The increase of the probability resulted in possibly significant increase in the income from balancing markets. This parameter depends on the need for frequency regulation and as studies show this need will increase in the future due to the increased penetration of renewables in the power systems.

However, the current trends also lean towards cross border trading and sharing of services for FS which would result in decreasing volumes and the market size for these services is already small. Moreover, an increase in competition in these markets is expected with the entering of solar power, demand side and storage. Whether wind power producers will get significant income from the provision of AS for FS is not a straight forward answer and will depend on many factors.

References

[1] ENTSO_E, “ENTSO-E Network Code for Requirements for Grid Connection Applicable to all Generators,” Brussels, 2013.

[2] “Survey on Ancillary Services Procurement and Electricity Balancing Market Design,” 2014. [Online]. Available: https://www.entsoe.eu/publications/market-reports/ancillary-services-survey/Pages/default.aspx. [Accessed 2015].

[3] H. Holttinen, J. Kiviluoma, N. Cutululis, A. Gubina, A. Keane and F. Van Hulle, “D2.2, REserviceS, Ancillary Services,” 2012.

[4] “Energy Roadmap 2050,” European Union, Belgium, 2012.

[5] F. Van Hulle, H. Holttinen and J. e. a. Kiviluoma, “D7.1, Synthesis report 1, REserviceS project,” 2014.

[6] EWEA, “Balancing Responsibility and Costs of Wind Power Plants,” 2016.

[7] “ICIS - Resources,” [Online]. Available: http://www.icis.com/resources/news/2016/03/30/9983079/spain-to-usher-3-5gw-of-wind-power-into-balancing-market/. [Accessed 2016].

[8] “Continental Europe Operation Handbook,” [Online]. Available: https://www.entsoe.eu/publications/system-operations-reports/operation-handbook/Pages/default.aspx. [Accessed 2016].

[9] ENTSO-E, “NC Load Frequency Control & Reserve: Overview Last Developments,” 2012.

[10] “Elia Belgium - Ancillary Services,” [Online]. Available: http://www.elia.be/en/products-and-services/ancillary-services. [Accessed 2015].

[11] “Ancillary Services,” [Online]. Available: http://www.elia.be/en/suppliers/purchasing-categories/energy-purchases/Ancillary-services#anchor2-7. [Accessed 2016].

[12] “The primary reserve: a solution for stabilising the frequency in the European interconnected system,” [Online]. Available: http://www.elia.be/en/products-and-services/~/media/files/Elia/Products-and-services/ProductSheets/S-Ondersteuning-net/S1_F_RES_PRIMAIRE.pdf. [Accessed 2015].

[13] “Elia Belgium - Purchase of Ancillary Services,” [Online]. Available: http://www.elia.be/en/products-and-services/ancillary-services/purchase-of-ancillary-services. [Accessed 2015].

[14] “The Secondary Reserve: A Solution to Restore Balance and Frequency,” [Online]. Available: http://www.elia.be/~/media/files/Elia/Products-and-services/ProductSheets/S-Ondersteuning-net/S2_F_RES_SECOND.pdf. [Accessed 2015].

[15] “Paid offtake interruption in order to preserve the grid,” [Online]. Available: http://www.elia.be/~/media/files/Elia/Products-and-services/ProductSheets/S-Ondersteuning-net/S4_F_INTERRUPTION.pdf. [Accessed 2015].

[16] “Tertiary Offtake Reserve: Dynamic Profile,” [Online]. Available: http://www.elia.be/~/media/files/Elia/Products-and-services/ProductSheets/S-Ondersteuning-net/S_Grid%20support_En.pdf. [Accessed 2015].

[17] “Ancillary Services: Volumes & Prices,” [Online]. Available: http://www.elia.be/en/suppliers/purchasing-categories/energy-purchases/Ancillary-Services-Volumes-Prices. [Accessed 2015].

[18] “Tertiary Production Reserve: A Solution to Major Imbalances and Congestion,” [Online]. Available: http://www.elia.be/~/media/files/Elia/Products-and-services/ProductSheets/S-Ondersteuning-net/S3_F_RES_TERT_PROD.pdf. [Accessed 2015].

[19] “Procurement of Control Power and Energy in Germany,” [Online]. Available: http://www.amprion.net/en/control-energy. [Accessed 2015].

[20] “Rules on Balancing - Germany,” [Online]. Available: https://transparency.entsoe.eu/balancing-domain/r2/rulesOnBalancing/show?name=&defaultValue=true&viewType=TABLE&areaType=MBA&atch=false&dateTime.dateTime=01.01.2015+00:00|UTC|YEAR&dateTime.endDateTime=01.01.2016+00:00|UTC|YEAR&biddingZone.values=CTY|10Y10. [Accessed 2015].

[21] “Primary control reserve,” [Online]. Available: https://www.regelleistung.net/ext/static/prl. [Accessed 2015].

[22] “Secondary control reserve,” [Online]. Available: https://www.regelleistung.net/ext/static/srl. [Accessed 2015].

[23] “Data for control reserve,” [Online]. Available: https://www.regelleistung.net/ext/data/?lang=en. [Accessed 2016].

[24] “Reference Technical Documentation,” [Online]. Available: http://clients.rte-france.com/lang/an/clients_producteurs/mediatheque_client/dtr.jsp. [Accessed 2015].

[25] “Procured reserves,” [Online]. Available: http://clients.rte-france.com/lang/an/visiteurs/vie/reserve_ajustement.jsp. [Accessed 2015].

[26] “Rules on Balancing - France,” [Online]. Available: https://transparency.entsoe.eu/balancing-domain/r2/rulesOnBalancing/show?name=&defaultValue=true&viewType=TABLE&areaType=MBA&atch=false&dateTime.dateTime=01.01.2015+00:00|UTC|YEAR&dateTime.endDateTime=01.01.2016+00:00|UTC|YEAR&biddingZone.values=CTY|10YFR. [Accessed 2015].

[27] “Ancillary service,” [Online]. Available: http://clients.rte-france.com/lang/an/clients_producteurs/services_clients/services_systeme.jsp. [Accessed 2015].

[28] “Operational data,” [Online]. Available: http://clients.rte-france.com/lang/an/visiteurs/vie/courbes_methodologie.jsp. [Accessed 2016].

[29] J. T. Saraiva, H. Heitor, N. Correia and R. Araújo, “Ancillary Services in the Iberian Electricity Market – Current Situation and Harmonization Approaches,” IEEE, 2011.

[30] “Rules on Balancing - Portugal,” [Online]. Available: https://transparency.entsoe.eu/balancing-domain/r2/rulesOnBalancing/show?name=&defaultValue=true&viewType=TABLE&areaType=MBA&atch=false&dateTime.dateTime=01.01.2015+00:00|UTC|YEAR&dateTime.endDateTime=01.01.2017+00:00|UTC|YEAR&biddingZone.values=CTY|10YPT. [Accessed 2015].

[31] REN, “Annual Report 2011-2015”.

[32] “Rules on Balancing - Spain,” [Online]. Available: https://transparency.entsoe.eu/balancing-domain/r2/rulesOnBalancing/show?name=&defaultValue=true&viewType=TABLE&areaType=MBA&atch=false&dateTime.dateTime=01.01.2016+00:00|UTC|YEAR&dateTime.endDateTime=01.01.2017+00:00|UTC|YEAR&biddingZone.values=CTY|10YES. [Accessed 2015].

[33] “ESIOS,” [Online]. Available: https://www.esios.ree.es/en. [Accessed 2016].

[34] *Agreement Regardig Operation of the Interonnected Nordic Power System (System Operation Agreement),* ENTSO-E, 2006.

[35] “Rules on Balancing - Denmark,” [Online]. Available: https://transparency.entsoe.eu/balancing-domain/r2/rulesOnBalancing/show. [Accessed 2015].

[36] “Rules on Balancing - Finland,” [Online]. Available: https://transparency.entsoe.eu/balancing-domain/r2/rulesOnBalancing/show?name=&defaultValue=true&viewType=TABLE&areaType=MBA&atch=false&dateTime.dateTime=01.01.2015+00:00|UTC|YEAR&dateTime.endDateTime=01.01.2016+00:00|UTC|YEAR&biddingZone.values=CTY|10YFI. [Accessed 2015].

[37] “Rules on Balancing - Norway,” [Online]. Available: https://transparency.entsoe.eu/balancing-domain/r2/rulesOnBalancing/show?name=&defaultValue=true&viewType=TABLE&areaType=MBA&atch=false&dateTime.dateTime=01.01.2015+00:00|UTC|YEAR&dateTime.endDateTime=01.01.2016+00:00|UTC|YEAR&biddingZone.values=CTY|10YNO. [Accessed 2015].

[38] “Rules on Balancing - Sweden,” [Online]. Available: https://transparency.entsoe.eu/balancing-domain/r2/rulesOnBalancing/show?name=&defaultValue=true&viewType=TABLE&areaType=MBA&atch=false&dateTime.dateTime=01.01.2015+00:00|UTC|YEAR&dateTime.endDateTime=01.01.2016+00:00|UTC|YEAR&biddingZone.values=CTY|10YSE. [Accessed 2015].

[39] “Ancillary Services - Electricity,” [Online]. Available: http://www.energinet.dk/SiteCollectionDocuments/Engelske%20dokumenter/El/8871-11%20v3%20Ancillary%20services%20to%20be%20delivered%20in%20Denmark%20-%20Tender%20conditions.%20Valid%20from%203%20October%202012.pdf. [Accessed 2015].

[40] “Frequency Containment Reserves,” [Online]. Available: http://www.fingrid.fi/en/powersystem/reserves/acquiring/normaloperation/Pages/default.aspx. [Accessed 2015].

[41] “Procurement of reserves,” [Online]. Available: http://www.fingrid.fi/en/powersystem/reserves/acquiring/Pages/default.aspx. [Accessed 2015].

[42] T. Kristiansen, “The Nordic Approach to Market-based Provision of Ancillary Services,” Elsevier, 2007.

[43] “No. 48/2015 - Update on Exchange Information No. 36/2015 (FRR-A contracting),” [Online]. Available: http://www.nordpoolspot.com/message-center-container/nordicbaltic/exchange-message-list/2015/q4/no.-482015---update-on-exchange-information-no.-362015-frr-a-contracting/. [Accessed 2016].

[44] “No. 11/2015 - Update on Exchange Information No. 52/2014 (FRR-A contracting),” [Online]. Available: http://www.nordpoolspot.com/message-center-container/nordicbaltic/exchange-message-list/2015/q1/no.-112015---update-on-exchange-information-no.-522014-frr-a-contracting/. [Accessed 2015].

[45] “Download Center,” [Online]. Available: http://www.nordpoolspot.com/download-center/. [Accessed 2016].

[46] EirGrid, “Grid Code,” [Online]. Available: http://www.eirgridgroup.com/site-files/library/EirGrid/GridCodeVersion4.pdf. [Accessed 2015].

[47] SONI, “Grid Code,” [Online]. Available: http://www.soni.ltd.uk/media/documents/Operations/Grid-Code/SONI%20Grid%20Code%20Version%20Aug%202015.pdf. [Accessed 2015].

[48] KEMA, “System Services International Review,” 2011. [Online]. Available: http://www.eirgridgroup.com/site-files/library/EirGrid/System-Services-International-Review-KEMA.pdf. [Accessed 2015].

[49] “DS3 Program,” [Online]. Available: http://www.soni.ltd.uk/Operations/DS3/. [Accessed 2015].

[50] EirGrid, SONI, SEMO, “DS3:System Services Review ,” [Online]. Available: http://www.eirgridgroup.com/site-files/library/EirGrid/System-Services-TSO-Recommendations-May2013.pdf. [Accessed 2015].

[51] “Ancillary Service Agreement,” [Online]. Available: http://www.eirgridgroup.com/site-files/library/EirGrid/Ancillary%20Service%20Agreement.pdf. [Accessed 2015].

[52] EirGrid & SONI, “Ancillary Services and Procurement Policy,” [Online]. Available: http://www.soni.ltd.uk/media/documents/Operations/Ancillary-Services/EirGrid%20SONI%20Ancillary%20Services%20Procurement%20Policy.pdf. [Accessed 2015].

[53] EirGrid, “Ancillary Services Statement of Payments and Charges,” [Online]. Available: http://www.eirgridgroup.com/site-files/library/EirGrid/AncillaryServicesStatementOfPaymentsAndCharges2015_2016.pdf. [Accessed 2015].

[54] SONI, “Ancillary Services Statement of Payments and Charges,” [Online]. Available: http://www.soni.ltd.uk/media/documents/Operations/Ancillary-Services/Ancillary%20Services%20Statement%20of%20Payments%20and%20Charges%202015-16.pdf. [Accessed 2015].

[55] EirGrid, SONI, “Operational Constraint Update,” [Online]. Available: http://www.eirgridgroup.com/site-files/library/EirGrid/OperationalConstraintsUpdateVersion1_24_April_2015.pdf. [Accessed 2015].

[56] “Ancillary Services Report 2014/2015,” 2015.

[57] “Transmission Licence Standard Conditions,” [Online]. Available: https://epr.ofgem.gov.uk/Content/Documents/Electricity%20transmission%20full%20set%20of%20consolidated%20standard%20licence%20conditions%20-%20Current%20Version.pdf. [Accessed 2015].

[58] “Procurement Guidelines,” [Online]. Available: https://transparency.entsoe.eu/balancing-domain/r2/rulesOnBalancing/show?name=&defaultValue=true&viewType=TABLE&areaType=MBA&atch=false&dateTime.dateTime=01.01.2014+00:00|UTC|YEAR&dateTime.endDateTime=01.01.2016+00:00|UTC|YEAR&biddingZone.values=CTY|GB!MB. [Accessed 2015].

[59] “Grid Code,” [Online]. Available: file:///C:/Users/s144147/Documents/UPC%202015-2016/Internship%20IREC/Ofgem%20UK/Complete%20Grid%20Code.pdf. [Accessed 2015].

[60] National Grid, “Mandatory Frequency Response Guide v1_1”.

[61] “Mandatory Frequency Response,” [Online]. Available: http://www2.nationalgrid.com/UK/Services/Balancing-services/Frequency-response/Mandatory-Frequency-Response/. [Accessed 2015].

[62] National Grid, “Firm Frequency Response 1.1”.

[63] “Frequency Control by Demand Management,” [Online]. Available: http://www2.nationalgrid.com/uk/services/balancing-services/frequency-response/frequency-control-by-demand-management/. [Accessed 2015].

[64] National Grid, “Fast Reserve v1.0”.

[65] National Grid, “STOR v1.1”.

[66] National Grid, “Procurement Guidelines Report,” [Online]. Available: https://transparency.entsoe.eu/balancing-domain/r2/rulesOnBalancing/show?name=&defaultValue=true&viewType=TABLE&areaType=MBA&atch=false&dateTime.dateTime=01.01.2014+00:00|UTC|YEAR&dateTime.endDateTime=01.01.2016+00:00|UTC|YEAR&biddingZone.values=CTY|GB!MB. [Accessed 2015].

[67] National Grid, “Services Reports,” [Online]. Available: http://www2.nationalgrid.com/UK/Industry-information/Electricity-transmission-operational-data/Report-explorer/Services-Reports/. [Accessed 2015].

[68] P. Campbell, *Network Code on Electricity Balancing,* Vienna: ENTSO-E, 2014.

[69] “Primary Control Reserve in the Netherlands,” [Online]. Available: https://www.regelleistung.net/ext/static/prlnl;jsessionid=64D23796F78940C6F6382A06D5B7188D. [Accessed 2015].

[70] “Frequency Containment Reserve,” [Online]. Available: http://www.fingrid.fi/en/powersystem/reserves/reservetypes/containment/Pages/default.aspx. [Accessed 2015].

[71] Elia System Operator, “Regles de functionnement du marche relatif a la compensation des desequilibres quart-haraires - Entre en vigueur partiellement en 2015 et intéralement a partir du 1er Janvier 2016,” [Online]. Available: http://www.elia.be/~/media/files/Elia/Products-and-services/Balancing/20150825_R%C3%A8gles_Balancing_FR.pdf. [Accessed 2015].

[72] “Implementation Guide,” 2012. [Online]. Available: http://www.tennet.org/english/images/120214%20SO%20SOC%2012-xxx%20Uitvoeringsregels%204%202%20%20UKclean_tcm43-19026.pdf. [Accessed 2015].

[73] “Frequency Restoration Reserve,” [Online]. Available: http://www.fingrid.fi/en/powersystem/reserves/reservetypes/restoration/Pages/default.aspx. [Accessed 2015].

[74] “LFC Technical Product Specification,” [Online]. Available: http://www.statnett.no/PageFiles/2581/LFC%20Technical%20Product%20Specification.pdf.

[75] “Effektreserv,” [Online]. Available: http://www.svk.se/aktorsportalen/elmarknad/effektreserv/. [Accessed 2015].

[76] “Fast Reserve v1.0,” [Online]. Available: http://www2.nationalgrid.com/uk/services/balancing-services/reserve-services/fast-reserve/.

[77] “Minute reserve,” [Online]. Available: https://www.regelleistung.net/ext/static/mrl. [Accessed 2015].

[78] I. d. l. Fuente, *Ancillary Services in Spain: Dealing with High Penetration of RES.*

[79] “Reg C2 - The balancing market and balance settlement,” [Online]. Available: https://www.energinet.dk/SiteCollectionDocuments/Engelske%20dokumenter/El/Regulation%20C2%20The%20balancing%20market%20and%20balance%20settlement.pdf.

[80] "Om regulerkraftmarkedet (RK)," [Online]. Available: http://www.statnett.no/Global/Dokumenter/Kraftsystemet/Markedsinformasjon/RKOM/Vilk%C3%A5r%20for%20RK-markedet%20-%2025%20juni%202015.pdf. [Accessed 2015].

[81] "Short Term Operating Reserve," [Online]. Available: http://www2.nationalgrid.com/uk/services/balancing-services/reserve-services/short-term-operating-reserve/. [Accessed 2015].

[82] "50Hertz News," [Online]. Available: http://www.50hertz.com/en/News/Detail/id/960/wind-farms-can-participate-in-balancing-market. [Accessed 2016].

[83] "Enercon - Current topics and trends," [Online]. Available: http://www.enercon.de/en/news/news-detail/cc_news/show/News/pilot-project-for-delivery-of-balancing-services-by-wind-farms-in-belgium/. [Accessed 2016].

[84] EWEA, "Wind energy scenarios for 2020," 2014.

[85] National Grid, "System Operability Framework 2015," 2015.

[86] "Future System Inertia," 2013.

[87] I. Lampropoulos, J. Frunt, F. A. Nobel, A. Virag, P. P. J. van den Bosch and W. L. Kling, "Analysis of the Market-based Service Provision for Operating Reserves in the Netherlands," IEEE, 2012.

ETSEIB