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Market Architectures for Cross-Border Procurement and Activation of Balancing Reserves and Balancing Energy

Deliverable 2.1

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1 Introduction

In Europe, the further integration of the internal electricity market is an ongoing process since the beginning of electricity market liberalization in 1999. In recent years, also the further development and opening of the balancing electricity market segment has been increasingly addressed in the energy policy discussion; not least due to the fact that at present the different national balancing electricity markets are still characterised by very heterogeneous patterns manifold (e.g. in terms of market structures, market rules, operational procedures and also prequalification criteria for balancing service providers interested to participate in this particular market segment; see e.g. ENTSO-E (2012)).

In order to start this challenging task of balancing market renewal in Europe, the European Commission and the two main European associations responsible in this field – ACER (Agency for the Cooperation of Energy Regulators) and ENTSO-E (European Network of Transmission System Operators for Electricity) – recently have agreed on a timeline to trigger an iterative process in this respect. However, this iterative process is not restricted to these two associations but also includes public consultations where several European stakeholders and policy makers in this field can provide their inputs. The inclusion of several important European market participants and policy makers is supposed to be necessary, not least due to the fact that the long-term goal of renewal of European electricity balancing market design unambiguously follows the most advanced concept (among those having been initially discussed by ENTSO-E, see ENTSO-E (2011a)), i.e. the so-called *'Multilateral TSO-TSO Balancing Model with Common Merit (Target Model)'*.

The aim of this report is to contribute to this development manifold. A selection of contributions is as follows: On the one hand, different market architectures for cross-border procurement and activation of balancing reserve capacities and balancing energy are elaborated in detail (i.e. describing possible bidding mechanisms and procedures qualified for practical implementation). On the other hand, also the interpretation of a Balancing Service Provider (BSP) is extended in the sense that also distributed generators, small sized energy storage and load response (known as 'Virtual Power Plant (VPP)') can contribute in this segment as a market participant.

The method applied in this report is to use the above mentioned documents of ACER and ENTSO-E as a basis in order to develop – starting from an entirely national balancing market without any sharing of balancing energy bids – gradually enhanced cross-border balancing market architectures (based on bid sharing) being consistent and compatible with the overall framework defined in the ACER and ENTSO-E documents. The most advanced market architecture described in this report coincides with the so-called *'Target Model'* already mentioned above.

This report provides the foundation for market architecture design enhancements of cross-border balancing markets in the FP7-project eBadge (see http://www.ebadge-fp7.eu). Moreover, in the eBadge project not only cross-border balancing market design details are addressed enabling the participation of VPPs as BSPs, but also corresponding modelling is conducted and a practical field/pilot study is implemented in the electricity market region of the Italian-Slovenia-Austrian border. For further details in this respect as well as comprehensive information on the overall objectives, working programme and the expected outcomes of the FP7-project eBadge it is referred to the above mentioned project website.

This report is organised as follows:

- In section 2 the key challenges and basic principles of cross-border procurement and activation of balancing reserves and balancing energy are addressed. This includes in particular the harmonisation needs in terms of balancing markets in Europe and the cross-border transmission congestion and counteracting imbalance activation problem. Also the basic principles of the different currently implemented concepts for cross-border procurement and activation of balancing reserves and balancing energy in Europe are briefly summarized.
- Section 3 provides an in-depth description of the market architectures for cross-border procurement and activation of balancing reserves and balancing energy considered in the eBadge project. Each of the four models is presented as follows: general approach, market for procurement of balancing reserves, market for procurement and activation of balancing energy, logistics and data flow requirements, determination of the amount of shared and unshared bids (if needed), clearing approach, and finally implications for VPPs as BSPs.
- Section 4 introduces and elaborates on the implementation of VPPs as BSPs in the proposed market architectures developed in the previous section 3. This includes a general description of the characteristics of VPPs and the requirements of VPPs to meet the prequalification criteria for BSPs in future balancing markets.
- A short conclusion wraps up this report.

2 Key Challenges and Basic Principles of Cross-Border Procurement and Activation of Balancing Reserves and Balancing Energy

2.1 European Policy Background

In recent years, several efforts to further develop and integrate the European electricity market have also explicitly addressed the balancing market segment in the European energy policy discussion and the corresponding policy documents. Mainly as a result of the individual historical developments of the different national balancing markets in Europe, at present they are characterised by a very heterogeneous pattern in terms of market structures, market rules, operational procedures and also prequalification criteria for balancing service providers being interested to participate in this particular market segment (see e.g. ENTSO-E (2012)). Against this background, the two main European associations responsible in this field – ACER (Agency for the Cooperation of Energy Regulators) and ENTSO-E (European Network of Transmission System Operators for Electricity) – recently have agreed on a timeline to trigger an iterative process for defining the cornerstones of future European balancing markets. More precisely, ACER started this process by developing framework guidelines for a fundamental renewal and set-up of the balancing markets also across the borders of the individual TSO's control areas. Subsequently, ENTSO-E has been invited to respond to these framework guidelines and to develop the cornerstones of a corresponding network code. A draft document in this context already has been delivered early 2013, followed by a comprehensive public consultation process in recent months where several European stakeholders have been invited to submit their inputs (for further details in this context (incl. link to the corresponding ENTSO-E website) it is referred to section 2.4.1 in this document). After the finalisation of this first iteration between ACER and ENTSO-E, however, European balancing market design can't be denoted be not finished. Rather it is the beginning of continuous amendments and improvements of European balancing market design in the years to come.

2.2 Harmonisation of Terms in Balancing Markets

As already mentioned in the previous section 2.1, at present there exist very heterogeneous structures and patterns when drawing the different parameter settings characterising national balancing markets in Europe. A comprehensive summary on country level in this respect is presented in ENTSO-E (2012). This summary also visualizes the importance for significant harmonization of market structures, market rules, operational procedures and also prequalification criteria for market participants interested in balancing service provision. A selection of these parameters being subject to harmonization is addressed in subsequent sections and chapters of this document. In the following, the foremost aspect in this context is briefly summarized only: the harmonization needs in terms of deviating interfaces between the market sub-segments within the time frame of balancing service provision in Europe. Before doing so, a definition of balancing reserve capacity and balancing energy is preceded:

- *Balancing reserve capacities (MW)* are made available for TSOs to balance (in case of activation) the electricity system in real time. These capacities can be contracted by the TSO with an associated payment for their availability and/or be made available without payment. Reserves can be either automatically or manually activated.
- *Balancing energy (MWh)* is finally the resulting energy flow as a consequence of activated balancing reserve capacities of TSOs to maintain the balance of the electricity system in real time.

The different balancing market sub-segments within the time frame of balancing service provision are mainly determined by maturity and activation mechanism of balancing reserve capacities. According to the new nomenclature proposed by ENTSO-E – the result of harmonisation of the heterogeneous pattern of the status quo across Europe (see Table 2.1 in detail) – the following categories exist:

- *Frequency Containment Reserves (FCR):* These are operating reserves for constant containment of frequency deviations from nominal value in the whole synchronously interconnected electricity system. Activations of these reserves result in a restored electricity system balance at a frequency deviating from nominal value. Operating reserves have activation time up to 30 seconds and are activated automatically and locally.
- *Frequency Restoration Reserves (FRR):* These are operating reserves to restore frequency to nominal value after electricity system imbalance. Activation up to 15 minutes, typically managed by an automatic controller. However, depending on product and country, FRR can also be activated manually (see in Table 2.1 below).

- *Replacement Reserves (RR):* These are operating reserves used to restore the required level of operating reserves to be prepared for a further electricity system imbalance. This category includes operating reserves with activation time from 15 minutes up to hours. They may be contracted or subject to markets.

In the following Table 2.1 an overview is presented indicating the allocation of FCR, manual and automatic FRR and RR to the status quo of existing “terms” in the balancing reserve and balancing energy service provision in different European market regions.

Table 2.1 Harmonisation of the terms in the different balancing market segments across Europe. Source: ENTSO-E (2011)

Sync. Area	Process	Product	Activation	Local/Central	Dynamic/ Static	Full Activation Time
BALTIC	Frequency Containment	Primary Reserve	Auto	Local	D	30 s
Cyprus	Frequency Containment	Primary Reserve	Auto	Local	D	20 s
Iceland	Frequency Containment	Primary Control Reserve	Auto	Local	D	variable
Ireland	Frequency Containment	Primary operating reserve	Auto	Local	D/S	5 s
Ireland	Frequency Containment	Secondary operating reserve	Auto	Local	D/S	15 s
NORDIC	Frequency Containment	FNR (FCR N)	Auto	Local	D	120 s -180 s
NORDIC	Frequency Containment	FDR (FCR D)	Auto	Local	D	30 s
RG CE	Frequency Containment	Primary Control Reserve	Auto	Local	D	30 s
UK	Frequency Containment	Frequency response dynamic	Auto	Local	D	Primary 10 s / Secondary 30 s
UK	Frequency Containment	Frequency response static	Auto	Local	S	variable
BALTIC	Frequency Restoration	Secondary emergency reserve	Manual	Central	S	15 Min
Cyprus	Frequency Restoration	Secondary Control Reserve	Auto/Manual	Local/Central	D/S	5 Min
Iceland	Frequency Restoration	Regulating power	Manual	Central	S	10 Min
Ireland	Frequency Restoration	Tertiary operational reserve 1	Auto/Manual	Local/Central	D/S	90 s
Ireland	Frequency Restoration	Tertiary operational reserve 2	Manual	Central	S	5 Min
Ireland	Frequency Restoration	Replacement reserves	Manual	Central	S	20 Min
NORDIC	Frequency Restoration	Regulating power	Manual	Central	S	15 Min
RG CE	Frequency Restoration	Secondary Control Reserve	Auto	Central	D	≤ 15 Min
RG CE	Frequency Restoration	Direct activated Tertiary Control Reserve	Manual	Central	S	≤ 15 Min
UK	Frequency Restoration	Various Products	Manual	D/S	N/A	variable
BALTIC	Replacement	Tertiary (cold) reserve	Manual	Central	S	12 h
Cyprus	Replacement	Replacement reserves	Manual	Central	S	20 min
Iceland	Replacement	Regulating power	Manual	Central	S	10 Min
Ireland	Replacement	Replacement reserves	Manual	Central	S	20 Min
NORDIC	Replacement	Regulating power	Manual	Central	S	15 Min
RG CE	Replacement	Schedule activated Tertiary Control Reserve	Manual	Central	S	individual
RG CE	Replacement	Direct activated Tertiary Control Reserve	Manual	Central	S	individual
UK	Replacement	Various Products but the main one is Short Term Operating Reserve (STOR)	Manual	D/S	N/A	from 20 min to 4 h

In the following, in this document – when talking in general (and not about some specific details of a particular national approach presented in section 2.4 of this report) – the following terms are used exclusively:

- Frequency Containment Reserves (FCR), automatic
- Frequency Restoration Reserves (FRR), automatic & manual
- Replacement Reserves (RR), manual

2.3 Key Challenges: Cross-Border Transmission Congestion and Counteracting Imbalance Activation

2.3.1 Availability of Sufficient Cross-Border Transmission Capacities for Balancing Reserve and Balancing Energy Procurement and Activation

Despite the ambition to enlarge the European balancing markets across the borders of the different TSOs' control areas, cross-border balancing markets will work in practise only, if there are sufficient physical cross-border transmission capacities available at that point in time when they are actually needed. This is one of the key aspects having to be taken into account in general, regardless which kind of cross-border balancing market concept finally is chosen (see in detail in this context in the following section 2.4 as well as section 3). The reason is that the different cross-border balancing market services compete with several other cross-border electricity trades in other market segments (e.g. in the hour-ahead and/or day-ahead market). Moreover, there exists an inherent conflict of different objectives in electricity market design (which can't be solved exactly due to the unalterable physical laws of electricity flows). In the following, further insights into the dilemma of electricity market design in this context are outlined briefly (see also Figure 2.1).

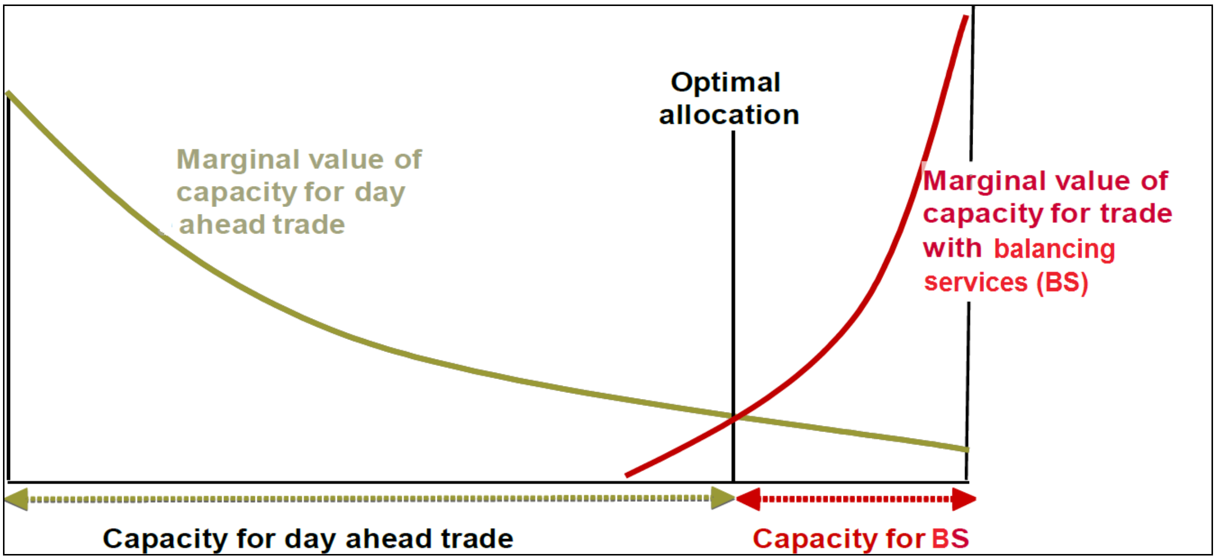

Figure 2.1 Optimal (welfare-maximising) allocation of physical cross-border transmission capacity between two market segments (day-ahead and balancing market). Source: ENTSO-E (2011).

In theory, the optimal (i.e. welfare-maximizing) allocation of physical cross-border transmission capacity between two market segments (e.g. hour/day-ahead market, balancing market; see Figure 2.1) can be explained easily: it is simply the trade-off between the descending marginal value of transmission capacity for cross-border electricity trades in the hour/day-ahead market and the increasing marginal value of transmission capacity for cross-border electricity balancing trades (see Figure 2.1 in detail).

In practise, however, the welfare-maximizing principle neither can be implemented exactly nor easily. The TSOs rather have to rely on tangible methods to estimate actually available physical cross-border transmission capacity for the balancing market services in case there is no ex-ante reservation for them.[1] In case there are no (or not sufficient) cross-border transmission capacities available at that point in time when they are actually needed, cross-border balancing energy activation and exchange simply has to be denied.

In order to bring forward this particular discussion, in the recent document on the draft network code on electricity balancing published by ENTSO-E (2013a) it has been recommended that a TSO can decide how to allocates cross-border transmission capacity for sharing and exchange of balancing reserves and balancing energy respectively:

(i) the TSOs can either use available cross-border transmission capacity after the intraday gate closure or
(ii) the capacity can be procured based on the methodologies described in ENTSO-E (2013a).

Furthermore, it is recommended that, in general, any cross-border transmission capacity that is available after intraday gate closure can be used for balancing purposes. The TSO can decide if it uses an additional provision methodology to make cross-border transmission capacity available in earlier timeframes by a

(i) probabilistic approach,
(ii) an allocation through a market-based co-optimization process or
(iii) reservation of cross-border transmission capacity.

When choosing the methodology, the TSOs have to consider that the probabilistic approach is not an option for highly congested cross-border transmission lines and

[1] In general, ex-ante reservation of a pre-defined physical cross-border transmission capacity for cross-border balancing energy exchange is possible. However, it is difficult/ambiguous to argue that this is not an arbitrarily interference into the basic market principles.

that the reservation methodology has to be used if no weekly auction of cross-border transmission capacity is in place. In all other cases the TSO can choose between all the methodologies. For further insights into this important topic it is referred to the on-going discussion/consultation process on the ENTSO-E website (www.entsoe.eu; electricity balancing), where also the corresponding working documents can be found.

2.3.2 "Imbalance Netting": Avoidance of Counteracting Imbalance Activations

The concept of so-called *'Imbalance Netting'* prevents that balancing energy services in different TSOs' control areas are activated in opposite direction, see e.g. Veen (2009), Veen (2010) and/or Doorman (2011) as well as the German TSOs' portal www.regelleistung.net. This means that an automatic coordination of the TSOs' imbalance state is implemented with the objective to minimize counteracting activations of neighbouring TSOs' control areas. The result of 'imbalance netting' is a redistribution of remaining imbalance in each control area, resulting in reduced balancing energy activation needs (and cost) among several TSOs involved (in case of no inter-TSO transmission congestion).

In general, it is important to note that the 'success' of 'imbalance netting' is dependent whether or not there exists cross-border transmission congestion between two TSOs' control areas. In case of transmission congestion, the 'imbalance netting' procedure is not effective. This means that in this case counteracting imbalance activations between two congested control areas of neighbouring TSOs have to be accepted. In case of non-congested cross-border transmission lines, imbalance netting is fully effective.

In Figure 2.2a and 2.2b below the situation before and after imbalance netting is indicated on an example of five control areas where some of the cross-border transmission lines are congested, others not.

The economic settlement of the reduced amount of balancing energy activation (to be precise, automatic and manual FRR) in the involved control areas due to the 'imbalance netting' approach is based on one settlement-price. This settlement price is an average price and is a function of the opportunity costs in the involved control areas (for details in terms of settlement price calculation it is referred to e.g. IGCC

(2012)[2]). The 'imbalance netting' approach has been already realised between the four TSOs' control areas in Germany and some neighboring control areas in Belgium, Netherlands, Denmark, Czech Republic and Switzerland.

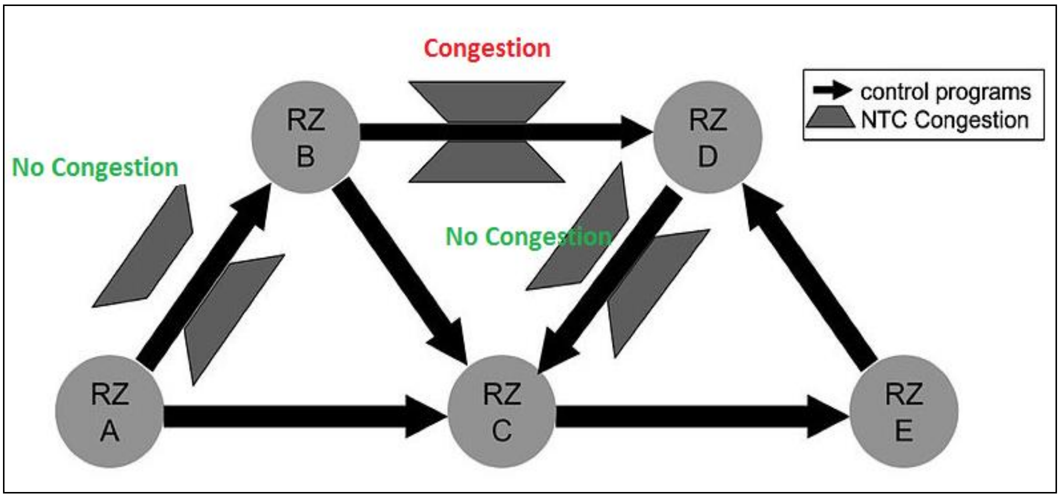

Figure 2.2a Cross-border congestion situation before imbalance netting. Source: www.regelleistung.net

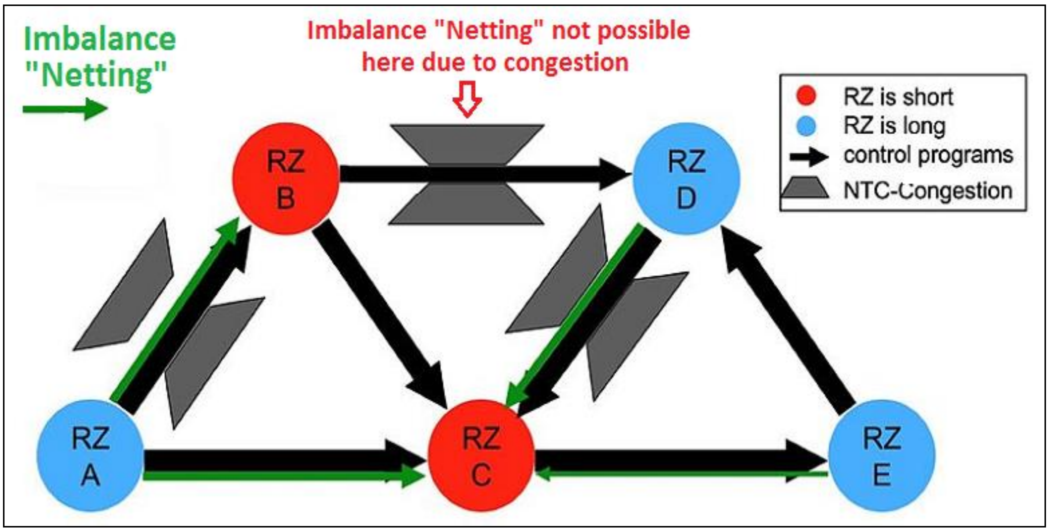

Figure 2.2b Imbalance netting on non-congested cross-border transmission lines. Source: www.regelleistung.net

The advantages of the imbalance netting approach can be summarized as follows (selection only):

- Reduced activation of balancing energy in the participating control areas;
- Reduces balancing system cost for activation of automatic/manual FRR in the participating control areas;

[2] IGCC is the so-called *'International Grid Control Cooperation'* initiated by the four German TSOs. IGCC (2012) is a frequently occurring market information document of these four TSOs explaining the developments of the German *'Netzregelverbund'* (Imbalance Netting).

- Settlement-model is based on the calculation of only one balancing energy price (€/MWh) which results from the opportunity costs of activation the automatic/ manual FRR in the participating control areas;
- The realization/implementation of ‘imbalance netting’ is relatively straightforward;
- Others.

On the contrary, the following challenges need to be taken considered (selection only):

- The benefits of ‘imbalance netting’ may be unevenly distributed among the neighbouring control areas if there are large differences in balancing cost;
- Others.

2.4 Basic Principles of different implemented Concepts for Cross-Border Procurement and Activation of Balancing Reserves and Balancing Energy in Europe

2.4.1 Overview on recent developments and the status quo

In recent years, different possible approaches on cross-border balancing service provision not only have been comprehensively discussed and developed, but some of them also have been implemented on different borders between Transmission System Operators (TSOs) throughout Europe. Figure 2.3 below presents an overview on the different cross-border balancing energy market design concepts in 2011 (see also Adam (2011)) being still in place at present. Notably, the following approaches in Figure 2.3 are of special interest not least due to the fact that they also have been prominently listed in an initial position paper of ENTSO-E in this context in 2011 (ENTSO-E (2011a)):

- Cross-Border BSP(Balancing Service Provider)-TSO Model
- Bilateral TSO-TSO Model
- Multilateral TSO-TSO Model without Common Merit Order
- Multilateral TSO-TSO Model with Common Merit Order

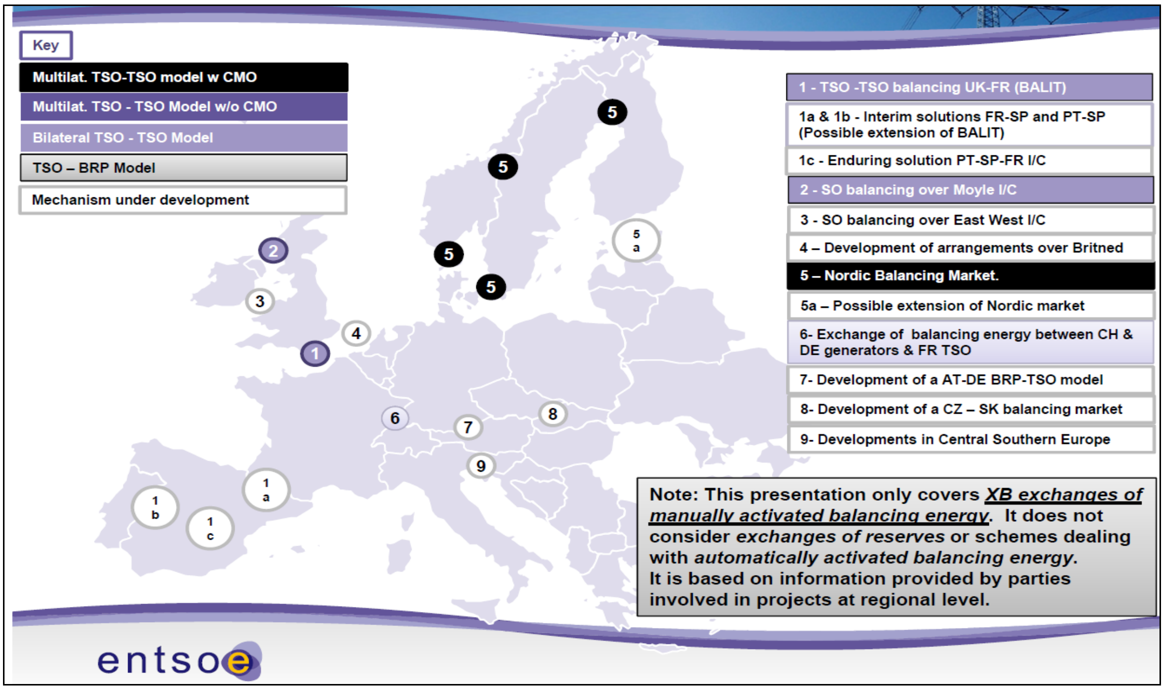

Figure 2.3 Different cross-border balancing market design concepts in Europe in 2011. Source: Adam (2011)

In the following subsection 2.4.2 the different cross-border balancing energy market design concepts are described in more detail. Special focus is put on the four[3] concepts having been outlined in the position paper by ENTSO-E (2011a), not least due to the fact that many important elements of several of them have been implemented on different TSO borders across Europe in recent years.

It is important to note, however, that in the meantime (i.e. in year 2013) the development – triggered by the publication of the Framework Guidelines of ACER (ACER (2012a)) and the corresponding response of ENTSO-E with the draft network code on electricity balancing (ENTSO-E (2013a))[4] – unambiguously follows the most advanced concept, i.e. the multilateral TSO-TSO Balancing Model with Common Merit (so-called 'target model').

2.4.2 Brief introduction into the different cross-border concepts

2.4.2.1 Cross-Border BSP-TSO Model

(i) Model description

In the cross-border BSP-TSO concept it is foreseen that Balancing Service Providers (BSPs) can offer balancing energy bids not only to the incumbent TSO in their own control area, but also to other TSOs in neighboring control areas. The offer of balancing energy bids by a BSP to a TSO other than the incumbent TSO has to be accepted by the incumbent TSO in the control area where the BSP is located. In case of activation of these kinds of balancing energy bids a cross-border balancing energy exchange takes place as long as there is sufficient cross-border transmission capacity available at the point in time when it is actually needed (see comprehensive discussion on that issue in section 2.3.1 in detail). Figure 2.4 below presents the basic principles of this concept. In Appendix 1 (Section A1.1), furthermore, two different implementation options of the cross-border BSP-TSO model are outlined.

[3] In general, there is no significant difference between the bilateral TSO-TSO model and the multilateral TSO-TSO model without common merit order, except the number of TSOs involved (bilateral = 2, multilateral > 2). Therefore, in the brief introduction into the different cross-border concepts these two models are commonly described in section 2.4.2.2.

[4] Including the corresponding consultation process triggered by ENTSO-E in 2013 (see also https://www.entsoe.eu/major-projects/network-code-development/electricity-balancing/).

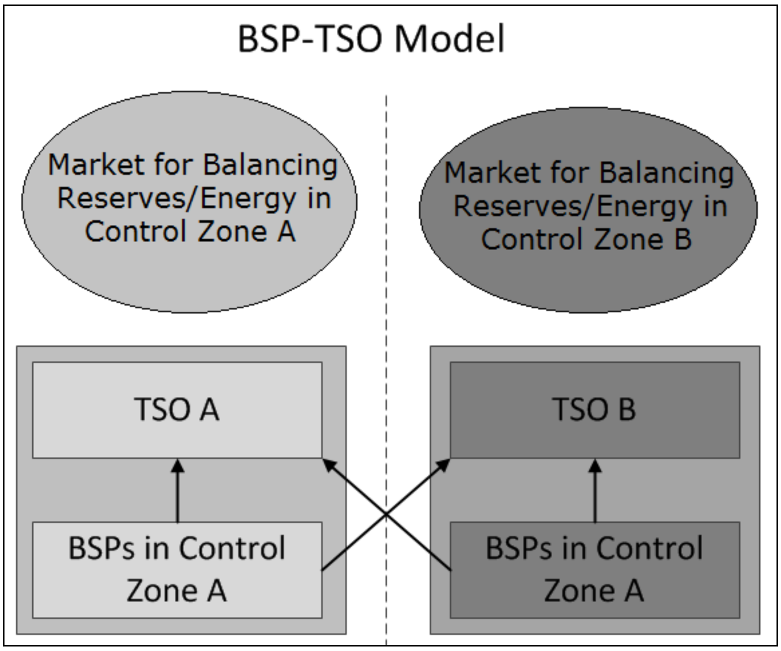

Figure 2.4 Basic principles of the cross-border BSP-TSO balancing model

(ii) Realized use cases

Since 2004, on the Austrian-German border a BSP-TSO balancing model has been implemented. This means that BSPs from Austria can participate in the manual FRR market in Germany. This is possible only since there is sufficient physical cross-border transmission capacity available on the Austrian-German border in almost all hours throughout a year. Besides the Austrian-German border there have been implemented elements of the BSP-TSO approach also on the French border to Germany and Switzerland.

(iii) Pros and cons of the cross-border BSP-TSO model

On the one hand, the cross-border BSP-TSO model is characterized by the following advantages (selection only):

- This concept is easier to implement than any other, more sophisticated cross-border balancing market model described in subsequent sections.
- It requires a low level of harmonization of the different balancing markets in the different TSOs' control areas.
- There is no significant impact on the balancing market set-up and operation itself; the participating BSPs are impacted only, depending on the decision where to offer their balancing energy bids (in general, BSPs will prefer to bid in the balancing energy market with the highest expected price level).
- Others.

On the other hand, there are the following disadvantages of the cross-border BSP-TSO model (selection only):

- The BSPs offering balancing energy bids in neighboring TSOs' control areas are confronted with limited information about the physical system state in the different TSOs' control areas and also cross-border transmission capacity availability.
- This can lead to inefficient use of balancing energy bids, meaning that balancing energy bids are offered in a control area where they are actually not necessarily 'needed'.
- Furthermore, this can lead to the situation that available resources may stand unused while they could be preferable used – from the total system efficiencies point-of-view – in the own control area of the incumbent TSO.
- Since the cross-border BSP-TSO concept also causes incremental IT, the benefit/cost ratio of the cross-border BSP-TSO model needs to be proven from the total system efficiencies point-of-view.
- Others.

2.4.2.2 Bilateral/Multilateral TSO-TSO Model (without Common Merit Order)

(i) <u>Model description</u>

In the bilateral TSO-TSO model (without common merit order) the BSPs bid implicitly into the balancing energy market of both neighboring TSOs by bidding in the balancing market in their own control area. Then, both involved TSOs construct – based on predefined mechanisms/rules[5] – offers of balancing energy bids to the partner TSO on the basis of unused/surplus balancing reserves that are not requested locally to meet the security margin and balancing energy expectations. As TSOs, due to their role of balancing the electricity system, are the only parties in the electricity supply chain in the position to identify the maximum possible amount of balancing energy that can be physically traded cross-border, the fact that they build the offers directly is an advantage of the bilateral TSO-TSO model and tends to lead to greater balancing energy exchange volumes compared to the cross-border BSP-TSO approach (see section 2.4.2.1 above). The multilateral version of this concept is the extension to more than two TSO involved.

Summarizing, in the bilateral/multilateral TSO-TSO model without common merit order each TSO keeps its own balancing reserves needed to meet security of supply

[5] See section 3.2 and 3.3 in detail, where different possible mechanisms/rules are further elaborated.

standards and each TSO also keeps its own procurement mechanisms in terms of balancing reserve and balancing energy bids. If a TSO has unused/surplus balancing energy bids, it can propose this balancing energy to neighboring TSOs (based on predefined mechanisms/rules). However, no reservation of cross-border transmission capacity is foreseen, only available cross-border transmission capacity can be used in case cross-border balancing energy wants to be activated and exchanged. If there isn't sufficient cross-border transmission capacity available, the balancing energy exchange is denied (again, see also section 2.3.1).

Figure 2.5 below presents the basic principles of the bilateral/multilateral TSO-TSO model (without common merit order). In Appendix 1 (Section A1.2), furthermore, a feasible practical implementation option of this concept is outlined.

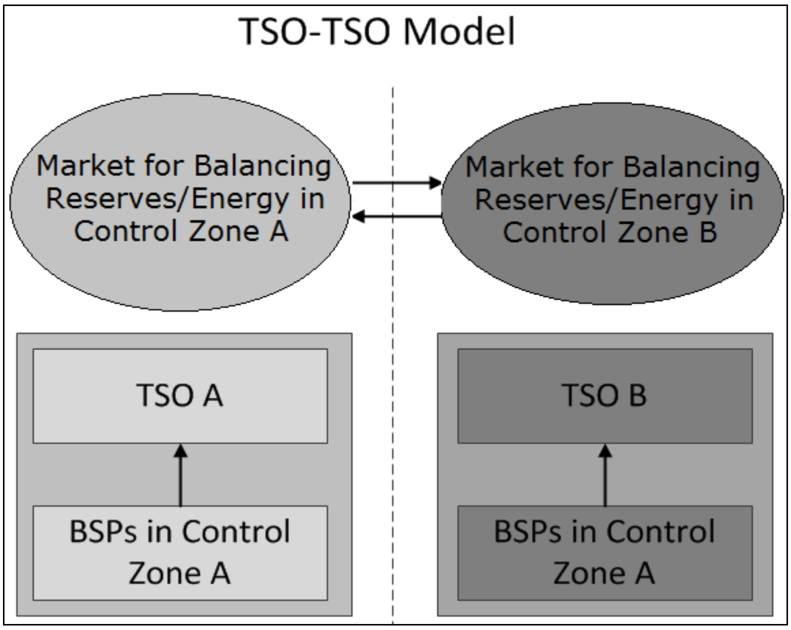

Figure 2.5 Basic principles of the bilateral/multilateral TSO-TSO model (without common merit order)

(ii) <u>Realized use cases</u>

In March 2009, the multilateral TSO-TSO model (without common merit order) has been successfully implemented on the border between France, UK and Ireland (FUI region). It is known as the so-called BALIT model (abbreviation for BAlancing Inter-TSO). BALIT corresponds to cross-border balancing energy exchange in the manual frequency restoration reserves market (FRR) between the involved TSOs in these countries. A possible extension of the BALIT model is planned with Spain (REE) and Portugal (REN).

(iii) Pros and cons of the bilateral/multilateral TSO-TSO model (without common merit order)

The bilateral/multilateral TSO-TSO model (without common merit order) is characterized by the following advantages (selection only):

- Each TSO keeps its own balancing reserves and also its own procurement mechanisms in terms of balancing reserve and balancing energy bids. Therefore, there is limited need for harmonizing the different balancing energy markets.
- The TSOs can identify the maximum possible amount of balancing energy that can be physically traded cross-border; therefore greater balancing energy exchange volumes can be expected compared to the cross-border BSP-TSO approach.
- The previous argument leads to higher total system efficiency.
- Others.

On the contrary, the following disadvantages of this concept have to be accepted (selection only):

- The implementation of predefined non-discriminatory mechanisms/rules is quite complex in practice (see e.g. also section 3.2 and section 3.3).
- Similar to the cross-border BSP-TSO model, the benefit/cost ratio of the bilateral/ multilateral TSO-TSO model (without common merit order) needs to be proven from the total system efficiencies point-of-view.
- Others.

2.4.2.3 Multilateral TSO-TSO Model with Common Merit Order

(i) Model description

The multilateral TSO-TSO model with common merit order, finally, is the approach where several TSOs cooperate in the cross-border procurement of balancing energy on the basis of one common merit order list. There is also a coordinated activation of balancing energy among the TSOs for the regional imbalance only. This concept ensures that the cheapest balancing energy bids are used first. Furthermore, this leads to a high degree of economic efficiency. However, also a high degree of harmonization (gate closure time, balancing products, etc.) of the different balancing markets in the different TSOs' control areas is necessary.

Figure 2.6 below presents the basic principles of the multilateral TSO-TSO model with common merit order.

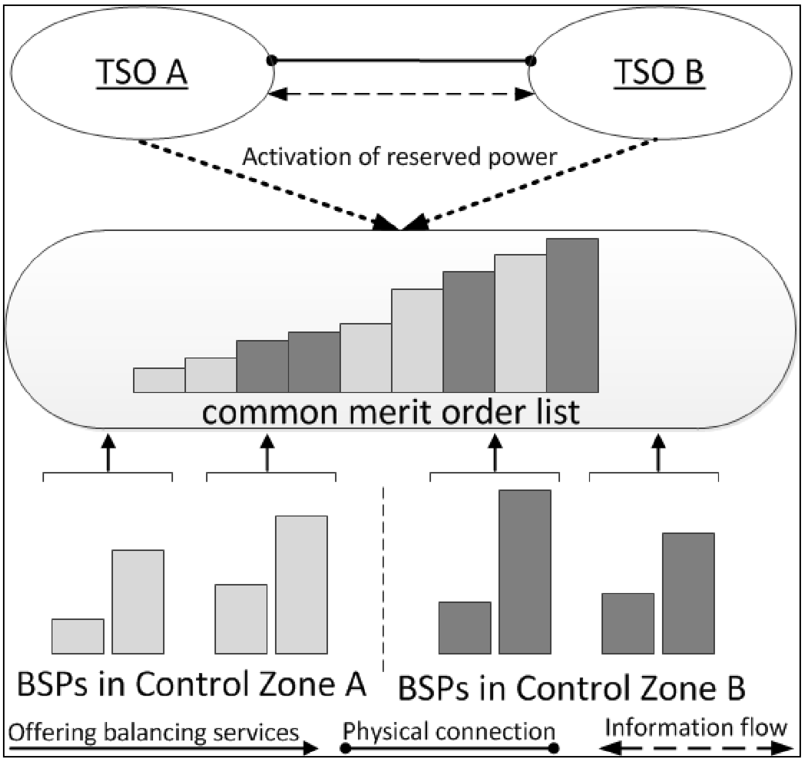

Figure 2.6 Basic principles of the multilateral TSO-TSO model with common merit order. Source: Veen (2010)

(ii) Realized use cases

Major elements of the multilateral TSO-TSO balancing market model with common merit order are already implemented in the common Nordic balancing market (covering the control areas of the four TSOs Energinet.dk, Svenska Kraftnät, Fingrid, and Statnett) and also the common balancing market in Germany jointly operated by the four TSOs Tennet, 50Hertz Transmission, Amprion and TransnetBW. The major cornerstones of each of these European balancing regions are outlined in the following:

- ***Nordic regulating power market:*** The Nordic regulating power market is utilised to reduce the excessive use of automatic frequency restoration reserve (automatic FRR) capacities in order to re-establish their availability. Regulating power is a manual frequency restoration reserve (manual FRR) market and can be fully activated within 15 minutes. This common manual FRR market is managed by the TSOs of the Nordic countries with a common merit order list. Bids can be offered to the market till 45 minutes before the operating hour. The price for regulating power results by the highest activated bid price, whereas each activated bid receives this price (marginal pricing). The spot market price 'Elspot' meanwhile represents the minimum price for upward-regulating power bids and the maximum price for downward-regulating power bids. Taking into consideration the potential intra-TSO and inter-TSO congestions in the transmission system, the TSO manages the activation of the cheapest possible regulating power. These imbalances are settled, one the one hand, under a 'one-price' settlement system for *Load Balance Responsibles (LBR)*[6] and, on the other hand, under a 'two-price' settlement for *Production Balance Responsibles (PBR)*,[7] see also Bang et al (2012). The costs for imbalances are generally low. The presence of large volumes of hydro power generation in the Nordic region is the main reason for this desirable feature. The existing Nordic market design for regulating power can be criticized for attracting medium to large scale generation only. Small scale participants are, in practice, excluded from the market.

- ***Germany balancing market:*** The German territory is split into four control areas operated by the TSOs Tennet, 50Hertz Transmission, Amprion and TransnetBW. These four TSOs have implemented a cross-border balancing mechanism representing a multilateral TSO-TSO balancing market with a common merit order for both automatic and manual frequency restoration reserves (FRR). With the introduction of the common tendering of automatic and manual FRR among all four TSOs the so-called *Reserve Connecting TSO*[8] conducts the pre-qualification check and procedure implementation of *technical units*[9] (i.e. Balancing Service Providers). For details in terms of pre-qualification parameters (tendering period, minimum bid size, etc.) for both automatic and manual FRR in Germany it is referred to the official internet platform *www.regelleistung.net* of the four German TSOs for allocating balancing reserves and balancing energy.[10] In addition, as already briefly described in section 2.3.2 of this document, the four German TSOs have already implemented the so-called *Imbalance Netting* approach, preventing that balancing energy services in different/neighboring control areas are activated in opposite direction.

[6] LBRs are typically electricity trading companies that through the pooling of consumers bid in one of the various electricity markets. The main task of a load balance responsible is to make a plan for the consumption the upcoming day.

[7] PBRs are by and large a power generation company, or several power generators joined together.

[8] The *Reserve Connecting TSO* is defined as that TSO, where the so-called *technical units* (i.e. Balancing Service Providers) are physically connected to the grid and to the control system (independently of the voltage level).

[9] Generation units or shiftable loads are denoted technical units.

[10] Status quo in Germany in 2013: the tendering period is 1 week and 1 day for automatic and manual FRR, respectively. The minimum bid size is 5 MW for both automatic and manual FRR.

(iii) Pros and cons of the multilateral TSO-TSO model with common merit order

The multilateral TSO-TSO model with common merit order, finally, incorporates several features targeted in the currently ongoing European debate on cross-border opening and internationalization of balancing markets (see e.g. ACER (2012a) and ENTSO-E (2013a)). Advantages of this concept are as follows (selection only):

- The cheapest balancing energy bids encompassing several TSOs' control areas are used first.
- There is also a coordinated activation of balancing energy among several TSOs involved for the total regional imbalance.
- This concept, furthermore, supports the so-called *imbalance netting* approach reducing the total amount of balancing energy activation needs (in case of availability of sufficient physical cross-border transmission capacities at that point in time when it is actually needed).
- This leads to the highest degree of economic efficiency compared to the previous balancing models described in section 2.4.2.1 and 2.4.2.2.
- Others.

However, there also exist the following challenges having to be addressed for successful implementation of the multilateral TSO-TSO model with common merit order (selection only):

- A high degree of harmonization (gate closure time, balancing products, etc.) of the different balancing markets in the different TSOs' control areas is necessary.
- The cross-border transmission capacity availability/congestion problem is also inherent in this model; this means that a successful activation of cross-border balancing energy is possible only if there are sufficient physical cross-border transmission capacities available at that point in time when it is actually needed.
- Others.

2.4.3 Comparison of the Different Cross-Border Balancing Market Concepts

In the following Table 2.2, a comparison and validation of the different cross-border balancing market concepts is conducted in qualitative terms. Summarizing, these are the following concepts:

- Cross-border BSP-TSO model (section 2.4.2.1)
- Bilateral/multilateral TSO-TSO model without common merit order (section 2.4.2.2; example: BALIT model)
- Multilateral TSO-TSO Model with common merit order (section 2.4.2.3; example Nordic regulating power market, German balancing market)

Table 2.2 Comparison of the different cross-border balancing market concepts ('+' = criterion supported, '-' = criterion not supported)

Criteria	Cross-border BSP-TSO model	Bilateral / multilateral TSO-TSO model without common merit order (BALIT)	Multilateral TSO-TSO model with common merit order	
			Nordic regulatory power market	German balancing market
Economic allocation efficiency	--	-	+	++
Short / medium term applicability in practise	++	+	-	--
Support of VPPs as BSPs	--	--	-	+
Harmonisation needs of neighbouring balancing markets	--	-	+	++
Market compatability / competition / transparency	--	-	+	+
Social welfare / system cost (global optimum)	--	-	+	++

3 Market Architectures for Cross-Border Procurement and Activation of Balancing Reserves and Balancing Energy considered in eBadge

In this chapter 3 those architectures on cross-border procurement and activation of balancing reserves and balancing energy are elaborated in detail being subject to comprehensive consideration and modelling in subsequent tasks and work packages of the eBadge project. Naturally, the different market architectures make reference to the different documents of ACER (Agency for the Cooperation of Energy Regulators) and ENTSO-E (European Network of Transmission System Operators of Electricity) having been published in this field recently, notably:

- ACER Framework Guidelines on Electricity Balancing (18 September 2012); see ACER (2012a) in detail.
- ENTSO-E Draft Network Code on Electricity Balancing (20 February 2013 (Version 1.14) and 24 May 2013 (Version 1.22)), see ENTSO-E (2013a).[11]
- and other related documents of these two associations in this field (e.g. ENTSO-E (2011a),[12] ACER (2011)[13]).

In the following, in total four different market architectures for national and cross-border balancing service provision are elaborated: two so-called 'benchmarking models' representing a national minimum and a bilateral/multilateral maximum model as well as two intermediate models indicating different cross-border mechanisms and fractions for sharing balancing energy bids. In particular, the following four market architectures are subject to in depth analyses:

1. National market-based TSO balancing model (benchmark for minimum; section 3.1) for procurement of balancing reserve bids and balancing energy bids as well as activation of balancing energy bids.
2. Bilateral/multilateral market-based TSO-TSO balancing model with surplus balancing energy exchange (see section 3.2). Different approaches for the

[11] On 17 June 2013, ENTSO-E has launched a web-based public consultation on the Network Code on Electricity Balancing and invited all interested parties to submit comments by 16 August 2013. The corresponding web-link is already indicated in footnote 4 of this document.

[12] ENTSO-E: Position Paper on Cross-Border Balancing (Working Group Ancillary Services), July 2011.

[13] ACER: Framework Guidelines on Capacity Allocation and Congestion Management (CACM) for Electricity, July 2011.

implementation of the surplus balancing energy bid exchange and reallocation to the corresponding national merit-order lists are presented.

3. Bilateral/multilateral market-based TSO-TSO balancing model with common merit-order and shared bids (see section 3.3).
4. Bilateral/multilateral market-based TSO-TSO balancing model with common merit order without unshared bids (benchmark for maximum; target model; see section 3.4).

In subsequent sections, each of the four market architectures is outlined according to the following structure:

- Introduction into the general approach
- Market for procurement of balancing reserves (manual FRR)
- Market for procurement of balancing energy and activation of balancing energy (manual FRR)
- Logistics and data flow requirements
- If needed, determination of the amount of shared and unshared bids
- Clearing approach
- Implications for Virtual Power Plants (VPPs) as Balancing Service Providers (BSPs)

Finally it is important to note that in the eBadge models presented in the following, the market segment of manual frequency restoration reserves (FRR) is subject to comprehensive analyses. However, an extension and interpretation of the market architectures for the provision of automatic FRR is also possible.

3.1 National market-based TSO Balancing Model (Benchmark for Minimum)

3.1.1 General approach

The balancing market within the control zone of a single TSO is organised based on the following subsequent steps for procuring and – in case activating – balancing services from different Balancing Service Providers (BSPs) fulfilling the prequalification criteria (see also Figure 3.1):

- Procurement of balancing reserves
- Procurement of balancing energy
- Activation of balancing energy of selected BSPs

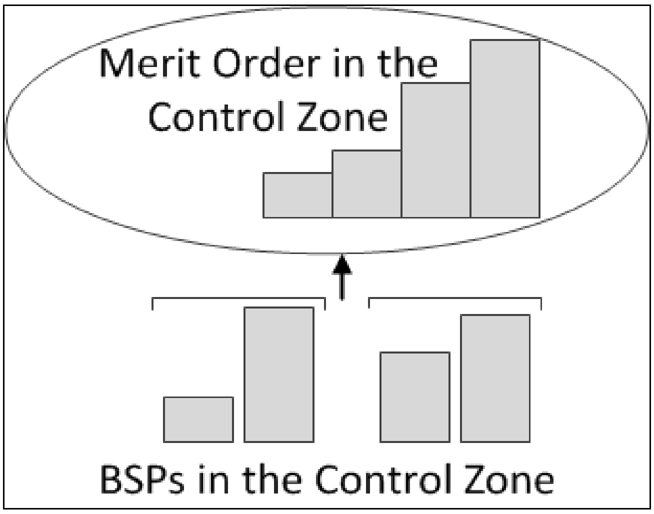

Figure 3.1 National market-based TSO balancing model. Source: own depiction.

For the first two mentioned steps above (procurement of balancing reserves and balancing energy), separate tenders exist. In addition, they are split for upward and downward regulation. Furthermore, both market segments expect different, well defined standard products to be offered and cleared in the corresponding market place for procurement of balancing reserves and balancing energy (e.g. frequency of tendering periods, different time period products, gate closure, minimum bid size, etc.). In the following, the major cornerstones for procurement of balancing reserves and balancing energy as well as activation of balancing energy are outlined briefly.

3.1.2 Market for procurement of balancing reserves (manual FRR)

Balancing Service Providers (BSPs) send their bids to a national platform. Two independent merit-order lists are built for upward and downward regulation. The tendering period of balancing reserves – period for the provision of bids for balancing reserves – can be a day, one calendar week or month. The clearing can be realized based on a pay-as-bid or marginal pricing concept, being the former the most common approach at present in various existing balancing markets within the EU.[14] However, in general both pricing concepts are supported by the market architecture equally. Furthermore, there is a need to define properly the minimum bid size for balancing reserve markets so as to increase the number of participants among the BSPs and competition between them.

3.1.3 Market for procurement of balancing energy and activation of balancing energy (manual FRR)

On the one hand, those bids of the merit-order for balancing energy are relevant, fulfilling both of the following criteria: (i) having been submitted together with the corresponding balancing reserve bids and (ii) having been selected in the procurement of balancing reserves. In general, it is possible that the BSPs can update (e.g. daily) their initial balancing energy bids (energy price, volume) during the balancing reserve tender (e.g. weekly). On the other hand, it shall be also possible for any of the BSPs to submit new/additional balancing energy bids (e.g. daily) without any contribution to the corresponding balancing reserve procurement tender (e.g. weekly).[15] The activation of balancing energy starts according to the merit-order list (balancing energy bids) with the cheapest energy bid. Again, two independent merit-order lists exist for upward and downward regulation. And finally, although the 'pay-as-bid' clearing is the common approach implemented in balancing energy markets at present in various TSOs' control zones within the EU, the market architecture also supports any other pricing concept (like marginal cost pricing).

3.1.4 Logistics and data flow requirements

The national market-based TSO balancing model expects a national platform allowing the BSPs to set bids for both balancing reserves and balancing energy (see also Figure 3.1). In addition, a communication infrastructure between the TSO in the

[14] At present, the Austrian, Italian and Slovenian transmission systems operates (AGP, TERNA and ELES) also use the pay-as-bid approach.
[15] This approach could clearly support the integration of Virtual Power Plants (VPPs) as BSPs.

national control zone and the different BSPs is necessary (e.g. telephone, Email, MOL (Merit-Order-List)-Server).

3.1.5 Clearing approach

The procurement of balancing energy is defined by the gate closure time of this market which can be shorter than that one in the balancing reserve market. For example, procurement of balancing reserves is conducted once per tendering period (e.g. one week), whereas the associated procurement of balancing energy can be set much shorter (e.g. day- or even hour-ahead of balancing energy activation).

3.1.6 Implications for Virtual Power Plants (VPPs)

In general, there are no particular additional implications for VPPs than those comprehensively discussed in section 4; meaning that a VPP is simply one out of many BSPs.

3.2 Bilateral/multilateral market-based TSO-TSO Balancing Model with Surplus Exchange

3.2.1 General approach

The bilateral/multilateral market-based TSO-TSO balancing model with surplus exchange is a further development of the previously described national approach. The aim of such a balancing market model is that the involved TSOs exchange some surplus balancing energy bids based on predefined criteria (for the basic principles see Figure 3.2 below). It is important to note, that the exchange is restricted to surplus balancing energy bids only (criteria and implementation options see below as well as in Appendix 2 in detail). The determination and procurement of balancing reserves is carried out separately by each of the TSOs; meaning that there exists no sharing and/or exchange of balancing reserves among the TSOs. Therefore, also no reservation of cross-border transfer capacity is needed to enable balancing reserve-sharing. However, a cross-border exchange of surplus balancing energy bids is feasible only if sufficient cross-border transfer capacity is available in case of activation (see also discussion in section 2.3.1 earlier in this document).

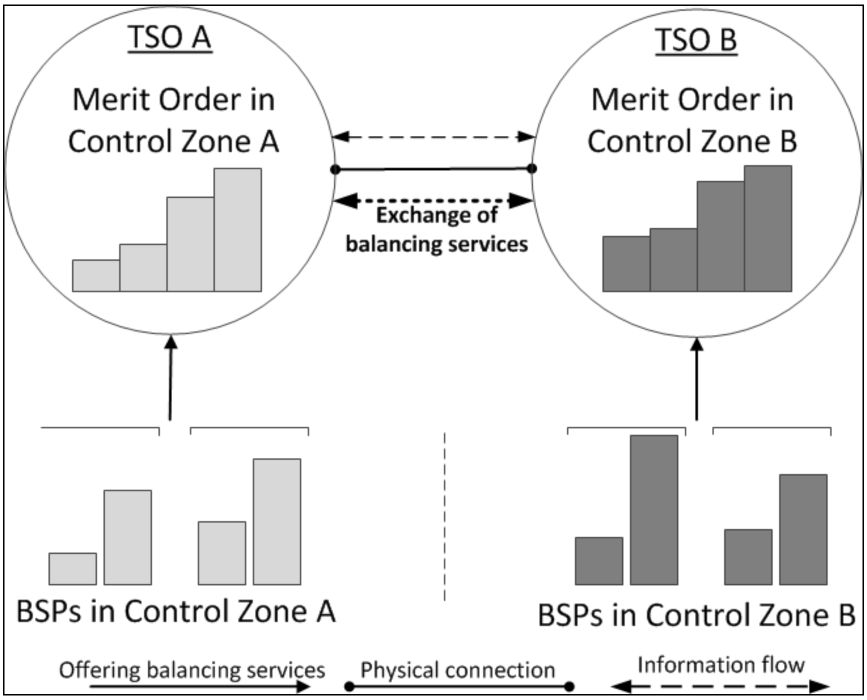

Figure 3.2 Structure of market-based TSO-TSO balancing model with surplus exchange. Source: Veen (2010), own depiction.

In detail, the cornerstones of the bilateral/multilateral market-based TSO-TSO balancing model with surplus exchange are as follows:

- In a first step, the same procedure is carried out as described in the previous approach – the national market-based TSO balancing model – in terms of both procurement of balancing reserve bids and procurement of balancing energy bids.
- In a second step, it is considered to exchange surplus balancing energy bids among different TSOs.[16] This second step is conducted by sorting the surplus balancing energy bids in an international platform and re-allocating the surplus bids in the national merit-order lists for balancing energy (criteria and implementation options see below as well as in Appendix 2). This results in a second (or amended) national procurement of balancing energy.
- In case of more than 2 TSOs involved in the multilateral approach, there might be an iterative set of further re-allocations of surplus balancing energy bids after the second step in order not to lose any of “low/cheap” balancing energy bids in this process among many TSOs. This process is described in detail in Appendix 2.

In general, the implementation of the bilateral/multilateral market-based TSO-TSO balancing model with surplus exchange will result – in case of activation – in a balancing energy flow between the offering TSOs and the requesting TSOs. However, there is neither a direct connection/link between a single BSP and a TSO other than the incumbent TSO nor between a single BSP and the international platform (see also Figure 3.2)[17].

As already indicated above, there are different possibilities to re-allocate the various surplus balancing energy bids of the international platform to the different national TSOs again (for details see in section 3.2.5 below as well as in Appendix 2).

In the following, the major cornerstones of this model – both procurement of

[16] In general, a harmonisation of the surplus balancing energy products and bids on the international platform would be sufficient for an appropriate exchange of surplus balancing energy bids among the different TSOs in case of activation. However, a harmonization of the different national approaches in terms of procurement of balancing reserves and balancing energy would naturally result in greater total system efficiency.

[17] The “BSP-TSO model” (see section 2.4 in detail) is not considered to be comprehensively studied in eBadge. Simply because it is expected to be impossible from the individual BSPs point-of-view to offer a binding balancing energy bid in a neighboring TSO’s control zone without having in-depth insight into the anatomy of the meshed transmission grid and inter-TSO load flow situation. A somehow functioning “BSP-TSO model” would implicitly expect less inter-TSO transmission congestion. This however isn’t the case across the European transmission grid at present, nor is it expected in the medium-term.

balancing reserves and procurement as well as activation of balancing energy – are outlined briefly.

3.2.2 Market for procurement of balancing reserves (manual FRR)

As already described above, in terms of procurement of balancing reserves the same procedure is carried out as described in the previous approach – the national market-based TSO balancing model. This means, that Balancing Service Providers (BSPs) send their bids to a national platform. Two independent merit-order lists are built for upward and downward regulation. For the tendering period of balancing reserves, the pricing concept for clearing as well as the minimum bid size for balancing reserves the same is true as for the national market-based TSO balancing model. It is important to note, that the determination and procurement of balancing reserves is carried out separately by each of the TSOs; meaning that there exists no sharing and/or exchange of balancing reserves among the TSOs.

3.2.3 Market for procurement of balancing energy and activation of balancing energy (manual FRR)

In the first step, there is no difference in the procurement of balancing energy compared to the previous national market-based TSO balancing model[18]. In the second and subsequent steps, however, there are deviations compared to the previous model. In the following, these steps are described more comprehensively (see also description of the general approach in section 3.2.1).

A collection of surplus balancing energy bids of the involved TSOs is implemented in an international platform. The surplus balancing energy bids are sorted in an incremental order, beginning with the cheapest surplus bid. Again, the surplus balancing energy bids in the international platform are separately treated for upward and downward regulation. In either case, a standardization of surplus bids coming from the different TSOs is necessary.

In a next step, a re-allocating of surplus balancing energy bids from the international platform to the national merit-order lists for balancing energy is conducted (criteria and implementation options see below as well as in Appendix 2). This results in an

[18] The first step here is the same like in the national market-based TSO balancing model in the sense of a “try run”.

amended national procurement list for balancing energy. As already stated above, in case of more than 2 TSOs involved in the international/multilateral approach there might be an iterative set of further re-allocations of surplus balancing energy bids after the second step.

After finishing the re-allocation process of surplus balancing energy bids on the national merit-order lists, the procedure is ready for activation of balancing energy in case it is needed. In general, activated cross-border balancing energy exchange takes place after the cross-border intraday market trades using remaining cross-border transmission capacity. As already critically discussed in section 2.3.1, no reservation of cross-border transmission capacity for cross-border balancing energy exchange is foreseen and/or can be expected. Therefore, cross-border exchange of activated balancing energy is feasible only if sufficient cross-border transmission capacity is actually available.

In addition it is important to note, that in the bilateral/multilateral market-based TSO-TSO balancing model with surplus exchange the cost of both delivered balancing energy in case of surplus exchange and cost of associated balancing reserves need to be covered by the receiving TSO benefiting from this surplus exchange.

In general, procurement of balancing energy (incl. surplus balancing energy bid exchange) can be conducted close to the point in time of balancing energy activation and cross-border balancing energy exchange (e.g. day-ahead or even up to an hour-ahead).

In terms of remaining cornerstones (e.g. pricing mechanisms, minimum bid size, etc.) describing the bilateral/multilateral market-based TSO-TSO balancing model with surplus exchange there is no difference compared to the previous national market-based TSO balancing model.

3.2.4 Logistics and data flow requirements

Besides the same national platform in each of the TSOs' control zones like in the previous national market-based TSO balancing model, also an international platform is needed here, enabling the different TSOs to forward their surplus balancing energy bids. Furthermore, an additional communication infrastructure is necessary between the involved TSOs and the international platform in order to manage the entire surplus bid exchange procedure and the national re-allocation of bids in the national merit-order lists. However, there is no need for extension of communication[19] between a BSP and its incumbent TSO (i.e. TSO where the BSP is physically allocated). The surplus balancing energy bids are forwarded by the incumbent TSOs to the international platform and not by the BSPs. Also several exchange and re-allocation procedures are operatively managed by the involved TSOs and the international platform.

3.2.5 Clearing approach

In the following, three possible approaches for the implementation of the "surplus exchange model" are outlined briefly (a detailed graphical explanation is presented in Appendix 2).[20]

<u>1st Approach</u>

As already elaborated previously in this section, after a national procurement of balancing energy (besides balancing reserves) of each TSO in a first step, in a second step a collection of surplus balancing energy bids – being forwarded from the different TSOs – is carried out on an international platform. These surplus balancing energy bids are the 'remaining' of a national 'try-run' clearing in the first step. In a second step, these surplus balancing energy bids are sorted in an increasing order, starting from the cheapest one. In a third step, a re-allocation of the different surplus balancing energy bids from the international platform to the national merit-order lists of those TSOs is conducted again, benefiting from one of these bids (compared to the initial situation of the purely national merit-order having been built in step 1).[21] The key question is, how to re-allocate the different surplus balancing energy bids from the international platform to the national merit-order lists of the different TSOs again, notably the most attractive ones:

- <u>Ranking principle 1:</u> The TSO with the highest percentage of imbalance in real-time (i.e. actual imbalance divided by compulsory balancing reserves times 100%) gets access to the most attractive existing surplus balancing energy bids in the international platform.
- <u>Ranking principle 2:</u> Each of the TSOs involved gets a specific amount of <u>all</u> existing surplus balancing energy bids from the common international platform. For example, a percentage share of bids can be determined again according to the

[19] compared to the national market-based TSO balancing model.

[20] As already stated earlier in the document, at present the 'pay-as-bid' pricing concept is the common approach implemented in balancing energy markets among the various TSOs within the EU. However, also marginal cost pricing could be applied. It is important to note, that the different approaches outlined below are qualified for both pricing concepts.

[21] To benefit in the sense to get access to a lower balancing energy bid and "inserting" it into the initial national merit-order list. This process in step3 will flatten the initial national merit-order list of those TSO benefiting from one of these bids being re-allocated in step 3. Note, the TSO having cleared with the lowest price in the first step in the national clearing can't improve its result in subsequent steps. This TSO is already "done" (see also description in Annex 2 in detail).

percentage of imbalance in real-time of the involved TSOs.

In this 1st approach, the entire process is finished after the re-allocation of surplus balancing energy bids (step 3), followed by the second national clearing (final step); this second national clearing is no 'try run' any more, it's considered to be the 'actual clearing'. A graphical explanation of this 1st approach is given in Appendix 2. The finalisation of the entire process after the second national clearing of balancing energy, however, can also have the disadvantage that some of the 'cheap' balancing energy bids still get lost. Therefore, in the following 2nd approach the process shown above is further elaborated to mitigate this particular problem/inefficiency which could occur (from the total system efficiency point-of-view).

2nd Approach

The 2nd approach takes care not to lose any of 'cheap' surplus balancing energy bids until the last TSO has finalised its re-allocation process after step n.[22] This means that the 1st approach presented above needs to be iteratively further developed and not to be finished after the first re-allocation of surplus balancing bids from the international platform. This is simply because there could 'appear' a new, unused surplus bid of a TSO afterwards. The reason is the flattening of the merit-order curve of this TSO as a result of the insertion of re-allocated bid(s) from the international platform with a lower price level than other re-allocated balancing energy bid(s) to other TSOs after the initial national procurement. Therefore, this 2nd approach suggests to prolong the process of the 1st approach and to start a next round of forwarding (to the international platform) and re-allocating (to the national merit-order lists again) of several available surplus balancing energy bids of several TSOs still involved in the process. From the total system efficiency's point-of-view this is an improvement in comparison to the 1st approach presented above. The disadvantage, however, is that more than two national procurement processes for balancing energy bids are needed. Moreover, ex-ante the number of procurements is not predictable. Even more, this process might be too complicated and inconvenient to be considered for practical implementation. For a detailed graphical explanation of this 2nd approach it is also referred to Appendix 2.

3rd Approach

This 3rd approach also builds upon further steps after a national procurement of balancing energy bids in a first step. It relies on the ranking of the clearing price levels of balancing energy bids in the first national procurement process. The subsequent steps of the procedure of this 3rd approach are as follows (for details see also the graphical explanation in Appendix 2):

1. Identification of the TSO with the lowest clearing price for balancing energy in the first national procurement round. This TSO is already "done" and cannot change its result in subsequent steps any more.
2. The surplus balancing energy bids from this TSO with the lowest clearing price level are forwarded to the TSO with the next cheapest clearing price after the first national procurement round of balancing energy.

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[22] n is the number of steps which can't be predicted ex-ante (explanation see in the following paragraphs).

3. This TSO receives the surplus balancing energy bids and integrates them in its initial national merit-order list and clears again.
4. Then the surplus balancing energy bids of this second TSO are forwarded to the TSO with the next cheapest clearing price after the first national procurement (i.e. TSO with the initial ranking number 3). A repetition of this procedure is conducted until the last TSO is "done".

The advantage of this 3rd approach is that the allocation of the surplus balancing energy bids to the different TSOs is very clear and transparent.

3.2.6 Implications for Virtual Power Plants (VPPs)

Similar to the previous approach – the national market-based TSO balancing model – there are no particular additional implications for VPPs than those comprehensively discussed in section 4; meaning that a VPP is simply one out of many BSPs.[23]

[23] It just must be guaranteed that possible congestion on distribution grid level is taken into account when allocating binding balancing energy bids on the national platform (being also subject to possible surplus exchange between TSOs). In terms of a possible bilateral/multilateral TSO-TSO surplus balancing energy exchange the VPPs are not actively involved. These arrangements are exclusively executed between the involved TSOs and the international platform.

3.3 Bilateral/multilateral market-based TSO-TSO Balancing Model with Common Merit-Order and Shared Bids

3.3.1 General approach

The bilateral/multilateral market-based TSO-TSO balancing model with common merit-order and shared bids can be interpreted as an intermediate step next to the so-called 'target model' (see section 3.4 of this document in detail). Moreover, this approach can deliver valuable experience before implementing the target model. The challenge of the TSO-TSO balancing model with common merit-order and shared bids, however, is to find criteria (or a set of criteria) determining both balancing energy bids need and need not to be shared among the different TSOs.[24] Sharing balancing energy bids on an international platform and, in case, activation of some of these balancing energy bids finally results in cross-border balancing energy exchange. This balancing energy exchange, however, is feasible only if there are sufficient cross-border transmission capacities available.

It is important to note that sharing of bids among different TSOs is restricted to balancing energy bids only. The procurement of balancing reserves is restricted to the 'footprint' of a TSO only; the same is true in terms of balancing reserve procurement for the two previous models, national market-based TSO balancing model (section 3.1) and bilateral/multilateral market-based TSO-TSO balancing model with surplus exchange (section 3.2).

Also in this model it is not foreseen that BSPs set their balancing energy bids directly on the international platform. The incumbent TSO, where the BSP is physically connected, is responsible for the cross-border data flows and the corresponding logistics to interact with the international platform and other TSOs (e.g. forwarding the shared bids directly to the international platform, data logistics in the context of the clearing process on the international platform, etc.); see also section 3.3.4.

In general, the bilateral/multilateral market-based TSO-TSO balancing market model with common merit order and shared bids relies on the following major cornerstones:

[24] From the total system efficiency's point-of-view in a model like that it is desirable to find criteria that several TSOs involved are willing to share the lowest price bids (and rather withhold the expensive ones). Transparent criteria need to be defined to determine the amount of unshared bids of each TSO. This is elaborated in the following as well as in Figure 3.3 below.

- Determination of those bids need not to be shared by each of the involved TSOs (i.e. amount of unshared bids starting from the most expensive one; see also Figure 3.3 in detail); this aspect is elaborated in detail in subsection 3.3.5 below.
- In general, after the clearing of the bilateral/multilateral common merit order (see also Figure 3.3) there is a balancing energy flow between the offering TSOs and the requesting TSOs. However, as already stated above, there is no direct connection/link between a single BSP and a TSO other the incumbent TSO or a single BSP and the common bilateral/multilateral platform.[25]
- The bilateral/multilateral market-based TSO-TSO balancing model with common merit-order and shared bids expects an even tighter harmonization of the different national approaches in terms of procurement of balancing energy bids to enable smooth system operation and improvement of total system efficiency.

In the following, the major cornerstones of this model – both procurement of balancing reserves and procurement as well as activation of balancing energy – are outlined briefly.

3.3.2 Market for procurement of balancing reserve (manual FRR)

In terms of procurement of balancing reserves the same procedure is carried out as described in the previous two approaches in section 3.1 and 3.2. This means, that Balancing Service Providers (BSPs) send their balancing reserve bids to a national platform. Two independent merit-order lists are built for upward and downward regulation. Also for the tendering period of balancing reserves, the pricing concept for clearing as well as the minimum bid size for balancing reserves the same is true as for the previous two models.

It is important to note, that the determination and procurement of balancing reserves is carried out separately by each of the TSOs; meaning that there exists no sharing and/or exchange of balancing reserves among the TSOs. Sharing is foreseen for some of the balancing energy bids only; in particular those having been procured simultaneously with the corresponding balancing reserve bids in addition to those necessary for the operational needs of each of the TSOs (see also description in section 3.3.3 and Figure 3.3 below in detail). This means, that after the simultaneous

[25] As already comprehensively explained in section 2.3, the ‘BSP-TSO Model’ is not considered to be comprehensively studied in eBadge. For details in this respect it is referred to the discussion in this section.

national procurement process of balancing reserve and balancing energy bids a 'separation' of balancing reserve bids is conducted in the national platform in the sense that those balancing reserve bids are denoted to be 'shared' being physically necessary and responsible to enable 'shared' balancing energy bids and, in case of activation, deliver 'shared' balancing energy.

3.3.3 Market for procurement of balancing energy and activation of balancing energy (manual FRR)

As already indicated in the procurement of balancing reserves in section 3.3.2 above, the bilateral/multilateral market-based TSO-TSO balancing model with common merit-order and shared bids also relies – similar to the previous two models – on a simultaneous national procurement of both balancing reserve bids and balancing energy bids. After this national procurement process the 'separation' of bids into 'shared' and 'unshared' balancing energy bids is implemented as indicated in the last paragraph of the previous section. Then those balancing energy bids dedicated to be 'shared' are forwarded immediately to an international platform where the multilateral/international common merit-order list (CMO) is built among the 'shared' (i.e. cheapest) balancing energy bids coming from the different TSOs (see also graphical explanation in Figure 3.3 below).

Also for this approach two independent merit-order lists for upward and downward regulation are needed both on national TSO level and on the international platform. As already mention at the beginning of this sub-section, a detailed definition of standard products not only for the national procurement of balancing energy bids but also for exchanging shared balancing energy is desirable.[26] In case of activation of shared balancing energy bids an exchange of balancing energy takes place after the execution of the cross-border intraday electricity markets. For doing so, remaining cross-border transmission capacity can/must be used. There is no reservation of cross-border transmission capacity foreseen for balancing energy exchange based on the concept of shared bids on the international platform.

3.3.4 Logistics and data flow requirements

Again, besides the same national platform in each of the TSOs' control zones like in the previous market-based TSO-TSO balancing model with surplus exchange, also

[26] Sharing of non-standardized products is hardly possible.

an international platform is needed here, enabling the different TSOs to forward their shared balancing energy bids. In order to manage the "sharing/unsharing procedure" there is no additional communication necessary between the involved TSOs (compared to the previous market-based TSO-TSO balancing model with surplus exchange). There is also no need of extension of communication between a BSPs and its incumbent TSO (i.e. TSO where the BSP is physically connected) in comparison to the previous model. The shared balancing energy bids are forwarded by the incumbent TSOs to the international platform and not by the BSPs. Also several exchange and re-allocation procedures are operatively managed by the involved TSOs and the international platform.

3.3.5 Determination of the amount of shared and unshared bids

The following approach can be used as a basis for assignment of the amount of unshared bids (see graphical consideration and explanation in Figure 3.3 in detail): determination of the historical deviation / operational needs on an annual basis of each of involved TSOs whereby a mechanism has to be implemented to constrain the forward of the cheapest balancing energy bids to the international platform. This means, that the most expensive balancing energy bids can be withheld and need not to be shared.[27] Also in terms of total system efficiency and higher competition in international balancing energy markets those bids shall be dedicated to be "unshared" showing the highest balancing energy prices.

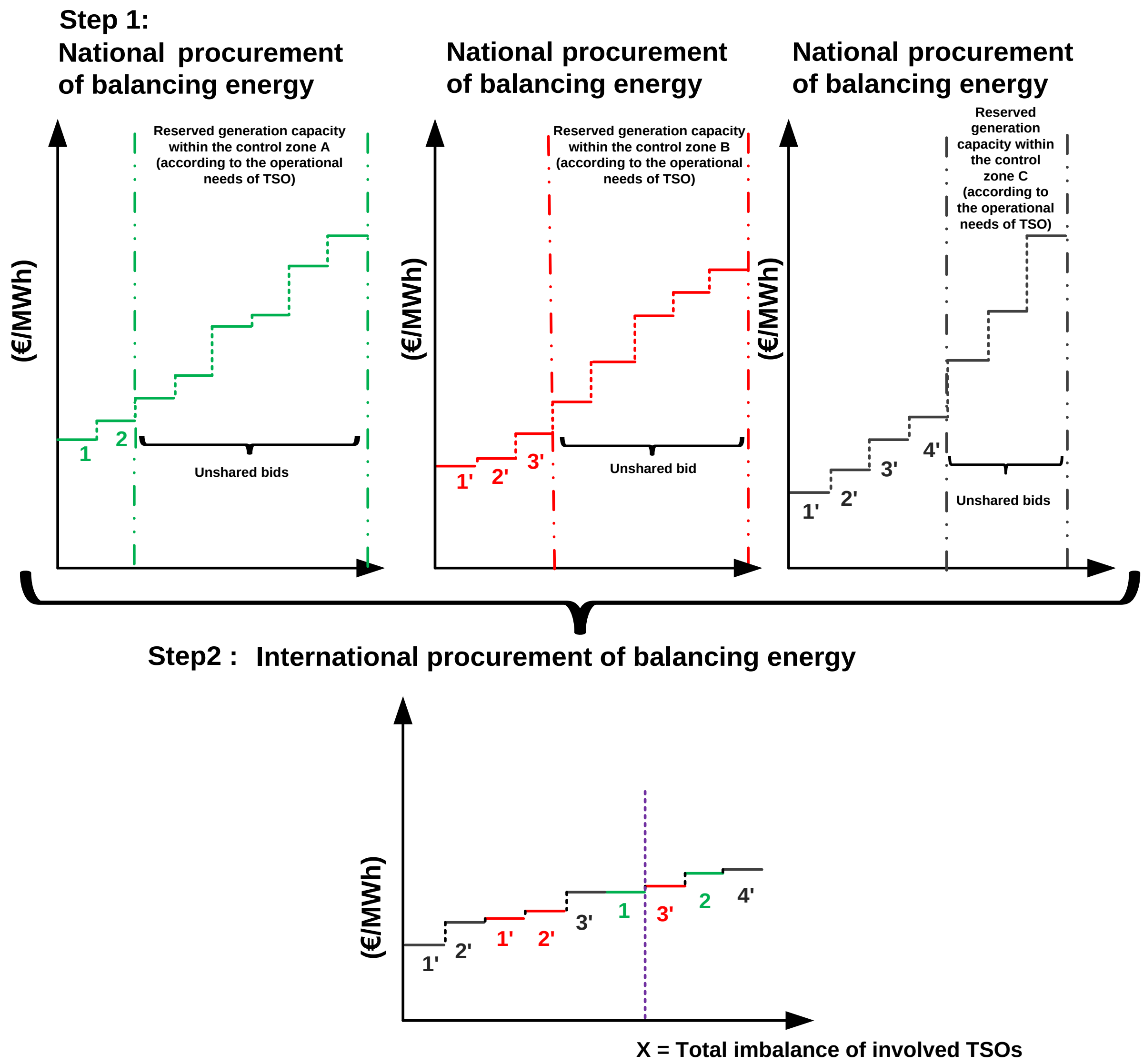
3.3.6 Clearing approach

In a first step, a simultaneous procurement of balancing reserve bids and balancing energy bids occurs in all participating TSOs at national level (see Figure 3.3 below). Then, the predefined (annually determined) amount of unshared bids is withheld. The remaining bids to be shared are forwarded to an international platform where a corresponding merit-order list is built. In a second step, a clearing of the merit-order list of shared bids is conducted on this international platform based on the total imbalance of all involved TSOs (see Figure 3.3 below in detail). In addition, Figure 3.3 also describes a possible imbalance settlement arrangement recommending a fair cost distribution between all participating TSOs. The recommended approach takes into account a weighted cost distribution factor as a function of the own imbalance of each TSO (see Figure 3.3).

[27] This means, that starting from the most expensive bids the determined amount of unshared bids can be withheld.

3.3.7 Implications for Virtual Power Plants (VPPs)

In general, there are no particular implications for VPPs (a VPP is one out of many BSPs). In terms of VPPs, the same is true as for the previous two models described in section 3.1 and 3.2.



Fair cost distribution between the participated TSOs according to own imbalance: Deriving of a weighted cost distribution factor as a function of TSO imbalance.

$X = I_A + I_B + I_C$ **X = Total imbalance of involved TSOs, I_A: Imbalance of TSO A, I_B: Imbalance of TSO B, I_C: Imbalance of TSO C**

$C_A = I_A/X*C_{B,t}$ **$C_{B,t}$: Total costs of activated balancing energy, C_A : Allocated cost to TSO A**

Figure 3.3 Bilateral/multilateral market-based TSO-TSO balancing model with common merit order and shared bids. Source: own depiction.

3.4 Bilateral/multilateral market-based TSO-TSO Balancing Model with Common Merit-Order without Unshared Bids (Benchmark for maximum; Target Model)

3.4.1 General approach

A further development of the previous bilateral/multilateral market-based TSO-TSO balancing model with common merit-order and shared bids finally results in a system where several bids of the Balancing Service Providers (BSPs) are shared on an international platform. As described in the previous market-based TSO-TSO balancing-model with common merit-order and shared as well as unshared bids, the procurement of balancing reserve bids and balancing energy bids is conducted by the incumbent TSO. Then, each TSO will forward the procured balancing energy bids to the international platform, the procured balancing reserve bids remain on national TSO level. This means, that the cross-border exchange among the TSOs is not based on balancing reserve sharing. Therefore, a reservation of cross-border transmission capacity is not needed. However, a cross-border exchange of balancing energy is feasible only if – in case of activation of balancing energy bids – sufficient cross-border transmission capacity is available.

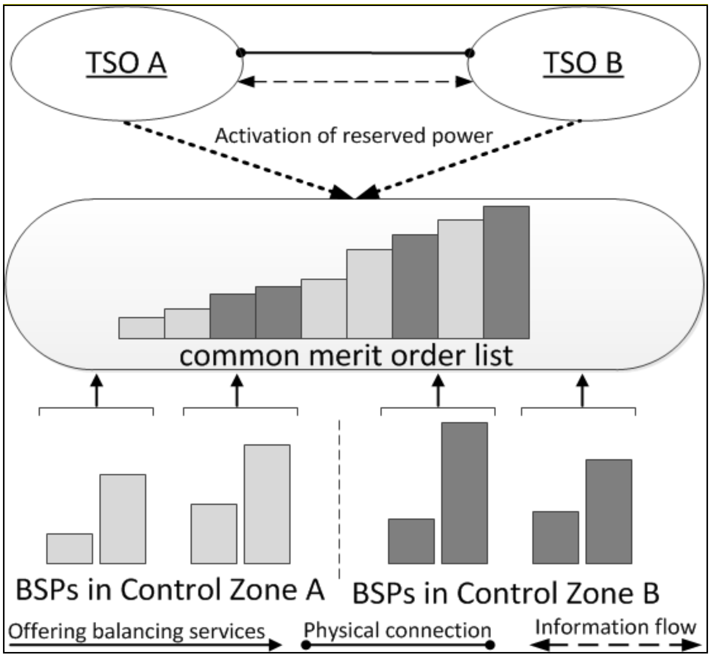


Figure 3.4 Bilateral/multilateral market-based TSO-TSO balancing model with common merit order (target model). Source: Veen (2010), own depiction.

Moreover, in case of activation of balancing energy there is a balancing energy flow between the offering BSPs (physically connected to an associated TSO) and a requesting TSO other than the TSO where the BSP is physically connected, see also Figure 3.4 above. Eventually, it is important to note that this final model – the target model – expects an entire harmonization and standardization in terms of different national parameters and products in the context of balancing energy service provision.

3.4.2 Market for procurement of balancing reserves (manual FRR)

In terms of balancing reserve procurement, in general, the same is true in this model like in the previous market-based TSO-TSO balancing-model with common merit-order and shared as well as unshared bids (see section 3.3.2 in detail). This means that balancing reserve procurement is conducted by the national TSOs.

3.4.3 Market for procurement of balancing energy and activation of balancing energy (manual FRR)

In terms of balancing energy procurement, in general, the same is true in this model like in the previous market-based TSO-TSO balancing-model with common merit-order and shared as well as unshared bids (see section 3.3.3 in detail). Again, cross-border exchange of balancing energy is feasible only if – in case of activation of balancing energy bids – sufficient cross-border transmission capacity is available.

3.4.4 Logistics and data flow requirements

Also this model expects besides the same national platform in each of the TSOs' control zones like in the previous market-based TSO-TSO balancing model with common merit-order and shared as well as unshared bids an international platform, enabling the different TSOs to forward their balancing energy bids. There is no additional communication necessary between the involved TSOs (compared to the above mentioned, previous balancing model). There is also no need of extension of communication between a BSPs and its incumbent TSO (i.e. TSO where the BSP is physically allocated) in comparison to the above mentioned, previous model. Again, several balancing energy bids are forwarded by the incumbent TSOs to the international platform and not by the BSPs. Furthermore, several exchange and re-allocation procedures are operatively managed by the involved TSOs and the international platform.

3.4.5 Clearing approach

In a first step, a simultaneous procurement of balancing reserve bids and balancing energy bids occurs in all participating TSOs at national level. Then, in a second step several balancing energy bids are forwarded to an international platform where a corresponding merit-order list is built. Finally, a clearing is conducted on this international platform based on the total imbalance of all involved TSOs.

3.4.6 Implications for Virtual Power Plants (VPPs)

In terms of implications for VPPs as BSP the same is true as for the previous three models presented in section 3.1, 3.2 and 3.3.

4 Virtual Power Plants (VPPs) as Balancing Service Providers (BSPs)

This chapter 4 introduces and elaborates on the implementation of Virtual Power Plants (VPPs) as Balancing Service Providers (BSPs) in the proposed market architectures for cross-border procurement and activation of balancing reserves and balancing energy in chapter 3. In particular, the following two aspects are considered in detail:

- General characteristics of VPPs (section 4.1)
- Requirements of VPPs to meet prequalification criteria (section 4.2)

4.1 General Characteristics of VPPs

VPPs can be referred to as aggregated units of electricity generation, storage or demand. Due to the spatial distribution of the units (in general also connected on different voltage levels of the electricity grid), VPPs also expect significant communication and IT-requirements. This implies also the challenge to be able to handle big data volumes. Besides both fluctuating renewable electricity generation as well as demand inherit an uncertainty in terms of output profiles that can be reduced amongst others by the composition of the individual units to aggregates. Aggregates like that – with or without storage – are denoted VPPs.

The spatial dispersion of fluctuating renewable electricity generation units can reduce large generation variations as widely-spread groups of e.g. wind turbines or PV plants – bundled as VPPs – can level the output profiles. The larger the geographical area of VPP dispersion, the lower the uncertainty is. Furthermore, different types of fluctuating renewable electricity generation technologies like wind and PV can occasionally counterbalance each other. In addition, the combination of many different customer groups with different load profiles can further reduce the risk of a VPP to deliver a predefined profile. Therefore, accurate forecast of fluctuating electricity generation and demand significantly contributes to reduce uncertainty. Moreover, forecasts depend on precise weather prediction methodologies; accuracy naturally increases closer to real-time. This already indicates that also the parameter settings of balancing electricity market design (e.g. gate closure time) are very important for successful integration of VPPs into this particular market segment.

4.2 Requirements of VPPs to Meet Prequalification Criteria

The characteristics of VPPs mentioned in section 4.1 have to be considered when integrating VPPs in the balancing markets, regardless whether or not cross-border concepts are envisaged in this market segment. Therefore, the regulatory framework – in particular the network codes of electricity balancing and the corresponding implementation of them in the national regulations – has to be designed accordingly.

Important aspects for VPPs as BSPs in the balancing market are – amongst others – the timing of the markets (e.g. gate closure), the standard/specific product(s) and the prequalification requirements defined by the TSOs of the corresponding balancing areas. Moreover, the definition and determination of a baseline is necessary, in particular when demand response bids of VPPs are considered (in order to be able to quantify the delta in case of activation of the corresponding bids). Some approaches in this context are given in the SEDC document (see SEDC (2012)). One baseline approach could also be to use the final schedules – i.e. the schedules that are final after the gate closure time of the intraday market – as a baseline. This would be is consistent with the existing market design.

As already mentioned above, the timing of the balancing market is relevant as the uncertainty of a VPP to deliver a particular output profile decreases the closer the gate closure time of the balancing energy market is to real-time. A long delivery period of the standard product (the maximum timeframe balancing energy has to be delivered) hinders the participation of VPPs in the balancing market. For instance, the reduction of one 4 hour block (11 am to 3 pm) to four 1 hour blocks increases the potential to offer balancing reserves by 10%, see the project *'REserviceS'* (Kreutzkamp et al (2013)).

Also a high minimum quantity of the standard products interferes with the integration of VPPs. Since the prequalification criteria also define necessary prequalification procedures and the IT- and monitoring requirements, they also determine the costs of the connection and entry into the balancing market. It is straightforward that more small sized distributed generation, storage and demand side units are able to participate in the balancing markets when no minimum capacity limits are defined.

In addition, the introduction of a reliability margin to guarantee 'firm' bids could be a further step towards the integration of VPPs into balancing markets. This reliability margin explains the probability that balancing energy actually can be delivered at the point in time when it is activated. A comparison with conventional power plants can be useful to get a rough estimate on a reliability margin for VPPs. Conventional power plants have a probability of an unplanned outage of 1-3 % (confidence interval of 97-99 %). The same benchmark can be applied to a VPP bidding into a balancing market. In Figure 4.1 the confidence interval is elaborated with an example of a day-ahead and an intraday generation profile with 97.5 % confidence intervals of an actual PV production. The coloured bars display the PV generation that is sold on the upward balancing market (green), day-ahead market (blue) and intraday market (yellow). The red bars show losses of the PV generation that cannot be sold. In case PV generation takes place in the downward balancing market no energy losses would occur. For further details in this context it is also referred to the project *'REserviceS'* (Kreutzkamp et al (2013)).

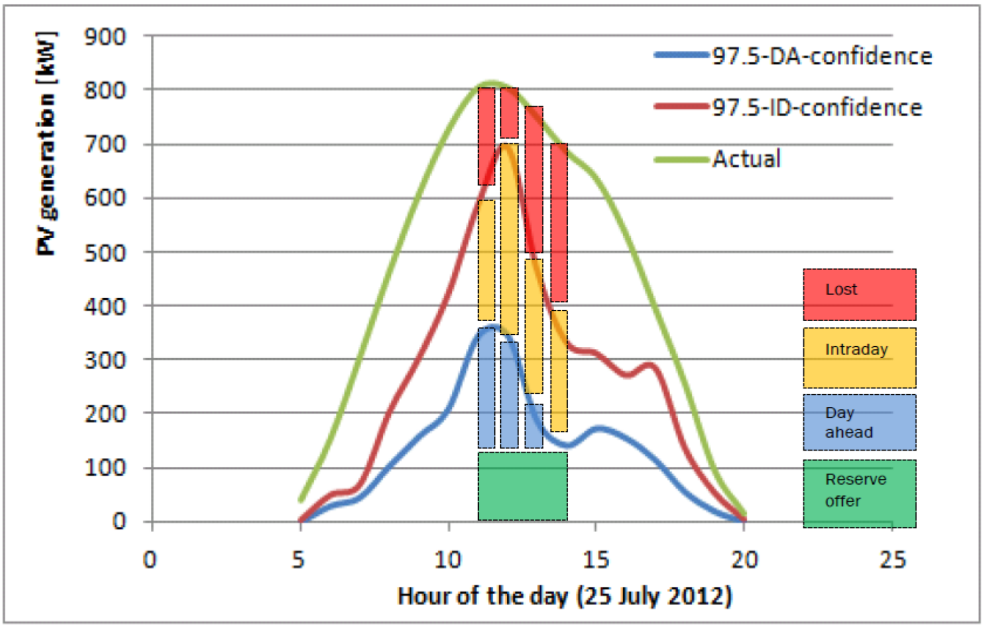


Figure 4.1 PV generation: Actual production, day-ahead and intraday 97.5 % confidence intervals. Soruce: Project *'REserviceS'*

In case no reliability margin is introduced, also other 'hedging' possibilities exist, e.g. contract with a conventional power plant backing up 'firm' balancing reserve capacity or extending a PV plant with storage technologies. Also financial hedging instruments could be envisaged. Last but not least, possible congestion on distribution grid level needs to be considered when considering and determining reliability margins. However, this aspect is not further elaborated in this report, since this section 4 is understood as an introduction into the VPP topic as BSPs only. A comprehensive elaboration of this topic is conducted in Deliverable 2.2 of the eBadge project.

5 Conclusions

This report aims at contributing to the challenging task of balancing market renewal in Europe; a policy process having been triggered by the European Commission and the two main European associations responsible in this field: ACER (Agency for the Cooperation of Energy Regulators) and ENTSO-E (European Network of Transmission System Operators for Electricity). More precisely, in this report not only different market architectures for cross-border procurement and activation of balancing reserve capacities and balancing energy are elaborated in detail, but also the interpretation of a Balancing Service Provider (BSP) is extended in the sense that also distributed generators, small sized energy storage and load response can contribute in this segment as a market participant (‘Virtual Power Plant (VPP)’).

In terms of balancing market architecture development presented in this report the starting point is an entirely national balancing market without any sharing of balancing energy bids. This concept is followed by two gradually enhanced cross-border balancing market architectures (considering different principles of bid sharing) being consistent and compatible with the overall framework defined in the ACER and ENTSO-E documents. The most advanced market architecture described in this report coincides with the so-called *‘Target Model’*.

The major outcomes of this report provide the foundation for market architecture design enhancements of cross-border balancing markets in the FP7-project eBadge. Moreover, in the eBadge project not only cross-border balancing market design details are addressed enabling the participation of VPPs as BSPs, but also corresponding modelling is conducted and a practical field/pilot study is implemented in the electricity market region of the Italian-Slovenia-Austrian border.

References

Abbasy A., R.A.C. van der Veen, R.A. Hakvoort, 2010: Timing of Markets – the Key Variable in Design of Ancillary Service Markets for Power Reserves, Proceedings, 33rd IAEE International Conference, Rio de Janeiro, Brazil, Bd. 33, S. 1-14, 2010.

ACER, 2012a: Framework Guidelines on Electricity Balancing, 18 September 2012a.

ACER, 2012b: Framework Guidelines on Electricity Balancing – Draft consultation, DFGEB-2012-E-004, 24 April 2012b.

ACER, 2011: Framework Guidelines on Capacity Allocation and Congestion Management (CACM) for Electricity, July 2011.

Adam, 2011: Planungen zur weiteren Entwicklung der Netzinfrastruktur in Europa (English: Development strategy of grid infrastructure in Europe), Kai Adam, Presentation at Dena Dialogforum, Berlin, 10th November 2011.

Bang C., F. Fock, M. Togeby, 2012: The existing Nordic regulating power market, FlexPower WP1-Report, 23.5.2012.

Brandberg, 2008: Brandberg, M.; Broman, N.; Nilsson, M.: Wind power and future trading with regulating power, doi 10.1080/14041040801899855, 2008.

Doorman G., R. van der Veen, A. Abbasy, 2011: Balancing Market Design, Sintef, August 2011.

Doorman Gerard, 2011: Exchange of Balancing Services between Synchronous Areas, Norwegian University of Science and Technology, 26 January 2011.

ENTSO-E, 2013a: Draft Network Code on Electricity Balancing, Version 1.14 / Version 1.22, 20 February 2013 / 24 May 2013a.

ENTSO-E, 2013b: Network Code on Load-Frequency Control and Reserves, 28 June 2013b.

ENTSO-E, 2012: Survey on Ancillary Services Procurement & Balancing Market Design (ENTSO-E Working Group), September 2012.

ENTSO-E, 2011a: Position Paper on Cross-Border Balancing (Working Group Ancillary Services), July 2011a.

ENTSO-E, 2011b: Development of balancing systems to facilitate the achievement of renewable energy goals, Nov. 2011b.

ENTSO-E, 2009: Operation Handbook, P1 – Policy 1: Load-Frequency Control and Performance, Version: v3.0 rev 15/01.04.2009.

ENTSO-E, 2006: Key Issues in Facilitating Cross-Border Trading of Tertiary Reserve and Energy Balancing, May 2006.

Friedl et al, 2012: Marktbasierte Beschaffung von Regelreserve, 12. Symposium Energieinnovation, Graz, 15-17.2.2012.

Gutschi et al, 2008: Potenziale und Hemmnisse für Power Demand Side Management in Österreich _English: Potentials and barriers for power demand side management in Austria, Paper, 10th Symposium Energy innovation Graz, 2008.

Holttinen et al, 2009: Design and operation of power systems with large amounts of wind power, IEA wind Task 25, final report, Phase one 2006-2008, 2009.

IGCC, 2012: Information zum Netzregelverbund und der internationalen Weiterentwicklung, Marktinformation der vier deutschen Übertragungsnetz-betreiber, Stand 15.9.2012.

Kreutzkamp et al, 2013: Ancillary Services by Solar PV – Capabilities and Costs, Deliverable 4.1, Project REserviceS, May 2013.

Mott MacDonald, 2013: Impact Assessment on European Electricity Balancing Market, Final Report, Contract EC DG ENER/B2/524/2011, 2013.

Müsgens F., A. Ochsenfels, 2011: Design von Informationsfeedback in Regelenergiemärkten, Zeitschrift für Energiewirtschaft, Bd. 35, Nr. 4, S. 249-256, August 2011.

Nyeng Preben, 2010: System Integration of Distributed Energy Resources – ICT, Ancillary Services, and Markets, PhD Thesis, Technical University of Denmark, Department of Electrical Engineering, 2010.

Paulus et al, 2011: The potential of demand side management in energy intensive industries for electricity markets in Germany, Journal Applied Energy, doi:10.1016/ j.apenergy.2010.03.017, 2011.

Pudjianto et al, 2007: Virtual power plant and system integration of distributed energy resources, IET Renewable Power Generation, vol 1, issue 1, pp. 10 - 16, Mar 2007.

SEDC, 2012: Establishing Demand Response in Europe: Regulatory changes and market models, Position Paper, Smart Energy Demand Coalition (SEDC), 2012.

Schlemmermeier Ben, 2009: Kurzgutachten zur Konsultation zum Gutachten „Optimierung der Ausregelung von Leistungsungleichgewichten“, Berlin, 2009.

Schütt Kristina, Clemens Krauß, 2012: Untersuchung zur Dimensionierung der ausgeschriebenen Regelleistung des Netzregelverbunds, Energiewirt-schaftliche Tagesfragen, 62. Jg. Heft 10, 2012.

Stadler, 2007: Power grid balancing of energy systems with high renewable energy penetration by demand response, Journal Utilities Policy, doi:10.1016/ j.jup.2007.11.006, 2007.

Universität Dortmund – Lehrstuhl für Energiesysteme und Energiewirtschaft, E-Bridge Consulting GmbH, 2009: Optimierung der Ausregelung von Leistungsungleichgewichten“, Gutachten im Auftrag der Bundesnetzagentur, Dortmund, August 2009.

Universität Dortmund – Lehrstuhl für Energiesysteme und Energiewirtschaft, E-Bridge Consulting GmbH, 2006: Bestimmung des regelzoneninternen Regelleistungsbedarf für Sekundärregelung und Minutenreserve, Gutachten im

Auftrag der Bundesnetzagentur, Bonn, September 2006.

van der Veen, R., 2012: Designing Multinational Electricity Balancing Markets, TU-Delft, 2012.

van der Veen, Abbasy, Hakvoort, 2012: A comparison of imbalance settlement designs and results of Germany and the Netherlands, Yeees-Seminar, 2012.

van der Veen et al, 2010: A qualitative analysis of main cross-border balancing arrangements, Paper, 7th International Conference on the European Energy Market (EEM), 2010.

van der Veen, Hakvoort, 2009: Balance Responsibility and Imbalance Settlement in Northern Europe – An Evaluation, mimeo, 2009.

Vukasovic M., F. Pink, 2012: DSM and benefits for the cross-border market integration, Konferenz Energieinnovation, TU-Graz, Februar 2012.

www.regelleistung.net (Allocation of Balancing Reserves and Balancing Energy in Germany), 2013.

Appendix

Appendix 1

A1.1 Implementation options of the BSP-TSO balancing model

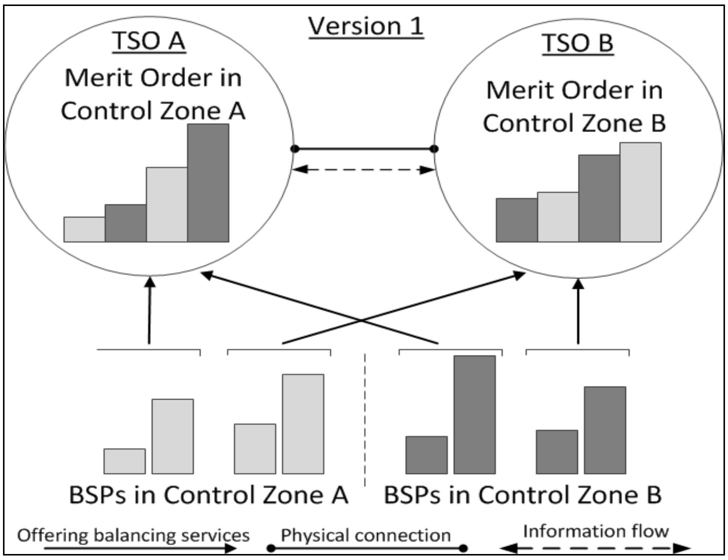


Figure A1.1a Implementation option 1 of the BSP-TSO balancing model. Source: Veen (2010).

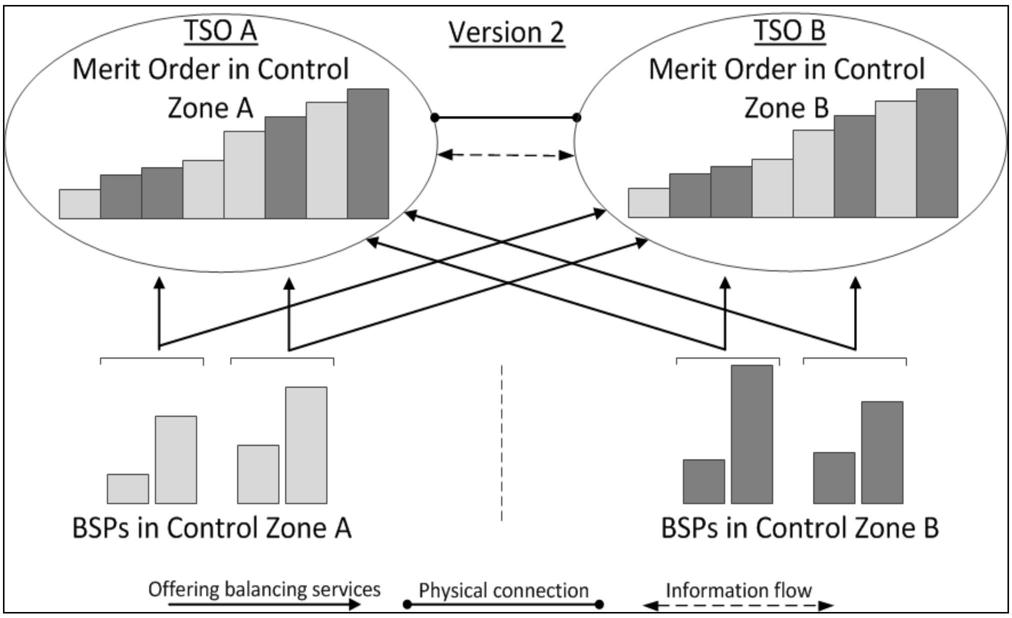


Figure A1.1b Implementation option 2 of the BSP-TSO balancing model. Source: Veen (2010).

A1.2 Implementation option of the bilateral/multilateral TSO-TSO balancing model (without common merit order)

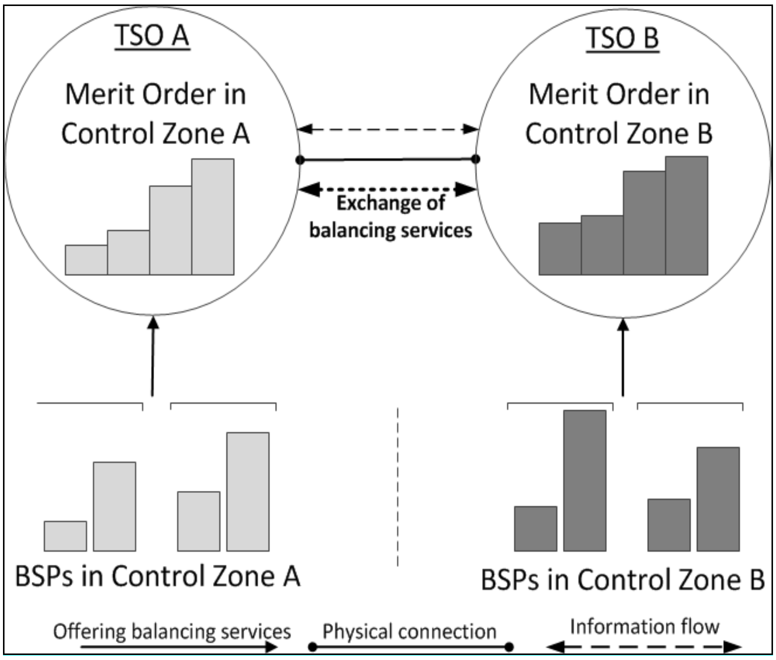


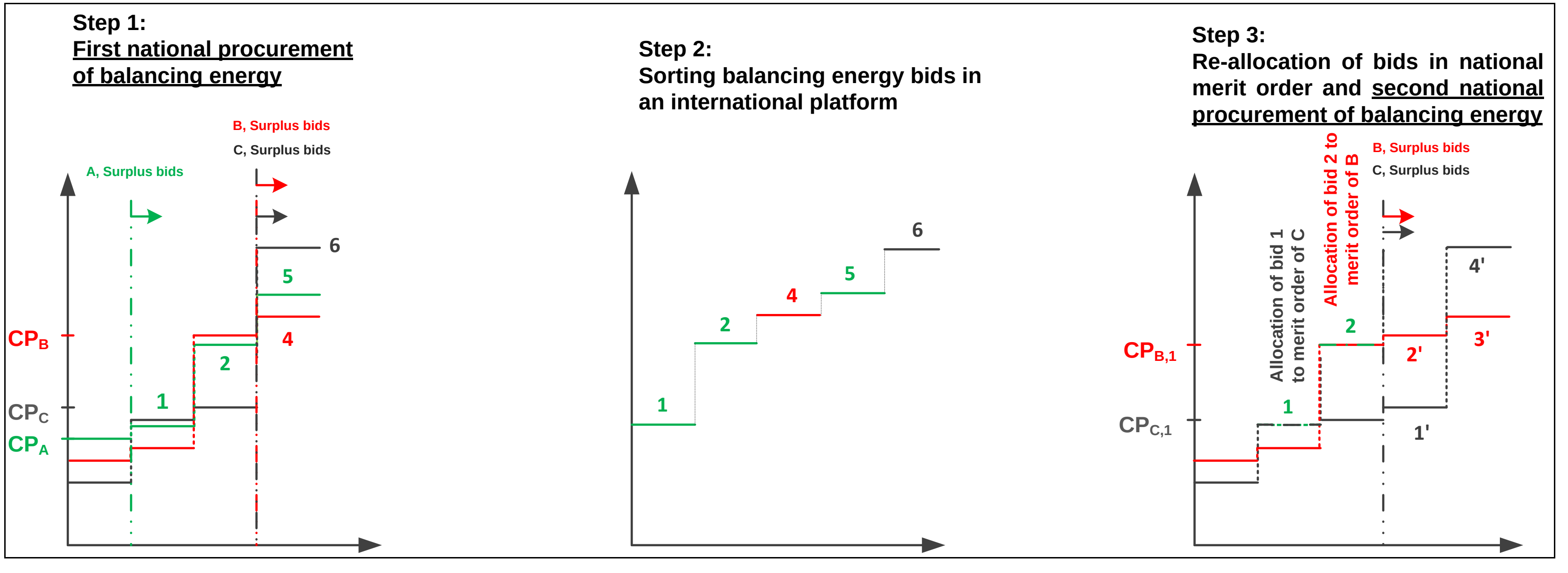
Figure A1.2 Implementation option of the bilateral/ multilateral TSO-TSO balancing model (without common merit order). Source: Veen (2010).

Appendix 2

A2.1: 1st Approach of "TSO-TSO Surplus Exchange"

In the 1st approach the following steps are conducted (see Figure below in detail):

- Step 1: Procurement of balancing energy bids and building up of an individual national merit-order list by each TSO. The TSO having cleared with the lowest price in the first step in the national clearing (i.e. TSO A in the Figure below), can't improve its result in subsequent steps. Therefore, this TSO (TSO A) is already "done".
- Step 2: Surplus balancing energy bids of each of the involved TSOs are forwarded to an international platform and sorted in an incremental order, starting with the cheapest.
- Step 3: Re-allocation of 'available' surplus balancing energy bids to the national merit-order lists of those TSOs benefiting from one of these bids (compared to the initial situation of the purely national merit-order having been built in Step 1). A benefit is meant in the sense to get access to a lower balancing energy bid (from the international platform) and 'inserting' it into the initial national merit-order list. This process will flatten the initial national merit-order list of the beneficiaries. Step 3 is finalised by a renewed, second national procurement process of balancing energy (being a combination of initial (national) and re-allocated (from the international platform) balancing energy bids).
- After this second national procurement of balancing energy the entire process according to the 1st approach is finished. The different national balancing markets are ready for 'actual clearing'. The lack of this 1st approach, however, is that it is accepted that also some 'cheap' balancing energy bids might get lost (e.g. in the far-right figure below it is bid 1'). In the following 2nd approach (next page), this particular problem/inefficiency is solved.



A2.2: 2nd Approach of “TSO-TSO Surplus Exchange”

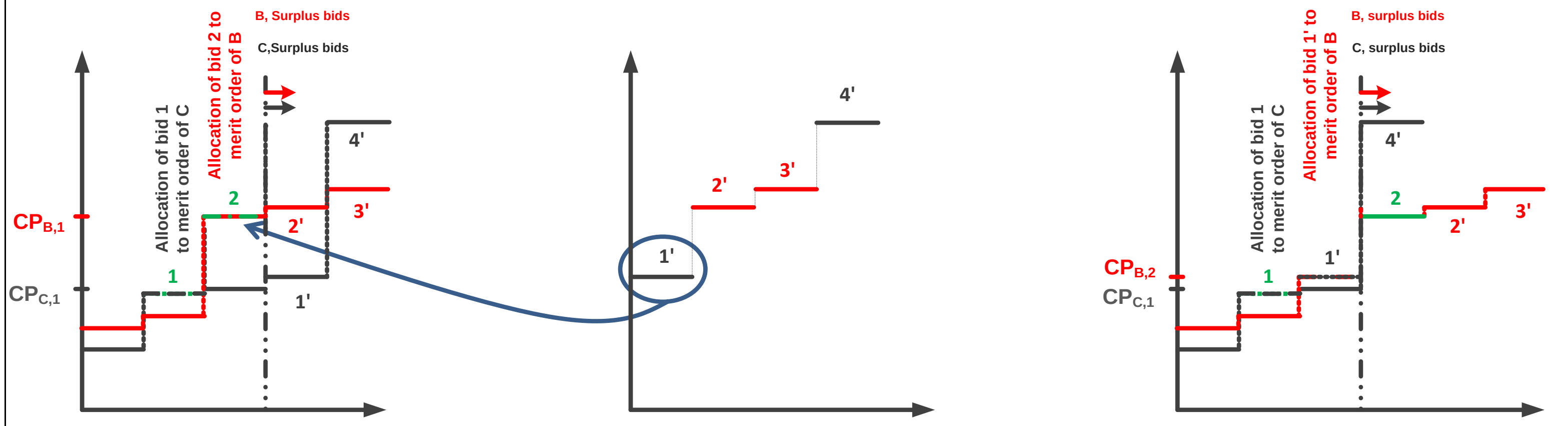
The 2nd approach is a prolongation of the 1st approach beyond Step 3 in the sense that further iterations of re-allocations of surplus balancing energy bids are conducted:

- Status quo after Step 3: After the second national procurement of balancing energy bids (as a result of re-allocation of surplus balancing energy bids from the international platform) there could ‘appear’ a new surplus balancing energy bid of a TSO (e.g. bid 1’ of TSO C in the figure below due to a flattening of the merit-order curve of this TSO C as a result of the insertion of forwarded bid(s) from the international platform) having a lower price level than other forwarded bids to other TSOs (e.g. bid 2 to TSO B) after the first national procurement of balancing energy.
- Step 4: Again, several available surplus balancing energy bids of all still involved TSOs must be forwarded to an international platform and the re-allocation of these bids in the national merit-order lists goes into a next round. Then only, it can be excluded that any ‘cheap’ balancing energy bid (e.g. bid 1’) gets lost. From the total system efficiency’s point-of-view this is an improvement compared to the 1st approach presented in the previous page.
- Step 5: Another national re-allocation and balancing energy bid procurement cycle starts (ex-ante it is not predictable how many iterations are needed if n TSOs are involved).

Status quo after step 3 in the previous model: Allocation of bids in national merit order and <u>second national procurement of balancing energy</u>

Step 4: Sorting energy balancing bids due to appearance of „new“ surplus bids in a common multilateral/ international platform

Step 5: Allocation of bids in national merit order and <u>third national procurement of balancing energy</u>



The „new“ surplus balancing energy bid 1’ is cheaper than the used green balancing energy bid 2 in the national merit order of TSO B. Bid 1’ can replace the mentioned bid 2 in a further step. Therefore, the bid 1’ doesn‘t get lost and TSO B will have a lower clearing price (compare CP$_{B,1}$ to CP$_{B,2}$)

A2.3: 3rd Approach of "TSO-TSO Surplus Exchange"

This 3rd approach relies on the ranking of the clearing price levels of balancing energy in the first national balancing energy procurement cycle, i.e. awarding those with the most attractive bids from the international platform having cleared in the first national balancing energy procurement cycle also with low price levels. The procedure of this 3rd approach is as follows:

- Step 1: Identification of the TSO with the lowest clearing price in the first national balancing energy procurement cycle (i.e. TSO A in the figure below). Then, this TSO A is already "done"; it can't change the result in subsequent steps. The surplus balancing energy bids from this TSO A with the lowest clearing are forwarded to the TSO with the next cheapest clearing price (TSO C in figure below) after the first national balancing energy procurement.
- Step 2: TSO C receives surplus balancing energy bids from TSO A and integrates them in its initial national merit-order list and clears again. Then, TSO C is "done".
- The surplus balancing energy bids from TSO C are forwarded to next TSO with the next cheapest clearing price after the first national balancing energy procurement (TSO B) and then the procedure is repeated until the last TSO is "done".