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Turn On the Grid of the Future

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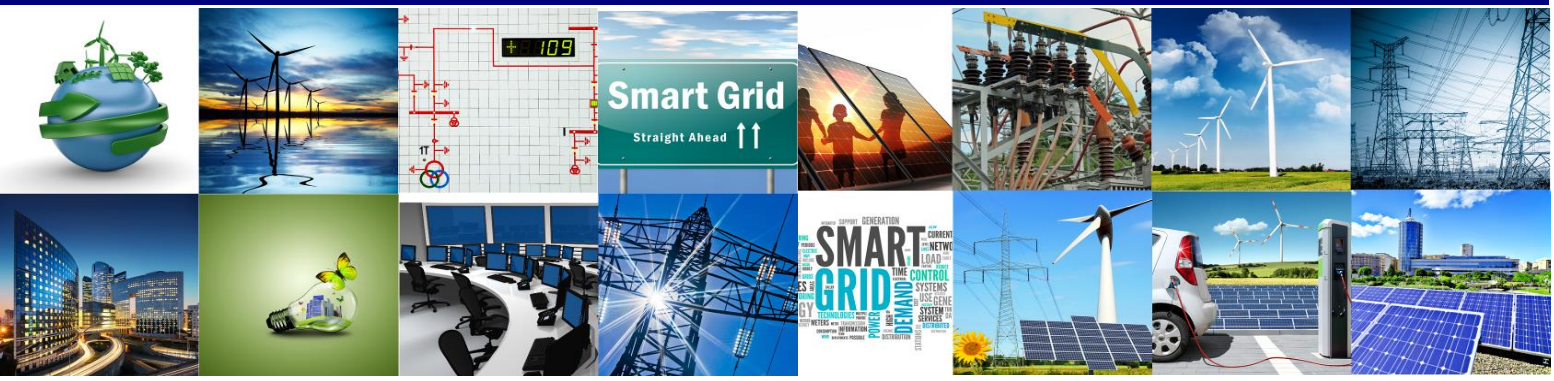

WP 3

Scenarios and case studies for future power systems

Deliverable 3.2

Market design supporting the Web-of-Cells control architecture

31/03/2018

ID&Title	**D3.2** Market design supporting the Web-of-Cells control architecture	Number of pages:	146

Short description (Max. 50 words):

A high-level market design supporting the functioning of architecture for frequency and voltage control developed within the Web-of-Cells power grid structure was proposed. The market mechanisms and conditions required to be implemented within the architecture to perform trading in balancing and voltage control products and establish the final Merit Order list for the architecture of frequency and voltage control were analysed and solutions proposed.

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Executive summary

Task 3.3 in the ELECTRA project focuses on development a high-level market design supporting the functioning of the architecture for frequency and voltage control, developed within the Web-of-Cells power grid structure, with a particular emphasis on the market mechanism and conditions required to perform trading of balancing and voltage control products involved in the real-time operation of the grid.

The structure of the Deliverable is as follows. In Chapter 2, the concept of design of the market for balancing and voltage control products is presented by proposing the general framework of market designing, suggesting levels of requirements for the establishment of a well-functioning market, describing the structure of a reference model, the composition of set of market design elements and the market design evaluation criteria. In Chapter 3, the approaches towards power sector organization in future are discussed, and a proposal is given. In Chapter 4, the high-level design of the wholesale electricity market for future power systems is suggested. The principles of a well-functioning market for balancing and voltage control products developed within the Web-of-Cells power grid structure are set in Chapter 5. Chapter 6 shortly discusses the structure of the reference model for the architecture of frequency and voltage control. The market actors and their roles in the market are provided in Chapter 7. Chapter 8 provides the classification and description of balancing and voltage control products. The options for the organization of the marketplace to trade the products and the related solutions are given in Chapter 9. In Chapter 10, the peculiarities of the auctioning are discussed. The options and the related solutions of general, balance planning, balancing and voltage control provision and imbalance settlement elements are discussed in Chapter 11. Chapter 12 provides the summary of market designs for the Use Cases. In Chapter 13, an assessment of market designs is given. The interactions between the designs of short-term electricity markets are analysed in Chapter 14. Conclusions are drawn in Chapter 15.

Terminologies

Abbreviations

ACER	Agency for the Cooperation of Energy Regulators
aFCC	Adaptive Frequency Containment Control
AS	Ancillary Services
AS market	Ancillary Service Market
bOTC	bilateral Over-The-Counter
BRC	Balance Restoration Control
BRP	Balance Responsible Party
BSC	Balance Steering Control
BSP	Balance Service Provider
BTU	Bid Time Unit
CHP	Combined Heat and Power
CoC	Competition Council
CSO	Cell System Operator
CTL	Control Topology Level
DA market	Day-Ahead Market
DER	Distributed Energy Resources
DSR	Demand Side Response
ENTSO-E	European Network of Transmission System Operators for Electricity
EV	Electric Vehicles
FCR	Frequency Containment Reserves
FRR	Frequency Regulation Reserves
GCT	Gate Closure Time
GOT	Gate Opening Time
HV	High Voltage
ID market	Intraday Market

IEM	Internal Electricity Market
IGCT	Initial Gate Closure Time
IRPC	Inertia Response Power Control
ISP	Imbalance Settlement Period
LR-based	Lagrangian Relaxation-based
LV	Low Voltage
MCP	Market-Clearing Price
MDI	Market Design Initiative
MIP-based	Mixed Integer Program-based
MO	Market Operator
MOC	Merit Order Collection
MOD	Merit Order Decision
MV	Medium Voltage
NRA	National Regulatory Authority
oOTC	organized Over-The-Counter
OTC	Over-The-Counter
PP	Power Plant
PPVC	Post-Primary Voltage Control
PVC	Primary Voltage Control
RES	Renewable Energy Sources
RES-E	Electricity Produced from Renewable Energy Sources
RoCoF	Rate of Change of Frequency
RR	Replacement Reserves
RT market	Real-Time Market
SI	System Imbalance
SO	System Operator
STU	Settlement Time Unit
STU	Schedule Time Unit

TPC	Total Procurement Cost
TSO	Transmission System Operators
UCs	Use Cases
V2G	Vehicle to Grid
VOLL	Value of Lost Load
WoC	Web-of-Cells

Table of contents

List of figures

List of tables

1 Introduction

The European power sector will undergo significant developments beyond 2020. Electricity production will shift from traditional fossil fuel-based units to units using intermittent Renewable Energy Sources (RES). Production will significantly move from central transmission to decentralized distribution network connected production. A wave of electrification of transport and space heating sectors will rise and strengthen up to 2050, resulting in increasing demand for electricity. Electricity storage technologies will become cost-effective solutions for the provision of balancing services. Extensive amounts of flexible loads having a fast activation and short ramp times will be available at all voltage levels. Consequently, the demand for activation of balancing capacities to correct the imbalances caused by forecast errors of intermittent RES and flexible loads will increase. The present balancing paradigm will be requested to be transformed from generation-following load to load-following generation. The location of balancing problems, which require activation of balancing capacity, and resources, which contribute to solving balancing issues, will move from transmission to distribution network level. Electricity consumption will become less predictable and volatile. Local storage will be a valuable source for balancing. The number of distributed resources capable of providing balancing capacity will significantly increase [1]. The expected trends request to change the approach towards balancing and voltage control issues and addressing them in practice. For this reason, new balancing and voltage control mechanisms are required.

The decentralized managed future where the power system is decomposed into grid areas, called Cells, which are capable self-providing (locally) balancing and voltage control services, is considered a reasonable solution to the expected developments in power system in future. Implementation of it means that each Cell has assigned to a Cell System Operator (CSO) who takes the responsibility of balancing capacity activation in real time by not requesting global information for this. In this way, local imbalance problems are addressed locally in the Cell quickly, securely and limiting complexity. The Web-of-Cells (WoC) power grid structure developed as a solution to these challenges encompasses a group of interconnected loads, concentrated production units, Distributed Energy Resources (DER) and storage units within defined grid boundaries corresponding to a physical portion of the grid and corresponding to a confined geographical area [1].

The WoC decentralized control architecture implements six Use Cases (UCs) for balancing (generation-demand) and voltage control: Inertia Response Power Control (IRPC), Adaptive Frequency Containment Control (aFCC), Balance Restoration Control (BRC), Balance Steering Control (BSC), Primary Voltage Control (PVC) and Post-Primary Voltage Control (PPVC). Each functionality is implemented through the number of UC specific functions, which are a black-box in this Deliverable (Figure 1-1), but are comprehensively analyzed in other Deliverables of the ELECTRA project (for example, in [2]). Within the framework of this Deliverable, focused on the procurement of the reserves that will be used during the real-time operation, only the Merit Order Collection (MOC) and the Merit Order Decision (MOD) functions are relevant.

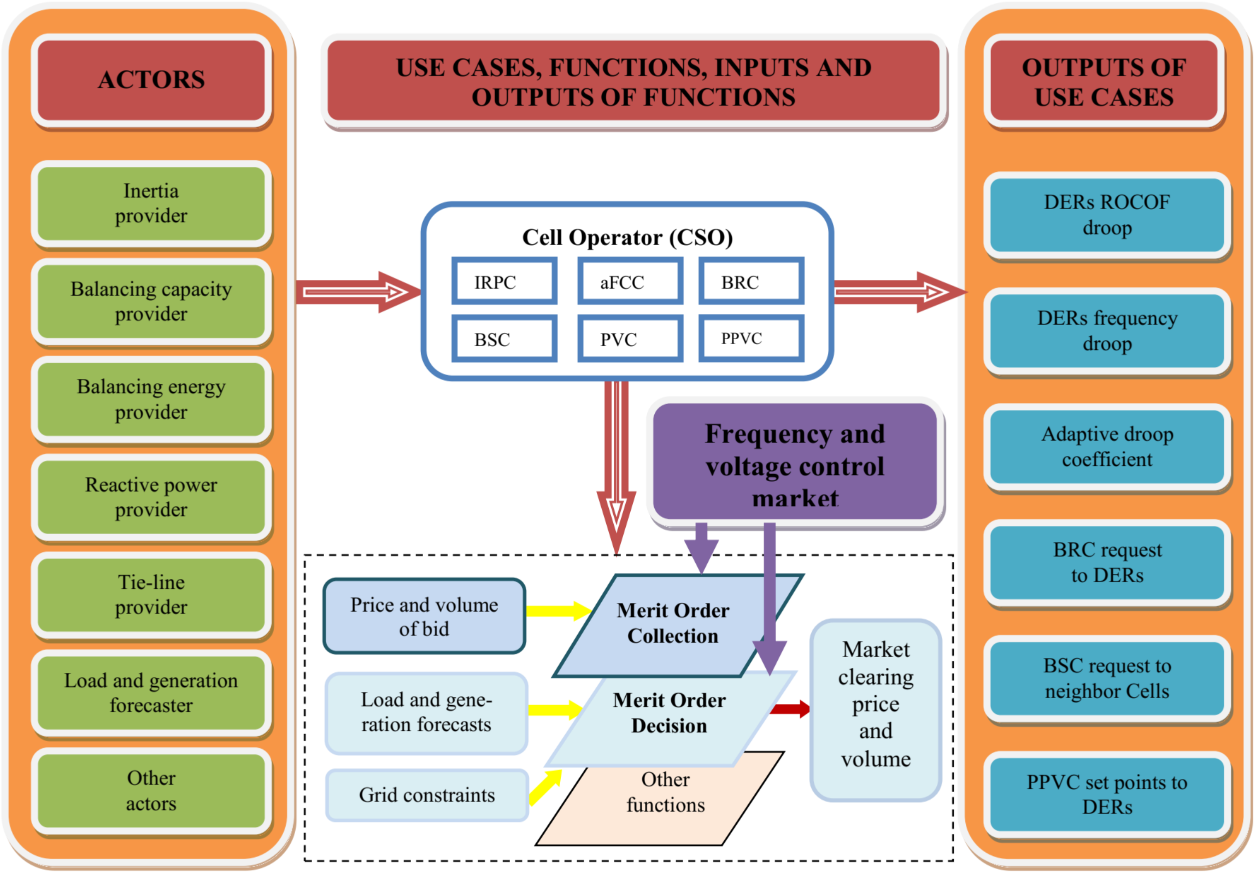


Figure 1-1. Architecture of frequency and voltage control for the future power systems

The market for the architecture of frequency (balancing) and voltage control is required to be developed and to be efficient for the purpose to implement the Merit Order Collection (MOC) and the Merit Order Decision (MOD) functions of the proposed control mechanisms to contribute to a well-functioning WoC power grid structure.

Thus, the Deliverable aims at proposing a high-level market design supporting the functioning of the architecture for frequency and voltage control developed within the WoC power grid structure, with a particular emphasis on the market mechanism and conditions required to perform trading of balancing and voltage control products involved in the real-time operation of the grid.

To implement the aim, the following tasks are set:

- To develop the concept of the market design supporting the architecture of frequency and voltage control within the WoC power grid structure by identifying the crucial structural elements of the market design;
- To determine the criteria for assessment of the market design supporting the architecture of frequency and voltage control within the WoC power grid structure;
- To analyse the alternative solutions of the market design elements by considering their advantages and disadvantages and against the assessment criteria;
- To prepare a high-level market design supporting the architecture of frequency and voltage control within the WoC power grid structure.

2 Concept of market designing

2.1 Definition of market design

So far various concepts of the market design have been developed by [3]-[6]. The concepts significantly depend on, and they are related to the practical policy goals for achievement of which market design is developed, the peculiarities of economic sector or country under the consideration, aspects of market design discussed, analysis method applied, assessment criteria used or other aspects.

Considering a great variety of factors, which disclose an array of research issues the market design covers, the market design supporting the architecture of frequency and voltage control proposed for the WoC power grid structure is developed considering to three concepts: “market”, “designing” and “market design”. The interrelation between them is given in Figure 2-1 and discussion is provided below.

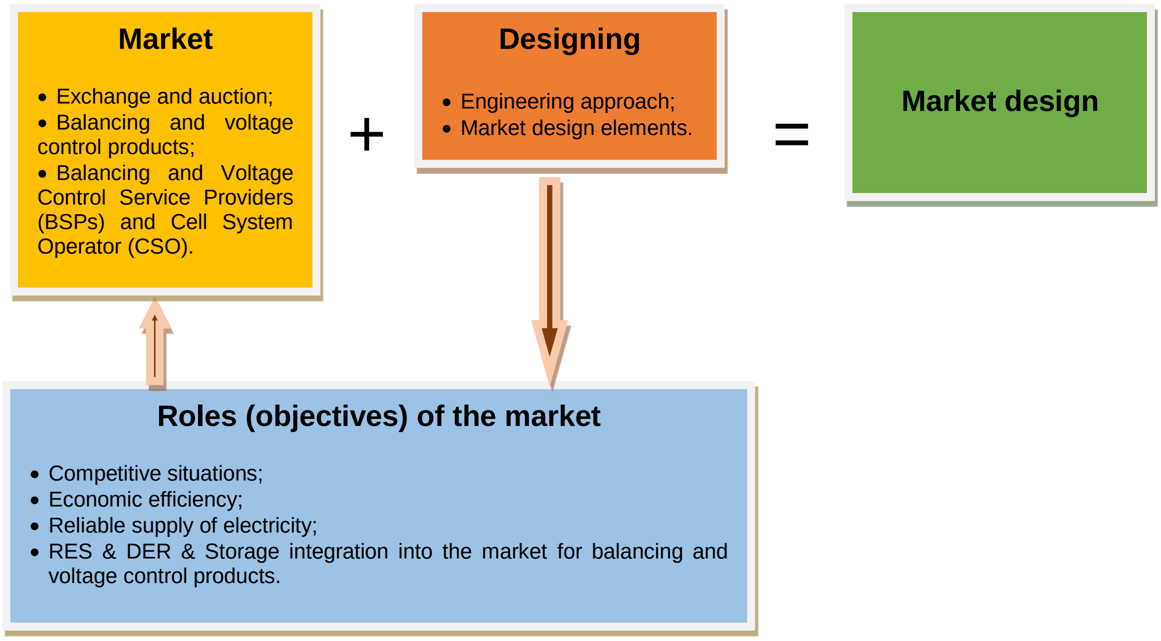


Figure 2-1. Structural representation of market design concept

Concept of the market for the architecture of frequency and voltage control. From the point of view of the architecture for frequency and voltage control developed for the WoC power grid architecture, the market works through the MOC and the MOD functions of the UCs, which are developed for frequency and voltage control, and it is understood as the mechanism and conditions required to be implemented with the purpose to make the proposed architecture functional.

– *Merit Order Collection (MOC) function* aims at collecting inertia, balancing capacity, balancing energy and reactive power bids (pairs of bid prices and volumes) from the relevant actors, ranking them by bid price and establishing an initial Merit Order list, composed of sequentially in price ascending order arranged accepted bids (volumes) of the actors.

- *Merit Order Decision (MOD) function* calculates a final Merit Order list by taking into consideration the initial Merit Order list, load and generation forecasts, operating constraints of the lines on which inertia, balancing capacity, balancing energy and reactive power are to be deployed. The function is analysed only at the scale that it affects the outcome of the final Merit Order list, which is the market-clearing price (MCP) and volume.

The economic theory [7] specifies the characteristics of the mechanism and conditions required. These are the physical or virtual institution or location, products traded and interacting market actors. Tailoring these characteristics to the architecture of frequency and voltage control, the market for the architecture of frequency and voltage control is defined as an auction-based exchange where the balancing and voltage control products, which are the UCs of the proposed architecture, are traded between the Balancing and Voltage Control Service Providers (BSPs) – inertia, balancing capacity, balancing energy and reactive power providers – and the CSOs. These are the core characteristics of the market and are addressed in the Deliverable.

Concept of the market for balancing and voltage control products. With the purpose to stress the relevance of the traded UCs of the architecture for frequency and voltage control, further in the text this market is called the market for balancing and voltage control products.

Roles (objectives) of the market for balancing and voltage control products. The concept of market should be originated from its roles (objectives) [8].

The primary role (objective) of the market is to establish competitive situations, particularly, preventing the creation or the strengthening of market power or prohibiting the abuse of a position of substantial market power (monopolization). By definition, competitive conditions should be established in the market and competitive constraints the market actors face, should be eliminated, meaning that a competitive market should be established. This role (objective) of the market is directly tailored to the architecture of frequency and voltage control. In addition, the architecture of frequency and voltage control includes the following eight attributes of a competitive market:

- An ease of market entry and exit;
- An absence of significant monopoly power;
- Widespread availability of information;
- An absence of market externalities;
- An achievement of public policy goals, such as ensure a reliable supply of electricity, increased production of electricity from RES;
- Trade in standardized products;
- Decentralized pricing scheme;
- Great variety of market actors.

Violations of any attribute of a competitive market hinder the market to achieve both its primary and secondary roles, which are as follows:

- To promote economic efficiency and lower delivered product costs;
- To foster liquidity;
- To avoid undue barriers to entry for new BSPs;
- To increase the choices for BSPs;
- To assure level playing field to all the BSPs;

- To be transparent;
- To be flexible;
- To fit for future;
- To be consumer-oriented.

Concept of designing. The mechanism design theory [9] provides the definition and determine design as an engineering approach to designing economic mechanisms toward desired objectives. The studies solutions how to achieve the determined objective. In a design problem, the goal function is the main "given", while the mechanism is the unknown.

Concept of market design. The concept of market design is broadly presented in literature. Summary is given in Annex 1: Definitions of the market design. By combining the concepts of architecture for frequency and voltage control, market and designing into a single new concept, *the market design for the architecture of frequency and voltage control is defined as a solution of the process of development the balancing and voltage control products, analysing relations between the BSPs and the CSOs, designing the institution and elements of the market in a way that the primary objective held for this market – to establish competitive situations – is met and, thus, the MOC and the MOD functions of the proposed architecture are implemented.* Indeed, the developed market design should contribute to the implementation of the secondary roles of the market as well.

Re-designing of the market for balancing and voltage control products. Within the architecture for frequency and voltage control, the re-designing of the conventional market for balancing and voltage control products is foreseen.

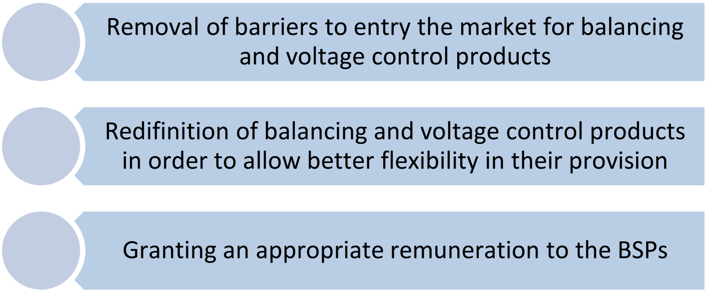


Figure 2-2. Process of market re-designing

The process of market re-designing (Figure 2-2) is initiated after observing that barriers to enter the market exist [5], frequency and voltage control products traded in the market do not satisfy the needs of actors and the aims they are used for; as well as if pricing mechanisms are not sufficient and cannot assure appropriate remuneration to the BSPs. The market re-designing is relevant for the WoC in the case the implemented mechanisms do not assure expected and sufficient market performance (competitive situations are not established) and as a result the MOC and the MOD functions of the proposed architecture cannot be implemented properly.

2.2 Process of market designing

2.2.1 Framework of market designing

The graphical representation of the market designing process is provided in Figure 2-3.

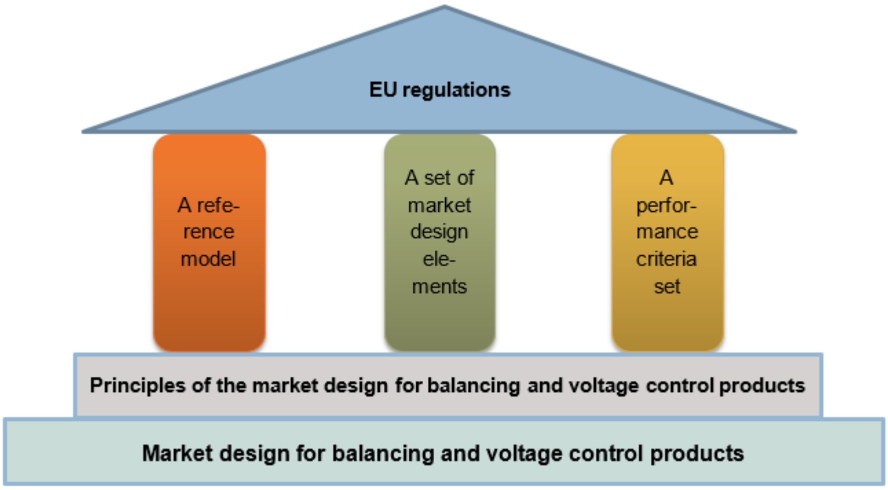


Figure 2-3. Structure of market designing

Designing the market for balancing and voltage control products encompasses of:

- Setting principles for a well-functioning market for balancing and voltage control products;
- Development of a reference model of a market for balancing and voltage control products;
- Finding alternatives to each market design element included into the set of market design elements;
- Analysis of European level Regulations on market design;
- Analysis of market design elements based on the performance criteria set.

2.2.2 Requirements for principles of a well-functioning market

The market for balancing and voltage control products is developed in accordance with the general principles of a competitive market, the principles of a wholesale electricity market and the principles of a market for Ancillary Services (AS) (Figure 2-4).

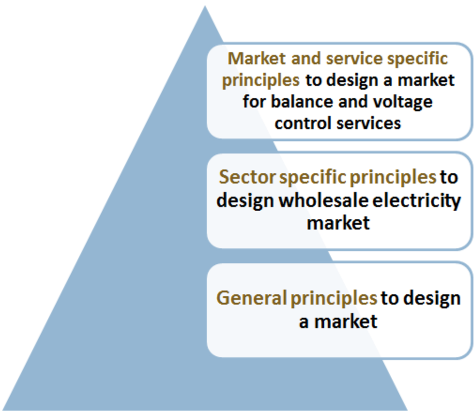


Figure 2-4. Levels of principles based on which the design of market for balancing and voltage control products is developed

2.2.3 Requirements for the reference model

A reference model of a market for balancing and voltage control products is developed in a way to introduce and define the concepts of market for balancing and voltage control products, including the main actors and their roles in the market during different stages of market organization and sub-markets established.

2.2.4 A set of market design elements

In addition to the reference model, a set of market design elements is considered within the architecture of frequency and voltage control. A set of market design elements is as an overall framework of the market design and a list of its variables, grouped by a market stage (see Figure 2-5).

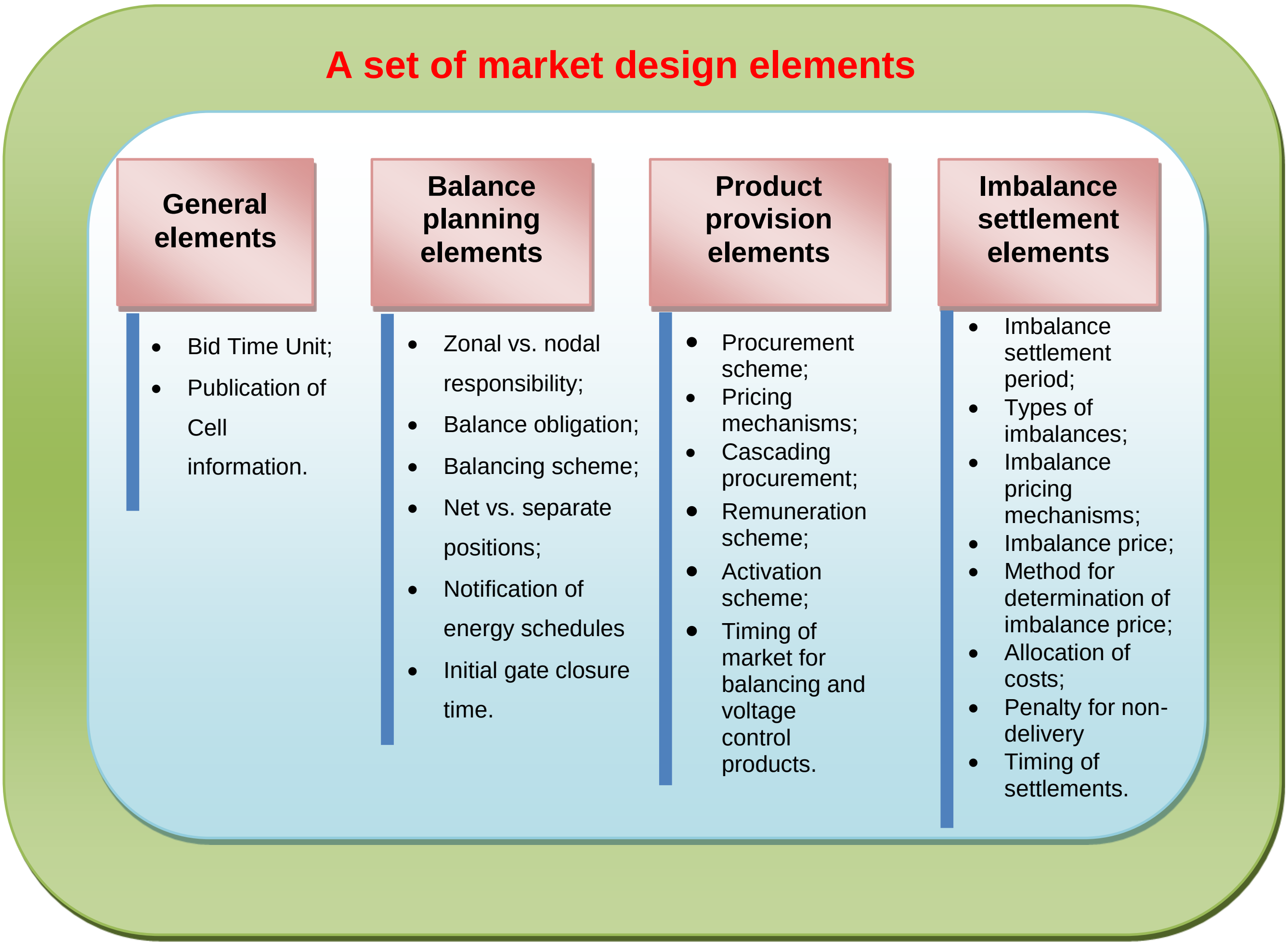


Figure 2-5. Levels of principles based on which the design of market for balancing and voltage control products is developed

The market design element means a variable on which decisions should be made in the process of designing the market for balancing and voltage control products. In Annex 2: Description of market design elements, a short description of each market design element is given.

2.2.5 Performance criteria set

Various market design elements differently affect the market performance. Seeking to evaluate which market design is the most suitable for the WoC concept, the performance assessment is done based on the performance criteria. Performance criteria set offers a set of high-level market performance criteria including measures for economic efficiency and security of supply, as well market-facilitation and sustainability measures. Description of assessment criteria is provided in Annex 3: Description of market design assessment criteria and interrelationship between the market design elements and the performance criteria is shown in Table 2-1.

Table 2-1. Overview of Balance Control Use Cases and corresponding Control Aims. Links between the market design elements and the performance criteria [10]

Market design elements	Performance criteria
Balance planning element	Balance planning accuracy
Balancing and voltage control products provision elements	Availability of balancing resources Utilization efficiency Price efficiency
Settlement elements	Cost allocation efficiency Balance planning accuracy
Publication of Cell information	Transparency
Responsibility for renewable generation Net vs. separate positions	Non-discrimination
Activation strategy	Balance quality
BTU & STU & ISP Timing of market for balancing and voltage control products	Operational efficiency

As it is seen from Table 2-1, balance planning elements impact on security of supply, balancing and voltage control products provision and settlement elements influence on security of supply and economic efficiency. Publication of national information is interrelated with the market facilitation criteria.

3 Split of electricity supply and generation from the operation of tie-lines

Generally, the market design is segregated into the integrated and unbundled systems and within the framework of WoC concept both systems are considered. The systems differ in distinct solutions to the trade-off between the tighter coordination and the greater reliance on markets. Moreover, two systems have different ways of procuring and pricing of products. The comparison of the systems is given in Figure 3-1 and Table 3-1.

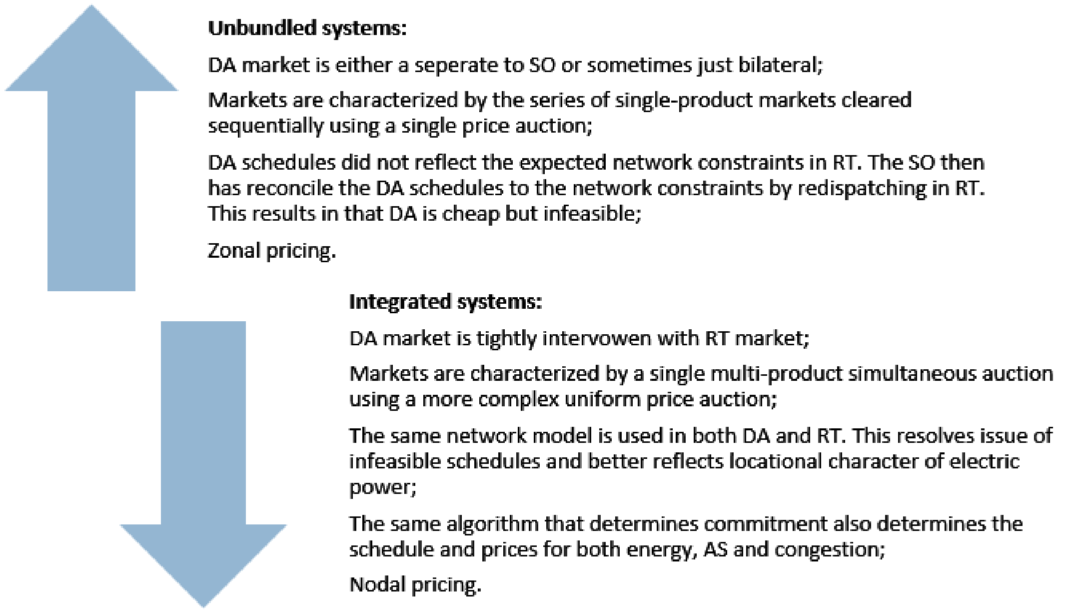


Figure 3-1. Comparison of integrated and unbundled systems (based on [11])

Unbundled systems. In Europe, presently, the unbundled systems exist [12]. The aim of the unbundling is to expose cross-subsidies and to improve efficiency via better pricing and stronger incentives for product / services variety [13]. The unbundling adopts the sequential approach of market clearing, where each market is operated separately and cleared sequentially. This means that energy and real-time adjustment capacity are unbundled into separately priced commodities in a sequence of separate markets. There is no explicit coordination of the markets for energy, transmission and reserves within the system. A basic feature of the unbundled system is an emphasis on the efficiency gains from the incentives inherent in a competitive market, where demand and supply compete and adapt to competitively formed market prices. The unbundled system allows physical bilateral trading alongside the organized markets, giving the market actors flexibility as to the means of trading. The peculiarity of the system is its complete reliance on the voluntary participation, except for plants designated must-run for local reliability [13]. The approach is easy to implement; however, some unexpected phenomena occur upon implementation. For example, lower cost bids having higher value are not utilized. Unrealized substitutability is the main reason why lower-cost but higher-value bids are not used. The cascading procurement is an option to overcome the disadvantage.

Integrated systems. In America, both unbundled and integrated systems exist [11]. However, there is a clear movement from the unbundled systems towards the tighter integration of the Day-Ahead (DA) with Real-Time (RT) markets. The main argument for the shift towards the integrated systems is that optimization is necessary to minimize the total cost of ensuring reliability and coordinating generation, transmission and reserves to meet predicted demand. Integrated systems are characterized as “smart” because the sophisticated optimization software is used to minimise the cost of serving load (or maximize gains if demand bids are included). The typical design of integrated systems includes a DA optimization of generation, transmission and reserves resulting in indicative plans to be re-optimized hour-ahead and in RT operations. Thus, an integrated market allocates resources according to the coherent plan and optimization expands the scope and completeness of the market by recognizing operating constraints. Pricing and settlements are based on the RT, it encompasses system-wide nodal differentiated opportunity costs (shadow prices). Pricing and settlement rules are complicated and often entail price discrimination. Thus, under the integrated approach the Ancillary Service (AS) markets are no longer free-standing markets, but are included into the unit commitment algorithms, which seek to minimize the cost to serve load subject to certain constraints. There is a shift from Lagrangian Relaxation-based (LR-based) technique to Mixed Integer Program-based (MIP-based) techniques, which allow for some of the less tractable solutions that characterize AS procurement to be solved more easily than partly heuristic methods of LR. Integrated systems imitate vertically integrated operations. Historically, they were dominated by thermal generators affected by start-up costs and ramping constraints and with must-run nuclear units. Long-term relational contracts specifying market rules, sanctions and reciprocal obligations are made among the market actors. The framework for AS procurement is characterized by movement towards nodal locational marginal prices-based systems with tighter integration between energy and AS and technical improvement within this paradigm towards MIP solutions [11]. A typical integrated market design uses three-part bid format where in addition to marginal cost, each supplier indicates its fixed cost of start-up and minimum running cost. Incentives are addressed via the settlement rules that specify financial payments. When competition is weak, integrated systems rely on the sanctions to control abuses. Integrated systems heavily rely on directives, sanctions and penalties. However, they are inefficient when they depart from prices measuring actual marginal cost of deviations. Integrated systems spread unrecovered start-up costs over all actors in the form of an “uplift” charge. The System Operator (SO) is the exclusive manager of all markets, including forward and spot, energy and transmission. The reason is to receive gains from tight coordination, long-term obligations and subsidies. The problems arise because the incentives for actors to cooperate are undermined.

Solution for the WoC concept. In the scope of WoC concept, viable European framework of the market design is adopted, which is the unbundled systems. The reason for the accepting the unbundled system is its attitude towards the roles of CSO. If the “smart” systems consolidate and optimize all the markets, then the unbundled systems doubt about the CSO needs to conduct these. The contributors of the unbundled systems argue that the CSO should be responsible for the transmission/distribution and RT balancing, including forward markets for transmission/distribution and reserves, but its roles should not be extended to forward energy markets. This means that the main motive for limiting the scope of the CSO’s roles is to isolate its monopoly control of transmission and distribution from competitive energy markets and enable unbundled pricing. Such the CSO’s “narrow” scope in the framework of the unbundled systems is sufficient for reliable operations.

Table 3-1. Comparison of Europe, United States and WoC market designs

	United States (California)	Europe (Austria)	Web-of-Cells (based on European market design)
Market Design	• Focus on physics of the power system • Co-optimization of energy and reserves • Nodal pricing • Higher probability of abuse of market power and mitigation processes in place • Higher responsibility with the market operator	• Focus on markets and economics • Sequential markets • Zonal Pricing and market coupling between zones (implicit/explicit coupling and redispatch) • Less probability of abuse of market power, no mitigation process • Higher responsibility and larger freedom for participants	• Focus on the combination of the local areas (cells) and the sequential markets • Sequential markets • Cell Pricing and market coupling between cells [35] • Less probability of abuse of market power • Higher responsibility and larger freedom for participants
Market Operations	• Bids per resource / per small aggregation • Hourly day-ahead market of ISOs • Real-time markets of ISOs with gate-closure-time 75 min before operating hour • Flexible ramping products • Mandatory provision of primary frequency response • REM functionality available by CAISO (energy management by CAISO in the regulation markets) • Pro-rata activation signal that also considers the flexibility potential in the next time steps • Settlement period: 5 minutes • Penalty for forecast deviations especially for load and the penalty depends on the state of the single resource • Forecast for RES and load can be done by CAISO for the market participants	• Bids per portfolio and not per resource (but reporting obligations for large units) • Hourly or quarterly day-ahead markets • Continuous or quarterly intraday markets with gate-closure-time of 30 min before operation, but scheduling reporting deadline with 45 min before operating hour across country borders • No flexible ramping product, but discussion started • Markets for primary frequency response • Optimization for storage on several markets necessary to be able to fulfil the energy management of the capacity • Merit order based activation signal for secondary control • Settlement period: 15 minutes • Settlements design is highly varying in Europe; in Austria the imbalance settlement design can be used to have an incentive for the flexibility. The height of the incentive depends on the state of the system (the higher the Area Control Error, the higher is the incentive) • Forecast for RES and load my market participants and by TSOs, but responsibility only with market participants	• Bids per resource / per small aggregation • Quarter hourly day-ahead market and Intraday markets • Gate-closure-time of 15 min before operation • Flexible ramping products • Sequential markets for Balance (Frequency) and Voltage control Merit order based activation signal for IRPC, FCC, BRC Settlement period: 15 minutes • Forecast for RES and load by CSOs, but responsibility only with market participants
Stakeholders	• Scheduling coordinators: Settlement, but settlement based on smaller regions / per resource	• Balancing portfolio operator: Settlement per portfolio	• Traditional European market players like balancing responsible groups are also in place in the WoC concept

	United States (California)	Europe (Austria)	Web-of-Cells (based on European market design)
	• Balancing authority groups control larger municipalities that are connected to the transmission grid of the ISO • Coordination with the DSOs: Information flow for combined flex activation: no unbundling requirement, but technical solutions needed • Integration of microgrids in the balancing markets discussed, but rules not defined yet	• Grid control room of "local" players • Coordination with the DSOs: Information flow for combined flex activation limited by unbundling • Micrograds cannot currently participate in the balancing markets	• New role of BSPs, BRPs, NRAs, CSOs • The CSO role can be interpreted by the traditional DSOs or TSOs or by new types system operators, that can be defined by regulation authorities
Integration of new participants	• Integration of variable energy resources in the balancing markets • Integration of prosumers in the balancing markets (Transactive energy (several demos and especially storage is getting in the markets))	• Integration of variable energy resources in the balancing markets: i) Wind is allowed to participate in the DE and AT markets already (with back-up) and ii) demo projects for PV • Integration of prosumers in the balancing markets: Several demos and first players prequalified with focus on storage, but first heat pump pool participating) • Trend in the direction of direct trading of participants especially in DE	• The focus of the WoC concept is the integration of renewable energies with getting them in the markets itself and with the support of flexibility • Integration of prosumers, storage, EVs in the balancing markets
Market Integration and Harmonisation	• Energy imbalance energy markets connect several states in the western area (not 100% comparable to Europe)	• Integration and harmonisation of markets and technical standards • Trend for integration of markets: Trend to harmonized gate-closure times • Integration of balancing markets: common auctioning of balancing control and activation from common merit order	

4 General design of wholesale electricity market

In the unbundled power system, electricity is traded in different wholesale electricity markets (Figure 4-1).

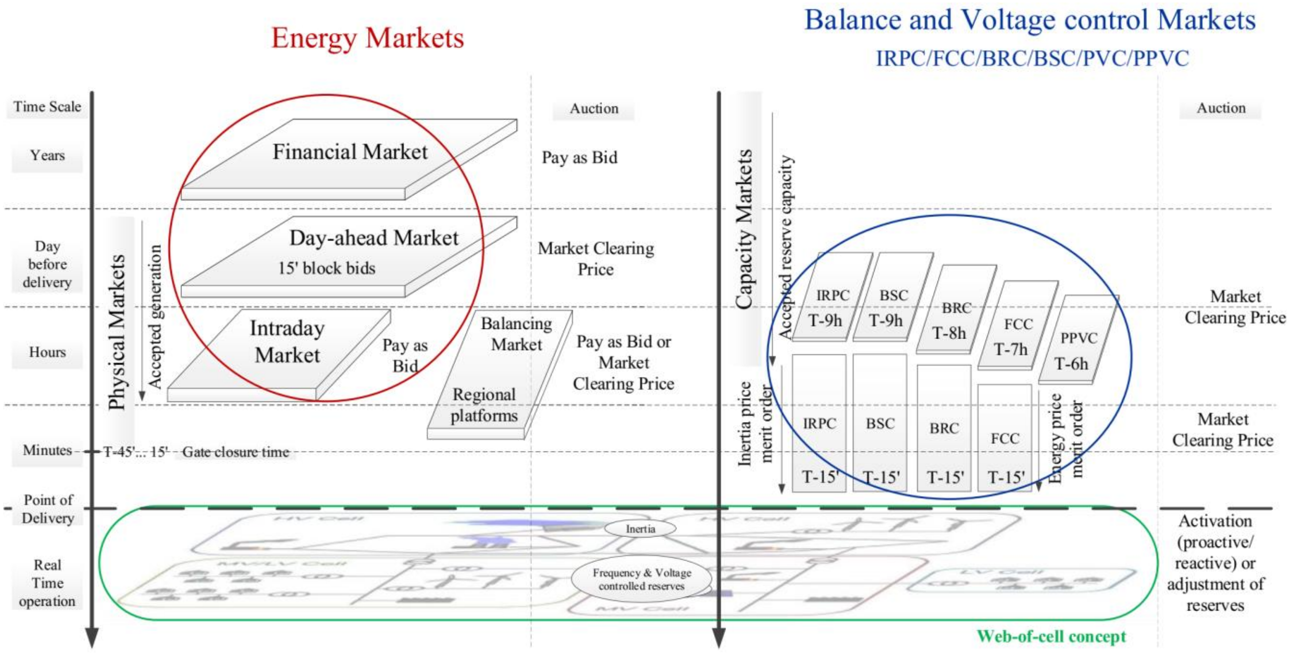


Figure 4-1. General structure of electricity market within the WoC concept

Financial market is used to enter into and trade in financial contracts, which are used for electricity price hedging and risk management. For the purpose to ensure future sales and reduce their vulnerability to possible electricity price decreases, the electricity producers use financial contracts. The large (industrial) electricity consumers buy electricity on derivatives markets to secure their future electricity consumption at upfront known costs and reduce their vulnerability to possible electricity price increases. Presently, the financial contracts have a time horizon up to six years, covering daily, weekly, monthly, quarterly and annual contracts. In future, the duration of contracts is reconsidered to fit the needs of future, however, it is expected that derivatives market will run from years before up to the day before delivery. The concept of the financial contracts to be the contracts to deliver / consume a certain amount of electricity at a certain time in the future for a price agreed upon today will be kept in future. The peculiarity of the financial contracts is that the system price is calculated by the Market Operator (MO) and is used as the reference price for the financial contract. Standardized and bilateral financial contracts are available and traded in future and forward markets. In future market standardized financial contracts, known as futures, are traded on power exchanges. In forward market flexibility ensuring bilateral financial contracts, known as forward, are traded Over-The-Counter (OTC) [14].

In a ***day-ahead market (DA market)***, which is established at the WoC level, electricity is traded one day before the actual delivery. The DA market remains of major relevance as, the Cell has to be in balance at the end of the DA market (i.e., scheduled generation in the Cell shall be equal to the forecasted demand in the Cell plus net export to another Cell). Electricity is traded both the day-ahead bilaterally (OTC trading) and on the day-ahead power exchange, as it is today.

Electricity buyer and seller have automatically access to the transmission capacity by submitting orders to the power exchange. Thus, electricity and transmission capacity are traded together. The DA market functions based on the Scandinavian model / practice. Based on it, the Transmission System Operators (TSOs) determine the trading capacity between each bidding area. Trading capacities for the next day are published on Nord Pool's website at 10:00 CET. 12:00 CET is the deadline for submitting bids for power which will be delivered the following day. The trading system feeds the information into a specialist computer system, which calculates the price, based on an advanced algorithm. The price is set where the curves for sell price and buy price meet, taking into account transmission capacities between areas. Hourly prices are typically announced to the market at 12:42 CET or later. Once the market prices have been calculated, trades are settled. From 00:00 CET the next day, power contracts are physically delivered (meaning that the power is provided to the buyer) hour for hour according to the contracts agreed [14].

In the ***intra-day market (ID market)***, which is established at the WoC level, electricity is traded on the delivery day itself. The ID market enables market actors to correct for shifts in their DA nominations due to better wind forecasts, unexpected power plant outages, etc. Electricity is traded ID on the power exchange continuously meaning that an organized OTC (oOTC) market, which is cleared continuously, runs. Presently, ID market is organized the following. At 14:00 CET, capacities available for Nord Pool's ID trading are published. The ID market opens three hours after the DA market closes (i.e. 15:00 CET). This is a continuous market, and trading takes place every day around the clock until one hour before delivery. Prices are set based on a first-come, first-served principle, where best prices come first – highest buy price and lowest sell price. The ID market supplements the DA market and market actors trade until one hour before the production hour in order to correct possible imbalances (such as if it becomes colder or windier than anticipated). The market actors trade between bidding zones if capacity is available. The ID market will become important as more wind power enters the grid. Wind power is unpredictable by nature, and imbalances between DA contracts and produced volume often need to be offset. This type of market can be a key enabler to increase the share of renewable energy in the energy mix. [14]. An approach is acceptable to the WoC concept.

The Market Operator (MO) provides the results of the energy-only markets (bilateral, DA and ID markets) to each CSO – such as production and consumption volumes of the Cell, tie-lines power flows and electricity prices – who then estimates the total balance in the Cell and based on the estimations, necessary “set-points” are set for each Cell.

In the ***energy balancing markets***, energy bids are collected in merit order list at the regional level between neighbouring cells, which enables CSOs to correct possible power system imbalances before RT, closer to defined “set-points” after ID market closure. The energy balancing markets open three hours after the DA market closes (i.e. 15:00 CET) and collects energy bids until 15 min before the production hour.

In the ***market for balancing and voltage control products,*** capacity for inertia, balancing capacity, inertia, balancing energy and reactive power is traded between the BSPs and CSOs at the intra-Cell and inter-Cell levels and settlements between the CSOs and the BRPs are carried out. As such, the market for balancing and voltage control products is split into a procurement side (i.e., procurement and activation of balancing and inertia capacities (if necessary, in real-time), as well as reactive power by the CSOs) and a settlement side (i.e., financial settlement of the BRP imbalances by the CSOs) (Figure 4-2).

At the procurement side of the market for balancing and voltage control products the BSPs sell IRPC, aFCC, BRC, BSC and PPVC services and the CSOs procure them. Procurement process is organized at intra and inter Cell levels. Each balancing and voltage control service is traded in a separate sub-market. The sub-markets for inertia capacity, inertia, balancing capacity and balancing energy for upward and downward regulation, inductive and capacitive reactive power are established too. The number and types of sub-markets for balancing and voltage control products are determined in Figure 4-3.

As it is seen from Figure 4-3, for each balancing product there are established two main types of sub-markets. These are sub-markets for balancing capacity and balancing energy or inertia capacity and inertia.

Sub-market for balancing capacity is a sub-market for balancing reserves, in which the BSPs are compensated for availability of balancing capacity. Volume of balancing capacity that the BSP has agreed to hold and in respect to which the BSP has agreed to submit bids for a corresponding volume of balancing energy to the CSO for the duration of the contract, is traded in balancing capacity sub-market. Balancing energy sub-markets are markets in which the BSPs are compensated for the actual delivery of electricity (i.e. compensated for utilization of balancing capacity). The WoC concept clearly distinct sub-markets for upward and downward regulation. The sub-market for upward regulation is established to procure balancing capacity and balancing energy for the purpose of negative cell balance deviation. The sub-market for downward regulation is developed to procure balancing capacity and utilize balancing energy for the purpose of positive cell balance deviation.

Electricity producers and loads participating in various timeframes wholesale electricity markets (forward, DA or ID markets) trade in electricity. At the same time, they are inertia providers, i.e. inertia as a by-product of electricity production is supplied to the power system as more electricity is produced. Thus, certain volume of inertia is available in the power system. After the clearing of wholesale electricity market, the CSO knows how much of inertia is expected to be in the Cell. If the CSO estimates that in RT there will be a shortage of inertia, the CSO organizes an auction for the procurement of inertia. Thus, in the sub-market for IRPC service provision capacity for inertia and volume of inertia, which exceeds the estimated threshold is traded. Thereby, the sub-market for the IRPC service is a small market.

In the sub-market for voltage control products reactive power is traded. Since voltage is a very local problem, therefore it is solved locally by local voltage service providers. It is expected that at least several voltage control service providers capable to locally solve voltage problems will be available in future.

At the settlement side, the CSOs sell balancing and voltage control products to the BRPs who are in imbalance and the BRPs pay for the provision of products. In particular, the individual BRPs might face a RT imbalance. The BRP’s imbalance is the quarter-hourly (15 min) difference between the BRP’s total injections and off-takes. The total imbalance in the Cell is the sum of all BRP imbalances. The CSOs maintain the system balance by activating balancing capacity. The balancing capacity market is not part of the pure energy-only market, since balancing capacity delivers both energy services (i.e., generating electric energy when activated) and capacity services (i.e., reserving generation capacity). The CSO is the single buyer of balancing capacity and contracts different types of balancing capacity.

In the market, the CSO takes the responsibility to balance the Cell by using available means after the ID market Gate Closure Time (GCT) and during the operational hour in order to maintain the frequency and voltage and to secure a stable operation. The CSO calculates the total System Imbalance (SI), i.e. the demand for flexibility in real time, resulting from the aggregated individual imbalances of the BRPs. The CSO then compensates for this SI by activating balancing capacities, which are contracted ahead of time from the market actors who provide balancing and voltage control products, i.e. BSPs. By reserving and of the capacity for inertia and balancing capacity, the CSO deals with the procurement side of the market, meaning that the CSO is responsible for the procurement of balancing and voltage control products from the BSPs to ensure operational security. Later, the CSO settles individual imbalances with the BRPs by applying imbalance prices to their imbalance positions, i.e. it deals with the settlement side of the market for balancing and voltage control products.

In addition to the CSO, two broad group of market actors' act in the market for balancing and voltage control products. In the procurement side of the market, the CSO actively communicate with the BSPs, from which it buys balancing and voltage control products. In the settlement side, the CSO sells the procured balancing and voltage control products to the BRPs.

Since the CSO is a single buyer of the balancing and voltage control products and a single supplier of them to the BRPs, thus, at the same time CSO is a monopsonist and monopolist in the market. If not regulated, the CSO could acquire a significant power, resulting in excess profits. Inefficiencies could appear. The information provided in Annex 4: Price setting under the monopsony and monopoly market structures explains this in detail. Seeking to limit the exploitation of the CSO's use of power in market, the NRA performs its regulatory roles in the market.

Moreover, aggregator takes part in the market. It performs the role of load and generation forecasting for the particular Cell. This information is used to establish the demand curve for the balancing and voltage control products, whereas the supply curves are established by the BSPs through the bidding process.

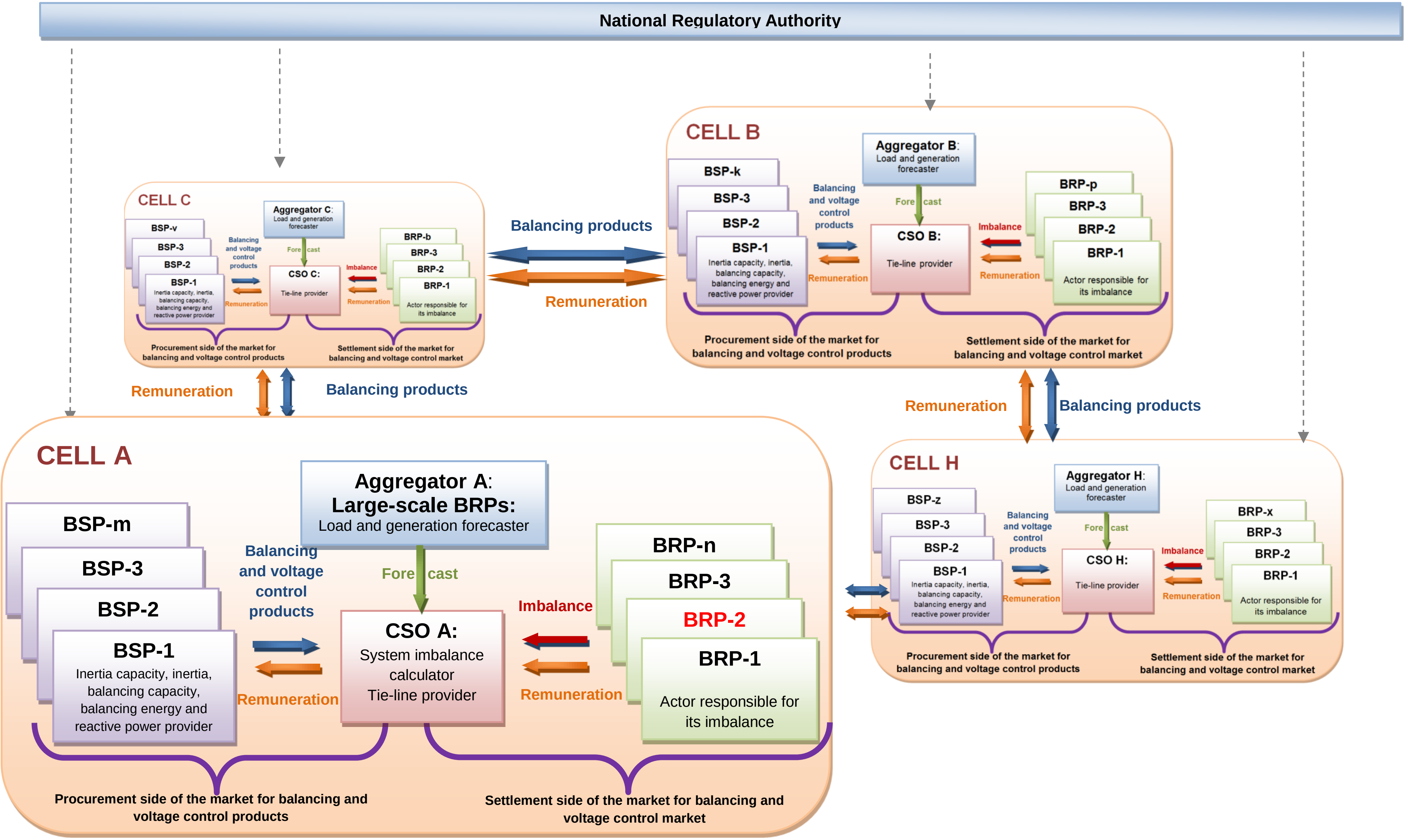


Figure 4-2. General structure of the market for balancing and voltage control products

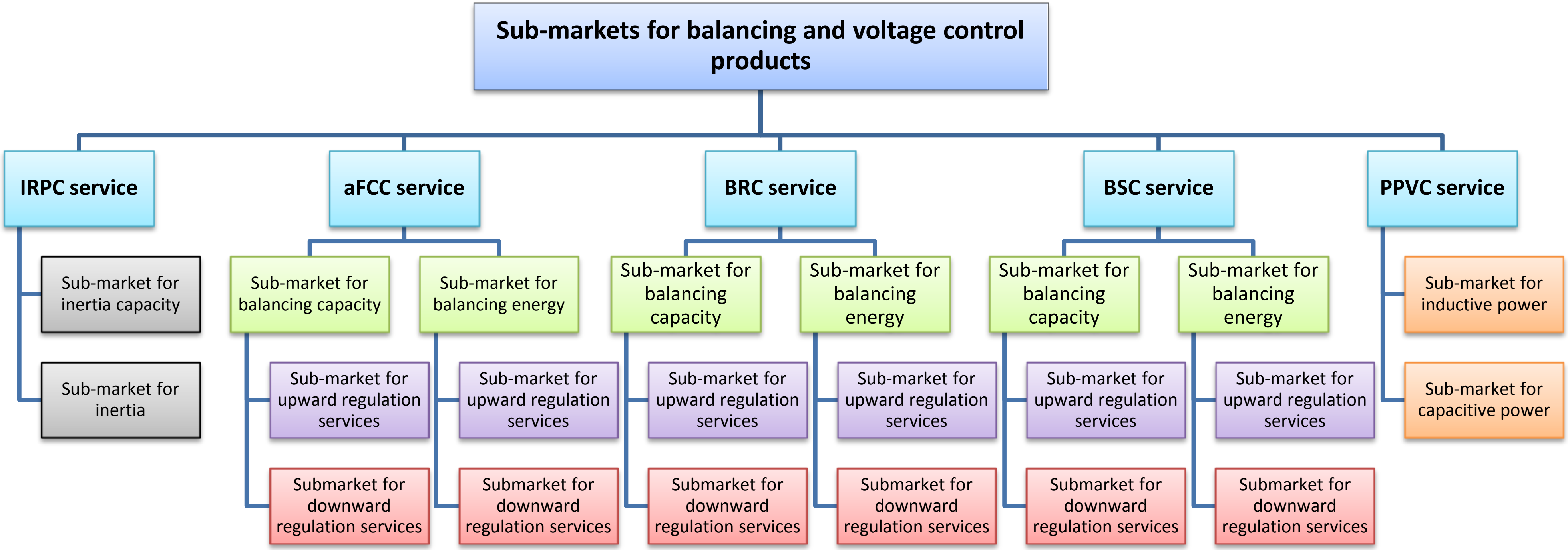


Figure 4-3. Sub-markets for balancing and voltage control products

5 Principles of a well-functioning market for balancing and voltage control products

General competitive market principles for the design of a market for balancing and voltage control products. The market for balancing and voltage control products is established in compliance with the general competitive market principles, which are presented below.

There are many market actors each with an irrelevant share of the market. Due to the peculiarities of the architecture for frequency and voltage control, each individual market actor is too small in relation to the size of the overall market for balancing and voltage control products. Outgoing from this, it is clear that individual market actor cannot make an influence on the price via a change in its own supply. However, the participation of small actors, who are the BSPs, is not necessarily desirable as transaction cost of including them may prohibit an increase in economic welfare.

In a competitive market for balancing and voltage control products, no market actor has a dominant power. The existence of significant monopoly power in a market restricts the participation opportunities of smaller competitors (actors) and potential new market entrants. The market pressure for competitive efficiency and innovation is reduced; consumer choice and price protection are weakened. An efficient, albeit underutilized way of mitigating the market power of traditional electricity generators is to introduce renewable electricity generators and demand response into the market for balancing and voltage control products.

None of market actors can change the price because they have not monopoly power to the market. More precisely, each market actor is considered to be a price taker. Price wars or “cutthroat competitions” should not show up in the market for balancing and voltage control products. This is achieved through the selected pricing mechanism.

An identical output is produced by each individual market actor, meaning that market supplies homogeneous or standardized products that are perfect substitutes for each other. The CSO and the BRPs perceive the frequency and voltage control products to be identical. This also means that market actors are anonymous. The principle is implemented through the selection of the respective marketplace, which is an auction-based exchange.

Quality of the balancing and voltage control product and its price are the only criteria based on which the products are exchanged. The principle is implemented through the selected scoring method and the selected marketplace.

Widespread availability of information. All market actors are well-informed in order to make effective decisions. Timely and relevant information is easily accessible. Barriers to information weaken the ability of the market to function efficiently. The principle is implemented through the proposed concept of market transparency for the architecture of frequency and voltage control.

The BSPs, the BRPs and the CSO have information about the prices charged in the market. If some BSPs decide to charge a price higher than the ruling market price, there is a substitution effect away from this BSP. The principle is implemented through the selected pricing mechanism and the proposed concept of market transparency for frequency and voltage control.

There are no barriers to entry & exit of market actors in long run, meaning that the market is open to competition from new BSPs. Free entry and exit makes markets function efficiently, but barriers to entry (e.g., restrictive licenses, very large investment requirements, participation fees, etc.) reduce possibilities for participation in the market, thereby limiting the extent of competition (and thereby market efficiency) that is possible. Weak institutions, and regulatory framework, which cannot preserve the sanctity of contracts create barriers for newcomers too. Market entry by new decentralized flexibility providers can increase competition in the market for balancing and voltage control and improve carbon balance of the electricity mix if fossil fuel-based reserve capacities can be replaced. These are examples of barriers to entry the market:

- Limitation of volume provided by the DERs;
- Uncertainty about the evolution of the rules;
- Mandatory provision for large producers;
- Existence of long-term contracts;
- A lot of different schemes with inappropriate rules;
- Entrance fee.

Public interest objectives are achieved. When the market achieves its goals of efficiency, innovation and consumer protection, it will at the same time achieve any special public interest objectives as well. There are no special public interest objectives to satisfy (e.g., universal coverage) that go beyond the capabilities of a well-functioning market.

Wholesale electricity market principles for the design of a market for balancing and voltage control products. The market design for the architecture of frequency and voltage control is established considering to the following principles of the wholesale electricity market design:

- Market design creates preconditions to electricity producers with appropriate incentives for investing in new power generation, including in electricity from RES, through the earning of additional revenue in the market for balancing and voltage control;
- Market design facilitates the participation of demand response. It creates incentives for offering demand-based adjustment capacity in the market;
- Market rules and market operation is fair, well-defined, transparent and understandable to all market actors;
- Market design creates price signals that reflect the time and locational value of the product;
- Market design is not static, the redesign is foreseen;
- Market rules are technology- and fuel-neutral;
- The CSO uses market-based mechanisms, as far as possible to ensure network security and stability.

In respect to principles set for the development of a well-functioning wholesale electricity market, the market for balancing and voltage control is established competitive, consumer-centred, flexible, non-discriminatory, transparent and fitting the future needs (Figure 5-1).

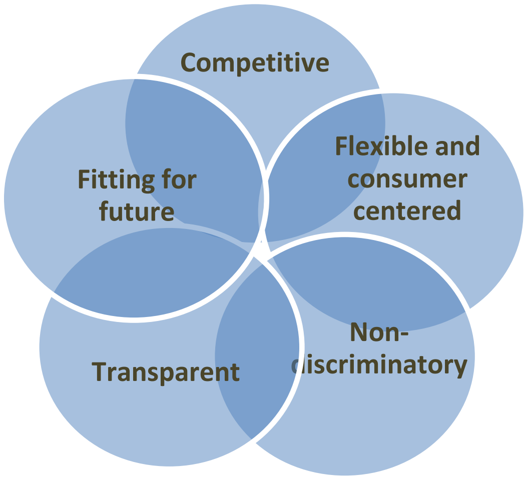


Figure 5-1. Principles for electricity market functioning in future

Flexible market is created by:

- Offering to consumers the possibility to actively participate in the market by adjusting their consumption to real time prices;
- Ensuring that markets provide the right signals for investments in production and the efficient use of available resources;
- Building missing electricity infrastructure and making better use of existing infrastructure;
- Ensuring flexible trading. For the efficient integration of RES into the grid, generators, suppliers and traders are able to trade electricity as close to real time as possible as this allows them to take account of better forecasts on how much solar or wind energy is produced;
- Eliminating regulated prices on one side and inefficient support schemes on the other. If electricity prices do not reflect the actual costs, this gives false signals to investors and consumers of electricity;
- Producers of electricity from RES are able to compete on an equal footing with conventional electricity producers.

Non-discriminatory markets are developed by eliminating technical rules, which are issued to discriminate against some market actors with regard to participation in the market for balancing and voltage control products. Presently, the discrimination is evident on voltage level of the connection point of the market actor or type of market actors (consumption units). Technical discrimination is based on the maximum level of reserves provided by type of the market actor or by priority given to the particular market actor. Specified requirements set for the particular resources (for example, for aggregated resources) are defined as technical discrimination. Thus, eliminating the rules creates preconditions for a development of a non-discriminatory market. Non-discriminatory markets are developed through the implementation of the “level playing field” principle. This principle means that all technologies and products are able to compete on a level playing field, with consistent rewards. Creating a level playing field between all the BSPs is important to ensure that least cost solutions for balancing the network are procured. To provide a level playing field and to ensure security of supply, the same principle of imbalance settlement is applied for load and generation.

Competitive markets. The procurement of balancing and voltage control products is market based with the purpose to maximize inclusiveness. This ensures that balancing and voltage control products are procured at least cost, so as to maximize the benefit to end-users. Products are procured through the market structure, which include shorter-term auctions. Where possible, long-term bilateral contracts are avoided.

Consumer-oriented (centered). Consumers are able to access all relevant markets, including the market for balancing and voltage control products, either directly or through the aggregators. They are exposed to the real cost of the power they consume at all times (including the cost of imbalances) and respond to price signals provided in the wholesale markets (DA, ID and balancing). This is achieved through the implementation of the dynamic pricing.

Transparent market. Transparency is essential for the implementation of the Internal Electricity Market (IEM) and for the creation of efficient, liquid and competitive wholesale markets, including the market for the balancing and voltage control products. It is also critical for creation a level playing field between the market actors and avoiding the scope for market power (if it exists) to be abused. Transparent market for balancing and voltage control products is established based on a multidimensional European wholesale electricity market transparency model discussed in Regulations [42]-[46].

Fitting for the future market. The market for balancing and voltage control products is designed to facilitate the evolution of the energy system. This includes the offering the ability for new technologies, as well as existing technologies used in new ways, to participate in the market without undue barriers to entry. This is achieved by keeping market design as simple as possible meaning that the market design requirements and assumptions for the particular technologies are avoided.

AS market principles for the design of a market for balancing and voltage control products. The market for balancing and voltage control services satisfies AS market specific principles:

- All market actors have access to the market for balancing and voltage control products either individually or through the aggregation.
- Market is organized in such a way as to ensure non-discrimination between market actors taking account of the different technical capability of generation from RES, demand side response and storage.
- The BSPs are paid commercial prices for provision of inertia capacity, inertia, balancing capacity, balancing energy and reactive power. Regulated prices are removed.
- The market for balancing and voltage control products foresees cross-Cell competition.
- With regard to the Merit Order list the market supports marginal pricing;
- The BSPs of the balancing capacity are obliged to bid in the balancing energy sub-market.
- An imbalance settlement charge is based on the marginal commercial prices offered by the BSPs during a given settlement period. Market for balancing and voltage control products defines a single price imbalance settlement as the only imbalance settlement method;
- The same principle of imbalance settlement (i.e. same settlement prices) is applied for load and generation.

6 Reference model

Within the WoC concept, the sub-markets for balancing (active power) and voltage control (reactive power) are decoupled from each other by keeping them in different time frames (Figure 6-1). The decoupling shows that separate reference models are prepared for each of sub-market.

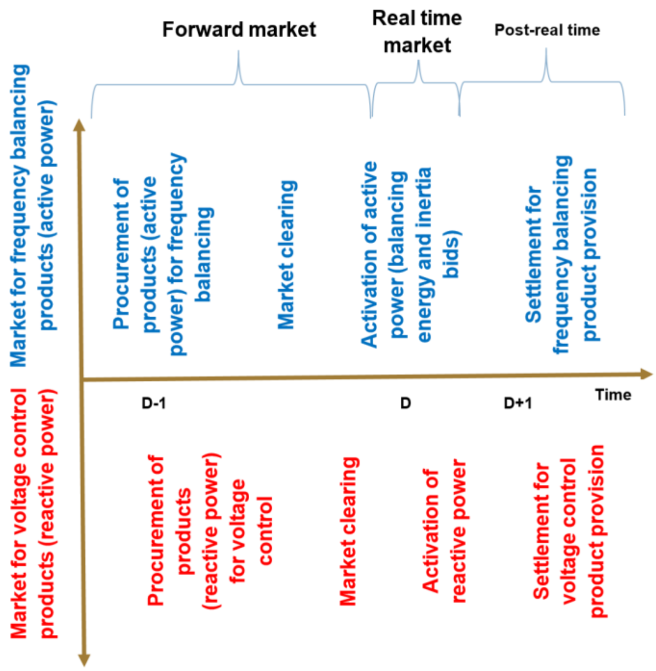


Figure 6-1. Relationship between sub-markets for balancing and voltage control products

Reference models (Figure 6-2 and Figure 6-3) characterize high-level model of the sub-markets for balancing and voltage control products. Namely, they encompass types of actors and their roles, sub-markets established and their sequence in time, as well as stages of exercised activity.

The sub-market for balancing products consists of three stages (Figure 6-2). During the stage of balance planning the BRPs are obliged to provide the CSOs planned energy production, consumption and trade schedules for every Schedule Time Unit (STU) within the day of delivery. During the stage of balancing product provision, the BSPs participate in the sub-markets for balancing capacity, balancing energy and inertia trading and submit bids to by the CSOs organized sub-markets for the procurement of the particular balancing product. During the stage of imbalance settlement, the CSOs settle energy imbalances (schedule imbalances) of the BRPs and activate balancing energy and inertia bids. Then the CSO distributes the related cost to the BRPs.

The sub-market for voltage control products consists of the same stages (Figure 6-3). During the stage of voltage control product provision, the CSO calls for reactive power offers from the BSPs. The BSPs participate in the sub-market for reactive power and provide bids regarding availability of reactive power. After negotiations, the CSO and BSPs enter into the agreements regarding reactive power availability. During the stage of balance planning the BRPs are obliged to provide the CSOs planned energy production, consumption and exchange schedules for every STU within the day of delivery. Information is used to score which BSPs will provide voltage control products in real time. During the day of delivery, the CSO asks for the activation of reactive power considering the demand. During the stage of settlement, the CSOs include the related cost as a fee structure for final electricity consumers.

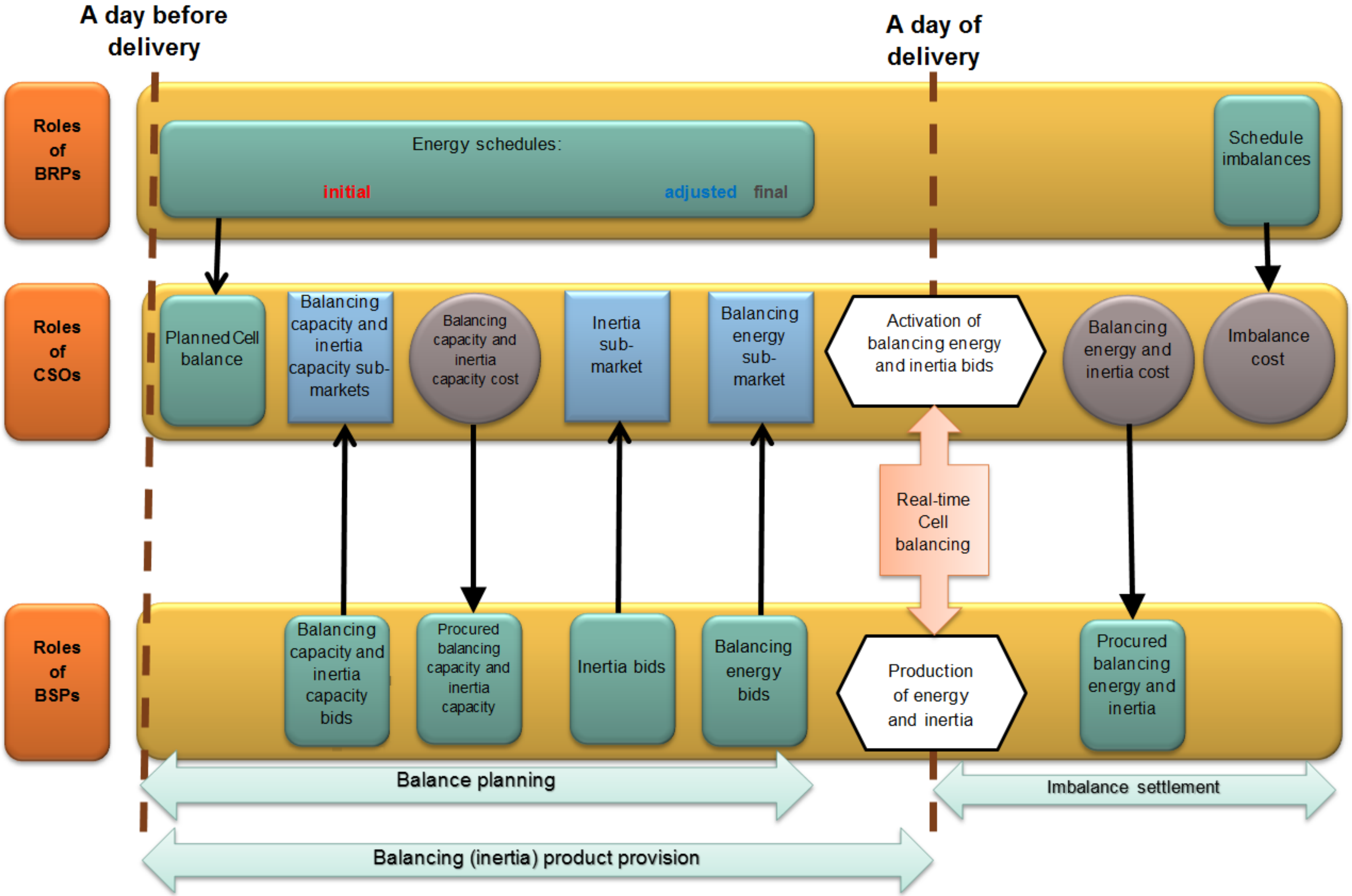


Figure 6-2. Reference model of the market for balancing products

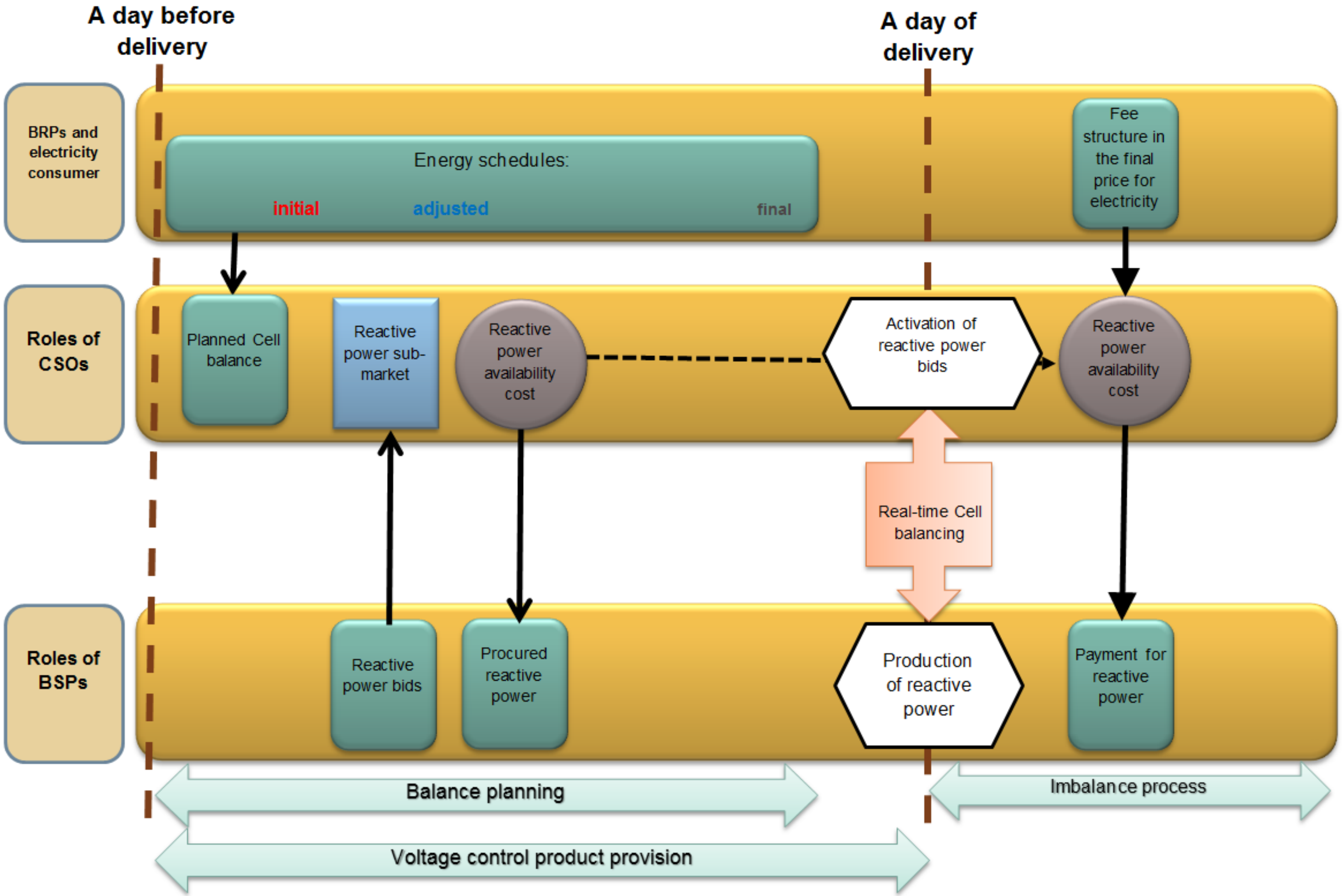


Figure 6-3. Reference model of the market for voltage control products

7 Market actors and their roles

The Balance Service Providers (BSPs), the Balance Responsible Parties (BRPs) and the Cell System Operators (CSOs) are three main types of actors acting at the procurement and the settlement sides of the market for balancing and voltage control products within the WoC power grid structure.

*The **Cell System Operator*** is a market actor procuring balancing and voltage control products from the BSPs to balance electricity consumption and production in real time and supplying them to the BRPs who are in imbalance. The CSO is responsible for the performance of the Cell operation, maintenance and development to ensure electricity supply in a safe, efficient and reliable manner. More precisely, it is responsible for the secure operation of the Cell, measurement of electricity demand on High Voltage (HV), Medium Voltage (MV) or Low Voltage (LV) grid, maintenance of HV, MV or LV grid and procurement of the balancing and voltage control products for its Cell [15], which demand arises due to the occurrence of the following events [16]:

- Unexpected RES generation variations;
- Unexpected consumption variations;
- Unplanned outages of generation and consumption capacity and grid elements;
- If discrepancies between the duration of DA / ID markets periods and real-time settlement periods exists;
- Discretization of continuous time in discrete market periods.

In relation to the market for balancing and voltage control products, the CSO is responsible for the preparation of *market regulations* to the BSPs and the BRPs too. Market regulations are established to regulate the rights and obligations of the BSPs and the BRPs in the market. The market regulations are guidelines that are necessary in order to ensure that the market for balancing and voltage control products will function properly and that settlement will be performed correctly. The market regulations deal with issues such as terms and conditions for a change of the BSPs, trading rules, daily handling of notifications, pricing mechanism and standards governing the transfer of data between the BSPs, BRPs and the CSO. The list of possible market regulations and short description of them is given in Annex 5: Analysis of the Energinet.dk market regulations.

In addition to market regulations, technical regulations are necessary. Technical regulations are guidelines that shall be important in order to ensure the physical operation and system security of interconnected high-voltage grids. The technical regulations are primarily aimed at BRPs, BSPs and CSOs. International obligations in connection with the physical system operation have typically been implemented in technical regulations. The list of possible technical regulations and short description of them is given in Annex 6: Analysis of the Energinet.dk technical regulations.

The CSO is responsible for preparation a strategy how it plans to procure balancing and voltage control products and provide open and equal access for the actors to the market for balancing and voltage control products. The strategy is submitted to the National Regulatory Authority (NRA). Annex 7: Analysis of Energinet.dk's ancillary services strategy provides information on the content and structure of the strategy.

*The **Balance Service Provider** (BSP)* is a market actor selling balancing and voltage control products to the CSO. They sell inertia, balancing capacity and balancing energy for upward or downward regulation and reactive power to the CSO. A list of the BSPs able to supply the CSO with balancing and voltage control products is given in Figure 7-1.

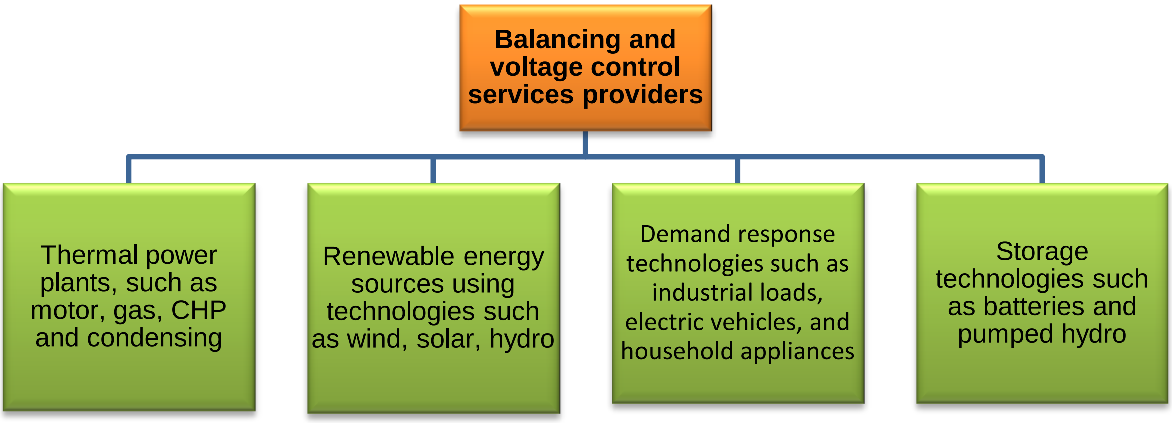


Figure 7-1. List of the BSPs who are sellers of balancing and voltage control products

As the share of intermittent RES significantly increases in future, additional flexibility will become a valuable source to balance real-time generation and consumption. The CSO will have to rely on flexible BSPs who could tailor (adapt) their generation and consumption by either producing and consuming above or below their set schedule with the aim to solve the imbalance in the Cell. Thus, in addition to presently acting BSPs, who are centralized thermal power plants, new BSPs will be requested and, indeed, available. They will be found at the distribution level. RES, demand response and storage technologies will be available as new BSPs in future. Moreover, seeking to increase the size of BSPs, an aggregation is believed to be of critical importance. Thus, aggregators as a separate type of BSPs will be requested under the WoC concept.

It will be necessary to have certain volume of inertia and frequency reserves. In addition to presently available sources of reserves for frequency and inertia – centralized thermal PP and hydropower – the new sources of reserves will be required. They could / shall be found at the distribution level. The new sources of reserves are RES, demand response and storage.

Demand response. Consumption devices typically hardly have any ramping limitations and have a very low start up (or shutdown) time. The reason is that the consumption devices often rapidly can change the process to consume more or less power or it can simply be turned ON/OFF and thus instantaneously change the power consumption. This makes flexible consumption devices ideal to participate in each control function. This further illustrates why it is very important to improve the possibility for these devices to participate in the markets for balancing services.

Rules for allowing aggregation are believed to be of critical importance, because allowing aggregation can greatly increase the size of available resources to the market for balance control services and lead to a more reliable, consistent response. The new guidelines on electricity balancing demand response and RES integration highly recommends this. The first markets have started this process already, e.g. Germany allowed the participation of wind. In Switzerland there exists a pool of small heat pumps.

Electric vehicles (EV) have technical characteristics that enable them to provide very short time flexibility products, when the charging system allows for flows of electricity from vehicle to grid (V2G). However, this is quite expensive, but in future it is expected the cost will reduce. Due to their low energy capacity, the EVs are best used as short time power reserves. EVs are able to change the flow of power they withdraw or inject into the grid very quickly and have flexible patterns of recharging before the next use. EVs are not suited for the wholesale electricity markets, such as DA and ID, where exchanges are made in terms of energy rather than capacity [5]. Experimental validation of IRPC and FCC has been conducted at [17] using EVs to provide synthetic inertia and frequency containment control.

Voltage drop could be counteracted by the injection of reactive power. Reactive power could be supplied by:

- *Capacitors*, which are entirely passive and consume no fuel;
- *Generators*, generally at very low cost. The cost for a generator to supply reactive power is mainly an opportunity cost because, while supplying reactive power consumes essentially no fuel, it does reduce the generator's ability to produce real power. This relationship is non-linear.
- *Synchronous condensers* that are run electrically. They take real power from the grid and return reactive power.

The roles and responsibilities of the BSP in the market for frequency and voltage control products are in line with the requirements determined in [18]:

- The BSP qualifies for providing bids for balancing energy or balancing capacity which are procured and activated by the CSO;
- Each BSP participating in the procurement process for balancing capacity submits and have the right to update its balancing capacity bids before the gate closure time (GCT) of the bidding process;
- Each BSP with a contract for balancing capacity submits to its CO the balancing energy bids corresponding to the volume, products, and other requirements set out in the balancing capacity contract;
- Any BSP has the right to submit to the CSO the balancing energy bids from the standard products for which it has passed the prequalification process;

*The **Balance Responsible Party** (BRP)* is a market actor responsible for its imbalances. The roles and responsibilities of the BRPs in the market for frequency and voltage control products are in line with the requirements determined in the [18]:

- In real time, each BRP strive to be balanced or help the power system to be balanced;
- Each BRP is financially responsible for the imbalances to be settled with the CSO.
- Prior to the intraday cross-zonal gate closure time (ICZGCT), each BRP may change the schedules required to calculate its position;
- After the ICZGCT, each BRP may change the internal commercial schedules required to calculate its position.

Annex 8 provides information on roles and responsibilities of the National Regulatory Authority.

8 Balancing and voltage control products

8.1 Classification and description of products

The ENTSO-E distinguishes three main classes of balancing products, which have different functions and technical characteristics. These are Frequency Containment Reserves (FCR) for primary control, Frequency Regulation Reserves (FRR) for secondary control and Replacement Reserves (RR) for tertiary control, for which different procurement and control requirements are stipulated [19].

European TSOs practice three types of voltage control mechanisms, which are primary, secondary and tertiary voltage control.

Within the WoC concept, new classes of balancing and voltage control products are developed and considered (Figure 8-1, Figure 8-3). They differ in functions, technical characteristics, procurement schemes and other requirements.

The mapping of balancing and voltage control products to the products currently provided in most power systems is shown in Table 8-1 and Table 8-2 below.

Table 8-1. Mapping of frequency balancing products of ELECTRA to the products currently provided in most power systems in Europe

Frequency balancing products within ELECTRA	Currently available balancing control mechanisms / products
Inertia Steering Control (IRPC)	N/A
Frequency Containment Control (FCC)	Frequency Containment Control (FCR)
Balance Restoration Control (BRC)	Frequency Restoration Control (aFRR, mFRR) Frequency Replacement Control (RR)
Balance Steering Control (BSC)	N/A

Table 8-2. Mapping of voltage control services of ELECTRA to the products currently provided in most power systems in Europe

Voltage control products within ELECTRA	Currently available voltage control mechanisms / products
Primary Voltage Control (PVC) (is not tradable within the WoC concept)	Primary Voltage Control
Post-Primary Voltage Control (PPVC)	Secondary Voltage Control
	Tertiary Voltage Control

In Figure 8-1, an expanded list of balancing products traded within the WoC power grid structure is presented by categorizing the balancing products into classes, directions, types and sub-types.

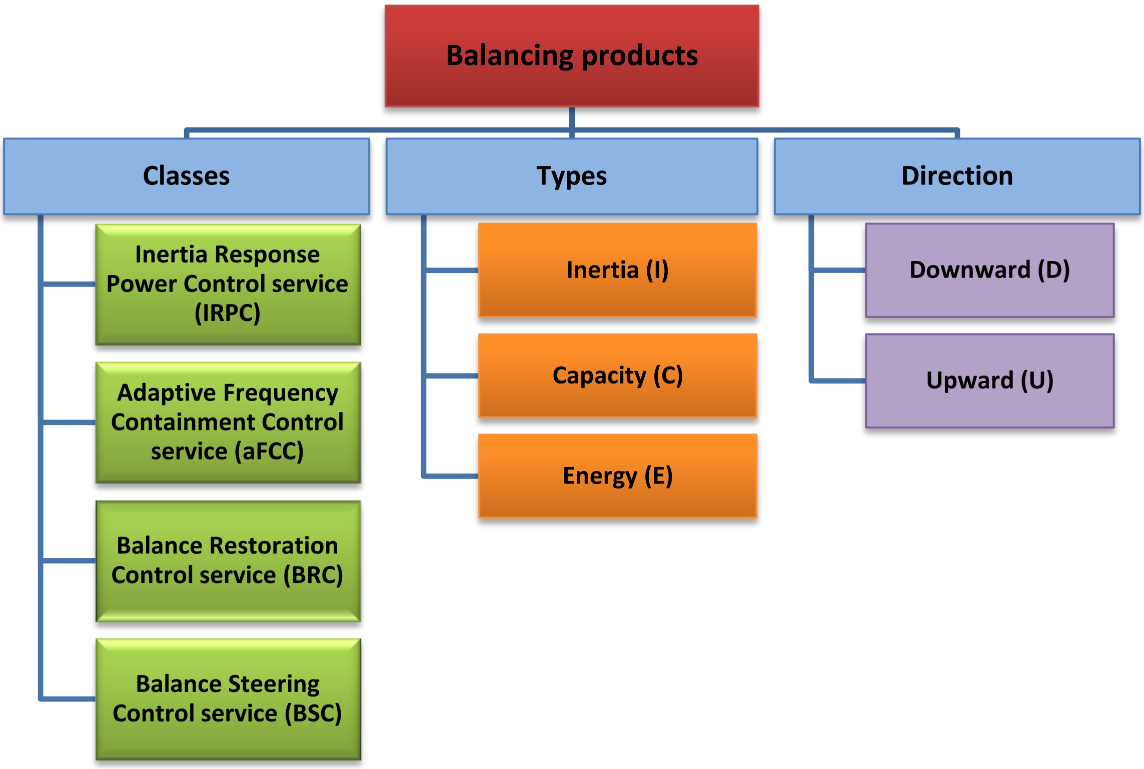


Figure 8-1. The categorization of balancing products

Within the WoC power grid structure, three classes of balancing products are traded with the purpose to keep the system frequency target value within the certain limits. Peculiarities of the classes of balancing products are as follows:

- *Inertia Response Power Control (IRPC) service* where each unit, involved in inertia control, automatically changes its level of inertia power response (synthetic inertia) depending on certain predefined characteristics. Reacts to frequency changes over time;
- *Adaptive Frequency Containment Control (aFCC) service* will not be fundamentally changed compared to today's schemes, except that the resources providing containment reserves will be different: generating units (in the broadest sense) as well as loads and storage distributed across the power grid within the cell that causes deviation. Reacts to deviations of the absolute frequency value so as to contain any change and stabilise frequency to a steady-state value;
- *Balance Restoration Control (BRC) service* initiates the restoration of the cell balance and load flows based on local information. It is assumed that (almost) all prosumers, that are connected through public communication infrastructure, will be able to offer fast BRC capacity, e.g. through their flexible loads, and possibly local storage. Reacts to absolute frequency deviations in conjunction with the tie line deviations from the scheduled interchanges so as to restore both quantities to their initial values;
- *Balance Steering Control (BSC)* service will mitigate the cell balance problem, by adjusting cell balance (tie-line power flow profile) set-points in a way, that two neighbouring cells can

agree to not each individually restore their balance, but they do it together in a way that requires less reserves activations while still contributing in the same manner to the system balance restoration. This can be considered as a peer-to-peer imbalance netting service

Based on today's operation a clear direct link between the quality of frequency balancing products and their price, could be established, showing that the quality of frequency balancing products (based on the frequency quality parameters, which are determined in Article 19 of Chapter 3 of [20]) is hierarchical in nature. Therefore, the primary control service is a higher quality-balancing product than the secondary control service, which in turn is a higher quality-balancing product than the tertiary control service. Thus, it is reasonable that higher quality balancing products were priced at higher prices. In the WoC concept, the relationship between the quality of frequency balancing products and their price could be kept too, however, there are some differences (Figure 8-2).

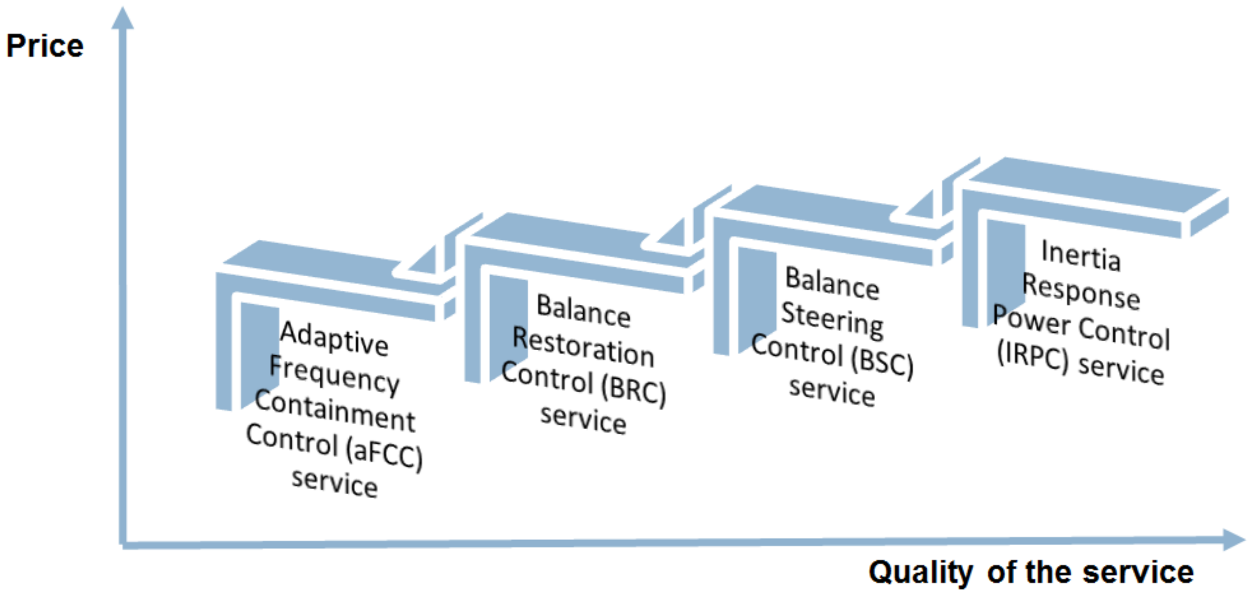


Figure 8-2. Relation between the classes of balancing products in respect to their quality and price

The IRPC service is the most difficult service, thus, it is expected that it will be the most expensive. The cost (price) – quality of the aFCC and BRC services should not vary, since the type and mechanisms of resources providing these two services are very similar and, if anything, the BRC service could be even more expensive because it is more crucial as a service. The BSC service is not anymore tertiary, hence cheaper, reserves. The BSC involves the change of tie-lines set points only and that is not based on reserves. This means that the commodity here is rather different that the other three services. In any case, the cost is expected to be higher than the BRC's because otherwise, the CSOs would always tend to modify their set-points and that should be done only in exceptional cases.

The cascading procurement principle is implemented to limit the exhibition of the reversal relationship between the price and quality of the balancing product. The cascading procurement principle is discussed in section 11.3.

Four types of frequency balancing products are traded. They are capacity for inertia, inertia, balancing energy and balancing capacity:

- *Capacity for inertia* means a volume of reserve capacity that the BSP has agreed to hold and in respect to which the BSP has agreed to submit bids for a corresponding volume of inertia to the CSO for the duration of the contract.
- *Inertia* means inertia used by the CSO and provided by the BSPs.
- *Balancing energy* means energy, either injected or withdrawn from tie-line, used by the CSO to perform balancing (to compensate for unforeseen imbalances and to guarantee the stability of the power system) and provided by the BSPs.
- *Balancing capacity* means a volume of reserve capacity that the BSP has agreed to hold and in respect to which the BSP has agreed to submit bids for a corresponding volume of balancing energy to the CSO for the duration of the contract. Balancing capacity is procured by the CSO ahead of real-time with the purpose to hedge the CSO against the risk of not having enough balancing energy bids by the BSPs in real-time.

Direction of the frequency balancing products (except, inertia) corresponds to upward and downward regulation. Upward regulation means an increase in generation (or decrease in consumption) and down regulation means a decrease in generation (or increase in consumption). Upward regulation is provided by units that are more expensive than the marginal unit of the DA or ID markets, meaning that the balancing product of upward regulation is traded at higher price than the day-ahead price. For downward regulation those units that already received payments from the DA and/or ID markets can save the fuel costs by decreasing generation. Splitting the market for procurement of balancing products into the sub-markets of “upward” and “downward” and do not setting / keeping the requirement for bid symmetricity creates preconditions and lead to increasing number of the BSPs in the corresponding sub-market. For example, loads are more familiar and capable of reducing load than increasing it. Therefore, if symmetric bids are not required, the available reserve capacity could be better used.

In Figure 8-3, an expanded list of voltage control products traded within the WoC concept is presented by categorizing them into classes and types.

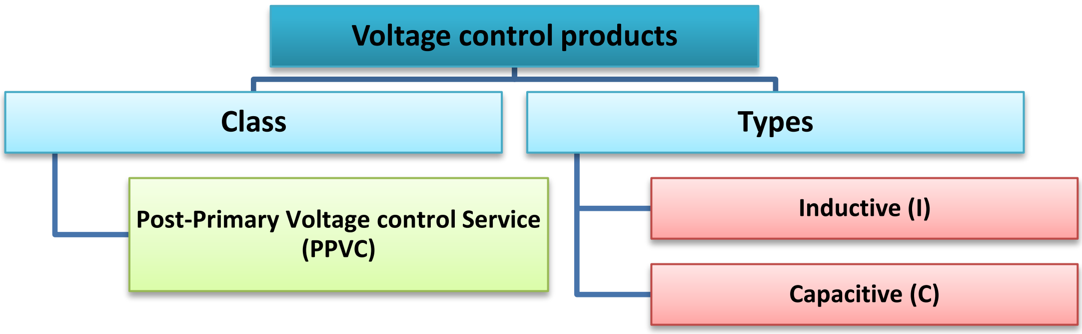


Figure 8-3. Categorization of voltage control products

Two classes of voltage control service are developed, however, only one class is developed as a product for trading purposes. This is:

- *Post Primary Voltage Control (PPVC) service* is the commitment to bring the voltage levels in the nodes of the power system back to nominal values while optimizing the reactive (and active) power flows in order to minimize the losses in the network. Each Cell is responsible for its own voltage control.

Two types of voltage control products are developed: consumption and injection of reactive power. Inductive reactive power is used when voltage is too high to compensate the capacitive reactive power. Capacitive reactive power is used when voltage is too low to compensate inductive reactive power. This is the case of HV network.

A detail description of the services is given in Deliverables D3.1 [1] and D4.2 [2].

Separate sub-markets are established to trade a particular class, direction, type and sub-type of balancing and voltage control products.

Coding of balancing and voltage control products is established to increase the transparency and operational efficiency of the market and with the purpose of quickly directing the BSPs and the CSOs to the appropriate sub-market. The following structure of coding the products is applied – C-D-T: YMD_H_Q, where C – class, D – direction and T – type of the balancing product and Y, M, D, H, Q – year, month, day, hour and quarter hour of balancing product delivery. Thus, under the coding aFCC-U-C: 20171026_15_00 the upward regulation (U) reserve capacity (C) for the provision of adaptive frequency containment control (aFCC) service is traded, when the balancing product has to be delivered on 26 October 2017 at 3 pm.

9 Marketplace

All balancing and voltage control products, which are needed to operate the power system, are procured in a marketplace. Three types of marketplaces are considered [14]:

- Exchange;
- Organized Over-The-Counter (oOTC);
- Bilateral Over-The-Counter (bOTC).

In the exchange, the BSPs submit generation and demand bids. The market is cleared once per predefined time period and a single market price is established.

In the oOTC trading, the BSPs submit generation and demand bids to a market platform, which is cleared continuously; the CSO bilaterally accepts the bid of the BSPs, resulting in different prices for each trade.

In the bOTC trading, the BSP agrees on a trade contract by directly interacting with the CSO. The oOTC and the bOTC trading can take the market price published by the exchange as the reference price.

An organized (institutionalized and centralized) marketplace instead of the decentralized (bilateral market) is established to trade balancing and voltage control products. The pursuit of transparency, confidentiality, anonymity and publicity are all relevant reasons for the selection of an organized marketplace for trading frequency balancing products. Exchange as a type of the organized market is chosen because of its advantage over the alternatives of the oOTC and the bOTC market. The advantages of the exchange are presented in Annex 9: Arguments for selection of the exchange.

In the exchange, only standard balancing and voltage control products are traded, meaning that contracts are uniform in regard to their structure and form. This enables the CSO to compare identical frequency balancing and voltage control products and activate the most cost-efficient solution. Standardized frequency balancing and voltage control products support the integration of RES and DER and storage technologies into the market. Due date, place of delivery, the time in which the deliveries take place and the conditions for clearing and settlement are standardized too. The set of rules such as the conditions to be admitted to trade on the exchange are made public and are the same for every BSP. Prices and revenues are made public too and these allow BSPs evaluating the position of their bids on the merit order list relative to bids from other BSPs. The participation is voluntary and non-discriminatory. Trading partners do not have to be found and the counterparty risk is minimized. Since the trading process is anonymous, the BSPs could keep their strategy in a secret. In addition, the process to offer flexibility in the market is easy with a low entry barrier.

All CSOs and BSPs use a common platform for trading frequency balancing and voltage control products, however, they are not pooling the bids and offers into a single integrated market, except in case of trading the BSC service, when every bid and offer available to one of the Cell is available to other Cells. This comes from the feature of the WoC concept that, basically, local problems should be solved locally and only in case there is a shortage in balancing capacity and balancing energy, they are procured from the neighbouring Cell by procuring the BSC service.

10 Auction

Purpose of the auction. Auction as an instrument to promote competition in procurement of balancing and voltage control products of all sub-markets, as a mechanism to coordinate efficient production, as an institution to determine the price and to conduct the trade in the exchange, and as the economic (market) mechanism to allocate the frequency balancing and voltage control products in economically efficient way within the WoC concept. In Annex 10: Arguments for selection of an auction [21], arguments for the selection of an auction, conditions to have a successful auction and methods encouraging the BSPs to participate in the auction and increase economic efficiency are given.

Types of auction. *Closed-type vs opened-type auction*. In relation to the extent to which information about orders submitted to the auction are provided, closed-type and opened-type auctions are considered.

In the closed (sealed-bid)-type auction, the BSPs, who are the auction participants during the bidding process, privately submit their bids and offers to the CSO, who is the auctioneer, and the CSO keeps this information private, such that there is no sharing of bidding information amongst the BSPs. The BSPs are informed whether they won or lost. In the opened-type auction bidding information available to the participants.

Closed-type auctions instead of opened- ones are established. It is expected that limiting the provision of information work as a constraint on exercising market power and thereby increasing prices of balancing and voltage control products.

Multi-unit vs single-unit auction. In relation to the number of units, which are available for the trade, a multi-unit auction instead of a single-unit one is established. In contrast to a single-unit auction, for which a single portfolio of units of balancing and voltage control product is available for the trade (and therefore only one BSP who suggested the lowest price for the portfolio of units wins the auction), in the multi-unit auction, multiple units of inertia, balancing and voltage control products are available for trade and many BSPs are winners in the auction.

The multi-unit auction design is selected for the WoC concept since it is in line with the roles that are set for the market of procurement of balancing and voltage control products, particularly, establishing competitive situations in the market, increasing utilization efficiency, increasing price efficiency.

Uniform auction vs discriminatory auction. Two types of closed-type multi-unit auctions differing in bidding formats and pricing mechanisms are considered within the WoC concept. They are uniform and discriminatory auctions.

The uniform auction design is selected when at least the one CSO and many competing BSPs participate in the market for inertia, balancing and voltage control products, which has to allocate multiple units of inertia, balancing and voltage control products. Subject to the uniform auction, the CSO collects all the bids and offers from the bidders (BSPs), creates an aggregate supply curve for the inertia, balancing and voltage control products, and match it with the requested volume of inertia, balancing and voltage control products. The CSO establishes the Market-Clearing Price (MCP) by matching supply and demand of inertia, balancing and voltage control products. Win the bidders (BSPs) whose bids, or sections of their bids, offered lower price than the MCP. All winners (BSPs) receive the same price (“pay-as-clear”), independently on their financial offers.

In contrast, the discriminatory auction could be selected in case only several BSPs participate in it. Subject to the discriminatory auction design, the BSPs are allowed bidding in a similar way as in the uniform auction, and the process for choosing the winners is the same. The auction differs in the price each bidder receives. In the discriminatory auction, the winners receive the price at which they bid ("pay-as-bid") but not the MCP. The closed-type discriminatory auction could be used in case the level of competition was low. The advantage of the discriminatory auction over the uniform auction is that it poses less risk to the market participants as they can trade inertia, balancing and voltage control product immediately instead of having to wait until the market-clearing. However, as matching bids are immediately cleared, this may not lead to welfare maximization and optimal allocation and utilization of resources. This is a serious drawback of the auction.

Due to a uniform auction's advantage to be fair and attract the participation of small bidders, this type of auction is chosen. Since this is a closed-type auction, no information is published before the clearing takes place. It is expected that under the WoC concept the level of competition is achieved high in the market and many small-scale BSPs participate here.

One-sided vs two-sided auction. In relation to types of market participants involved in the auction both one-sided and two-sided auction designs are relevant for the WoC concept.

The peculiarity of the one-sided auction is that only the BSPs bid (price and volume) in the auction. They form the price-responsive supply curve. The nature of demand, for establishment of which the CSO is responsible, is price-non-responsive. The CSO determines the requested volume of balancing and voltage control products before the auction is held and no price is established at which the CSO would prefer to procure the balancing and voltage control products. The CSO is not allowed to bid price because it is a single buyer and can dampen the price, which then could be too low for the BSPs to participate in the market for balancing and voltage control products.

The need for one-sided auction comes from the feature of the WoC concept that "local problems should be solved locally". The feature leads to the establishment of the monopsonistic market structure (one-sided), where the CSO is a single buyer of inertia, balancing and voltage control products and there are many local small-scale BSPs supplying the inertia, balancing and voltage control products. One-sided auction is established to trade the IRPC, aFCC, BRC and PPVC services.

Principally, the two-sided auction design features a number of CSOs and BSPs from different Cells and enables the active participation of supply and demand sides to compete on a level-playing-field basis, where both the BSPs and CSOs are allowed to bid. It enables forming the aggregated price-responsive demand curve too, when the CSOs bid both quantity and price in the auction and in such a way show their preferences.

The two-sided auction is established for trading the BSC service, since cross-Cell trade in the BSC service is allowed, thus, more than one buyer exists. The advantage of the two-sided auction over the one-sided auction is that the former ensures lower transaction cost for the BSPs and the CSOs. Thus, operational efficiency improves. It helps to control market power, increase price and utilization efficiencies and enhance the social welfare of the market through the establishment of competitive situations in the market too. This is important when the supply of electricity is very tight and inefficient generation units have to run and set the MCP.

Consistency of auctioning. Depending on the consistency of the auctions held during the time, two categories of auctioning (*sequential and simultaneous auctioning*) were considered for the

WoC concept. Based on their peculiarities, the WoC concept develops an idea of the hybrid auctioning, which combines the features of both sequential, which is applied in European countries, and simultaneous, widely used in USA, auctioning.

The *hybrid auctioning* takes into account the approach of the sequential auction that market for electricity (DA and ID) products and market for balancing and voltage control products are cleared sequentially, meaning that the market for inertia, balancing energy and reactive power is cleared after the clearance of DA and ID markets. Winners in the sequential auctioning are chosen easily by selecting the lowest price-offering participants for each product separately. The advantage of the sequential auctioning is clarity in general power market structure, which better facilitates understanding of market processes, consistency in clearance of sub-markets, which assure that many local cost minimums are found, explicit trading rules and variety of sub-markets established, which increase the opportunities for participation in the electricity market. This type of auctioning is selected as a core auctioning mechanism because of its practical use in European countries. The transformation of electricity markets auctioning to simultaneous auctions shall mean significantly increased cost.

Subject to the simultaneous auctioning, the products to bidders are allocated along with the minimization of joint bid cost of providing energy and inertia, balancing energy, balancing capacity and reactive power services. Thus, one global minimum is established in this case. The advantage of the mechanism is a strong coupling between the products. In this approach, it is hard to justify the schedule and pricing of the product.

The WoC concept improves the sequential market mechanism by adding the cascading procurement principle widely applied in the simultaneous auctions. In result, the balancing and voltage control products are procured by the CSO in a way that total cost of providing services is reduced (but not minimized as in the case of simultaneous auctioning). That is, the reduction of total cost of balancing and voltage control products is achieved through the application of the cascading procurement principle, which is described in sesction 11.3.

If the sequential auction mechanism approach for the WoC concept is under the consideration, the CSO should think about several group of reasons for and against spreading the demand for balancing and voltage control products over a sequence of auctions. They are summarized in Annex 11.

Types of proposals submitted to the auction. Types of proposals submitted to the action are the types of the BSPs formal statement regarding their actions in the balancing and voltage control sub-markets. The BSPs who are electricity generators can state that they will reduce / increase the volume being generated, and suppliers who are flexible enough can state to increase / reduce their demand. In the auction, these formal statements shall be called *bids* and *offers*:

- An *offer* is a proposal to increase generation or reduce consumption;
- A *bid* is a proposal to reduce generation and increase consumption.

Thus, the BSPs submit offers for the upward regulation services and bids for the downward regulation services in response to the CSO formal request for upward and downward regulation.

Offer and bid requirements. In addition to price and volume, grid location, response speed, regulating speed, activation time, activation duration, and activation method, among others are relevant for the WoC concept.

The WoC concept accepts the minimum requirements for the standard product bid and offer, which are determined in Article 25 of the European Commission's Regulation [18]. They are presented in Table 10-1.

Table 10-1. Requirements for bids and offers of the standard products

Characteristic	IRPC	aFCC	BRC	BSC	PPVC
Ramping period	< 1 MW·s/s	< 1 MW/s	< 10 MW/min	Same with BRC	< 1 MVA/min
Full activation time	< 1s	2-5 s	10-30 s	10-30 s	30 s
Minimum and maximum quantity	< 1MW·s	< 1 MW	1 MW	1 MW	1-5 MVA
Preparation period	< 1 s	< 5 s	< 1 min	< 1 min	< 5 min
Deactivation period	< 20 s	10-30 s	10-30 s	10-30 s	10-30 s
Minimum and maximum duration of delivery period	15-60 min				
Validity period	15 min	15 min	15 min	15 min	120 s
Mode of activation	Merit order	Merit order	Merit order	Merit order	Optimal power flow calculation

The list of standard products for balancing and voltage control products set out at least the following variable characteristics of a standard product to be determined by the BSPs during the prequalification or when submitting the standard product bid:

- Volume of the bid;
- Price of the bid;
- Divisibility;
- Location;
- Minimum duration between the end of deactivation period and the following activation.

Symmetric bidding and offering requirements. In many markets, the provision of balancing capacity requires symmetrical products for upward and downward regulation (that is, if a unit offers 5 MW of upward ramping capability, it must also offer 5 MW of downward ramping capability). This requirement can be costly to fulfil. For instance, solar or wind power can provide downward regulation, but it would be costly to provide the same amount of upward regulation. Aggregation of units capable of providing upward and downward regulation could fulfil the symmetric bid requirement. However, as it is argued by [5], if products are only symmetrical, the aggregator will not be able to provide the optimal amount of available reserves, since there may not be the same amount of upward and downward reserves. For instance, when consumption level is decreasing or low, an aggregator of demand response units will have more downward reserves than upward reserves. If symmetrical bids are required, an aggregator will be forced to bid the minimum of the available upward and downward reserves, regardless of total capacity. In a system without the symmetric reserve requirement, any capable unit may provide reserves in one direction. Therefore, symmetric bid requirements restrict flexibility of certain units and add additional costs for reserve provision [22].

Within the WoC concept symmetric bidding requirements are not set.

Scoring of offers and bids. Each bid and offer in the auction have two components: volume (in kgm^2, MW, MWh, VAr) and price (in EUR/kgm^2, EUR/MW, EUR/MWh, EUR/VAr). Bids and offers are selected on the basis of the price of inertia capacity, inertia, balancing electricity, balancing capacity and reactive power only. Selected bidders are required to provide accepted volumes of inertia, electricity and reactive power and to keep the accepted volume of capacity for inertia and balancing capacity free for the entire trading period.

Order types. These are:

- *15-minute order*. This is a quarter-hourly order, which is a market actor's offer with respect to a specified volume of capacity for inertia, balancing capacity, inertia, balancing energy and reactive power, Cell area and price for a given delivery period of the applicable delivery day.
- *30-minute order*. This is a half-hourly order, which is a market actor's offer with respect to a specified volume of capacity for inertia, balancing capacity, inertia, balancing energy and reactive power, Cell area and price for a given delivery period of the applicable delivery day.
- *60-minute order*. This is an hourly order, which is a market actor's offer with respect to a specified volume of capacity for inertia, balancing capacity, inertia, balancing energy and reactive power, Cell area and price for a given delivery period of the applicable delivery day.

In a case where an actor submits more than one order for the same delivery period, the order submitted latest in time and not rejected by the auctioneer will over-write and cancel all prior orders in respect of such delivery period.

Product resolution. Product resolution (in kgm^2, MWh, MW and VAr) is the minimum bid and offer size. It is set considering the volume of installed production capacity and the size of units producing inertia, electricity and reactive power, which are technically qualified for submitting bids and offers to the market for balancing and voltage control products. In power markets, having large electricity producing units, the minimum bid size is set high reflecting their actual technical capabilities.

The transformations in the production structure of the power systems and shift towards wider use of RES & DER in future will require updating the minimum bid sizes. More likely, that the minimum bid and offer sizes shall be reduced because small-scale RES & DER power plants will be offering balancing capacity and producing electricity, inertia or reactive power.

If in future the minimum bid and offer sizes will be set at the current level, RES & DER power plants will be left out of the market, since they will not have sufficient production capacities to meet the required minimum bid and offer sizes. Thus, the minimum bid and offer sizes of the current level will serve as an entry barrier to many small-scale RES & DER power producers. In this case, the principle of non-discrimination when establishing the market for balancing and voltage control products will be damaged. The consequences of the violation of this principle shall be serious since competition in the market for balancing and voltage control products will be reduced. Only qualified large-scale power producers will provide the balancing and voltage control products. Thus, if concentration in the market shall increase due to the participation of several large producers, it is likely that the remaining large-scale actors will have possibilities to exploit power in the market. As a result, price for balancing and voltage control products will increase and costs of providing them to consumers will increase too.

Thus, with the aim to better manage the development of costs, the WoC concept considers setting the minimum bid and offer sizes in relation to the technical capabilities of power plants. The minimum bid and offer sizes should be set at a level that new actors, especially RES & DER, demand response and storage, could enter the market and increased competition between the BSPs.

However, it is valuable to think if the minimum bid and offer sizes has to be set at all, since they have a shade of discrimination which is not required in the markets. If it is set too low, discrimination of some market actors shall remain, but the cost of bidding and information aggregation by the CSO shall increase and could be even higher than the benefit in terms of price reduction. Indeed, the discrimination of market actors could be reduced allowing aggregators participating in the market, and use their value to aggregate at the Cell level negligible generators, storage and demand response providers. In relation to aggregations, the minimum bid and offer size define the minimum level of aggregation necessary to deliver reserve and is a key parameter for the participation of RES & DERs, storage, and demand response providers. If the minimum bid and offer size is set too high, it will be difficult for aggregators to participate as it would require managing an overly cumbersome number of small generation sources. However, market designers may want to set bid and offer sizes at a high level to minimize the number of market participants and the associated transaction costs. Within the WoC concept no minimum bid size is set.

Quotation method. A formal statement of promise made by the BSP to supply balancing capacity, balancing electricity, inertia and reactive power required by the CSO to perform its functions at specified prices, volumes and within a specified period; and, vice versa, a formal request made by the CSO to procure particular balancing and voltage control services at specified prices, volumes and within a specified period.

One-way and two-way price and volume quotations are considered within a WoC concept:

- *One-way price quotation* means that only the BSPs submit prices to the auction. These prices are known as the offer prices:
  - Offer price represents the minimum price that the BSP is willing to receive for the balancing and voltage control product;
- *Two-way price quotation* means that both the BSPs and the CSO submit prices to the auction. These prices are known as offer and bid prices.
  - Offer price represents the minimum price that the BSP is willing to receive for the balancing and voltage control product;
  - Bid price represents the maximum price that the CSO is willing to pay for the balancing and voltage control product.
- *Two-way volume quotation* means that that both the BSPs and the CSO submit sell and purchase volumes to the auction.

Volume quotation. Volume quotation is physical unit. In case of:

- Balancing capacity – MW
- Balancing electricity – MWh
- Inertia – kgm^2
- Capacity for inertia – MW*s (stored energy in mass)
- Reactive power – VAr

Price quotation. Price quotation is Euros and cents per unit. In case of:

- Balancing capacity – EUR/MW
- Balancing electricity – EUR/MWh
- Inertia – EUR/kgm^2
- Capacity for inertia – EUR/(MW*s) (stored energy in mass)
- Reactive power – EUR/VAr

Tick size. Tick size is the minimum price fluctuation / change. The minimum price change for each product is stipulated in the contract specifications. The general practice is that exchange may temporarily determine the minimum price change exceeding the provisions in the contract specifications, if this determination is appropriate to reduce negative impacts to the market integrity and liquidity. The tick size could be reduced for the purpose to save money of market actors. The following tick sizes are set for:

- Capacity – 0.01 EUR/MW
- Electricity – 0.001 EUR/MWh
- Inertia – 0.01 EUR/kgm^2
- Capacity for inertia – 0.01 EUR/(MW*s)
- Reactive power – 0.01 EUR/VAr

Currency. Orders are submitted in EUR, price calculation is done in EUR.

Price cap and price floor. Price cap is usually implemented to avoid excessive pricing by generators, especially in cases when the price elasticity of demand is low. If price cap is set, it should be set at the Value of Lost Load (VOLL) in order to encourage investment in needed peaking plants, but it could be set lower for the purpose of market power mitigation. The VOLL represents the average value that consumers attach to a unit of electric energy not supplied, and thus reflects their willingness to pay to avoid demand curtailment. The "Winter Package" foresees that prices should reflect the true value of electricity and price caps should be removed, except they reflect value of lost load [23]. In particular, the Article 9 of Proposal for a Regulation on the Internal Market for Electricity [23] sets that "*…there shall be no maximum limit of the wholesale electricity price unless it is set at the value of lost load. There shall be no minimum limit of the wholesale electricity price unless it is set at a value of minus 2000 EUR or less and, in the event that it is or anticipated to be reached, set at a lower value for the following day. This provision shall apply, inter alia, to bidding and clearing in all timeframes and include balancing energy and imbalance prices …".* The issue price caps and scarcity pricing in relation to provisions of "Winter Package" was discussed in [24].

The transition to a low carbon generation mix (with more variable RES and more technologies with low marginal costs) and integration the technologies into the market for frequency balancing and voltage control products implies higher price volatility of the products and more frequent and extreme price spikes. For this reason, price caps in the market for balancing and voltage control products is applied only in the rare situations when supply and demand do not match (when the supply and demand curves do not cross). In these cases, price caps are set sufficiently high so as not to distort investment signals. The WoC concept assume that prices of balancing and voltage control products reflect the true value of electricity and price caps are removed, except they reflect VOLL.

11 Market design elements

11.1 General elements

Bid time unit. The Bid Time Unit (BTU) is main time unit in the market for balancing and voltage control products, which divides the balance responsibility between the CSO and the BSPs. It is the time over which bids of balancing and voltage control products are specified [10]. For example, if balancing energy bids are submitted for half hour "chunks", these "chunks" are referred to BTU. Then each day is split into the 48 BTUs (based on [25]). It is also called market time unit when speaking about bidding for inertia, balancing capacity availability, balancing electricity or voltage delivery for a certain time period.

Within the WoC concept, the BTU is closely linked to the energy Schedule Time Unit (STU), which divides responsibility between the CSO and the BRPs, and Imbalance Settlement Period (ISP), the period for which imbalance of the BRP is calculated. The recommendation to link BTU to STU and ISP comes from the need to harmonize time units to increase operational and price efficiencies. The explanation of how different types of time units are interrelated is derived from the analysis of the following chain of events – information (in terms of prices of balancing and voltage control products) received from a particular BTU is used to price an imbalance of a particular ISP, which is established taking into account energy schedules from a particular STU. Thus, if time units of BTU, STU and ISP are not equalized and harmonized the operational efficiency and price efficiency reduces. Operational efficiency reduces because additional tasks should be performed by the market participants to normalize the results of transactions exercised in one type of time unit (for example, in the BTU) in a way that they could be available for use in other types of time unit (for example, in the ISP). The comparability of information received from time units of different length is complicated. Moreover, more time, qualified personnel and physical infrastructure is required, which increases cost and reduces price efficiency. Thus, it is necessary to analyse the impact of the BTU on the operational and price efficiencies from the broader perspective, including from the perspective of energy scheduling and imbalance settlement too.

The WoC concept considers short and long BTU&STU&ISP. Short BTU&STU&ISP is selected of 15 minutes and long BTU&STU&ISP – of 60 minutes. It is expected that a short BTU&STU&ISP provides the BRP with a stronger incentive to balance the available energy portfolio than a long BTU&STU&ISP because more accurate information is available on short terms and deviations from the scheduled energy will be smaller. Thus, balance planning accuracy shall increase. This shall lead to smaller energy imbalances at the Cell level. Thereby, the CSO will activate less balancing energy bids, as demand for balancing energy will be lower. Indeed, reduced demand for the balancing energy will lower imbalance price, which in turn will diminish incentives for the BRPs to balance their energy portfolios, as imbalance cost could be smaller than cost if the balancing efforts were placed. However, short BTU&STU&ISP shall raise the transaction cost because energy schedules and balancing energy bids shall be submitted and imbalance shall be calculated frequently. Within a short BTU&STU&ISP, the reduced demand for balancing energy will influence on the improvement of criteria of the availability of balancing resources in a way the BSPs will have more opportunities to provide balancing energy even if they have abundant commitments in the ID market. Subject to the abundant commitments in the ID market and long BTU&STU&ISP the BSP may be technically incapable to provide balancing energy for BTU&STU&ISP of 60 minutes. If only few BSPs are capable to provide balancing energy, they can start using power in the market and offer balancing energy at price not reflecting actual cost. Thus, price efficiency shall reduce. Within the framework of the WoC concept, the BTU&STU&ISP is set of 15 minutes.

Publication of market information at Cell level. Information about conditions in the market for balancing and voltage control products should be publicly provided to assure development of a transparent market for balancing and voltage control products. In Figure 11-1, high-level framework of a transparent market for balancing and voltage control products is given. Based on the findings, the framework was tailored to the market for balancing and voltage control products within the WoC concept.

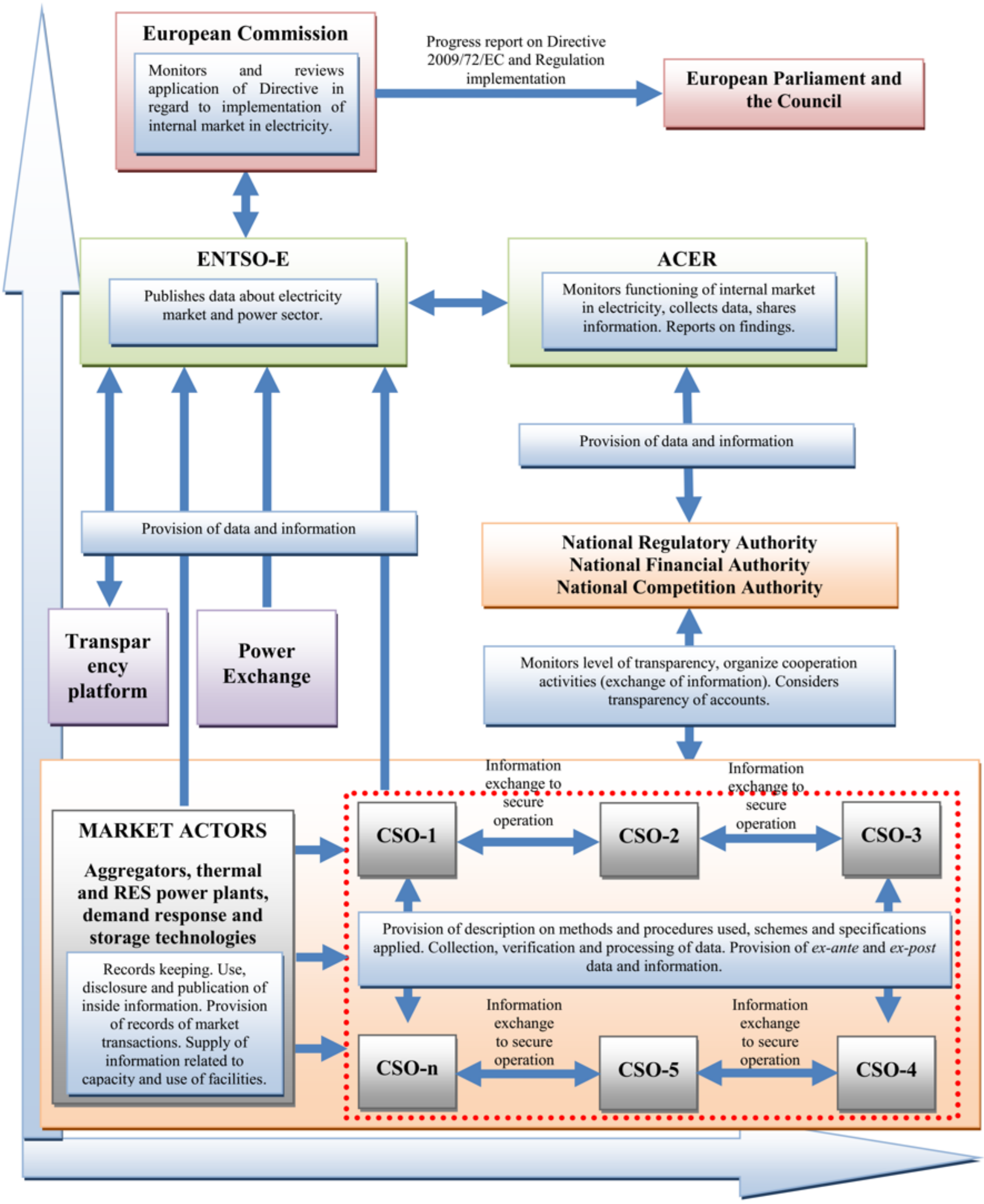


Figure 11-1. High-level framework of a transparent market for balancing and voltage control products

The market for balancing and voltage control products is considered to be transparent if market transparency is achieved horizontally and vertically. Horizontal transparency is achieved in the market for balancing and voltage control products when the same level market actors (such as various types of electricity generators or CSOs) exchange all relevant *ex-ante* and *ex-post* data and information among themselves timely for the efficient decision making. Requirements for data are set the following:

- Data is regularly updated and is provided for different timeframes;
- Data is up to date, easily accessible, downloadable;
- Data are available for at least five years.

Vertical transparency is achieved in the market for balancing and voltage control when the market actors supply this data and information to the superior level institutions and authorities, such as ENTSO-E and ACER. The latter networking institutions have an obligation to supply data and information to the most superior-level institutions, such as European Commission.

Within the framework of a transparent market for balancing and voltage control products, the market actors have obligations regarding data and information supply, their publication and other roles the implementation of which increase the transparency in the market.

Within the proposed framework of transparency in the market for balancing and voltage control products, the European Commission is left with its obligation set in the Directive 2009/72/EC on Common Rules for the Internal Market in Electricity [42], i.e. to monitor and review the use of the Directive on Common Rules for the Internal Market in Electricity [42] and submit an overall progress report to the European Parliament and the Council.

In relation to market transparency, the Agency for the Cooperation of Energy Regulators (ACER) is obliged to monitor the functioning of the internal market in electricity, including the market for balancing and voltage control products. Every year the ACER is obliged to announce a report on its findings [44]. Moreover, on the basis of the developed model for the wholesale energy market transparency [45], the ACER takes responsibility against the market monitoring, data collection and information distribution. Indeed, the qualitative implementation of the obligations increases transparency in market for balancing and voltage control.

In the scope of market transparency, the European Network of Transmission System Operators for Electricity (the ENTSO-E) is obliged to make the data available publicly through a free of charge central information transparency platform. The platform aims at evenly distributing all important market data and information among the market actors [46] who need this data and information for the decision making. In addition, seeking to use the sources of transparency in a more efficient way, the ENTSO-E has a right to receive data and information through the third parties such as power exchanges and transparency platforms too [46].

The National Regulatory Authority (NRA), the financial authorities and the national competition authorities, who are the representatives of the Member States, have obligations regarding transparency of accounts [42]. In addition, the NRA has a responsibility to monitor the level of transparency in the market, providing information about status of the market to permit the European Commission to exercise its role of observing and monitoring the internal market in electricity [42], including the market for balancing and voltage control products. The NRAs, financial authorities and national competition authorities are obliged to cooperate to ensure a coordinated approach when solving the issue of market abuse in wholesale energy markets [45]. The mutual exchange of information regarding suspicions is an instrument of the cooperation [45].

In relation to [43], the CSO is obliged to provide the CSO of other neighbour cell all relevant data and information to ensure the secure and efficient operation. In addition, within the information exchange mechanism [43], the CSO is responsible for the publishing of *ex-ante* and *ex-post* data related to network availability, network access, network use, data concerning cross-Cell trade, generation and demand forecasts, as well as data for cross-Cell market for balancing and voltage control products. The CSO increase transparency in market by supplying the market with descriptions on congestion-management method, procedures in use for the congestion management and capacity-allocation, scheme for calculation of the interconnection capacity and specifications of products offered too. The latter information is required for and requested by the market actors for the negotiation of all types of transactions in wholesale electricity products. Moreover, the CSO, being the primary source of information, facilitate the collection, verification and processing of data. It is also obliged to provide the cell users with the information they need for the efficient access to, including use of, the cell [42].

Market actors are obliged to use, disclose and publish inside information, supply their records of market transactions and information related to the capacity and use of facilities for production, storage, consumption or transmission of electricity [45]. Provisions on record keeping require the market actors to keep relevant data relating to all transactions for at least five years [42].

The problem of transparency in the market for balancing and voltage control products is solved by establishing regulating provisions regarding:

- Qualitative requirements for data and information;
- Minimum data set and its availability for the MOC and the MOD making;
- Roles for the actors regarding data and information;
- Data placement;
- Data and information publication.

11.2 Balance planning elements

Zonal vs. nodal responsibility. If the BRPs must submit energy schedules for each network node, and are penalised for deviation per node, “nodal balancing” is applied. If energy schedules are at the level of geographically defined subsystems of the control area, “zonal balancing” is applied.

Within the WoC concept the BRPs shall submit energy schedules at the level of the Cell. Thus, “Cell balancing” is applied. This will impact on an accurate account of imbalances in relation to location and, indeed, is favourable for an application of a uniform pricing mechanism.

Balance obligation. In the balance planning stage, the balance obligation of the BRP is limited to the part of balance obligations of the BRP, which provide a response to question which particular market actors are obligated to submit individual or portfolio schedules for consumption and / or production to the CSO. When responding to the question, the WoC concept refers to the concepts of the Nordic imbalance settlement model, where a comprehensive definition of the BRP is given. The WoC concept considers that the BRP means a company that has a valid imbalance settlement agreement with a company providing imbalance settlement services to electricity market actors, and a valid balance agreement with the CSO, and manages a balance obligation on its own behalf as a producer, consumer or trader of electricity or on the behalf of other producers, consumers or traders of electricity. From the definition of the BRP, it is clear that, namely, producers, consumers and traders of electricity have a balance obligation. Historically, conventional power producers had a balance responsibility. Within a market with high shares of renewable energy, the responsibility for RES-E producers is considered too. Responsibility for renewable production means the distribution of balance responsibility for renewable production between the BRPs and the CSO. Balance responsibility for renewable production may lie completely or partially with the CSO, or renewable producers may have the same balance responsibility as conventional producers.

When responding to the issue, the WoC concept refers to the Article 15 of the Electricity Directive, which requires that HV SO adopted non-discriminatory rules on balancing, meaning that all market actors should be treated equally. In most EU Member States where wind power has a share above 2% in annual production (14 out of 18 Member States for which data was received) wind power producers are already balancing responsible in financial or legal terms. In these countries, wind power producers generally have the same balancing rules as conventional generation [26]. However, in some Member States, certain types of power generation (notably wind and solar, but possibly also other technologies) are excluded from this obligation or have a differentiated treatment [27].

The Article 4 of the Proposal for a Regulation on the Internal Market for Electricity [23] is dedicated to determining the balance responsibility. It sets that all market participants shall aim for system balance and shall be financially responsible for imbalances they cause in the system. They shall either be BRPs or delegate their responsibility to a BRP of their choice. Member States may provide an exemption of a provision in cases these are:

- Demonstration projects;
- Generating installations using RES or high-efficiency cogeneration with an installed electricity capacity of less than 500 kW;
- Installations benefitting from support approved by the Commission under Union State aid rules.

From 1 January 2026, exemption from the provision shall apply only to generating installations using RES or high-efficiency cogeneration with an installed electricity capacity of less than 250 kW.

In [26], it is suggested that all considerations by policy makers on balance responsibilities by wind power producers need to take into account market maturity as well as the penetration level of wind power in the respective power system. Market-specific boundary conditions under which balancing responsibility by wind power generators can be assumed include [28]:

- Existence of a functioning ID and balancing market;
- Balancing market arrangements providing for the participation of wind power generators, as e.g. short bidding periods;
- Market mechanisms that properly value the provision of AS or grid support services for all market participants including wind power;
- A satisfactory level of market transparency and proper market monitoring;
- Sophisticated forecast methods in place in the power system;
- The necessary transmission infrastructure.

An example, how balance responsibility could be determined is provided in Annex 12 for Italy.

In compliance with the provisions of Article 4 of European Commission’s Proposal for a Regulation of the European Parliament and of the Council on the Internal Market for Electricity [23], WoC concept takes over the provisions regarding balance responsibility of RES. However, seeking to avoid discrimination between market actors and treat them equally, the WoC concept goes further and will become stricter in future in a way that after the transitory period (after 2025), during which issues discussed by [26] are solved, no exemptions should be applied and all installations, independently of their source, should face the imbalance costs. The WoC concept considers that RES-E producers must participate fully in the balancing mechanisms. This means that they should have the same responsibilities as other type generators and be allowed to provide balancing resources subject to common rules.

Balancing scheme. The WoC concept considers two pure balancing schemes: *portfolio balancing* and *unit-by-unit balancing*. Under the portfolio balancing scheme, aggregations of units are allowed. This can reduce imbalances, even if the costs to the system of the imbalances are dramatically different across locations. For example, under the portfolio scheme, if one unit produced 5 MW less than scheduled, and one unit produces 6 MW more than scheduled, the net imbalance is positive 1 MW. Under a unit-by-unit scheme, if one unit produced 5 MW less than scheduled, and one unit produced 6 MW more than scheduled, the imbalance would be 5 MW for the first unit and 6 MW for the second unit [22]**.**

In the framework of the WoC concept, both balancing schemes are valid. For large units (for example, over 10 MW) a unit-by-unit balancing scheme shall be applied, since it assures very accurate accounting of imbalance (at unit level!) and puts responsibility for the imbalance to a particular unit which caused it. The variable renewables units under 10 MW could be aggregated and the imbalance settlement could be calculated at a portfolio level.

Net vs. separate positions. If separate production and consumption positions exist, the BRPs have to submit separate energy schedules for production and consumption that are settled separately. If a “net position” applies, there is only one type of scheduled position that includes both generation and consumption.

Considering to existing “good practice” [28]-[29], separate energy schedules for production and consumption shall be notified by the BRPs to the CSO. Energy schedules for trade shall be notified separately from consumption, i.e. the existing practice today. Moreover, energy schedules for import and export shall be notified to the CSO separately too as the trade directions (into the Cell and from the Cell) are understood to be equivalent to production and consumption, respectively.

The notifications of energy schedules for production, consumption and trade, which all together form the background for the balance settlement, shall consist of:

- *The general notification submitted by the BRP to the CSO the day before the day of operation*. Subject to the general notification, the BRPs submit the general initial energy schedules based on volumes of bilateral and day-ahead trade at 15 minutes intervals (resolution) for all the STUs of the following day. The CSO receives the general notification not later than at 13 o’clock on the day before the day of operation for all the STUs on the day of delivery.
- *The adjusted notification submitted by the BRP to the CSO the day before the day of operation*. Subject to the adjusted notification, the BRP submits energy schedules based on adjusted volumes of bilateral, day-ahead and intra-day trade at 15 minutes intervals (resolution). The CSO receives the adjusted notification not later than at 17 o’clock on the day before the day of operation.
- *The final notification submitted by the BRP to the CSO during the day of operation*. Subject to the final notification, the BRP submits schedules based on adjusted volumes of bilateral, day-ahead and intra-day trade at 5 minutes intervals (resolution). The CSO receives the final notifications not later than 45 minutes before the energy delivery.

After receiving energy schedules, the particular CSO aggregates the BRPs production, consumption, tie-lines power flows and trade energy schedules at the Cell level and derives the net position at the Cell level.

Initial gate closure time. Initial Gate Closure Time (IGCT) is the point in time, at which the BRPs must submit a general initial energy schedule to the CSO. Based on the European practice, this often happens right after the DA market clearing, when the first information on electricity volumes and prices is available, and is applied to all the STUs on the day of delivery. The WoC concept relates the IGCT time to the time period from the DA market closure to the ID market opening. If the ID market opens three hours after the DA market closure, this is the time period during which the IGCT should be set. Therefore, if the DA market closes at 12:00 am (12-36 hours before physical delivery is scheduled to take place) and the hourly prices of energy are announced to the market at 12:42 am, then, this is the point in time from which the IGCT time could be start determined. Then, if the ID market opens at 3 pm, this is the final time for IGCT time setting. The decision on the particular IGCT time shall depend on how strongly the interests and priorities of the BRPs and CSOs are taken into account. Indeed, each actor would wish to have more time to perform their responsibilities and, as a consequence, the cost did not significantly increase. Thereby, the BRPs would wish that the IGCT time was set as close as possible to the opening time of the ID market, whereas the CSO would wish to receive initial energy schedules as soon as possible after the DA market closure.

The WoC concept assumes that particular time should be selected following the criterion of reasonableness meaning that BRPs have sufficient time to prepare the initial energy schedules and the CSOs has enough time to aggregate them and take decision regarding volume of balancing energy is required for the Cell. The below several factors, affecting the IGCT time are mentioned. Broadly speaking, these are factors, which directly can be related to the design, structure and outcomes of forward and DA, for inertia, balancing and voltage control products markets:

- *Number and size of participants in the forward and DA markets*. Many small actors actively trading in forward (bilateral) and DA markets will affect the time needed for the CSO to aggregate the submitted energy schedules. Thus, it shall require more time and as a result the IGCT time shall be set early right after the announcement of the DA market results;
- *Liquid and competitive wholesale electricity markets representing large volumes of electricity traded there by a lot of market actors*. This shall require more time by the CSO to aggregate data, thus, request for an early IGCT time setting.
- *Complexity and variety of products available and used in forward and DA markets* should influence on the BRPs who will need time to collect energy information, calculate their positions in different sub-markets and aggregate data. The same is true in case the BRPs will deal with a variety of products in forward and DA markets. Huge amount of information flowing through different sub-markets and products will require more time from the BRPs to collect and treat them properly. Standard formats of information provision prepared by the CSO could serve as a measure for better time planning and will help to perform the task of data collection, treatment and provision faster. Moreover, the CSO will need itself less time to aggregate energy schedules of all the BRPs if energy schedules are provided in standardized forms.
- *The use of centralized market places / institutions (for example, power exchanges) for trading electricity when the market institution itself provides information to the CSO to*

calculate the initial energy balance. The establishment of the liquid centralized market institution with a large part of trade done through it will take-off the responsibility of the BRPs to submit initial energy schedules to the CSO. Instead, the power exchange could be responsible for the data provision. As a single entity, it could provide data faster to the CSOs than many small BRPs. The BRPs could submit adjusted energy schedules later. Thus, the initial gate closure time could be set early.

- *The requirement for a highly detailed initial energy schedules will affect the BRPs and the CSO time needed to prepare information at the required detail level and aggregate data, respectively*. Thus, the BRPs and the CSOs will ask for more time. Thereby detailed and complex energy schedules should be prepared using standardized forms to save time.
- *Re-scheduling possibility is the right of the BRPs to adjust (update) energy schedules based on the latest available information and submit repeatedly to the CSO without any sanctions and penalties*. The foreseeing of such possibility to the BRPs shall reduce their time requirements for the late initial gate closure time.

11.3 Balancing and voltage control products provision elements

Procurement scheme. Several schemes for the procurement of balancing and voltage control products are considered. They are summarized in Figure 11-2 to 11-5.

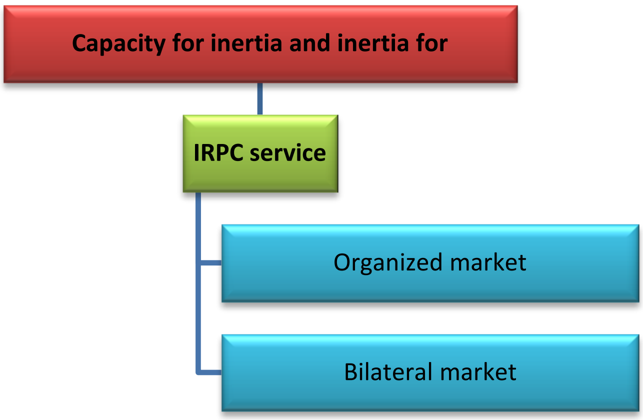


Figure 11-2. Methods for procurement of inertia

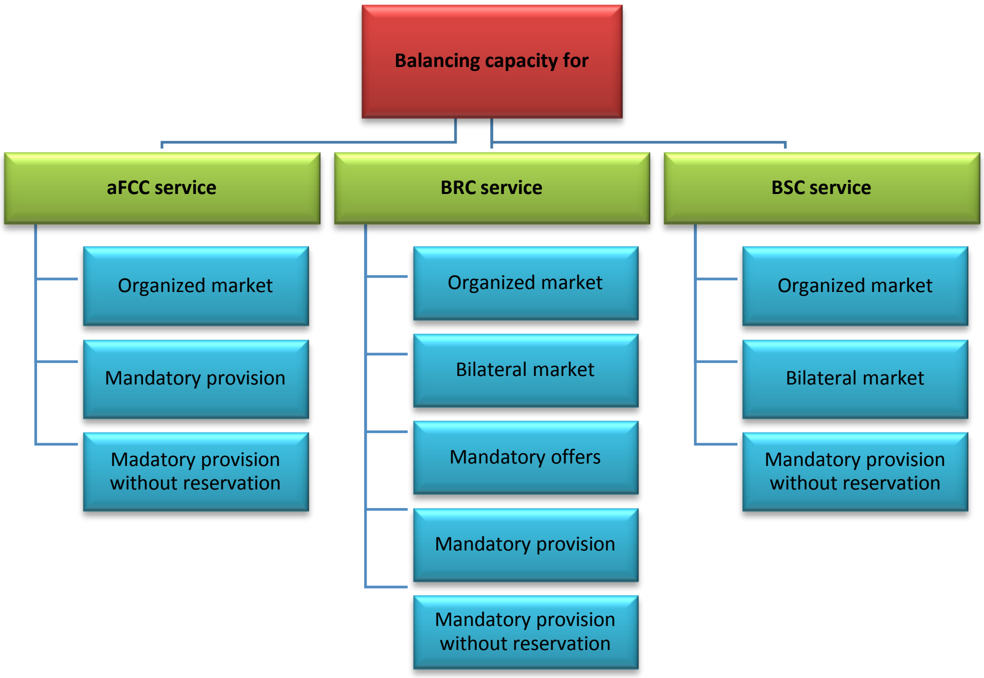


Figure 11-3. Methods for procurement of the balancing capacity

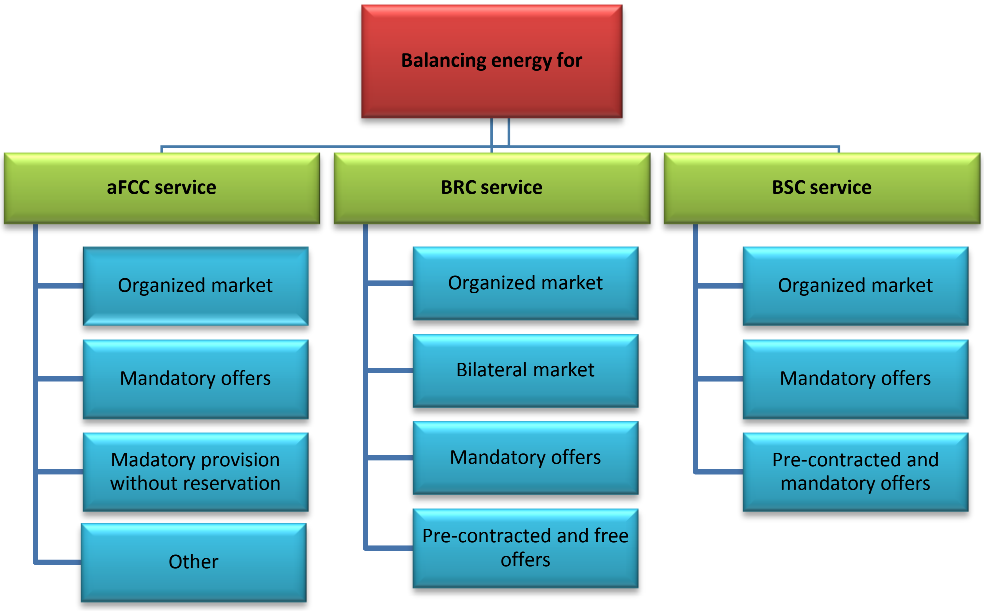


Figure 11-4. Methods for procurement of the balancing energy

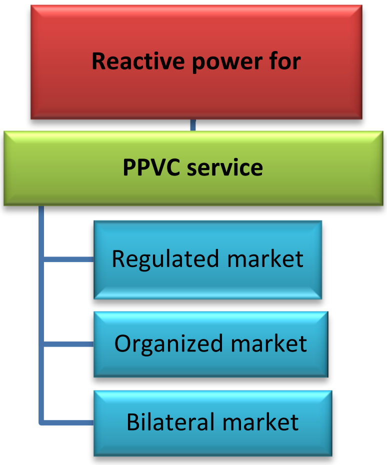


Figure 11-5. Methods for procurement of the voltage control product

Organized and bilateral markets (bOTC) are recognized as two main market arrangements from the several market models implemented around the world for procurement of balancing and voltage control products.

Balancing and voltage control products could be provided by the BSPs to the CSO by bidding in the organized market. The peculiarity of the procurement scheme is that there is no contract or obligation for the BSPs to offer the capacity for inertia, balancing capacity, inertia, balancing energy and reactive power in the market; the BSPs voluntarily participate in the market and bid a volume and price at which would wish to sell. This is a centralized market, where the CSO utilizes a merit order to dispatch the generators and loads in a least cost manner. Besides, standardized products with a short duration are exchanged. The organized market model enhances transparency and fosters competition. The drawback of the market model is high data management costs and availability to facilitate the exercise of market power by some BSPs.

Balancing and voltage control products could be acquired by the CSOs in the bilateral market, when the BSPs and the CSO negotiate a contract regarding the offered balancing and voltage control product (its quantity and quality) and its price. Negotiations (through the customization) provide a flexible way to determine prices, quality of the service, financing terms and other, but they are costly (high transaction cost) and time consuming. The CSO and the BSPs may want customized contracts that offer flexibility because there are many uncertain factors that have an influence on predictions of electricity consumption, production and price in the future. The flexibility enables them to make adjustments more easily and at lower cost when the factors become better recognized. The economists argue that this type of market arrangements is decisive to the functioning of electricity markets, because they provide parties with price stability and certainty necessary to perform long-term planning and to make rational and socially optimal investments. Bilateral contracts are valuable since they protect the BSPs and the CSOs against price uncertainty and make revenue and payment streams more predictable. As a result, investment decisions are facilitated. Within the WoC concept they could be used to provide location based services (reactive power) where there are potentially insufficient volumes of competition. The bilateral market is a decentralized market, where the CSO is constrained in scheduling by negotiated contract price and volume. The advantage of the bilateral market model against the compulsory provision is the fact that the CSO procurers only the amount it needs and deals only with the cheapest BSPs. However, the bilateral market model has drawbacks [30]:

- The terms of the bilateral contracts are not disclosed to the third parties;
- They lack in transparency that is desirable if one of the participant is a monopoly (for example, at least the CSO);
- Negotiations can be long, complex and costly;
- Because of high transaction cost of the bilateral contracts, price and volume are often fixed for a long time. The condition can be harmful to at least one party if terms in the market change.

The distinction feature of bilateral markets is the continual process of trading with prices unique to each transaction.

If the first two procurement schemes considered within the WoC concept have voluntary basis, the latter procurement schemes are based on the principle of mandatory (compulsory) meaning that the BSPs may be obliged to provide balancing services through so-called mandatory offers, mandatory provision or mandatory provision without reservation:

- Subject to the procurement scheme of the mandatory offers the generators connected to the network are obliged to offer the remaining / available capacity to the CSO;
- The procurement scheme of the mandatory provision obliges the generators connected to the network to reserve a certain amount of capacity in order to meet the CSO requirements for a fixed price set by the CSO, NRA or for free.
- The procurement scheme of the mandatory provision without reservation means that it is mandatory for the dispatchable units to be able to provide balancing capacity, but these units are not required to reserve balancing capacity to provide this service.

The compulsory provision is “fair” if all the BSPs belonging to a certain class are obliged to provide the same absolute or relative amount of the balancing services. The requirements for the compulsory provision are often set in a way that does not takes into account the whole complexity of issues which impact on low fairness and poor transparency. As a result:

- Volume of the balancing services may exceed what is required, thus, imposing needless cost to the BSPs.;
- Compulsory provision may not inevitably minimize cost since both high- and low-cost BSPs are treated equally.

Altogether, these reduce price efficiency.

Theoretically, the CSO may own balancing resources themselves and use them. However, the Article 40 of the Proposal for a Directive on Common Rules for the Internal Electricity Market (“Winter Package”) [23] states that high voltage system operators should not own assets that provide AS. The Article 36 and the Article 54 of the Proposal [18] on DSOs and TSOs ownership of storage facilities set that DSOs and TSOs should not be allowed to own, develop, manage or operate energy storage facilities, which also means that if they do not own they cannot use the facilities for the purpose of AS provision.

Within the framework of a new market design proposed in the “Winter Package”, the EC provides a valuable interpretation of the future direction, by not only having a very strong focus on making markets for the balancing products, but also ensuring that these markets are driven by competition between market participants and not gradually becoming included in the realm of SOs. The WoC concept is in agreement with this notion. Namely, the WoC concept agrees on the statement that "*the procurement processes of balancing energy is transparent while at the same time confidential...*" and *"…the procurement of balancing capacity … is organized in such a way as to be non-discriminatory between the market participants…*". Moreover, the rules for the procurement of balancing capacity should comply with the following principles [18]:

- The procurement method is market-based for at least the secondary (frequency restoration reserves) and the tertiary (replacement reserves) control. Non-competitive procurement methods seldom provide a clear signal of the real cost of energy and capacity and are more vulnerable to corruption;
- The procurement process is performed close to real time to the extent possible;
- The contracted volume is divided into several contracting periods".

Taking the requirements established in the "Winter Package", advantages and disadvantages of the procurement schemes into account, it is recommended that the CSO would use the organized market for the procurement of balancing products: inertia capacity, inertia, balancing capacity and balancing energy.

The WoC concept keeps an idea that voltage control product is a commercial service. Thus, it is not provided for free, the practice, which is viable in some European countries, including Germany. The WoC assumes that voltage control service is provided by the generating units on the voluntary basis. This is the reverse attitude towards the existing practice in Europe, where, generally, the provision of the service is mandatory / compulsory. Moreover, the regulations of European countries allow exemptions. For example, in Greece RES are exempted from the provision of the voltage control service. In Hungary, the voltage control service provision is mandatory if the installed capacity of the power plant is more than 50 MW and the power plant is connected to the transmission grid or 132 kV. In Spain, all units connected to the transmission grid with the rated power equal or above 30 MW should provide the voltage control service. The WoC concept considers that any exemption has a discriminating color, thus, should be eliminated by developing a transparent and non-discriminating procurement scheme for the voltage control service. The argument that generating plants must use the (free-of-charge) reactive power to balance the rise in voltage caused by them leads to unequal treatment of generation, storage and purchasing installations, with the latter even generally being said to have a voltage-lowering effect [31]. Outgoing from this, the WoC concept speaks for the procurement scheme subject to which voltage control service may be provided on the voluntary basis by all types and size of the generating units that are connected to all levels of the grid.

The WoC concept assumes that market-based approach regarding the procurement of reactive power should be taken. It should provide the corresponding stimulus to orient the provision of reactive power in line with needs and at minimal costs, to the extent that there are incentives for a careful use of reactive power in terms of providing it, but also in terms of deploying it and of the related losses and restrictions to the transmission capacity [31].

The WoC concept assumes that priority should be given to the procurement of the voltage control service in the organized market instead of the regulated and bilateral markets. However, there is no a requirement to organize an auction: because of the strong local reference of reactive power, it should also be possible on a bilateral basis [31].

In the organized market, namely market decides on the price of the service, but not the relevant regulatory authority, which may be completely lack or poor of information about the company's costs and the quality of the services it delivers. In the bilateral market, the contracted parties who provide the voltage control service are paid based on their offer price (pay-as bid), which is known by economists as discriminatory. As such it is not accepted by the WoC concept. Moreover, since the voltage control services are local, they could be agreed on bilateral basis in cases there are potentially insufficient volumes of competition, which result in the exercise of market power [30].

Pricing mechanism. Market-based pricing mechanisms and pricing exercised by the NRA or the CSO are considered (Figure 11-6).

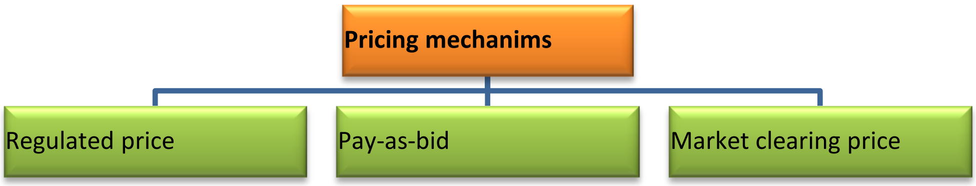


Figure 11-6. Pricing mechanisms for balancing and voltage control products

By definition, the regulated price is set by the NRA or the CSO and is the same for all the BSPs. The use of regulated price is related to the mandatory provision of the products by few BSPs (often large producers) since there is no information to choose the BSPs based on their cost [5]. As it is argued by [5], even if the rules allow for new entrants, such as aggregators to propose products, the selection of the reserve will be made by an administrative rule, which would not allow new actors to compete effectively with incumbent actors. Thus, this form of pricing should be or is used, when market power is an issue in the market. However, a regulated price is not a desirable since it reflects very imperfectly the actual cost of providing the products, especially, if cost changes in time and circumstances [30]. This means that regulated price does not take into account the market value of electricity generation [5]. With a fixed guaranteed and unchanging price, a generator can receive cross-subsidies [5].

Two alternative market-based pricing rules are considered. These are uniform (pay-as-clear) and pay-as-bid pricing rules.

In uniform pricing, all the actors with accepted bids are paid a uniform (single) price, which is called the Market-Clearing Price (MCP), regardless of their bids. The MCP is determined as the offer price of the highest accepted offer in the market, as it is shown in Figure 11-7.

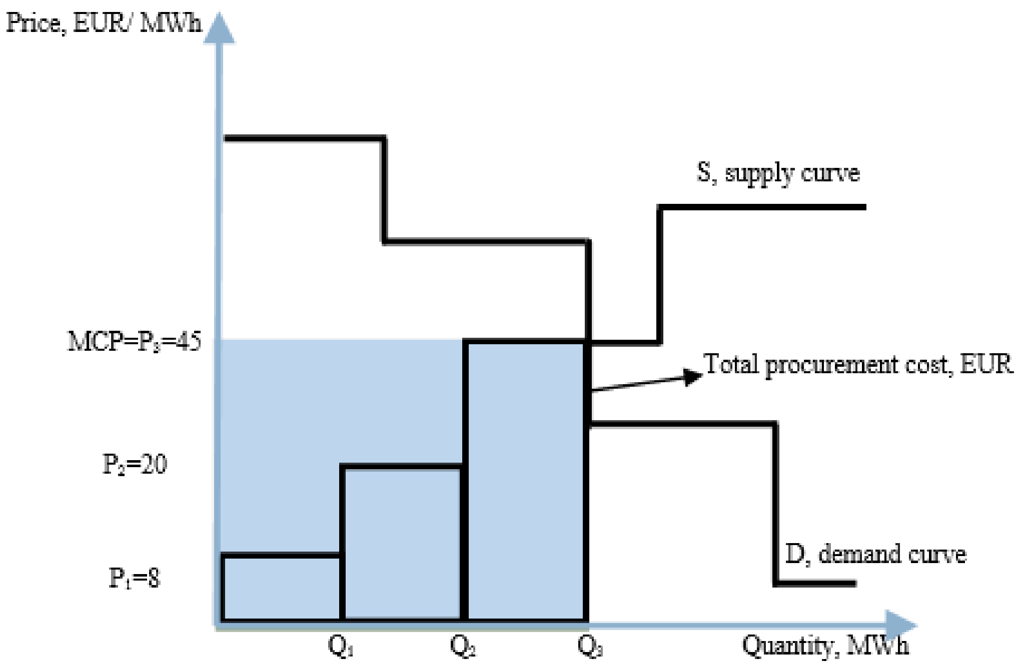


Figure 11-7. Price determination and total procurement cost subject to uniform pricing rule

The concept of the unified pricing rule (Figure 11-7) is explained by using an example of a market for balancing products with the BSP owning solar unit having low production cost of 8 EUR/MWh, the BSP owning a base-load coal generation unit having production costs of 20 EUR/MWh, and the BSP with a gas-fired peak generation unit having more than twice higher production costs of 45 EUR/MWh. Off-peak, when demand for balancing product is low, solar and coal generation units are requested to meet the demand. The MCP for balancing product is set by the BSP's, who owns a coal generation unit, submitted offer price, which is 20 EUR/MWh. On-peak, when demand is high, both solar, coal and gas-fired generation units are required to meet the demand and the MCP is set by the offer of the BSP, who owns gas-fired generation unit, which is 45 EUR/MWh. On-peak, the BSPs, who are the owners of both solar, coal and gas-fired generation units, receive the MCP, which is 45 EUR/MWh (Figure 11-7). The difference between the MCP on-peak and the production costs of solar and coal allow the capital-intensive solar and coal generation units to recover at least some of their fixed cost. It is beneficial to apply the MCP because the price aligns the actions of the BSPs and CSOs with maximizing the gains from the trade.

The reason for the application of the uniform pricing rule to determine the price in the market for balancing and voltage control products is twofold:

- *The incentive to provide for efficient dispatch*. The uniform pricing rule means that the BSPs offer balancing and voltage control products at prices closely reflecting their marginal costs. This result in operationally efficient dispatch meaning that demand is supplied by the lowest cost resources and technologies, which are owned by the BSPs;
- *The optimal investment* means that the sound generation technologies are constructed in right places at required time with the investment risks borne by the investors but not tariff payers.

[32] considers four principal criticisms against the application of the uniform pricing rule to set the MCP (Figure 11-8).

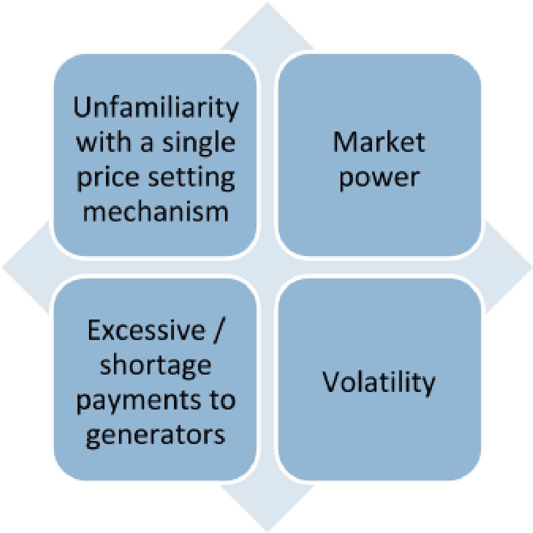


Figure 11-8. Principal criticism of the uniform pricing rule

The critique [32] of employing the uniform pricing rule includes a reference to the thoughtful unfamiliarity with the price setting process and application possibilities. However, critics do not notice that the pricing mechanism is successfully implemented in other commodity markets. Nowadays, considering to its wide application in all timeframes of electricity market, the argument is not significantly relevant, but it should be taken into account when introducing a unified pricing rule in newly developed markets, including the market for balancing and voltage control products. The potential exercise of market power is a concern too, but if a market power is a concern under the uniform pricing rule, it is also a concern under an alternative pricing rule, i.e. pay-as bid. [32] argues that the shift from a uniform pricing rule does not prevent the exercise of market power. A number of measures available to mitigate market power that is consistent with the uniform pricing rule could be used. Since the MCP could set by the expensive offers (for instance of gas-based generators), there is a criticism about the excessive level of payment to base-load resources such as coal and nuclear generators – particularly to owners of old assets those construction costs were lower than presently new construction cost. This means that BSPs owning old base-load generation units receives high operational profit. However, the excessive payments to the BSPs is reduced by allowing of varies technologies, including RES having low marginal cost participating in the market. The current practice shows that subject to the uniform pricing rule and high shares of electricity from RES (RES-E) in the market, electricity prices are low or even negative. The generation side is threatened by closure of conventional power plants that are presently experiencing decreasing profitability due to low electricity prices and limited number of operating hours. However, changes in pricing rule at reducing or increasing profitability to the generating assets are unfair. It would signal to the investors in generating assets that they are exposed. Volatility of prices caused by the unified pricing rule is an issue too but forward contracts could be applied to hedge against price variability and reduce exposure to volatility.

Under the pay-as-bid pricing rule, prices are set based on a first-come, first-served principle, where best prices, which are the lowest selling prices offered by the BSPs, come first. Figure 11-9 illustrates price setting and total procurement cost of the pay-as-bid pricing rule.

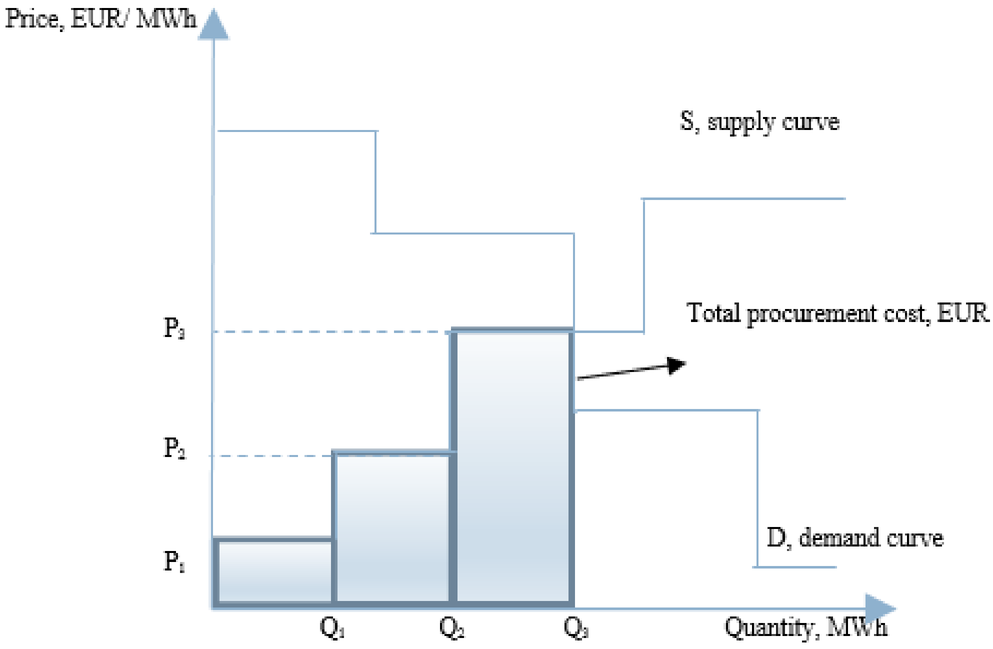


Figure 11-9. Price determination and total procurement cost subject to pay-as-bid pricing rule

As it is seen from Figure 11-9, in a pay-as-bid pricing, the BSPs with the accepted bids are paid according to their bids, i.e. prices P_1, P_2 and P_3, respectively. No single MCP is established under the pay-as-bid pricing rule. Total Procurement Cost (TPC) is the sum of individual procurement cost, as it is expressed by Eq. (1):

$$TPC=\sum P_n \times Q_n \qquad (1)$$

where: n – is the identification BSP; P_n – price of accepted bid of the n-th BSP; Q_n – volume of accepted bid of the n-th BSP.

Thus, total procurement cost, which is defined as the payment by the CSO as a representative of demand side, typically involves the demand paying a price that is equal to the BSPs weighted-average price. Using the BSPs-weighted average price ensures that the total payment by the CSO equals total paid to the BSPs.

The pay-as-bid pricing rule typically is put forward as a measure to mitigate market power, reduce the payments to the BSPs and reduce volatility, i.e. to tackle the issues of the uniform pricing. The pay-as-bid pricing rule used for continuous trading meaning that the BSPs and the CSOs submit supply and demand bids to a central platform (exchange) and matching bids are continuously cleared on an individual basis. The continuous trading order book is visible to all actors and contains all submitted bids that have not cleared yet. The BSPs can cancel submitted and not-cleared bids at any time. Continuous trading bids are matched based on price-time priority: orders are matched in sequence of the attractiveness of their price. If offers have identical prices, the time of submission is the decisive factor. It implies that the BSPs have to anticipate the MCP and accordingly mark up their bids. There is no empirical or experimental evidence that pay-as-bid or other alternatives would reduce prices significantly compared to a single MCP design. In fact, some evidence suggests that pay-as-bid would increase prices compared to explicitly setting the single MCP. Moreover, pay-as-bid has some significant drawbacks:

- When bidding truthfully, non-marginal BSPs may face lower remuneration for the balancing products they supply compared to the uniform pricing. In such cases the counterparty (CSOs) faces more favourable prices compared to a uniform pricing, but risks losing the opportunity to match bids if it waits too long. Thus, continuous trading with a pay-as-bid pricing may incentivize actors do to not bid truthfully, which may result in incorrect demand and supply signals;
- A market based on continuous trading with the pay-as-bid pricing instead of discrete auctions with the uniform pricing includes a certain first-come-first serve characteristic, as matching bids are immediately cleared, which may not lead to welfare maximization and optimal allocation of balancing resources, especially in illiquid markets;
- An important question regarding the organization of continuous trading with a pay-as-bid pricing that is not answered yet includes the optimal number of auctions and their timing, taking into account the impact on liquidity;
- Inefficient dispatch. Under the pay-as-bid, a profit maximizing offer involves predicting the MCP. When uncertainties exist, the forecast is inaccurate and different BSPs will forecast different price values. Since the CSO uses offers to decide on the dispatch, this means that occasionally a high marginal cost BSPs with a lower offer will be dispatched instead of low marginal cost BSP submitting higher offer, i.e. the efforts to maximize profits will result in inadequate dispatch decision. Inefficient dispatch wastes costly resources and is undesirable;
- Another inefficiency of pay-as-bid pricing is the cost of forecasting market prices that it will impose on all BSPs and CSOs. Under the uniform pricing rule, the BSPs are motivated to bid at marginal cost, which are readily available to them. If the method is changed to pay-as-bid, uncertainty about market price calculation and large cost to forecast it are introduced. Moreover, small companies achieve much higher cost per unit of output, although they put as much efforts to forecast price as large ones.
- Bias against small BSPs. The basic argument against pay-as-bid pricing rule is that the BSPs face relatively greater costs in the assessment required to form their offers for pay-as-bid pricing rule than assessment required for offers for uniform pricing rule. Under the pay-as-bid pricing rule, the MCP is forecasted instead of offering a price reflecting the marginal cost. This requires market knowledge and more investment in market analysis and data gathering are required. Large BSPs could spread the associated cost across a greater amount of output while this is not possible by small BSPs who as a result may lose their competitive position. From this perspective, pay-as-bid is more favourable to large BSPs. A pay-as bid pricing rule make it relatively harder for new entry by small BSPs than entry under the uniform pricing rule.
- Difficulties with market monitoring. The aim of market monitoring is to assess if prices are not competitive. The assessment is done considering the offers. Under a pay-as-bid pricing rule, competitive offers involve mark-up above the marginal cost. There is no easy to assess if or not such offers are exploiting market power, i.e. market power monitoring becomes impossible under the pay-as-bid pricing rule. Under the uniform pricing rule there is a particular test to monitor market power. This is an assessment whether offers track marginal cost.
- Investment. Under the pay-as-bid pricing rule, the prices paid to the BSPs would be driven towards recovery of operating cost only. This would fail to provide enough remuneration to cover investment cost. Owners of generating assets will find themselves going bankrupt

and no new investment will be available. Thus, pay-as-bid impede capacity expansion, which alongside with a demand-side response is a measure for a better performance of the market. The pay-as-bid impede new entry, which is a measure of mitigating market power.

- Tend to weaken the competition in generation that is the remedy against of monopoly power, which may cause the steady price increase at times of peak demand.

Pricing mechanism for the WoC power grid structure is chosen in a way that the selected pricing mechanism performed three important functions:

- *Signalling,* meaning that changes in prices provide information both to the CSO and the BSPs about changes in the market conditions, prices reflect scarcities and surpluses,
- *Transmission* of preferences meaning that through the choices the CSO send information to the BSPs about the changing nature of needs;
- *Rationing* meaning that when there is a shortage of balancing product, its price will rise and deter some CSO from buying the balancing product.

In relation of the pricing mechanism to perform signaling function, the regulated fixed price does not satisfy it, since it is established by the NRA or the CSO but not by market forces. Unified and pay-as-bid pricing rules satisfy all functions of the pricing mechanism. The “Winter Package” foresees that the unified pricing rule as an advanced method of pricing should be applied for the pricing balancing energy instead of pay-as-bid.

Considering to results of analysis of advantages and disadvantages of different pricing mechanism and in accordance to the proposal of “Winter Package”, that prices should be formed based on demand and supply and price signals should drive the market to react to shifting energy demands and fluctuating renewable energy generation, the concept of Web-of-Cells power grid structure suggests that all balancing products are priced by a unified pricing rule.

Cascading procurement. A sequential auction with uniform and without the substitution of a higher-quality service for a lower-quality service may result in a price reversal. “Price reversal” is the phenomena when prices for lower-quality services are set higher than prices for higher-quality services. Lower-quality products clear at higher prices than higher-quality products due to lower capacity availability after the initial rounds of procurement. To examine how the price reversal may occur, a behaviour of the generator, which keeps small capacity for higher-quality service and as a result maintains large capacity for lower-quality service that is offered at high price, could be discussed. In this case, the CSO has to satisfy demand for higher-quality service by purchasing it from other generators. Consequently, the CSO has no choice but to pay high price for lower-quality service offered by the first generator since there is no sufficient lower-service providers as they sold their capacities for higher-quality service. The lack of competition is increased and it becomes necessary to plan measures preventing the generator to introduce low-quality service for higher prices. In the perfectly competitive markets, the phenomenon should not be found. The WoC concept foresees what is called the cascading procurement to solve the issue of the “price reversal”.

To achieve the cascade, the sub-markets of balancing products are cleared in sequence starting with the highest quality and applying the rule of substituting the higher-quality lower-cost services for the lower-quality higher-cost services if total procurement cost is reduced. Qualities of reserves are graded by quickness and sureness of their response. The benefit of the variable of market design – the cascading procurement – is both reduced procurement cost and expanded supply.

The main question is how the substitution should be conducted? The WoC concept assumes that any surplus of high-quality balancing product could be by the auctioneer (CSO), automatically transferred to the market for lower-quality service and so on. This should increase the efficiency of the markets compared to the absence of a cascade.

It is worth noting that cascading procurement contributes to the reduction of price reversal but it cannot avoid. For example, if there is shortage in the market for low-quality service and totally, but not in markets for high- and medium-quality services, then the price in the market for low-quality service is set higher than in other markets. In such case, high-quality reserve units will try to sell in the market for low-quality service. Indeed, this could result in an inefficient use of reserves.

Remuneration scheme. Balancing and voltage control products are procured on commercial basis and the BSPs are remunerated for the provision of these products.

The CSOs can apply different remuneration mechanisms for the BSPs who provide balancing products and voltage control products (Figure 11-10). The BSPs could be remunerated either for availability or / and utilization of capacities.

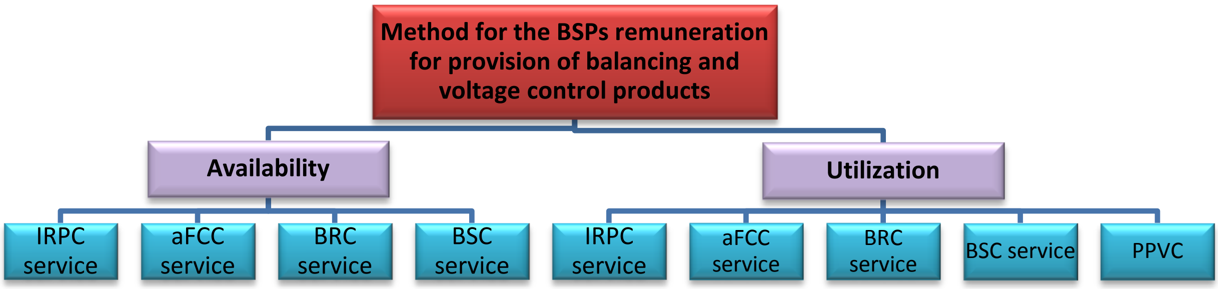


Figure 11-10. Methods of the BSPs remuneration for balancing products

In case of aFCC, BRC and BSC services, the CSOs pay the BSPs for balancing capacity availability (i.e. for holding balancing capacity) and for its utilization (i.e. for the delivery of balancing energy) (Figure 11-10):

– The availability payment is made to the BSP in return for the balancing capacity being made available to the CSO during the market time unit. The availability payment is equal to the price (EUR/MW) at which all the BSPs are paid for holding balancing capacity for the market time unit;
– Later, when balancing capacity is called upon, in addition to the availability payment the CSO pays a utilization price (EUR/MWh) for balancing electricity delivery. The utilization price may be noticeably different from the price the BSP asked for the activation of balancing capacity. The utilization price therefore reflects the prevailing market price at the time of use.

In case of IRPC service the BSPs are remunerated for availability of inertia providing capacity (EUR/(MW*s)) and for its utilization (delivery of inertia) (EUR/kgm^2) too.

In case of PPVC service, the BSPs are remunerated for usage (utilization) of reactive power. The requirements for the remuneration mechanism are as follows [31]:

– The remuneration mechanism is logical and technology-neutral, and covers all grid levels, whilst still permitting differences for specific voltage levels;

- The remuneration mechanism is developed in a way an attention is paid to the reflection of cost of providing the reactive power (EUR/VAr);
- The participation and remuneration take place without distinction between installations of consumers, grids, generating plants and storage operators.

Activation strategy. In Europe, most TSOs instruct the BSPs in parallel and the requested balancing service is distributed pro-rata to the BSPs connected to the Load-Frequency Controller (pro-rata activation). Five TSOs select the cheapest energy bids based on the merit order (merit order activation) [33].

Considering to the European practice, the CSO may apply two types of activation schemes for the BSPs. These are pro-rata and merit order schemes.

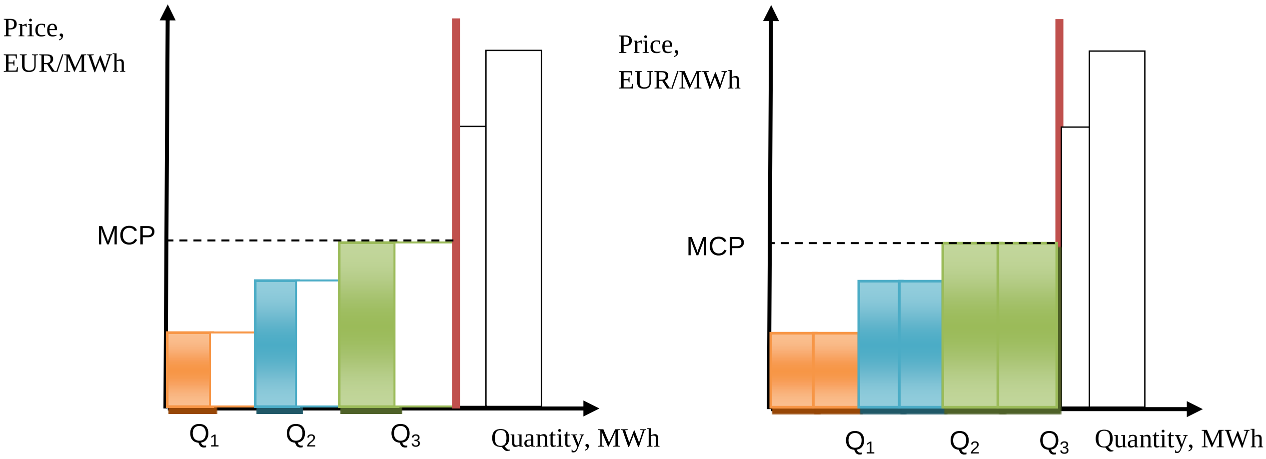


Figure 11-11. Activation schemes for the WoC concept: a) pro-rata and b) merit order

In the pro-rata activation scheme, all balancing products providing units are activated simultaneously, which ensures that all available ramping speed is used (Figure 11-11 a). However, the activation does not take into account differences in energy price or energy cost. A merit order activation scheme activates bids one-by-one in energy price order (Figure 11-11 b). Consequently, only the ramping speed of the activated bids is used.

Two different methods may be applied by the CSO to activate balancing service. These are “continuous” activation and step-wise activation. Subject to the “continuous” activation, the signal that the load-frequency controller sends to the CSO is updated every particular period with the new set-point following the required ramp for the BSP. The BSPs are required to follow this signal. Subject to the step-wise activation, the CSO activates an energy bid at once by a single set-point change. The BSP shall respond within the balancing service full activation time and at least with a linear ramp rate.

“Continuous” activation is typically used with pro-rata activation scheme and step-wise activation with merit order activation.

In compliance with Article 29 on activation of balancing energy bids from common merit order list [18], each CSO shall use cost-effective balancing energy bids available for delivery in its Cell based on the merit order list, i.e. within the WoC concept merit order activation is applied. Inertia is activated based on merit order principle. The reactive power is activated based on optimal power flow calculation.

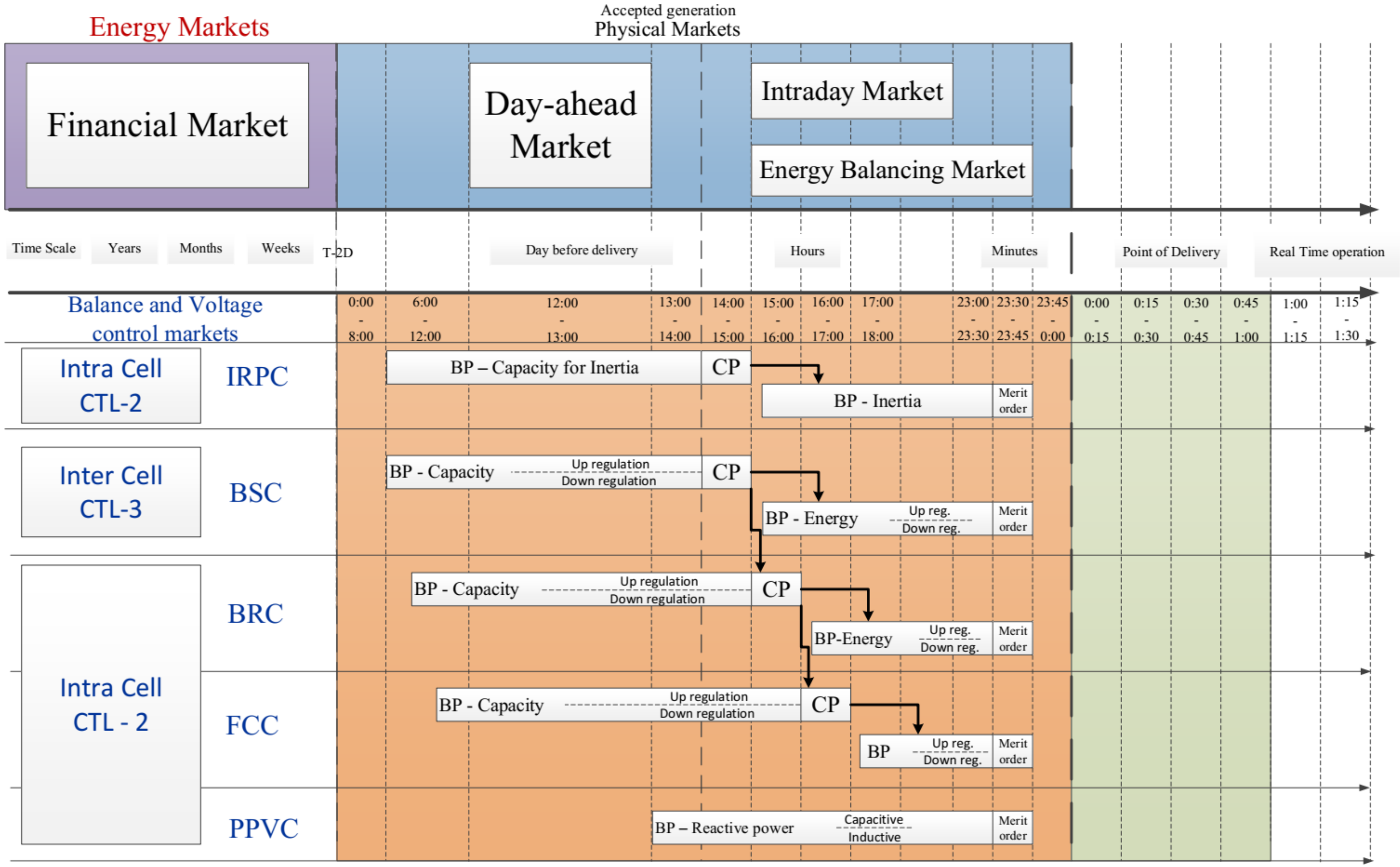
Timing of market for balancing and voltage control products. The composition and alignment in time of timing of sub-markets for balancing and voltage control products are provided in Figure 11-12.

As it is seen from Figure 11-12, the trade in balancing and voltage control products are organized in Cell- and inter-Cell levels. The IRPC, aFCC, BRC and PPVC services are traded within a particular Cell, but the BSC service is traded between the Cells, i.e. the CSOs organize a common auction to trade in the BSC service.

The timing of sub-markets for balancing and voltage control products is organized in a way that initially, the BSPs decide on in which sub-market – inertia or balancing capacity – they take part in. Those BSPs who decide to participate in the sub-market for inertia and whose bids are accepted for a particular market time unit, are not allowed participating in other sub-markets for this market time unit. The same is valid for the BSPs who bid the balancing capacity. Those BSPs who decided to participate in the sub-market for balancing capacity for a particular service and whose bids are accepted for a particular market time unit, are not allowed participating in other sub-markets, except in the sub-market for balancing energy. Moreover, those BSPs whose bids of higher quality balancing capacity are rejected by the market can bid the sub-market for lower-quality frequency balancing capacity or bid the sub-market for voltage control services, if they satisfy bidding requirements.

The sub-markets for balancing capacity are organized earlier than sub-markets for balancing energy, since balancing energy bids are submitted to the market by the BSPs who won balancing capacity auction and thus have an obligation to keep the balancing capacity for the particular market time unit. Thus, a clear interrelationship of the timing of sub-markets for balancing capacity and balancing energy is established. The sub-market for balancing energy opens several minutes later, after the clearing of the sub-market for balancing capacity.

The sub-markets for upward and downward regulations are organized in parallel, i.e. they have the same timing.



Note: *BP* – bidding process; *CP* – clearance process.

Figure 11-12. Timing of sub-markets for balancing and voltage control products and their interrelationship

The WoC concept assumes that sub-markets for balancing capacity and balancing energy for the aFCC, BRC and BSC services are organized / arranged in a sequential manner. After a sub-market for balancing capacity for the BSC service is cleared, a sub-market for balancing capacity for the BRC service is cleared and later on a sub-market for balancing capacity for the aFCC service is cleared. For the implementation of the principle of cascading procurement and in such a way limiting the emergence of “price reversal” effect of lower quality balancing capacity to be priced at a higher price, higher quality balancing capacity is cleared one hour earlier than lower quality balancing capacity. This hour is required both to move rejected by the market higher quality balancing capacity bids (the bids submitted but not accepted by the sub-market) to a sub-market for lower quality balancing capacity, if they correspond to technical requirements of this sub-market, and clearing the sub-market.

The timing of sub-markets for reactive power is organized in a way that merit order is established. According to the current specification of PPVC, no merit order function is considered. Activation is based on real-time OPF (which considers as an initial assumption that all resources have the same price).

An approach taken into account when setting the timing of sub-markets is discussed in detail in Annex 13.

11.4 Imbalance settlement elements

In real time, deviations from scheduled supply and demand of electricity need to be solved by the CSO through the activation of balancing capacity.

The concept of imbalance settlements refers to how imbalances (i.e. how many MWh, kgm^2 or VAr and at what time) and imbalance prices (i.e. how the balancing costs are allocated per deviated MWh, kgm^2 and VAr) are determined.

The method for allocating cost to market actors plays an important role in terms of encouraging economic efficiency and creating incentives for market actors to support the system supply-demand balance. The method for allocating balancing costs differs widely among countries, and may create an opportunistic value for aggregation [22]**.**

Imbalance settlement period. Pursuant to the “Winter Package” [23] and the European Commission’s Regulation establishing a guideline on electricity balancing [18]. The length of the Imbalance Settlement Period (ISP) is important variable of the market design because it influences on:

- The imbalance pricing methodology (i.e. single or dual);
- The balancing processes required (use of replacement reserves or not);
- The products (e.g. scheduled, pure energy products or only direct activated power products);
- The volume calculation (request or metered).

Pursuant to the European Commission’s Regulation establishing a guideline on electricity balancing [18], the harmonisation of the imbalance settlement period within and between synchronous areas is envisioned. The Regulation [18] imposes the requirement that the imbalance settlement period should not exceed 15 minutes in future, however, each TSO is left with the right to request an exemption from the requirement. In such case, the TSO will have to perform a specific cost-benefit analysis. According to [18], the imbalance settlement period must be 15 minutes in all control areas by 1 January 2025. As it is expected, the harmonisation of the imbalance settlement period to 15 minutes in Europe should support intraday trading and foster the development of a number of trading products with same delivery windows.

In response to the request, the imbalance settlement period of 15 minutes is applied for the WoC concept meaning that the BRP is responsible to have a balanced portfolio at quarter-hourly (15 min) periods.

Types of imbalances. Pursuant to the European Commission's Regulation establishing a guideline on electricity balancing [18], in the WoC imbalance settlement model, each CSO calculates final position, allocated volume and imbalance:

- For each BRP;
- For each imbalance settlement period;
- In each imbalance area, which is the Cell area.

Position means the declared energy volume of the BRP used for the calculation of its imbalance. Each CSO calculates final position of the BRP using the approach that the BRP has three final positions. They are:

- Production;
- Trade;
- Consumption.

Allocated volume means an energy volume physically injected or withdrawn from the system and attributed to a BRP, for the calculation of the imbalance of that BRP.

Imbalance means an energy volume calculated for the BRP and representing the difference between the allocated volume attributed to that BRP and the final position of that BRP within a given imbalance settlement period. An imbalance indicates the size and the direction of the settlement between the BRP and CSO. An imbalance can be:

- Positive imbalance meaning that the BRP is in surplus of electricity,
- Negative imbalance meaning that the BRP is in shortage of electricity.

Outgoing from the theoretical considerations presented above, three types of imbalances of the BRP are calculated:

- Production imbalance;
- Consumption imbalance;
- Trade imbalance.

Production imbalance. Production imbalance volume is calculated based on received settlement data as the deviation between allocated volume of production (= metered production) and final position (= notification of production) based on Eq. (2):

$$Production\ imbalance = Metered\ production - Notification\ of\ production \qquad (2)$$

The calculation is made per Cell at the BRP level and accounts data from parties included into the BRP's hierarchy. Most probably there will be several BRPs per Cell, thus, this should be reflected in the calculations. The production imbalance arises when there is a difference between the actual metered production and the planned production (notification of production). If the BRP produces more electricity than it planned to do, the production imbalance is positive, meaning that there is a surplus in the production imbalance. Thus, the BRP consequently creates a demand for downward regulation. Subject to the negative production imbalance, the actual production is less than planned. The BRP purchase imbalance power from the CSO in order to cover the deficit and creates the demand for upward regulation. The graphical representation of the production imbalance elements is given in Figure 11-13.

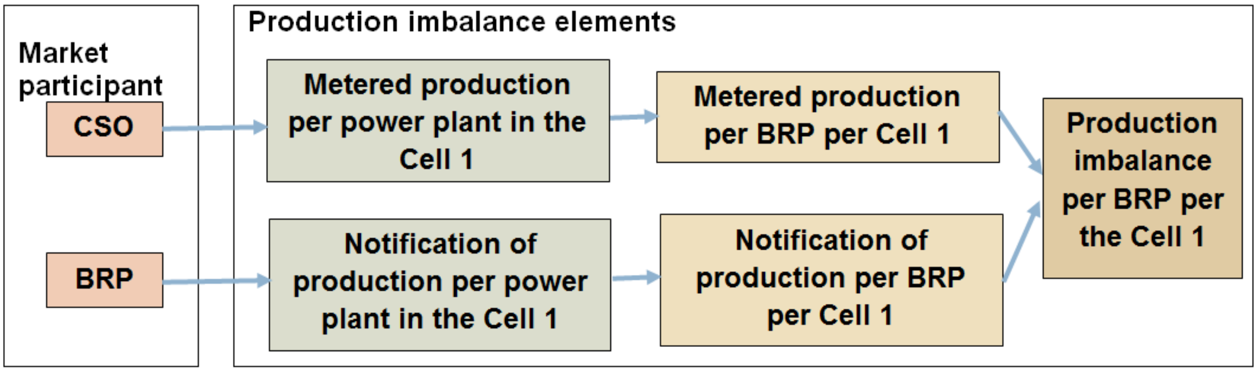


Figure 11-13. Elements of the production imbalance

Trade imbalance. Trade imbalance volume is calculated based on received settlement data as a difference between allocated volume of trade (= metered trade volumes) and final position (= notifications of trade) based on Eq. (3):

$$Trade\ imbalance = (Metered\ export - Metered\ import) - (Notification\ of\ export - Notification\ of\ import) \quad (3)$$

The deficit in trade imbalance arises in case planned trade volume exceeds actual trade volumes. In this case the BRP buys balancing energy from CSO, who itself purchase upward regulation services from BSPs. If the actual net trade volume of BRP to the Cell is higher than the expected (planned) net trade volume, the BRP has a positive trade imbalance, meaning a surplus in trade imbalance. The BRP sells the surplus to the CSO, who itself purchase downward regulation services from the BSPs. Eq. (2) could be re-written to Eq. (4) to show that trade imbalance consists of export imbalance and import imbalance:

$$Trade\ imbalance = (Metered\ export - Notification\ of\ export) - (Metered\ import - Notification\ of\ import) \quad (4)$$

The graphical representation of production imbalance elements is given in Figure 11-14.

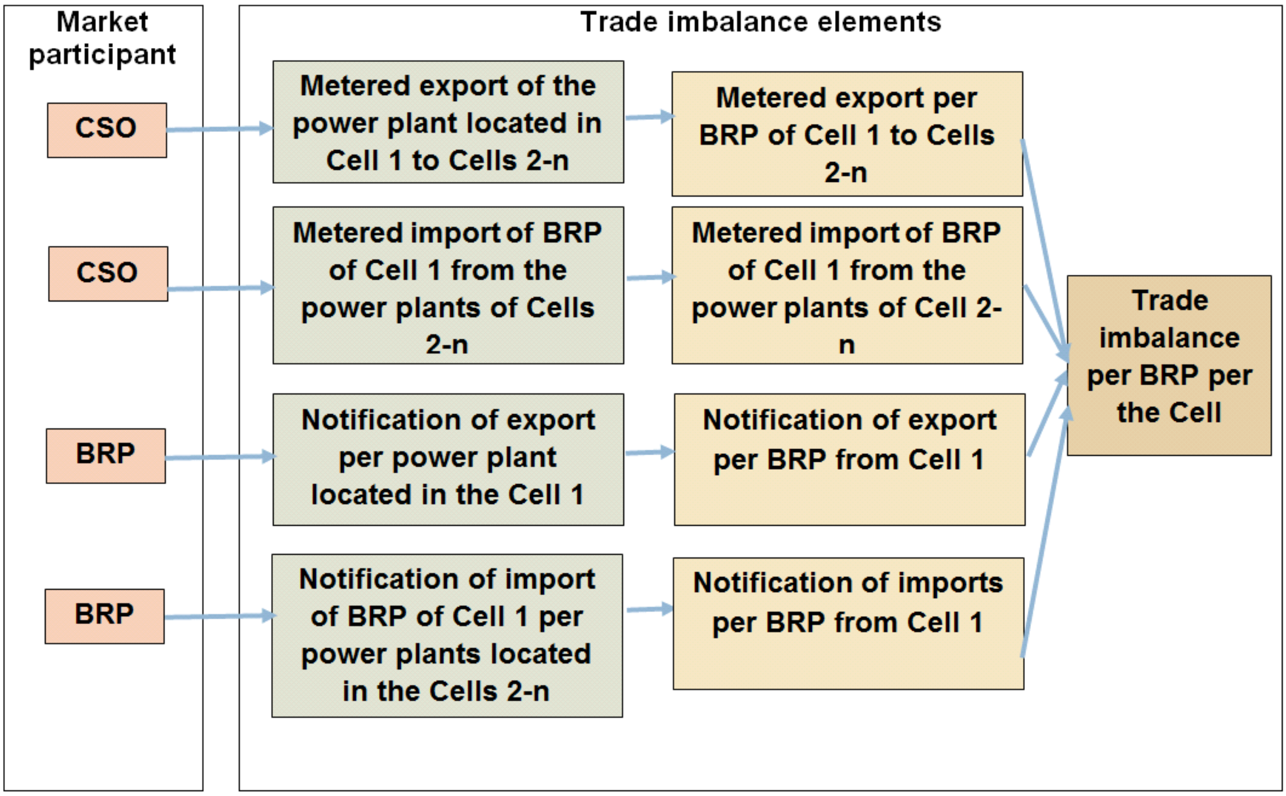


Figure 11-14. Elements of the trade imbalance

Consumption imbalance. Electricity consumption is calculated as a function of electricity production and trade. Outgoing from this, the metered and planned consumptions are calculated by Eq. (5) and Eq. (6), respectively:

$$Metered\ consumption = Metered\ production + (Metered\ export - Metered\ import) \quad (5)$$

$$Notification\ of\ consumption = Notification\ of\ production + (Notification\ of\ export - Notification\ of\ import) \quad (6)$$

The consumption imbalance is calculated by Eq. (7):

$$Consumption\ imbalance = Metered\ consumption - Notification\ of\ consumption \quad (7)$$

If notification of consumption in Eq. (7) is replaced by Eq. (6), then the consumption imbalance is calculated by Eq. (8):

$$Consumption\ imbalance = Metered\ consumption - Notification\ of\ production - (Notification\ of\ export - Notification\ of\ import) \quad (8)$$

As it is seen from Eq. (8), the notification of consumption is not an element of consumption imbalance. The consumption imbalance of the BRP is the difference between the metered consumption and notifications of production and trade. If the consumption imbalance is positive, the BRP has a surplus of electricity, which is sold to the CSO who then purchase downward regulation services from the BSPs. If the consumption imbalance is negative, then the actual consumption is smaller than the planned consumption. In this case, the shortage in consumption imbalance is covered by purchasing electricity from the CSO, who then purchase the upward regulation services. The graphical representation of the consumption imbalance is given in Figure 11-15.

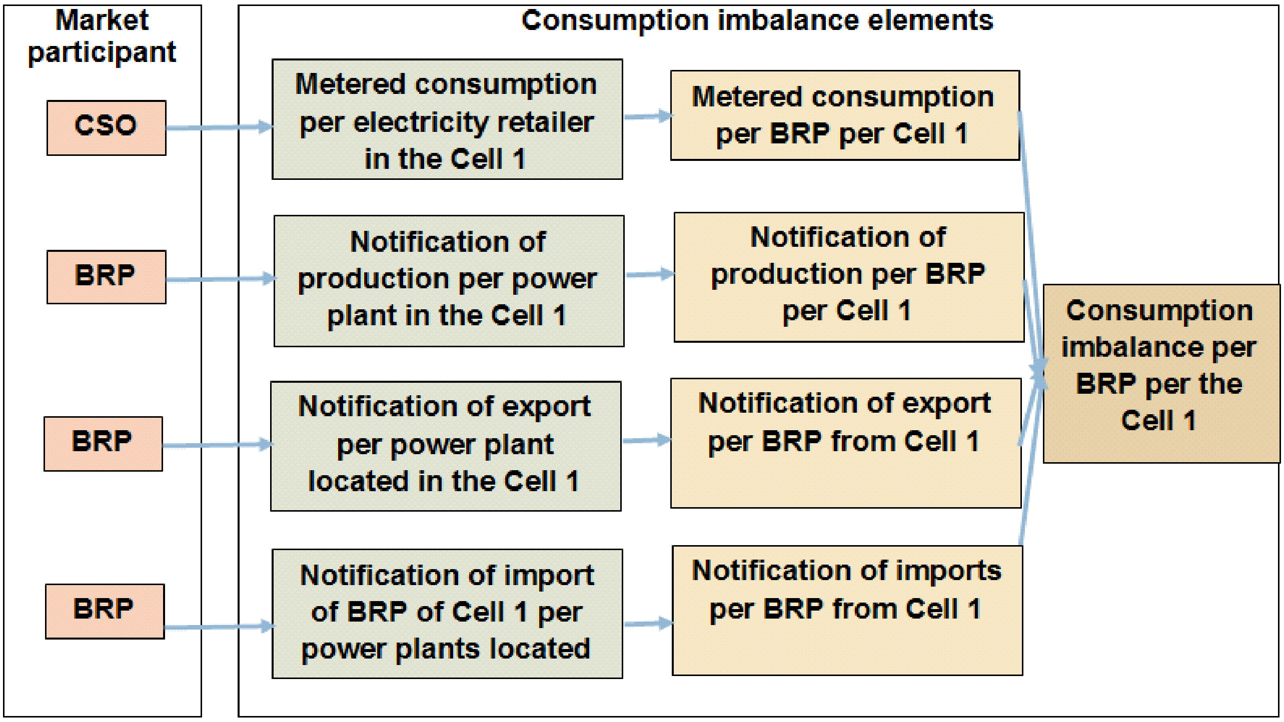


Figure 11-15. Elements of the consumption imbalance

Imbalance price. Each CSO determines the imbalance price for:

- Each ISP;
- Its imbalance price area, which is the Cell;
- Each imbalance direction.

Imbalance pricing mechanism. This is the pricing mechanism used to determine the imbalance prices.

A main design choice for this variable is whether these prices are identical (“single pricing”) or not (“dual pricing”). In Europe, both single and dual approaches for imbalance pricing exist. Imbalance pricing rules have been demonstrated to impact the bidding strategies for wind generators therefore have to be adequately assessed [22]. Considering to the Article 52 of the European Commission’s Regulation establishing a guideline on electricity balancing [18], the WoC concept considers both options.

Under the dual pricing, the imbalance price depends on the direction of the BRPs imbalance in relation to the direction of the net system imbalance. If the BRP’s deviation is in the opposite direction of the net system imbalance, it receives the DA price because the BRP contributes to the reduction of the net system imbalance. If the BRP has an imbalance in the same direction as the net system imbalance, it pays the marginal or average energy price of the activated balancing capacities.

The regulators prefer a dual pricing scheme since it avoids the BRPs to be incentivized to speculate on the direction of the net system imbalance. To reduce the demand for balance capacity on the procurement side of the market, the BRP can help the TSO keep the system balanced by intentionally incurring imbalanced positions in the opposite direction of the net system imbalance, which is known as “passive balancing”. With dual pricing, there is little incentive to provide passive balancing since the DA market price is applied to the BRPs imbalances in the opposite direction of the net system imbalance.

The dual pricing mechanism gives a profit for the CSO due to application of the DA market price instead of regulation price in case the BRP’s imbalance is in opposite direction to the net system imbalance. The profit then could be used to finance the fixed availability payment for balancing capacity.

With a single pricing approach, an imbalance price is based e.g. on the marginal cost of the activated balancing capacities. Imbalance always is priced according to the regulation price in the main direction of regulation in the Cell. Thus, the imbalance price for the BRPs is either a downward or upward regulation price determined for the Cell, irrespective the BRPs has a positive or negative imbalance. This means that it is not relevant whether the BRPs contribute to the net system imbalance or not, they are paid or receive a unified (single) price. Also with a single pricing there can exist an incentive for the BRPs to support the system indirectly. The price stays the same for all, but the volume can be either positive or negative. Price x Volume can result in either positive or negative costs, depending if the BRP supports the system this can result in costs or revenues. During an upward regulation time unit, the imbalance price for all the BRPs is the upward regulation price and, during a downward regulation time unit, the imbalance price is a downward regulation price. If no direction (no regulation has been carried out during an hour), then the DA price formed in the Cell is applied. Single pricing mechanism incentivizes the BRPs to perform a passive balancing. The reasoning for this is as follows:

- The CSO performs upward regulation, if the net system imbalance is negative. Usually, the upward regulation price is higher than the DA price and the greater the quantity of upward reserves is activated, the higher the upward regulation price (which is the imbalance price for the BRP) is achieved. High upward regulation price motivates the BRPs to have a positive imbalance, sell electricity surplus to the CSO and receive a high upward regulation price.
- The CSO performs downward regulation, if the net system imbalance is positive. Usually, the downward regulation price is lower than DA market price. Thus, the BRPs will seek to achieve a negative imbalance, buy electricity from the CSO at low downward regulation price.

Such behaviour of the BRPs is understood as a good contribution to the increasing flexibility which demand will rise in future because of ongoing transition towards variable RES and closure of the conventional power plants which experience decreasing profitability due to low electricity prices and a limited time of operation, but highly depends on the implementation of the price and the coupling of the price to the spot market. In case it is not coupled to the market, it could result in non-optimal arbitrage possibilities.

The single pricing does not give the CSO a profit from the market. Therefore, the fixed costs of the CSO have to be financed in another way.

The peculiarities of imbalance pricing mechanisms are given in Table 11-1.

Table 11-1. Peculiarities of imbalance pricing mechanisms

Net system imbalance	BRP's imbalance	BRP's role	CSO's role	BSP's role	Main direction of regulation	Type of price applied to BRP
Dual pricing mechanism						
Positive	Positive	Sells power to the CSO	Buys power from the BRP and sells it to the BSP	Withdraws power surplus	Downward regulation	Downward regulation
	Negative	Buys power from the CSO	Sells power to the BRP and buys it from the BSP	Injects power deficit	Downward regulation	Day-ahead
Negative	Positive	Sells power to the CSO	Buys power from the BRP and sells it to the BSP	Withdraws power surplus	Upward regulation	Day-ahead
	Negative	Buys power from the CSO	Sells power to the BRP and buys it from the BSP	Injects power deficit	Upward regulation	Upward regulation
Single pricing mechanism						
Positive	Positive	Sells power to the CSO	Buys power from the BRP and sells it to the BSP	Withdraws power surplus	Downward regulation	Downward regulation
	Negative	Buys power from the CSO	Sells power to the BRP and buys it from the BSP	Injects power deficit	Downward regulation	Downward regulation
Negative	Positive	Sells power to the CSO	Buys power from the BRP and sells it to the BSP	Withdraws power surplus	Upward regulation	Upward regulation
	Negative	Buys power from the CSO	Sells power to the BRP and buys it from the BSP	Injects power deficit	Upward regulation	Upward regulation

The WoC concept supports the single pricing mechanism because it assumes that there should be no imbalance pricing asymmetries, meaning that there should be no different prices paid for being positive or negative within a given settlement period. Moreover, the WoC concept keeps an idea that a single pricing should be applied to all types of imbalances, i.e. production, consumption and trade. For the reason of transparency, clearness and simplicity the balance incentivizing components that countries sometimes add to the regulation prices to punish the BRP imbalances in the same direction as the system imbalance or to incentivize all BRPs to keep their balance are not foreseen in the WoC concept. Moreover, single pricing leads to the lowest actual imbalance cost and results in the highest cost allocation efficiency. It does not discriminate against small market actors because the relatively higher imbalances of small BRPs are offset by the profits of being in the right direction, which happens often for small BRPs. However, this mechanism gives weaker incentives for balance planning accuracy, which may be an issue for systems with lacking balancing resources [10].

Method for determination of imbalance price. The imbalance price reflects the procurement cost of activated balancing capacity. It is based either on the marginal or average price of activated balancing capacity. There is a broadly accepted approach that marginal pricing is economically more correct and will impact on more efficient allocation of resources than average pricing. With the marginal pricing the imbalance price is set equal to the price of the marginal accepted bid, while with the average pricing the imbalance price is calculated by dividing the total activation cost by total activated volume of balancing capacity. The WoC concept assumes that choice between the application of marginal vs average pricing for the determination of an imbalance price should be linked with the balancing product pricing mechanism. If the marginal pricing method is applied to determine the price for the BSPs for provision of balancing product, then the same method should be applied to determine the imbalance price for the BRPs. If pay-as-bid pricing method is applied for the provision of balancing services, then the average pricing method should be used for the determination of the imbalance price.

In [18], it is argued that marginal pricing provides BRPs with more accurate signals into the cost to cope with their imbalances and gives a greater incentive to avoid imbalanced position. The WoC concept keeps an idea that priority should be given to the imbalance price, which is calculated based on the marginal upward and downward regulation prices.

Allocation of balancing capacity costs. The method used to allocate the balancing capacity costs. These costs are usually allocated to all system users through adaptation of the system services tariff. Alternatives are an additional price component in the imbalance price, a separate fee structure for BRPs, and the assignment of reserve obligations to market participants.

Within the WoC concept, a separate fee for the BRPs, who are responsible for the imbalances, is set.

Allocation of balancing energy costs. The method used to allocate the balancing energy costs. Imbalance settlement serves to allocate the balancing energy costs to the BRPs in proportion to their energy imbalances. An alternative may be to recover a part of the balancing energy costs through the system services tariff.

Imbalance settlement serves to allocate the balancing energy costs to the BRPs in proportion to their energy imbalances.

Penalty for non-delivery: The penalties for lack of response in the provision of balancing and voltage control products services or the penalty that BSPs pay for not delivering requested inertia and / or reactive power. If the BSP's bid regarding inertia and reactive power provision was accepted by the CSO, but this BSPS is not able to provide inertia, reactive power when called upon, an additional penalty is applied.

Timing of settlement. The frequency of settlement determines the periods over which costs are aggregated and settled in one transaction, and the time of settlement determines the time lapse between the end of the aggregation period and the financial settlement.

When deciding on the timing of the settlement, the WoC concept considers two criteria, i.e. the CSO or the BRPs should be paid in a timely and organized manner. It's worth paying attention to these criteria because if they are not follow the CSO and BRPs could fall into the traps of lack of cash flow, too many customer debts and a lack of proper bookkeeping.

In respect of the criteria of the organized (well-planned) manner of the settlement, a clear step-by step settlement process is established. It consists of:

- *Computation routines*. The collectors of metered data shall have a responsibility to collect and submit registered time series of consumption, production and trade data to the CSO. The submission time of metered data of a particular day shall be selected considering the criteria of reasonableness meaning that the collector of metered data has sufficient time to collect and provide registered data, which are correct and prepared on the basis set requirements, to the CSO at low as possible cost. This could be at earliest the second weekday after the day of delivery. This means that the collectors of metered data submit data every day, i.e. on daily basis. Then the CSO shall aggregate data and send balance computations with 15 minutes specifications of imbalances in MWh to the respective BRPs on the fourth weekday after the day of operation. Considering to the quarterly established imbalance price the imbalances expressed in MWh shall be converted to the EUR.

- *Dates of payment*. During this process, the CSO decides how often it will invoice. It is relevant to pay attention to cash flow and not allow too much time between invoices. Once or twice a month is the recommended frequency. The practice is that big business could allow themselves to send invoices rarely (for example, once a month), whereas for small business this could be a mistake since it will delay some receivables by two to three weeks which will impact on their activity. Instead, they should try to send invoices within a week after the delivery or more often. Within the WoC concept invoicing or crediting shall take place once per the entire calendar month. The settlement basis shall be established on the imbalance computations, which by the CSO shall be prepared and submitted to the BRPs daily. Cash (financial) settlements regardless of product will take place as follows:
- Amounts payable into the CSO account should be paid till the end of the month followed after the month of delivery, for example, on 25th day of the following month;
- The CSO shall pay the amounts from its account till the end of the month followed after the month of delivery, for example, on 25th day of the following month;
- In case the BRP has several positions (production, consumption and / or trade), net payments shall be made with the aim to reduce transaction cost.

The CSO wants the BRPs paid quickly; therefore, it makes this as easy as possible by accepting a range of payment options. Although some payment methods will cost the CSO in transaction fees, it is likely to be worth for the CSO because the CSO gets paid more speedily. To ensure timely payment, the CSO can either charge a late fee, or even more effective, offer a discount for early payment. Invoicing should be clear and contain useful information [34].

12 Summary of market designs for the Use Cases

12.1 Inertia Response Power Control

The key market design elements for the IRPC service are summarized in Table 12-1.

Table 12-1. Summary of the market for the IRPC service trading

Market design element	Inertia capacity	Inertia
Marketplace element		
Type of market to procure inertia	Day of operation / delivery	
Approach to market design	Exchange	
Economic mechanism to allocate resources	Auction	
Types of auctions	One-sided	
Bidding format of the auction	Closed	
Categories of auctions	Uniform	
Auction based on number of units, which are available for the trade	Multi-unit	
Consistency of auctioning	Hybrid auctioning	
Types of proposals submitted to the auction	Offers and bids	
Method for bids and offers scoring	Price criteria	
Order types	15 min (quarter-hourly), 30 min (half-hourly) and 60 min (hourly) orders	
Product resolution in physical units	No minimum bid requirement	
Quotation method:	Continuous submission of orders until gate closure	
– Volume quotation, MW*S; kgm2	two-way	
– Price quotation, EUR/(MW*s); EUR/kgm2	one-way	
Tick size	0.01 EUR/(MW*s)	0.01 EUR/kgm^2
Price cap / floor	Removed, except it reflects VOLL	
Market actors		
Inertia providers	Condensing PP, CHP, renewable PP (hydro PP and wind PP) and storage (batteries)	
Inertia provision	Voluntary. However, synthetic inertia providing resources are exclusively committed to provide synthetic inertia, i.e. they are not used to provide other balancing	

Market design element	Inertia capacity	Inertia
	and voltage control products at the same market time unit.	
General variables		
BTU & STU & ISP	15 min	
Product provision elements		
Procurement scheme	Organized market	
Pricing mechanism	Market clearing price	
Method of remuneration	Inertia capacity availability	Inertia capacity utilization
Activation strategy		Merit order
Timing of the auction-based market:		
– Gate opening time	T-18 h (18 hours from real time)	T-8.75 h
– Gate closure time	T-10 h	T-0.5 h
– Bidding session	8 h	8.25 h
– Frequency of bidding	Hourly	Hourly
– Clearance / Merit Order process	T-9 h	T-0.25 h
– Frequency of clearance / Merit Order	Hourly	Hourly
– Product resolution in time	Quarter-hourly (15 min), half-hourly (30 min), hourly (60 min)	
– Market time unit (delivery time)	From one to four quarters (4 x 15 min)	
Cascading procurement	No	
Imbalance settlement element		
Penalty	If inertia is not supplied. penalty is paid by the inertia providers	
Cost recovery scheme	Final electricity consumers	
Allocation of inertia cost	Tariff structure in the final price for electricity	
Timing of settlement	Once a month	

In future, the use of the IRPC service will be relevant because of the IRPC peculiarity to provide system support to dynamic stability, contribute to the frequency transients (as opposed to long-lived) compensation and regulate in real time the available amount of inertia within a Cell [35].

The IRPC will be the only control scheme for the frequency transients' compensation. The transients of frequency will be caused by severe imbalances due to the faults, and less severe imbalances due to the load or generation changes [35]. The imbalances will arise because of various reasons, but changes in the regulatory environment including commitments taken regarding a significant reduction of GHG emissions and ambiguous targets in respect to RES volumes, causing significant structural changes in electricity production mix, will remain among the most important and will provide enhanced incentives for the provision of IRPC service.

As the share of renewable energy having near zero marginal cost significantly increase in the energy market, the conventional generation having high marginal cost and presently being the source of inertia, which is a by-product of energy production by thermal and hydro generators, will be displaced in an economically efficient dispatch and will be withdrawn from the energy market. This means that currently provided conventional synchronous inertia will be scarce sometimes, especially in summer or at day when plenty of renewable energy is available in the market. Certainly, phasing out of nuclear units and increasing imports through the HVDC connections will reduce inertia levels too. With an insufficient inertia, frequency will drop rapidly, as a high Rate of Change of Frequency (RoCoF) will be achieved, causing the frequency to reach the load-shedding (involuntary disconnection) value before reserves have reacted sufficiently. Controversially, with high inertia, the frequency decrease will be slower (i.e. adding inertia response power smooths frequency variations) and the primary frequency control reserves (i.e. frequency containment reserves, FCR) will have more time to react and increase the frequency back towards the nominal value. To maintain the power system security, it will be essential to provide innovative services. Thus, the relevance of the IRPC will be meaningful in future.

When developing market design for the IRPC service the assumption that the Cell has sufficient local reserves capacity to solve the Cell balancing problems locally and the fact that inertia is used the first (earliest) of all available frequency control alternatives in the decentralized WoC power grid structure is taken into account [36].

The synthetic inertia will be supplied by a large number of invertor-based DER such as RES and storage. Customer loads will have possibilities to participate in the market because of its overall goal to facilitate more competitive markets. The synthetic inertia providers are exclusively responsible for the provision of synthetic inertia and are not used for other purposes in the same timestep. From the market perspective, the provision of the IRPC service is voluntary and no discrimination of providers in terms of technology used, size of the provider, resource used is applied if the BSPs satisfy the approved standard qualitative requirements.

The CSO is a single entity responsible for the procurement of inertia, thus, it is a single buyer of the IRPC service for the Cell. Since the IRPC service is procured by the single entity – the CSO – a monopsony market is established. Its peculiarity is that as the only buyer, a monopsony controls the demand-side of the market completely. The monopsonist has a market power both in choosing how much of inertia to procure and setting the price for inertia (Annex 4). The CSO with a monopsony buying power have a degree of monopoly selling power. This could enable them to make high profits at the expense of consumers if the market regulator did not perform its role in the market (Annex 4). Seeking to reduce the monopsonist's market power in inertia market the IRPC service providers should be left with a right to freely decide on which market they want to participate – and widely use market based mechanism instead of inertia purchase agreements to procure inertia.

The auction-based market is applied because of its superiority against fixed price sale to be more flexible and perhaps less time-consuming compared to negotiating a price. Within the class of market mechanisms, which allocate scarce resources, one particular characteristic of the auction is that the price formation process is explicit. That is, the rules that determine the final price are usually well-understood by all parties involved.

Sequential market meaning that clearing of energy and the IRPC service is separate and sequential. The IRPC service is cleared after the DA energy market is cleared first. Such an approach is applied in Nordic countries, Italy, Spain, California, Texas, etc. [37].

Closed-type auction is employed meaning that bids are not publicly observable and the potential IRPC service providers submit their bids without the knowledge of the bids made by others [38]. At the same time, this is the discrete auction meaning that actors submit supply and demand bids, which are aggregated to form the supply and demand curve. The intersection determines the uniform market-clearing price [39].

One-sided auction is used, since one buyer (the CSO) wants to procure the IRPC service. The auction design affects, which bids are accepted and their payments.

Bids in the auction are scored considering to the price criteria.

A uniform pricing rule is applied meaning that all market actors with the accepted bids are paid a uniform price – the MCP – regardless of their bids. The MCP is determined through the marginal pricing method meaning that all bids are submitted based on variable cost of inertia and fixed cost are recovered during the long-term through the difference between MCP and variable cost.

The inertia providers are paid for availability of inertia capacity and for its utilization.

The IRPC can automatically be invoked at any moment regardless of the system state (normal operation or contingency) [35].

Inertia is traded in 15 minutes chunks. Each hour is split into 4 settlement periods. Each settlement period is settled in isolation from the settlement periods around it. This means that all information used in the settlement calculations is at the settlement period level, which includes inertia reserves information, forecasted load and generation, constraints.

The trading arrangements are designed in a way that 30 min before real-time all contracts are frozen / finalized, i.e. at a certain point it is no longer possible to change contracted volumes for a 15-min market time unit.

At the settlement side of the market, once per month the final electricity consumers pay for the inertia provision through the separate tariff structure. The tariff is calculated considering to total cost of inertia provision.

12.2 Balance Steering Control

The key market design elements for the BSC service are summarized in Table 12-2.

Table 12-2. Summary of the market for the BSC service trading

Market design element	Balancing capacity	Balancing energy
Marketplace element		
Type of market to procure BSC service	Day of operation / delivery	
Approach to market design	Exchange	
Economic mechanism to allocate resources	Auction	
Types of auctions	Two-sided	
Bidding format of the auction	Closed	
Categories of auctions	Uniform	
Auction based on number of units, which are available for the trade	Multi-unit	
Consistency of auctioning	Hybrid auctioning	
Types of proposals submitted to the auction	Offers and bids	
Method for bids and offers scoring	Price criteria	
Order types	15 min (quarter-hourly), 30 min (half-hourly) and 60 min (hourly) orders	
Bid requirements	Asymmetric	
Product resolution in physical units	1 MW	1 MWh
Quotation method:	Continuous submission of orders until gate closure	
– Volume quotation	two-way	
– Price quotation	two-way	
Tick size	0.01 EUR/MW	0.001 EUR/MWh
Price cap / floor	Removed, except it reflects VOLL	
Market actors		
BSC providers	Condensing PP, CHP, motor, gas PP, hydro PP, wind PP, solar PP, industrial loads, electric vehicles, household appliances, batteries, pumped hydro PP	
BSC provision	Voluntary. However, the BSPs are exclusively committed to provide balancing capacity, i.e. they are not allowed to provide other balancing and voltage control products at the same market time unit.	Mandatory, since balancing capacity was procured.

Market design element	Balancing capacity	Balancing energy
General variables		
BTU & STU & ISP	15 min	
Product description		
Technical requirements	– Must activate its full capacity in 10-30 s – Must be able to provide reserve power for 1 h	
Directions	Upward and downward	
Product provision elements		
Procurement scheme	Organized market	
Pricing mechanism	Market clearing price	
Method of remuneration	Balancing capacity availability	Balancing capacity utilization
Activation strategy		Merit order
Timing of the auction-based market:		
– Gate opening time	D-18 h (18 hours from real time)	T-8.75 h
– Gate closure time	T-10 h	T-0.50 h
– Bidding session	8 h	8.25 h
– Frequency of bidding	Hourly	Hourly
– Clearance / Merit Order process	T-9 h	T-0.25 h
– Frequency of clearance / Merit Order	Hourly	Hourly
– Product resolution in time	Quarter-hourly (15 min), half-hourly (30 min), hourly (60 min)	
– Market time unit (delivery time)	From one to four quarters (4 x 15 min)	
Cascading procurement	Yes	
Imbalance settlement element		
Imbalance settlement unit	15 min	
Imbalance pricing mechanism	Single	
Method for determination of imbalance	Marginal price	
Cost recovery scheme	BRPs	

Market design element	Balancing capacity	Balancing energy
Allocation of BSC cost	A separate fee structure for the BRPs	
Timing of settlement	Once a month	

Condensing PP, CHP, motor, gas PP, hydro PP, wind PP, solar PP, industrial loads, electric vehicles, household appliances, batteries, pumped hydro PP are the BSPs of the BSC service for upward and downward regulation during peak and off-peak hours.

The BSC service is traded in the exchange, where a two-sided auction based-market is established. In such type of the market the BSC service is traded inter-Cell. This means that the BSPs, located in one Cell provide the BSC service to the CSO of the other Cell, thus, inter-Cell trade in the BSC service is allowed. The BSPs bid the market the price at which they are ready to sell the particular volume of balancing capacity and form / establish an initial Merit Order list, which is the supply curve of the balancing capacity for the BSC service. By providing prices at which they are willing to buy a particular volume of balancing capacity, the CSOs establish the price elastic demand curve. The equilibrium price and volume of balancing capacity for provision of the BSC service is set at the point where supply and demand curves intersect. The bids of the BSPs, which are not accepted by the sub-market for the BSC (capacity) service, are moved to the sub-market for the BRC (capacity) service. The BSPs whose bids are accepted agree to hold balancing capacity for a particular market time unit and they are remunerated for balancing capacity availability at the equilibrium price, which is the MCP. The BSPs, whose bids are accepted, later submit balancing energy bids (price and volume) to the auction and establish an initial merit Order list for balancing energy. Respectively, the CSOs bid (price and volume) to the auction and establish the demand curve for balancing energy for the BSC service considering to the accepted balancing capacity volumes. If balancing energy bids of the BSPs are accepted and these BSPs are called in real-time, they are remunerated for the utilization of balancing capacity at a price which is the MCP of balancing energy. Thus, the BSPs are remunerated for both availability of balancing capacity and its utilization. The CSOs recover cost of the BSC service provision from the BRPs who were in imbalance during the particular market time unit. These BRPs pay a separate fee structure for their imbalance.

12.3 Balance Restoration Control

The key market design elements for the BRC service are summarized in Table 12-3.

Table 12-3. Summary of the market for the BRC service trading

Market design element	Balancing capacity	Balancing energy
Marketplace element		
Type of market to procure BRC service	Day of operation / delivery	
Approach to market design	Exchange	

Market design element	Balancing capacity	Balancing energy
Economic mechanism to allocate resources	Auction	
Types of auctions	One-sided	
Bidding format of the auction	Closed	
Categories of auctions	Uniform	
Auction based on number of units, which are available for the trade	Multi-unit	
Consistency of auctioning	Hybrid auctioning	
Types of proposals submitted to the auction	Offers and bids	
Method for bids and offers scoring	Price criteria	
Order types	15 min (quarter-hourly), 30 min (half-hourly) and 60 min (hourly) orders	
Bid requirements	Asymmetric	
Product resolution in physical units	1 MW	1 MWh
Quotation method:	Continuous submission of orders until gate closure	
– Volume quotation	two-way	
– Price quotation	two-way	
Tick size	0.01 EUR/MW	0.001 EUR/MWh
Price cap / floor	Removed, except it reflects VOLL	
Market actors		
BRC providers	Condensing PP, CHP, motor, gas PP, hydro PP, wind PP, solar PP, industrial loads, electric vehicles, household appliances, batteries, pumped hydro PP	
BRC provision	Voluntary. However, the BSPs are exclusively committed to provide balancing capacity, i.e. they are not allowed to provide other balancing and voltage control products at the same market time unit.	Mandatory, since balancing capacity was procured.
General variables		
BTU & STU & ISP	15 min	
Product description		
Technical requirements	– Must activate its full capacity in 10-30 s – Must be able to provide reserve power for 1 h	

Market design element	Balancing capacity	Balancing energy
	– Have a minimum power 1 MW	
Directions	Upward and downward	
Product provision elements		
Procurement scheme	Organized market	
Pricing mechanism	Market clearing price	
Method of remuneration	Balancing capacity availability	Balancing capacity utilization
Activation strategy		Merit order
Timing of the auction-based market:		
– Gate opening time	T-17 h (17 hours from real time)	T-7.75 h
– Gate closure time	T-9 h	T-0.50 h
– Bidding session	8 h	7.25 h
– Frequency of bidding	Hourly	Hourly
– Clearance / Merit Order process	T-8 h	T-0.25 h
– Frequency of clearance / Merit Order	Hourly	Hourly
– Product resolution in time	Quarter-hourly (15 min), half-hourly (30 min), hourly (60 min)	
– Market time unit (delivery time)	From one to four quarters (4 x 15 min)	
Cascading procurement	Yes	
Imbalance settlement element		
Imbalance settlement unit	15 min	
Imbalance pricing mechanism	Single	
Method for determination of imbalance	Marginal price	
Cost recovery scheme	BRPs	
Allocation of inertia cost	A separate fee structure for the BRPs	
Timing of settlement	Once a month	

Condensing PP, CHP, motor, gas PP, hydro PP, wind PP, solar PP, industrial loads, electric vehicles, household appliances, batteries, pumped hydro PP are the BSPs of the BRC service for upward and downward regulation during peak and off-peak hours.

The BRC service is traded in the exchange, where one-sided auction based-market is established. In such type of the market the BRC service is traded only intra Cell. This means that the BSPs, located in the Cell provide the BRC service to the CSO of this Cell, thus, no inter-Cell trade in the BRC service is available. The sub-market for the BRC service considers the bids which were not accepted by the sub-market of the BSC service and were moved to this sub-market.

The BSPs bid the market the price at which they are ready to sell the particular volume of balancing capacity and form / establish an initial Merit Order list, which is the supply curve of the balancing capacity for the BRC service. By providing only volume, which the CSO is willing to buy, the CSO establish the price inelastic demand curve. The equilibrium price and volume of balancing capacity for provision of the BRC service is set at the point where supply and demand curves intersect. The bids of the BSPs, which are not accepted by the sub-market for the BRC service, are moved to the sub-market for the aFCC service. The BSPs whose bids are accepted agree to hold balancing capacity for a particular market time unit and they are remunerated for balancing capacity availability at the equilibrium price, which is the MCP. The BSPs, whose bids are accepted, later submit balancing energy bids (price and volume) to the auction and establish an initial Merit Order list for balancing energy. Respectively, the CSOs bid (only volume) to the auction and establish the price-inelastic demand curve for balancing energy for the BRC service considering to the accepted balancing capacity volumes. If balancing energy bids of the BSPs are accepted and these BSPs are called, they are remunerated for the utilization of balancing capacity at a price which is the MCP of balancing energy. Thus, the BSPs are remunerated for both availability of balancing capacity and its utilization. The CSOs recover cost of the BRC service provision from the BRPs who were in imbalance during the particular market time unit. These BRPs pay a separate fee structure for their imbalance.

12.4 Adaptive Frequency Containment Control

The key market design elements for the aFCC service are summarized in Table 12-4.

Table 12-4. Summary of the market for the aFCC service trading

Market design element	Balancing capacity	Balancing energy
Marketplace element		
Type of market to procure aFCC service	Day of operation / delivery	
Approach to market design	Exchange	
Economic mechanism to allocate resources	Auction	
Types of auctions	One-sided	
Bidding format of the auction	Closed	
Categories of auctions	Uniform	
Auction based on number of units, which are available for the trade	Multi-unit	
Consistency of auctioning	Hybrid auctioning	

Market design element	Balancing capacity	Balancing energy
Types of proposals submitted to the auction	Offers and bids	
Method for bids and offers scoring	Price criteria	
Order types	15 min (quarter-hourly), 30 min (half-hourly) and 60 min (hourly) orders	
Product resolution in physical units	<1 MW	<1 MWh
Quotation method:	Continuous submission of orders until gate closure	
– Volume quotation	two-way	
– Price quotation	one-way	
Tick size	0.01 EUR/MW	0.01 EUR/MWh
Price cap / floor	Removed, except it reflects VOLL	
Market actors		
aFCC providers	Condensing PP, CHP, motor, gas PP, hydro PP, wind PP, solar PP, industrial loads, electric vehicles, household appliances, batteries, pumped hydro PP	
aFCC provision	Voluntary. However, the BSPs are exclusively committed to provide balancing capacity, i.e. they are not allowed to provide other balancing and voltage control products at the same market time unit.	Mandatory, since balancing capacity was procured.
General variables		
BTU & STU & ISP	15 min	
Product description		
Technical requirements	– Deployment of reserve power from 0% to 50% in 15 s and from 50% to 100% in 30 s – Maintain the reserve power for at least 15 min – Reserves must be activated within few seconds from the frequency incident	
Directions	Upward and downward	
Product provision elements		
Procurement scheme	Organized market	
Pricing mechanism	Market clearing price	

Market design element	Balancing capacity	Balancing energy
Method of remuneration	Balancing capacity availability	Balancing capacity utilization
Activation strategy		Merit order
Timing of the auction-based market:		
– Gate opening time	T-16 h (16 hours from real time)	T-6.75 h
– Gate closure time	T-8 h	T-0.50 h
– Bidding session	8 h	6.25 h
– Frequency of bidding	Hourly	Hourly
– Clearance / Merit Order process	T-7 h	T-0.25 h
– Frequency of clearance / Merit Order	Hourly	Hourly
– Product resolution in time	Quarter-hourly (15 min), half-hourly (30 min), hourly (60 min)	
– Market time unit (delivery time)	From one to four quarters (4 x 15 min)	
Cascading procurement	No	
Imbalance settlement element		
Imbalance settlement unit	15 min	
Imbalance pricing mechanism	Single	
Method for determination of imbalance	Marginal price	
Cost recovery scheme	BRPs	
Allocation of aFCC cost	A separate fee structure for the BRPs	
Timing of settlement	Once a month	

The market design for the aFCC service trading is similar to one applied for other balancing service trading. The aFCC service is traded in the exchange, where an auction-based market is established. In the market for the aFCC service, balancing capacity and balancing energy for upward and downward regulation are traded for peak and off-peak hours. Condensing PP, CHP, motor, gas PP, hydro PP, wind PP, solar PP, industrial loads, electric vehicles, household appliances, batteries, pumped hydro PP provide the aFCC service on voluntary basis to a single buyer, who is the CSO. The BSPs are remunerated for both availability of capacity and its utilization. A uniform pricing rule is applied to determine the price of the aFCC service and remunerate the BSPs. The costs are recovered from the BRPs once a month through the separate fee structure, which size depends on the BRPs imbalance. The difference exists in timing of the sub-market. The aFCC service is traded hourly but it is the last one in sequence of all balancing products traded in the market for balancing products.

12.5 Post-Primary Voltage Control

The key market design elements for the PPVC service are summarized in Table 12-5.

Table 12-5. Summary of the market for the PPVC service trading

Market design element	Reactive power
Marketplace element	
Type of market to procure PPVC service	Day of operation / delivery
Approach to market design	Exchange
Economic mechanism to allocate resources	Auction
Types of auctions	One-sided
Bidding format of the auction	Closed
Categories of auctions	Uniform
Auction based on number of units, which are available for the trade	Multi-unit
Consistency of auctioning	Hybrid auctioning
Types of proposals submitted to the auction	Offers and bids
Method for bids and offers scoring	Price criteria
Order types	15 min (quarter-hourly), 30 min (half-hourly) and 60 min (hourly) orders
Product resolution in physical units	No minimum bid requirement
Quotation method:	Continuous submission of orders until gate closure
– Volume quotation	two-way
– Price quotation	one-way
Tick size	0.01 EUR/VAr
Price cap / floor	Removed
Market actors	
PPVC providers	Condensing PP, CHP, motor, gas PP, hydro PP, wind PP, solar PP, industrial loads, electric vehicles, household appliances, batteries, pumped hydro PP

Market design element	Reactive power
Reactive power provision	Voluntary
General variables	
BTU & STU & ISP	15 min
Product description	
Technical requirements	
Directions	Inductive and capacitive
Product provision elements	
Procurement scheme	Organized market
Pricing mechanism	Market clearing price
Method of remuneration	Reactive power utilization
Activation strategy	Optimal power flow calculation
Timing of the auction-based market:	
– Gate opening time	T-11 h (11 hours from real time)
– Gate closure time	T-0.50 h
– Bidding session	10.5 h
– Frequency of bidding	Hourly
– Clearance / Merit Order process	T-0.25 h
– Frequency of clearance / Merit Order	Hourly
– Product resolution in time	Quarter-hourly (15 min), half-hourly (30 min), hourly (60 min)
– Market time unit (delivery time)	From one to four quarters (4 x 15 min)
Cascading procurement	No
Imbalance settlement element	
Penalty	If reactive power is not supplied. Penalty is paid by the reactive power providers
Cost recovery scheme	Final electricity consumers
Allocation of PPVC cost	Tariff structure in the final price for electricity
Timing of settlement	Once a month

Reactive power, which supports voltage control, does not travel far due to high inductive impedances. It therefore is very localized which, in turn, inhibits a broad competitive market. Challenges for reactive power markets are further compounded by rules governing the procurement and use of reactive power capabilities. In general, all generators except wind plants are required to be capable of providing reactive power within a power factor range defined in their interconnection agreement, although in Spain new operating procedures are being studied to require wind turbines to provide voltage control. Compensation for provision of this service varies by transmission provider. In the United States, there is no requirement to compensate generators for reactive power within the power factor range unless the transmission provider is compensating its own generators. Generators typically are paid for fixed costs as well as opportunity costs [40].

The sub-market for voltage control is developed based on the principles of an hourly market for VAr capacity use. In the WoC market design, the CSO runs a sub-market for PPVC service. Here the product is VAr utilization. The CSO collects VAr bids from the market actors through the auction-based exchange and distributes the VAr needs among the actors in order to satisfy the reactive power requirements. Merit order principle is applied for this purpose and price of the product is determined based on the MCP. The sub-market for PPVC service runs after the clearing of DA market. In the proposed market design for the PPVC service, the CSO acts as the single buyer of VAr and is responsible for the market settlement. In order to achieve the market settlement, the CSO collects bids from several VAr providers, who are condensing PP, CHP, motor, gas PP, hydro PP, wind PP, solar PP, industrial loads, electric vehicles, household appliances, batteries, pumped hydro PP, ranks them in price (EUR/VAr) ascending order with the purpose to meet the requirements for reactive power demand for each quarter-hour of the market time unit. The costs of reactive power utilization are recovered from the final electricity consumers through the tariff structure in the final price for electricity. The bill is issued once a month. If reactive power bids were accepted by the market, but reactive power was not supplied by the BSPs, these BSPs are penalized.

13 Assessment of the alternative market designs

For assessment of the alternative market designs, solution and simplified test case provided in Annex 14 is used. Two cases are compared between each other: the market is organized based on 1 hour and 15-min bids. In comparison, it assumed that participants have ideal information, without forecast errors and perfect competition. In this case, participant participation in ID and energy balancing markets is neglected. Figure 13-1 represent scheduled demand and generation within cells after DA market for a 24-hour period.

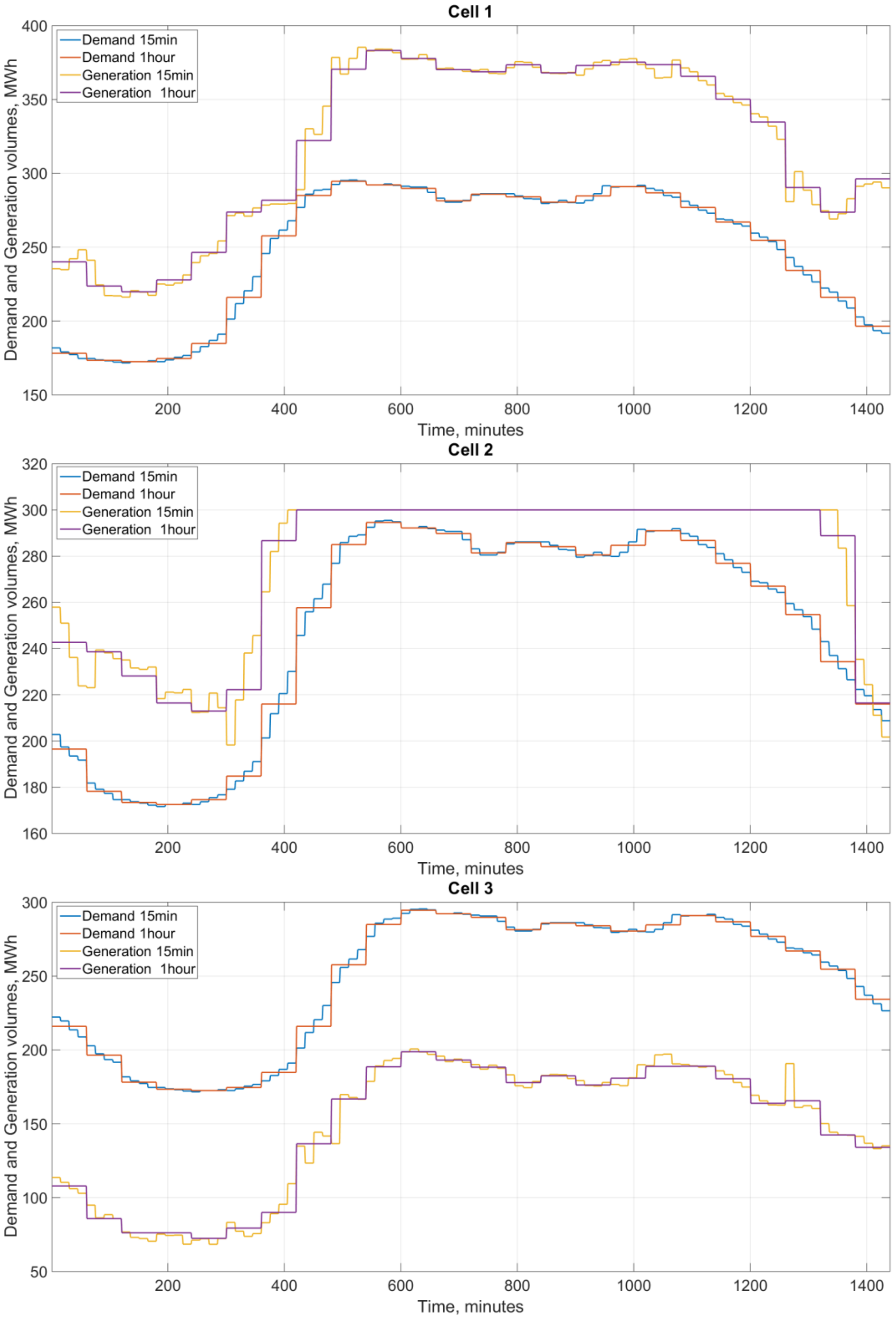


Figure 13-1. Scheduled Demand and Generation within cell

Figure 13-2 represent scheduled total tie-lines flows between cells, taking into account N-1 criteria.

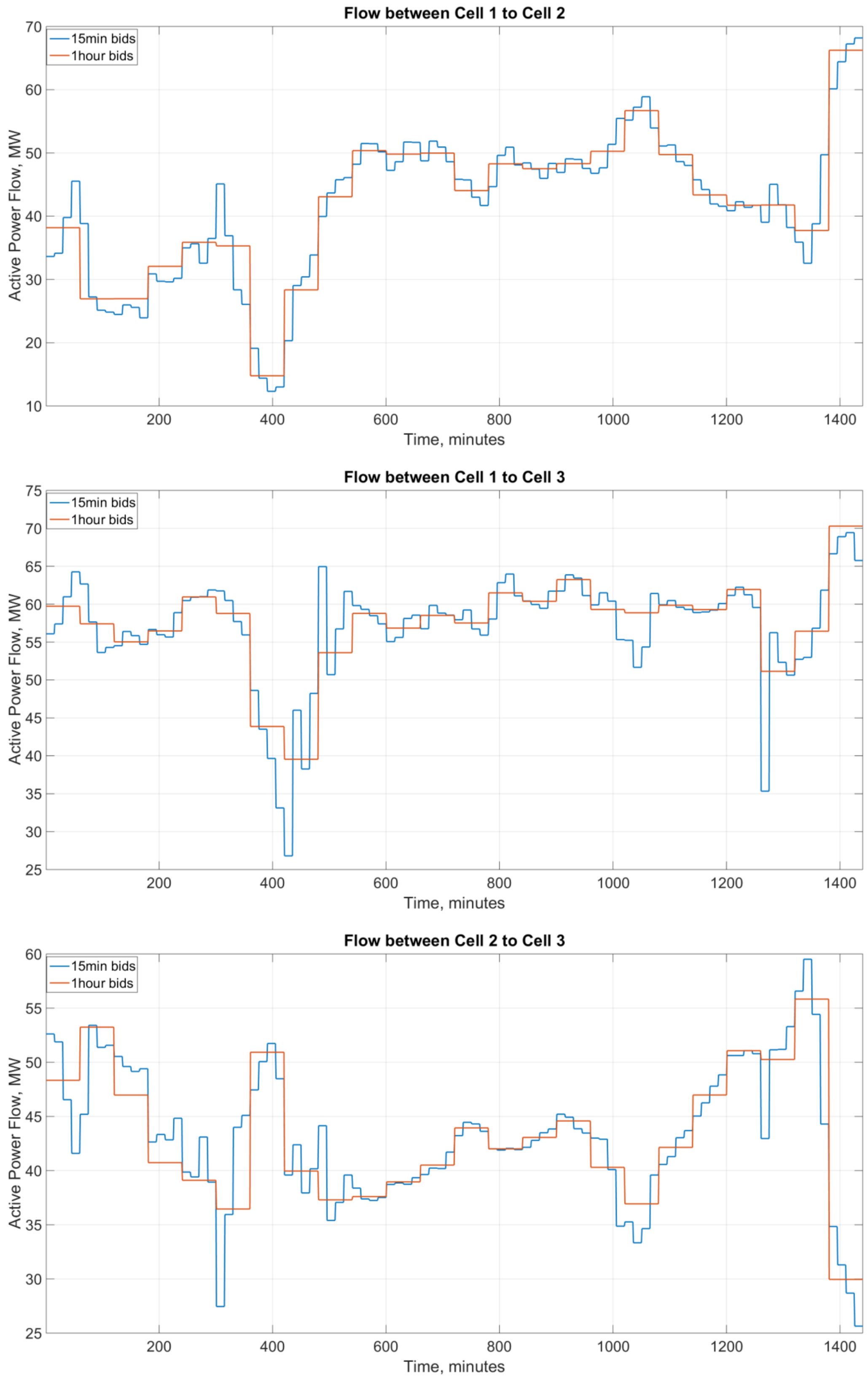


Figure 13-2. Scheduled power flows between cells

Table 13-1 represent summary of the markets organized based on 1 hour and 15-min bids.

Table 13-1. Summary of the markets

	1 hour			15 min		
	Total Production, MWh	Total Consumption, MWh	Social Welfare, EUR	Total Production, MWh	Total Consumption, MWh	Social Welfare, EUR
Cell 1	7680,5	5958,6	17’811’285	7670,5	5959,3	17’813’333
Cell 2	6653,0	5958,6	17’844’497	6658,1	5959,3	17’846’489
Cell 3	3542,2	5958,6	17’835’933	3549,1	5959,3	17’837’308
Total	17875,8	17875,8	**53’491’716**	17877,8	17877,8	**53’497’131**

The calculation of energy market design for assurance of balance planning accuracy showed that DA market time units timing of the market are of pivotal importance. Shortened DA market time units to 15 min from 1 hour allow increase overall system social welfare and BRP possibility to trade at sub-hourly time scale, increasing balance planning accuracy, availability of balancing resources and price efficiency, decreasing financial risk to face the imbalance price.

14 Interaction between the designs of short-term electricity markets

Short-term electricity markets are defined as markets that take place from DA stage until physical generation and consumption [39]. These markets include DA, ID and RT markets. The Chapter analyses the interactions between the recommended design of the market for balancing and voltage control products and designs of DA and ID markets.

14.1 The interaction between the market design for balance and voltage control and day-ahead market

Considering to the Article 53 of the European Commission's Regulation establishing a guideline on electricity balancing [18], the WoC concept develops an idea that all boundaries of the DA market time unit coincide with the boundaries of the imbalance settlement period. Shortened DA market time units to 15 min would allow for an improved alignment with the settlement period, as it was showed and discussed in [39]. The arguments to shorten DA market time units from 1 hour to 15 min are as follows. When the BRP has a possibility to trade at sub-hourly time scale, he will be allowed intra-hourly electricity variations to be dealt with by the means of trading in a DA market. While not having this possibility may not be a problem for BRPs who have self-balancing capabilities, smaller BRPs encounter the financial risk of being dependent on the CSO who deals with those variations by activating reserves, thereby smaller BRPs face the imbalance price. This is especially the case if the ID market is based on hourly market periods too. The graphical representation given in Figure 14-1 shows that the BRP who has a limited self-balancing capability and facing intra-hourly electricity variations may not avoid imbalance (Figure 14-1a). Although the BRP has a net balanced position for a particular hour (for market period from 8:00 am to 9:00 am), imbalance emerge during each imbalance settlement period because of an unaligned market time unit to imbalance settlement period. If there are no discrepancies between DA market time unit and imbalance settlement period, the imbalance position may be avoided (Figure 14-1b).

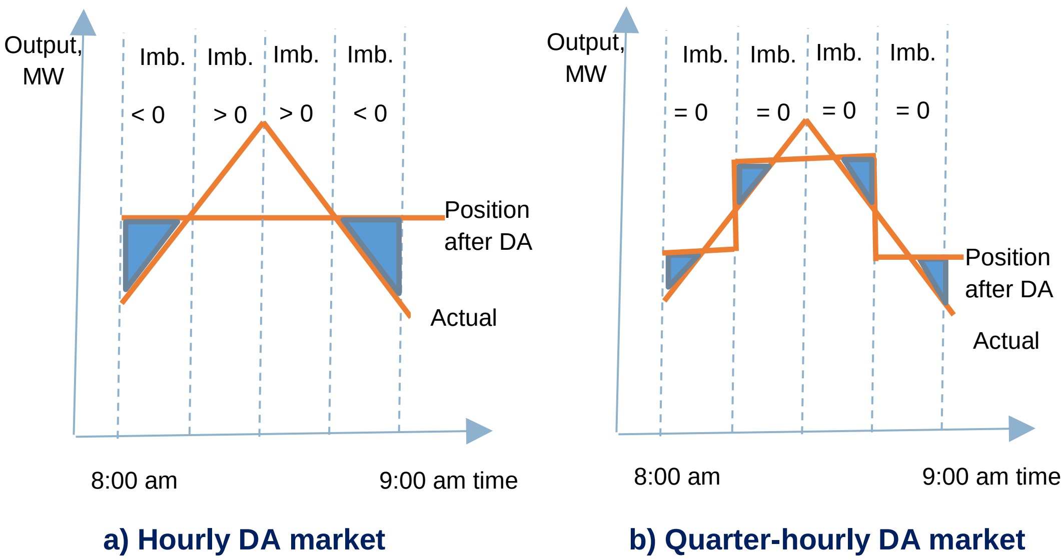
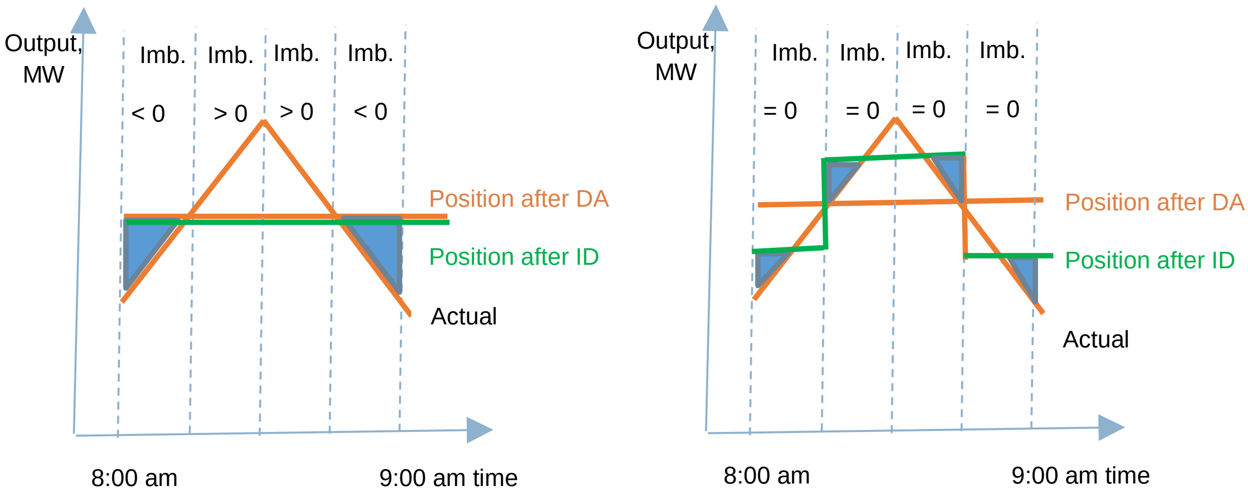


Figure 14-1. Impact of the discrepancy between DA market time unit and imbalance settlement period on the BRP's imbalance (based on [39])

Aligned DA market time unit with the imbalance settlement period shift some electricity demand from the CSO in RT to DA market and supply from self-balancing to the DA market and from BSPs to DA market participants. Intra-hourly variations are dealt with through the trading in DA market not only through the self-balancing.

14.2 The interaction of the market design between for balance and voltage control and intraday market

After clearing of the DA market, the BRPs have a possibility to update their positions in ID market by purchasing additional volume of electricity or selling surplus of electricity to the market. Thus, the ID market creates possibilities to balance BRP's position closer to real time. Trading in ID market may reduce demand for the balance and voltage control services. Thus, the necessity of the ID market is reasoned.



a) Hourly DA and ID markets **b) Hourly DA and quarter-hourly ID market**

Figure 14-2. Impact of the discrepancy between DA and ID markets time unit and imbalance settlement period on the BRP's imbalance (based on [39])

The ID market time unit becomes a decisive for occurrence of the BRP's imbalance and application of an imbalance price. Assume that an hourly DA market is established when a quarter-hourly imbalance settlement period is applied. As it was showed in Figure 14-2a, the BRP faces intra-hourly imbalances due to the discrepancy between the DA market time unit and an imbalance settlement period; thereby an imbalance price is applied to the BRP. If the hourly ID market is established and the BRP uses it to balance the position, the opportunities to avoid the imbalance are limited because intra-hourly electricity variations, which are the source of imbalance and a reason for application of an imbalance price (Figure 14-2a). The presence of quarter-hourly ID market provides this opportunity (Figure 14-2b). Therefore, establishment of a quarter-hourly ID market is required since it compensates for the misalignment between the DA market time unit and imbalance settlement period. Subject to the quarter-hourly ID market, the BRPs with limited self-balancing capabilities are less dependent on the CSO to balance their imbalance positions and are thus less exposed to imbalance price. Then, less balancing capacities and balancing energy are required by CSO.

15 Conclusions

Within this Deliverable a high-level market design supporting the functioning of architecture for frequency and voltage control developed within the Web-of-Cells power grid structure was proposed. Particular emphasis has been placed on the market mechanism and conditions required to be implemented within the architecture to perform trading in balancing and voltage control products and to establish the final Merit Order list.

An integrated approach has been considered combining the concepts of market and its objectives, principles of market functioning, reference model, market design elements, designing and market assessment criteria, has been considered for this proposal of market design supporting the control architecture for the WoC.

During the research core elements of the market were analysed. These are – exchange where balancing and voltage control products are traded between the BSP and the CSOs. The results showed that with an increasing volume of intermittent RES integrated into the power markets, new types of the BSPs are requested. Thus, in addition to the centralized thermal power plants, small-scale RES, demand response and storage technologies are available at the distribution level. With the purpose to increase the size of the BSPs, aggregators will play an important role too. An organized marketplace (exchange), contributing to improvement of operational efficiency, developing preconditions for competition, assuring transparency and level-playing field to all the BSPs and the CSOs, is established. Auction is used as an instrument promoting competition, as an institution determining price and as the economic (market) mechanism used to allocate the balancing and voltage control products in economically efficient way. With the aim to overcome market failure due to the missing market problem, new categories, classes, types and sub-types of balancing and voltage control products are suggested and traded in separate sub-markets. The link between the quality of balancing products and their price is established through the implementation of the principle of cascading procurement and by considering the distance to real time of auction.

The analysis of market design elements for assurance of balance planning accuracy showed that BTU & STU & ISP are set of the same length. Priority is given to a short-term BTU & STU & ISP, which is 15 min. It is expected that a short-term BTU & STU & ISP provides the BRP with a stronger incentive to balance the available energy portfolio than a long-term BTU & STU & ISP because more accurate information is available on short-terms and deviations from the scheduled energy will be smaller.

The analysis of market design elements for improving operational efficiency of the market for balancing and voltage control products showed that BTU and timing of the market are of pivotal importance. The BTU is selected in relation to the energy schedule and imbalance settlement time units. Moreover, priority is given to the short-term BTU instead of long-term since it increases balance planning accuracy, availability of balancing resources and price efficiency.

The sequential approach to market for procurement of balancing and voltage control products organization is applied meaning that market for lower quality balancing and voltage control product is closed and cleared after the clearance of the market for higher quality balancing and voltage control product. The length of bidding process is selected in a manner that sufficient time is left to the BSPs for bidding (trading) balancing and voltage control products. Moreover, the GOT and the GCT are coordinated with DA and ID markets. The GCT is set as close as possible to real time, ensure sufficient time for necessary balancing processes and set after the intraday GCT. With the purpose to increase liquidity, price efficiency and utilization efficiency in the market, bidding and clearance of balancing and voltage control products are performed often and time horizon reduced. It is suggested that bidding and clearance of balancing and voltage control products are executed hourly. Auctions for the procurement of balancing capacity are organized not earlier than one day ahead from real time because more accurate information is available close to market time unit; therefore, cost-reflectivity in price increases and more BSPs will participate in the market. Balancing product procurement cycle should be short (for instance, quarter-hour), since it shall contribute to new entries, and providers with a small portfolio of either generation units and/or schedulable load, will be capable to participate in the market for balancing products.

The analysis of market design elements for improvement of price efficiency showed that balancing and voltage control products are supplied by the BSPs on voluntary basis and procured by the CSOs on commercial basis through the organized markets. The organized market assures transparency, equity, anonymity, clear trading and pricing rules, as well fosters competition. Moreover, standardized products are traded here. The BSPs are remunerated for balancing capacity availability and its utilization in real time. The need to be remunerated for the balancing capacity shall come from the market structure, where CAPEX (instead of OPEX) intensive power plants shall be abundant.

The analysis of market design elements for improvement of utilization efficiency showed that pricing mechanisms are of high importance. Seeking to improve utilization efficiency, priority is given to the market-based pricing mechanisms instead of regulated pricing. Subject to the market-based pricing mechanisms, market forces influence on the level of price and its changes, but not the regulator who establishes it based on average cost. Moreover, priority is given to a uniform pricing rule instead of pay-as-bid. An incentive to provide for an efficient dispatch and contribution to optimal investments are relevant reasons for an application of a uniform pricing rule. For the pay-as-bid pricing rule, the features of first-come-first-served, high transaction cost, untruthfully bidding and others send wrong signals to the market, may not lead to welfare maximization and optimal allocation of balancing resources, and cause difficulties in monitoring. These features are drawbacks of the pay-as-bid pricing rule and quite good arguments for uniform pricing rule, which tackles them. The principle of the cascading procurement is implemented too. Its implementation serves as an element limiting the behaviour of lower quality balancing and voltage control products to be priced at higher prices (“price reversal”). By implementing the principle, the bids submitted but not accepted by the sub-market of higher quality balancing products shall be shifted to the sub-market for lower quality balancing products (if they satisfy technical requirements). In such a way, cost effective balancing resources are utilized and balancing cost reduced.

The analysis of market design elements for cost allocation efficiency disclosed that seeking to avoid imbalance pricing asymmetries, to achieve the lowest imbalance cost but the highest efficiency when allocating cost, the priority should be given to a single pricing mechanism. Moreover, marginal pricing method as an approach economically viable for determination of imbalance price is selected, since it provides the BRPs with accurate signals about the cost and provides more incentive to avoid imbalanced position.

The analysis of market design elements for improvement of transparency of market for balancing and voltage control products showed that within the WoC power grid structure the European wholesale electricity market transparency framework is respected, since it proposes a multidimensional model for increasing market transparency. Particularly, vertical and horizontal approaches regarding market transparency are kept, qualitative requirements for data and information are set, roles for the actors regarding data and information are established, data placement issue is found as a relevant measure of market transparency, and data and information publication is made publicly available. Indeed, considering the peculiarities of the architecture of frequency and voltage control, as well as the design of market for balancing and voltage control products, the European wholesale electricity market transparency framework is updated. Specifically, new types of market actors (CSO, BSPs -RES & DER & Storage technologies, aggregators-, BRPs) and their roles are considered when collecting, processing and publishing data and information and minimum data set and its availability for the MOC and the MOD making is formed.

The analysis of market design elements for implementation of level playing field principle (non-discrimination) in the market showed that all market actors are responsible for keeping power system in balance and are financially responsible for imbalance they cause in the system. This means that RES-E producers participate fully in the balancing mechanism, they have the same responsibilities as other type generators, are allowed to provide balancing resources subject to common rule, and face the imbalance costs. In addition, seeking to create level playing field for all technologies in the market for balancing and voltage control products, separate energy schedules for production and consumption are notified by the BRPs to the CSO. Energy schedules for trade are notified separately from consumption, i.e. the existing practice today. Moreover, energy schedules for import and export are notified to the CSO separately too as the trade directions (into the Cell and from the Cell) are understood to be equal to production and consumption, respectively.

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17 Disclaimer

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18 Annexes

Annex 1: Definitions of the market design

At the end of 2016, the European Commission announced the “Winter Package” – a package of regulatory proposals and facilitating measures that aim at modernizing the economy and boosting investments in clean energy related sectors. The legislative package addressed three-core issues – increase in energy efficiency, global leadership in renewable energy and a fair deal for consumers.

In response to the set goal to be leading in renewable energy worldwide and to increase the share of renewable energy at least to 27% in 2030, Europe announced a “Market Design Initiative” (MDI). The MDI is recognized as a crucial first step from an old, centralized energy system based on fossil fuels and big utility companies to a new energy system, which consists of a great number of installations using variable in nature resources (such as wind and solar) connected in a decentralized manner at a distribution level.

The European Commission's new electricity MDI aims at improving the functioning of the internal electricity market in order to allow electricity to move freely to where and when it is most needed, reap maximum benefits for society from cross-border competition and provide the right signals and incentives to drive the right investments, while fully integrating increasing shares of renewable energies. For this reason, Europe needs decentralized, more competitive and better-connected energy markets to integrate new energy technologies that are needed to drive decarbonization. Thus, the market design must be changed in step with the changing energy systems, in particularly with rapid penetration of renewable energy.

The increasing volumes of renewable energy will affect the market design in three ways [1]:

- The variability and uncertainty of wind and solar energy will increase requirements for various balancing and voltage control services, affecting the scheduling and pricing of those services;
- Their impacts will vary depending on system conditions, which makes the demands for balancing and voltage control services difficult to generalize across timescales and systems;
- Allowing variable renewable energy to participate in markets for balancing and voltage control services will offer more supply to the market, but will cause challenges because of the unique characteristics of the variable resources.

In the framework of “Winter Package” the “***market design***” is determined as the set of arrangements, which govern how market actors generate, trade, supply and consume electricity and use the electricity infrastructure. The new electricity MDI includes [2]:

- Rules which ensure that increasing amounts of decentralized renewables can be integrated into the energy system, and that the system overall becomes more efficient and flexible;
- A legal framework guaranteeing participation by citizens in self-production, storage and consumption of renewable energy and demand response, either individually or collectively;
- Effective implementation of regulatory oversight to ensure that the market functions properly and that there is a level playing field for renewables, efficiency and flexibility.

The implications of the new electricity MDI on the market design of the WoC concept is discussed in the D3.3 and is a methodological input for the D3.2.

In [2], the "***market design***" is determined in relation to the benefits it could provide:

- Enhanced energy security and cooperation between national energy markets, to share flexible resources;
- If capacity mechanisms don't support fossil fuels, this will avoid reliance on dirty energy and provide a level playing field for energy efficiency and demand management tools;
- Consumers and local governments will be empowered to participate actively in the transition to a lower carbon energy market;
- Local jobs and growth, plus emissions reductions through the development of clean and renewable technologies – for power supply, heating, cooling and transport;
- Europe can lead on developing innovative digital industries that will deliver the energy systems of the future;
- If the market protects and incentivizes people to save energy and use it more wisely, families can save on energy bills and energy poverty can be addressed more effectively.

In [1], the "***market design***" is discussed in relation to the challenges it has to meet and tackle in XXI century:

- *Minimize complexity and introduce flexibility*. Nowadays markets have complex designs, which consolidate economics, engineering and physics of power system. The complex market design is crucial in promoting the targeted results, although make it hard to attract broad and deep participation in the market. Moreover, too much complexity requests frequent revisions of market, market redesigning and weakens transparency. For these reasons minimal complexity for the development of market for balancing and voltage control services is foreseen.

- *Encouraging investment.* In many wholesale electricity markets prices are established based on the marginal pricing method, when market price depends upon the variable costs be recovered during the long-term through the difference between the established price in the market and costs of production. When electricity generators or investors calculate of production of the marginal producer, but it does not account capital costs, that have to be the returns of projects and energy prices decrease with increasing penetration of zero variable cost generation sources, other revenue sources become substantially relevant. Price volatility caused by RES-E may complicate the recovery of capital costs for the area accommodated with RES and for conventional supplies too. Thus, establishing additional markets, including markets for balancing and voltage control services, having investment encouraging designs is highly demanded. Moreover, clear, long-term, transparent energy policies are proved to be good measures to provide strong long-term investment signals too.
- *Harmonizing across timescales.* Electricity markets provide short-term price signals (seconds to days), which are effective when allocating available capacity. However, the experiences of the countries show that electricity markets are ineffective at providing incentives for the optimal amount of long-term installed capacity to meet reliability. A challenge for the market design is how to translate short-term price signals to long-term installed capacity.

- *Ensuring market depth*[1]*.* The straightforward market design is a source for a deep market. In contrast, complexity of market design and trading through the bilateral contracts, which provide long-term revenue certainty for the individual market participants, but remove generators from the merit order list, impede the depth of the market. The implications for the systems with high shares of variable RES but significant bilateral contracts are the following:
  - Most energy delivery is purchased months to years in advance, locking in generation that most probably is inflexible and leaving a small DA and RT market for new, innovative, and flexible supply;
  - Spot-market prices might be inconsistent with marginal costs due to the limited supply of flexibility;
  - Limited participation in the DA and RT markets decreases market efficiency by reducing the potential for market software to optimize supply resources based on their bid costs.

[5] argues that market design is tightly constrained by technology and the International Bank for Reconstruction and Development (2011) states that every design has to be adapted to the specifics of each power system by paying attention to the government's policy objectives, the degree and nature of competition in the electricity market, the interest and prospective role of the private sector, the availability of generation, the variety of different technologies, and the existing regulatory and institutional frameworks in which the suppliers will operate.

In [3], "***market design***" is determined as the global combination of administrative rules and market mechanisms used to ensure electricity provision to final consumers. Market design describes the sequence of events of the overall electricity market from long-term (years in future) to real time (seconds or minutes), it specifies what tasks will be part of the system and what their functions will be.

Moreover, ***"market design"*** examines the reasons why markets institutions fail and considers the properties of alternative mechanisms, in terms of efficiency, fairness, incentives, and complexity, to fix the problems [4]. This concept of the market design expands the definition of the new electricity MDI in a way it pays attention on the subjects of market design (reasons of market failure and elements improving market functioning) and the market design evaluation criteria (efficiency, fairness, etc.).

When speaking about implementation of alternative mechanisms, the concept of ***"market redesigning"*** is relevant. [3] defines ***"market re-designing"*** as a three-step process. The process of market redesigning should be initiated after observing that barriers to enter the market exist, products traded in the market do not satisfy the needs of market participants and the aims they are used for; as well as if pricing mechanisms are not sufficient and cannot assure appropriate remuneration to the BSPs. The market redesigning is relevant for the WoC in the case the implemented mechanisms do not assure expected and sufficient market performance.

A ***market failure*** occurs when the invisible hand pushes in such a way that individual decisions do not lead to socially desirable outcomes. Any time a market failure exists, there is a reason for

[1] Market depth means a long list of buyers and sellers at various prices in the order book. This is good for investors because it means that the market is not dependent on any one market participant to provide adequate liquidity. The market's ability to sustain relatively large market orders without impacting the price. http://www.investopedia.com/terms/m/marketdepth.asp

possible government intervention into the market to improve the outcome. Thus, the concept of market failure provides a strong a reference to the roles of government in the market for balance and voltage control services. Issues such as the scale the government could intervene the market for balance and voltage control services, measures of intervention and the results of the intervention are worth discussing.

In future, the design of the market for balancing and voltage control services will be essential to facilitating the transition to a low-carbon electricity system, in which variable RES, storage and demand side response (DSR) and other nascent technologies will play an increasingly significant role.

References:

[1] Nordic Energy Regulators (NordREG), “Development of a Common Nordic Balance Settlement”, 2006, http://www.nordicenergyregulators.org/wp-content/uploads/2013/02/Common_Nordic_balance_settlement.pdf

[2] “What is the Energy Union and the Market Design Initiative?”, 2016, https://www.clientearth.org/energy-union-market-design-initiative

[3] Borne, O., Korte, K., Perez, Y., Petit, M., Purkus, A., “Barriers to entry in electricity reserves markets: review of the status quo and options for improvements”, 2017, https://pet2017paris2.sciencesconf.org/139091/document

[4] Ostrovsky & Pathak, 2017, http://www.nber.org/workinggroups/md/md.html

[5] Wilson, R., “Architecture of Power Markets”, Graduate School of Business Stanford University. Research Paper No 1708, 2001, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.201.8737&rep=rep1&type=pdf

Annex 2: Description of market design elements

Element	Description
General elements	
Bid time unit	The main time unit in the market for balancing and voltage control products, which divides the balance and voltage control responsibility between the CSO and the BSPs. It is the time over which bids of balancing and voltage control products are specified [1]. For example, if balancing energy bids are submitted for half hour "chunks", these "chunks" are referred to Bid Time Unit (BTU). Then each day is split into the 48 BTUs (based on [2]). It is also called market time unit when speaking about bidding for balancing capacity availability or balancing energy delivery for a certain time period.
Balance planning elements	
Timing of market for balancing and voltage control products	This is the most pivotal market design variable in the set of market design elements [4]. It is recognized as a very fundamental variable but having essential impact on bidding behaviour of the BSPs and, thus, on market performance.
Bidding session	This is a period of time during which the BSPs can bid balancing and voltage control product into the market. The length of the bidding session depends on gate opening and closure times of the market for balancing and voltage control product. Within the bidding session, all orders are placed by the BSP who can submit, modify and / or cancel them.
Gate opening time (GOT)	This is the point in time, when submission of a balancing and voltage control product bid for a standard balancing and voltage control product on an initial merit order list becomes permitted in the exchange. The GOT is set at the point that sufficient time is left for inertia, balancing capacity, balancing energy and reactive power bidding. If the GOT is a decisive variable of market design and is considered as influencing on the bidding behaviour, thus, from the perspective of equity, it should be determined on the same principals, and its relevance should be treated equally for all the market time units.
Gate closure time (GCT)	This is the point in time, when submission, update or cancellation of balancing and voltage control product bids submitted by the BSPs and CSOs on an initial merit order list is no longer permitted [3]. After the GCT all submitted offers are legally binding.
Frequency of bidding	The results of analysis on timing of markets [4] and [5] show that increasing the time horizon of the market for balancing products reduces market liquidity and efficiency.
Frequency of clearance	When frequency of bidding process and the frequency of market clearance differs, the consequences on efficiency and liquidity become much more evident. If frequency of bidding and frequency of market clearance differ, the number of the BSPs who offer balancing capacities for the market is limited and this reduce volumes of balancing capacities offered to the market. As a result, market liquidity decreases, market power increases, more possibilities to abuse power in the market arise and market efficiency decreases. The use of different frequencies for bidding process and market clearance leads to higher price overall too, since indirect lost opportunity cost is added to bid prices that in turn decrease price efficiency (cost reflective prices). Then, the total cost of providing balancing service consist of actual (physical) cost – such as O&M, fixed cost – and opportunity cost. The latter cost is impacted

Element	Description
	by the market design. This shows that a particular market design can cause introduction of high opportunity cost, which increase bid prices.
Distance to real time of the auction	The distance to real time of the auction meaning the time ahead from real time when the auction / agreement for a specific balancing capacity product takes place. In case of balancing energy, this is the time ahead from real time when the CSO activates a given balancing product.
Balancing product resolution in time (or market time unit)	This is the maximum resolution for which the balancing and voltage control product can be bid into the market. In case of balancing capacity, this is the market time unit during which the BSPs must have balancing capacity available. In case of balancing energy, this is the market time unit during which the BSPs must deliver balancing energy. It could be understood as the length of the balancing and voltage control product procurement cycle too.
Zonal vs. nodal prices	The geographical aggregation level at which BRPs must submit energy schedules.
Balance obligation	The responsibility of the BRP to continuously plan for and achieve balance between the electricity supplied and withdrawn by one or several producers, consumers or traders of electricity and to perform the financial settlement of any imbalances arising from the electricity supplied and withdrawn by these parties. Thus, the balance responsibility refers to the obligation of market participants to deliver / consume exactly as much power as the sum of what they have sold and / or purchased on the electricity market. Balance responsibility implies that the costs of the balancing actions taken by the CSO are generally to be compensated by the market participants, which are in imbalance.
Balancing scheme	This is the portfolio or unit-by-unit balancing schemes.
Net vs. separate positions	Production, consumption and trade positions.
Balancing and voltage control provision elements	
Procurement scheme	This is the background of the bid an offer, which closest to real operation time. In a narrower sense, which is applied in the WoC concept, the procurement scheme is the main method used by the CSO to procure balancing and voltage control products to perform its roles in the market for balancing and voltage control products and the power system.
Remuneration scheme	This is the method how the BSPs are paid for the provided balancing products.
Pricing mechanism	It refers to the system where the forces of demand and supply determine the prices of balancing and voltage control products and the changes therein. Within the WoC concept, pricing mechanism describes the means by which decisions taken by the COs and the BSPs interact to determine the allocation of scarce resources between competing uses.
Activation scheme	The scheme or procedure applied by the CSO regarding the activation of bids of balancing and voltage control products, including order of activation (the degree to which the CSO deviates from merit order) and time of activation (proactive vs. reactive).
Reserve requirements	The Cell area requirements for procurement of balancing capacity, including requested volumes and technical characteristics of the balancing resources.
Imbalance settlement elements	
Imbalance settlement period	This is the time unit for which the imbalance of the BRP is calculated.

Element	Description
Types of imbalances	This is production, consumption and trade imbalances.
Imbalance pricing mechanism	This is the pricing mechanism used to determine the imbalance prices.
Imbalance price	It reflects the procurement cost of activated balancing capacity.
Method for determination of imbalance price	It is based either on the marginal or average price of activated balancing capacity.
Timing of settlement	The frequency and time of settlement of procured balancing and voltage control products and BRP imbalances.

References:

[1] Van der Veen, R. A.C.; Hakvoort, R. A., "The electricity balancing market: Exploring the design challenge". Utilities Policy, 43, 186-194, 2016.

[2] ELEXON (2015). The electricity trading arrangements: a beginner guide", 2015, https://www.elexon.co.uk/wp-content/uploads/2015/10/beginners_guide_to_trading_arrangements_v5.0.pdf

[3] "Commission Regulation establishing a guideline on electricity balancing", 2017, https://ec.europa.eu/energy/sites/ener/files/documents/informal_service_level_ebgl_16-03-2017_final.pdf

[4] Abbassy, A., van der Veen, R.A.C., Hakvoort, R.A., "Timing of Markets – the Key Variable in Design of Ancillary Service Markets for Power Reserves", 2010, https://www.sintef.no/globalassets/project/balance-management/paper/timing-of-as-and-short-term-markets_abassy_2010.pdf

[5] 21stCenturyPower.org, "Market Evolution: Wholesale Electricity Market Design for 21st Century Power Systems", 2013, http://www.nrel.gov/docs/fy14osti/57477.pdf

Annex 3: Description of market design assessment criteria

Security-of-supply criteria

- ✓ ***Availability of balancing resources*** is the availability of resources for meeting reserve requirements and resolving system imbalances in real-time.
- ✓ ***Balance planning accuracy*** is defined as the accuracy with which energy schedules reflect actual energy exchanges, i.e., the accuracy with which the system balance is planned.
- ✓ ***Balance quality*** is the effectiveness of maintaining the control area balance, i.e., keeping to scheduled cross-border exchanges, and maintaining system frequency, i.e., keeping to nominal system frequency (which is 50 Hz in Europe).

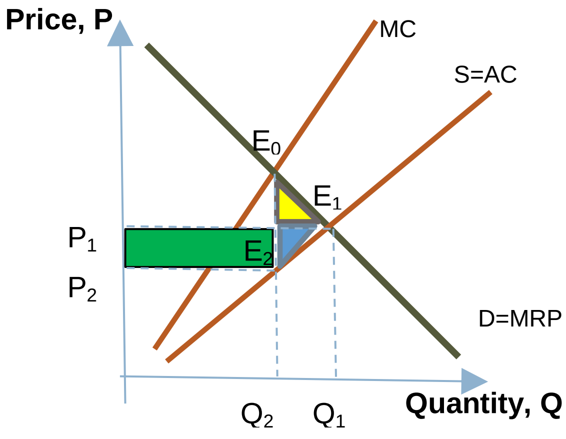
Economic efficiency criteria

- ✓ ***Cost allocation efficiency*** concerns the efficiency with which the balancing service costs are allocated to the market, i.e., whether market parties pay for balance management to the degree that they benefit from it (or have caused the need for it).
- ✓ ***Utilisation efficiency*** is defined as the economic efficiency of the utilisation of available balancing resources, i.e., the degree to which the least and cheapest balancing resources are used to maintain the system balance.
- ✓ ***Price efficiency*** involves the cost-reflectivity of balancing service prices paid to BSPs.
- ✓ ***Operational efficiency*** concerns the economic efficiency of handling the transactions related to the administrative processes in the balancing market, including those of energy schedule and balancing service bid submission and balance settlement.

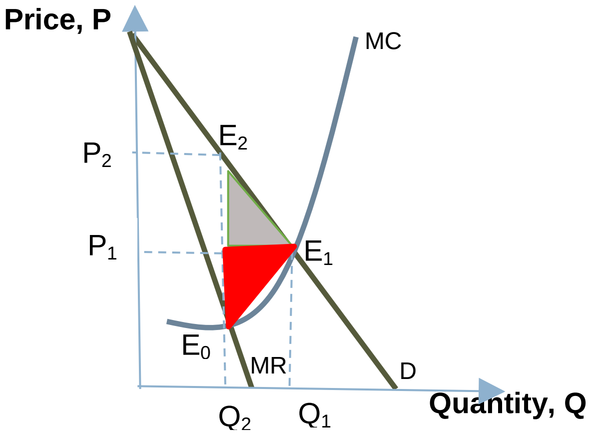
Market-facilitation criteria

- ✓ ***Transparency*** concerns the information availability, symmetry and clarity on balancing market design and performance.
- ✓ ***Non-discrimination*** involves the equality of balancing market rules and conditions for different market parties (BRPs and BSPs).

Annex 4: Price setting under the monopsony and monopoly market structures



(a) Monopsony model



(b) Monopoly model

How does the monopsony decide how much to procure or how much to pay? How does it maximize its profit?

To answer the question a classical monopsony model is analysed. Its peculiarity is that the monopsony faces the upward-sloping supply curve S, indicating that suppliers require a higher price to increase the quantity of output supplied. The higher price must be paid not just to the additional quantity of output supplied by an additional supplier, but to total quantity of output supplied by all suppliers. Within this market structure, the monopsonist shall be a wage-searcher rather than a wage-taker. If a monopsonist shall want to buy a larger quantity of output, it shall pay a higher price, given by the height of the curve S. The market supply curve (S) shall be also the average cost (AC) curve for the monopsonist. Because the monopsonist shall pay a higher price to procure more quantity of output from suppliers, the marginal cost (MC) shall be greater than the average cost (AC) at each level of quantity supplied. This is why, the monopsonist‘s MC shall lie above the market supply curve S. Marginal revenue product (MRP) shall indicate the change in revenue resulting from procuring additional quantity. This curve is negatively-sloped due to the law of diminishing marginal returns. The monopsonist shall maximize its profit at a point E_2, where MRP shall intersect MC. The monopsonist shall procure Q_2 quantity of services from suppliers and shall pay a price P_2. In a competitive market, the company (monopsonist) would procure higher quantity of service from suppliers (Q_1) at a higher price (P_1) (the rule for price setting in a competitive market is MR=MC). The price (P_2) paid by a monopsony shall lower and the quantity procured (Q_2) shall be less than the benchmark of the perfect competition at point E_1. The result shall be that, within the monopsony market structure, the monopsonist shall win the **green** area in terms of savings, however it shall loss the **yellow** area because it shall buy less, but this shall not be a problem since **yellow** area shall be smaller than the **green** one. The suppliers shall loss the **blue** area because they shall sell cheaper and less quantity than the optimum (at a point E_1). The general result shall be a *social welfare loss* of the monopsony market structure, which shall be the sum of the **yellow** and **blue** areas (equal to the area of $E_0E_1E_2$). The social welfare loss means that the society, as a whole, is away from the optimum, so it is losing welfare due to the greedy action of the buyer.

How does the monopolist decide how much to sell and at which price? How does it maximize its profit?

A market structure characterized by a single seller of a unique product with no close substitutes is called a monopoly. As the single seller of a unique good with no close substitutes, a monopolist has no competition. The peculiarity of a monopoly market model is that a monopolist, who is a price maker, faces a negatively-sloped demand curve (D), which is the market demand curve for the product and also the average revenue (AR) curve for the monopolist. The D indicates that to sell a larger quantity of output, the monopolist must lower the price. The marginal revenue (MR) generated from selling extra output is less than a price. This is due to the law of diminishing marginal returns. Therefore, MR curve is below the D curve. As a profit-maximizing company that equates marginal revenue (MR) with marginal cost (MC), the price (P_2) charged by the monopolist is greater than marginal cost (MC). The inequality between price (P_2) and marginal cost (MC) is what makes monopoly inefficient. The monopolist shall maximize its profit at a point E_2, where MR intersects MC. The monopolist shall sell Q_2 quantity of services to buyers and shall ask a price P_2. In a competitive market, the company (monopolist) would sell higher quantity of service to buyers (Q_1) at a lower price (P_1). The price ask by a monopoly is higher and the quantity sold is less than in the benchmark of the perfect competition. The result is that, within the monopoly market structure, the deadweight loss (triangle) will be received. Loss in consumer surplus is the **brown** area, because buyers will buy more expensive and less quantity than the optimum (at a point E_1). The producer loss shall be **red** area. The *social welfare loss* of the monopoly market structure is the sum of **brown** and **red** areas (equal to the area of $E_0E_1E_2$).

References:

[1] Definition of Monopsony, http://www.economicshelp.org/labour-markets/monopsony/
[2] AmosWEB Encyclonomic Webpedia, “Monopsony”, http://www.amosweb.com/cgi-bin/awb_nav.pl?s=wpd&c=dsp&k=monopsony
[3] AmosWEB Encyclonomic Webpedia, “Monopoly”, http://www.amosweb.com/cgi-bin/awb_nav.pl?s=wpd&c=dsp&k=monopoly
[4] Jimenez, D.G., “A monopsony is also a market failure: WalMart”, 2012, http://www.energyoutofthebox.com/a-monopsony-is-a-also-market-failure-walmart/

Annex 5: Analysis of the Energinet.dk market regulations

Denmark being a constituent part of the common Nordic-Baltic wholesale electricity market, which is recognized as a market developed based on the market principles, also well represents the advanced Nordic balancing philosophy on rules and procedures for balancing. The country was chosen for the analysis because it has well-developed and comprehensive regulations for power market operations. Regulations are a well-structured, therefore provide clear understanding on principles and terms of market functioning. The market regulations consist of 14 independent regulations with associated appendices. Regulations A-G primarily deal with the wholesale market, while regulations H1, H2, H3 and I relate to the retail market. The regulations can be found on Energinet.dk's homepage under Electricity – Regulations – Market Regulations.

The main topics and the target groups of the individual regulations are described briefly below.

- **Regulation A: Principles for the electricity market**. Outlines the main principles for the Danish electricity market model. Is aimed at present and potential players in the wholesale market wanting to gain a high-level view of the various market places etc.
- **Regulation B: Terms of electricity market access**. Describes how Energinet.dk's tariffs are structured. Is aimed at present and potential players.
- **Regulation C1: Terms of balance responsibility**. Defines the concept 'balance responsibility' and outlines the contents of the 'Agreement on balance responsibility', which new players must sign in order to become a balance responsible party.
- **Regulation C2: Balancing market.** Describes how Energinet.dk has organised the regulating power and balancing markets and outlines the rules for settling regulating and balancing power. Is aimed primarily at enterprises that are active in the wholesale market.
- **Regulation C3: Handling of notifications and schedules**. Describes how Energinet.dk and balance-responsible parties are to handle notifications and schedules. Is aimed primarily at enterprises that are active in the wholesale market.
- **Regulation D1: Settlement metering.** Defines in detail the requirements for the settlement metering to be performed by the grid and regional transmission companies and how to aggregate the data obtained from such metering into energy statements to be used for settlement purposes. Is aimed primarily at grid companies and metering point administrators.
- **Regulation D2: Technical requirements for electricity metering**. Defines technical requirements for electricity metering in Energinet.dk's area and for any associated installations and control routines. Is aimed primarily at grid companies and metering point administrators.
- **Regulation E: Settlement of environmentally friendly electricity generation**. Describes the various settlement rules (price subsidies etc.) and the terms of settlement for wind turbines and other electricity-generating plants. Is aimed primarily at plant owners and others wanting to gain a high-level view of the various settlement rules.
- **Regulation F1: EDI communication with the DataHub in the electricity market**. Defines standards for data communication, i.e. the mutual transfer of notifications, metered time series etc. between the market players and Energinet.dk. It is aimed at grid companies, balance responsible parties and IT suppliers.

- **Regulation G: Discretionary policy and data protection procedures**. Describes how Energinet.dk handles any confidential and commercial information received. Is aimed primarily at market players forwarding confidential information.
- **Regulation H1: Change of supplier**. Defines the rules for change of supplier etc. and the relationships between customer, electricity supplier and grid company in this connection. Is aimed primarily at electricity suppliers and grid companies.
- **Regulation H2: Metering and load-profile settlement**. Defines rules for metering and load-profile settlement in the retail market. Is aimed primarily at electricity suppliers, grid companies and metering point administrators.
- **Regulation H3: Settlement of wholesale services and taxes**. This regulation contains general and specific requirements for handling subscriptions, fees, tariffs and taxes in the DataHub with a view to settlement between grid operator, Energinet.dk and balance supplier. Is aimed primarily at grid operators and balance suppliers.
- **Regulation I: Master Data. Defines master data**. Is aimed primarily at electricity suppliers, grid companies and metering point administrators.

References:

[1] Energinet.dk, "Overview of the Energinet.dk market regulations", 2016, http://energinet.dk/SiteCollectionDocuments/Engelske%20dokumenter/El/Overview%20of%20the%20Energinet.dk%20market%20regulations.pdf

Annex 6: Analysis of the Energinet.dk technical regulations

The technical regulations are divided into three groups with a number of different regulations within each group.

- **Regulations for system conditions**. The regulations specify function requirements and principles for the entire power system, including rules for system dimensioning, load shedding requirements, system requirements for MVAr balance, etc.
- **Regulations for grid connection**. The regulations specify the system properties that plants must possess in order to be connected to the Danish public electricity supply grid as well as the grid impacts plants must be able to withstand in order to continue to provide stable operation.
- **Regulations for system operation**. The regulations specify rules governing how plant owners, operators, balance-responsible parties and TSO must act to ensure stable, reliable system operation. They include provisions on and procedures for system operation as well as requirements for the collaborating control centres. They also specify the AS which electricity-generating plants must supply to the grid, outline guidelines for the decommissioning of plants, assign responsibility for the provision of measurements for system operation purposes and the preparation of communication procedures - for day-to-day operation as well as alert states.

References:

[1] Energinet.dk, http://energinet.dk/EN/El/Forskrifter/Technical-regulations/Sider/default.aspx

Annex 7: Analysis of Energinet.dk's ancillary services strategy

Analysis of the content of the Danish AS strategy discloses the commitments of the Energinet.dk's taken regarding challenges it has to solve, principles on which it will have to operate in order to tackle the challenges and actions it will have to take during the middle-term.

The AS strategy should be seen in light of Energinet.dk's group strategy plan and explains how the ancillary services area can contribute to meeting the three commitments set out in the strategy plan:

- To guarantee a high level of security of supply for electricity and gas – now and in the future
- To take responsibility for an economically viable transition
- To contribute to a healthy investment climate in the energy sector.

With a view to addressing these challenges, Energinet.dk centre the strategy on three principles:

- **Internationalisation**, which offers the opportunity to procure AS abroad while strengthening Danish suppliers through improved sales opportunities;
- **Competition**, including providing better opportunities for new technologies and suppliers to participate in the markets and ensuring that all major sup-plies to the power system are priced correctly;
- **Transparency**, including providing better insight for the market players into Energinet.dk's internal processes and making more information about the markets available.

Specific initiatives are defined in the strategy:

- Structured efforts to strengthen international alliances;
- Common market for FCR (primary reserve capacity) with Germany, the Netherlands, Switzerland and Austria;
- Analysis of possible FCR via DC connections;
- Nordic market for FRR-A capacity and activation;
- Cross-border trading in FRR-A activation in relation to Germany. FRR-A supply ability maintained through calls for tenders for supply ability;
- Trading in regulating power (FRR-M activation) between the Nordic and continental synchronous area (Germany);
- Analysis of the possibilities of more market-based purchasing of properties required to maintain power system stability (initiative 10 forms the foundation for this initiative and must be completed first);
- Analysis of the possibilities for new valuation of services and properties that are not currently regarded as AS;
- Adaptation of market rules with a view to removing the barriers for new potential suppliers, such as flexible electricity consumption and wind power;
- Documentation of Energinet.dk's procedures for handling AS;
- Initiatives for improving market transparency.

References:

[1] Energinet.dk's ancillary services strategy 2015-2017, http://energinet.dk/SiteCollectionDocuments/Engelske%20dokumenter/El/Energinet.dk%27s%20ancillary%20services%20strategy%202015-2017.pdf

Annex 8: Roles and responsibilities of the National Regulatory Authority

The independent national regulatory body – NRA – is mandated, according to its competence, to perform the state regulatory functions in the electricity and renewable energy sectors to ensure a proper implementation, supervision and control of the regulated electricity and renewable energy activities, rights and responsibilities of energy companies and consumers; as well as to ensure a fair competition in the electricity sector. NRA role in the electricity and renewable energy activities shall be important, since the NRA shall be responsible for the stable regulatory framework that would facilitate the necessary investments in new generating capacity and networks, thereby contributing to security of supply.

In order to achieve the determined target, the NRA shall perform the following functions:

- Approves the state regulated pricing methodologies;
- Approves the accounting requirements for the regulated activities;
- If necessary, prepares and submits to the Government the principles of the state regulated pricing;
- Determines by the state-regulated prices and their ceiling;
- Evaluates the cost of services taking into account a reasonable return on investment, approves energy network optimization, development and reconstruction, as well as additional energy network operator costs associated with renewable energy development;
- Approves rules on connection of electricity equipment to the grid;
- Approves connection fees of energy facilities (networks, systems and equipment);
- Determines the requirements for the secure and reliable energy supply and service quality and monitors the compliance with them;
- Determines technological, financial and managerial capabilities of energy companies and their evaluation procedures;
- At least once a year publishes recommendations concerning the compliance of energy prices with criteria of transparency and non-discrimination, and submits them to the Competition Council (CoC);
- Controls how the state regulated prices and tariffs are applied;
- Supervises, if the restrictive contractual practices, including exclusivity clauses, when large non-household customers can be prevented or limited to contract simultaneously with more than one supplier in the energy sectors, are present and informs the CoC about such practices;
- Oversees the scale of market opening and competition at wholesale and retail levels and its effectiveness, prices applied to the households (including prepayment systems), the share of consumers who changed their supplier and the share of consumers disconnected from the network as well as cases when energy activities make distortions or restrictions in the market;
- Conducts market studies to ensure effective competition in the energy sector and prevent large (influential) entities to abuse the power in the market
- Control the effective separation of activities in the energy sector in order to ensure the independence of transmission and distribution activities from the commercial energy interests and to prevent cross-subsidization;

- Issues the licenses for energy activities, changes them, suspends the validity of licenses, eliminates the suspension and the validity of the license of the license, supervises the licensed activities of the energy companies;
- Combines planned investments of energy companies, which prices are regulated;
- Determines the amortization rates of fixed asset used in energy activities which prices are regulated by the NRA;
- Designates the CSOs and market operator and carries out the activities of their supervision and control;
- Gives the fines to energy companies, which provide regulated activities, for violations of provisions in order to ensure their compliance with the statutory conditions;
- Approves the rules on fines imposed on energy companies, which perform regulated activities, for violations of provisions;
- Within the competence carries out the state supervision function in the area of protection of energy consumers’ rights and interests;
- Approves rules on electricity market surveillance;
- To assure the access conditions to storage;
- Approves rules on electricity market research.

Annex 9: Arguments for selection of the exchange

- Exchange reduce trading cost since there is no need for an expensive process of negotiation and writing of contracts, assessment of the creditworthiness of the counterparty, which is the case of bilateral market;
- Exchange creates preconditions to increase competition through the establishment of clear, transparent and non-discriminating trading rules;
- It provides publicly observable price, which is simpler and more accurate with regard to demand and investment;
- Exchange relies on a single price while in a case of bilateral market the prices are tailored (adapted) to individual BSPs;
- The distinguishing feature of the exchange is that it does not use side payments;
- Although exchange compared to the bilateral market provides less flexibility as the CSO and BSPs cannot specify any contract terms they desire, however this leads to the superiority of the exchange in that it can operate much faster than bilateral markets. Exchange routinely execute trades in quarter-hour time units while bilateral markets shall take hours to weeks. In balancing markets, velocity is relevant. Because of its velocity, exchange can operate much nearer to real time than bilateral markets. This makes exchange to be a choice for the market for balancing products.

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Annex 10: Arguments for selection of an auction

The main arguments for the choice of the auction are derived from the following advantages of the auction:

- It is a fair, open, transparent, objective, non-discriminatory, and timely process, which well corresponds the determined roles of the market for the procurement of frequency balancing and voltage control products to be market facilitating;
- It is transparent since it functions on a set of the determined rules which are well-known by the BSPs and the CSOs before the auction is held;
- It uses an efficient price discovery mechanism, minimizing information and transaction costs. Prices are determined explicitly. That is, the rules, which determine the price, are well-understood by all BSPs and CSOs involved;
- It finds the price of the auctioned balancing product in a competitive way and from this point is more attractive and less discussed solution to the regulatory pricing which is based on the cost establishment;
- It ensures procurement of frequency balancing and voltage control products at the lowest possible price for BRPs;
- It is the ideal selection mechanism when the “product” to be procured is clearly specified and spelled out in contractual terms on an ex-ante basis, and there is sufficient competition;
- It is proved to be a very effective mechanism for attracting new players in the market;
- It increases the competition and transparency of the procurement process, making it less likely to be challenged in the future as the political and institutional scenarios change;
- As a coordination mechanism the auction finds the BSPs with the lowest cost to meet demand in the market for frequency balancing and voltage control products. Therefore, resources with the lowest possible cost meet demand. Minimizing the total cost is an important public policy goal and an explicit auction design feature. In case of the BSC service, the CSOs bids participate in a process too and provide a relevant price “elasticity” that helps establishing competitive situations through the mitigation of the potential exercise of market power and;
- The auction is applied because of its superiority against fixed (regulated) price sale to be more flexible and less time-consuming compared to negotiating a price;

Two groups of the conditions should be assured in order to possess a successful auction for procurement of balancing and voltage control products. These are:

- Existence of competition is of the high importance for efficient auction. Competition or lack of it (e.g., market power, collusion) are usually structural issues. They are affected by the number and nature of players, market concentration, types of offered products or specific regulations;
- The CSO is willing to award a bid solely based on a financial offer (price);
- Robustness of the institutions and the whole regulatory framework. Independent regulators are significantly relevant due to the need for regulatory supervision;

- Regulatory stability meaning that the auction rules are not constantly changing;
- Transparency and fairness of the process. Lack of transparency in the process is related to the dissemination of information among auction participants before, during, and after the auction. A way to increase transparency is to have a publicly available independent ex-post audit of the process.

Any good auction design encourages participation. Whether the goal is economic efficiency, maximum revenues, or lowest costs, greater participation of BSPs improves auction performance [1]. The methods encouraging the BSPs to participate in the auction and increasing economic efficiency include:

- *Reduction of the BSPs participation costs*. The reduction of participation cost is a method to encourage potential BSPs to take part in the market. Thus, the entry fee is set moderate. However, the BSPs demonstrate their credit worthiness, which are understood as an entering barrier for the inefficient BSPs. Seeking to reduce cost for the BSPs, the CSO provide relevant information on what is procured and other, which helps the BSP to assess its participation possibilities in a market for inertia, balancing and voltage control products. Large BSPs could assume that participation cost is irrelevant / insignificant for them, but from the market design point of view a signal about the marginal bidders (the BSPs) who are smaller in size but are very important for competition is send to the market. If they are not attracted to the market large-scale BSPs will acquire more opportunities to exercise the power in the market.
- *Limitation of the design complexity*. Challenges and issues the market has to deal with commits the auctioneer establishing stricter gaming rules leading to complex auction designs which are developed to solve them and to limit the attempts made by the BSPs to game with and within the system with the aim to increase the BSPs revenues and profits. The complexity of market designs may raise participation costs and thus eliminate the marginal BSPs from the market because they may not have enough resources to work out all the issues generated by the complexity. Although some amount of complexity may be needed for the auction to effectively meet its objectives, but a good design strikes the right balance between necessary complexity and participation costs.
- *Reduction in the BSPs uncertainty*. The BSPs do not like uncertainty; therefore, they allocate resources for uncertainty (risk) management which in turn increase participation cost. Auction rules can significantly affect the BSPs uncertainties and if rules expose the BSPs they do not take part in the auction due to high participation costs. Consequently, the BSPs are discouraged from being marginal bidders in the market and the efficiency of the auction reduces. Therefore, it is essential paying attention on the rules and provisions reducing the BSPs uncertainty in the market.
- *Elimination of possible conflicts of interest*. The conflicts of interests arise if one of the BSPs is affiliated with the auctioneer, who for example, is the CSO. If the market designer and administrator is the distribution or transmission network company and at the same time owns generation assets or has a power marketer that may wish to participate in the auction, the incentives for self-dealing is assured. This is an actual issue, since the CSO has access to information that is not public. To avoid the conflict of interest, the management of the auction should be delegated to a third party independent of the CSO and its affiliates. Thus,

the independent market administrator should be established in such case and he / she should implement and enforce the rules of the auction.

References:

[1] Morey, M.J., “Power Market Auction Design. Rules and Lessons in Market-based Control for the New Electricity Industry”, Edison Electric Institute, 2001, http://web.mit.edu/esd.126/www/MktsAuctions/EEI.pdf

Annex 11: Reasons for and against spreading the demand for balancing and voltage control products over a sequence of auctions

If the sequential auction mechanism approach for the WoC concept is under the consideration, the CSO should think about several group of reasons for and against spreading the demand for balancing and voltage control products over a sequence of auctions. They are:

- *Transaction costs*: When transaction costs of bidding in an auction shall be high compared to the profits the bidders (BSPs) expected to receive in the auction, participation shall be negligible, thereby competition shall reduce, but the cost of procuring the products shall be tended to increase. In this case, the auctioneer (CSO) may thus give priority to a single auction over a sequence of auctions in order to keep transaction costs low.
- *Price discovery*: A sequence of sealed-bid auctions is a type of the auction, which is between a single sealed-bid auction and a descending auction in terms of information disclosed through the auctions. When there is uncertainty about the value of the balancing and voltage control product being auctioned, a sequence of sealed-bid auctions improves the price discovery relative to a single sealed-bid auction.
- *Risk aversion*: Due to some unexpected events, the market clearing price (MCP) in an auction might be very high or low. Risk-averse price-taking bidders (BSPs) shall prefer a sequence of auctions over a single auction. If there is a single auction, bidders (BSPs) might end up receiving this very high or low a price for all their frequency balancing and voltage control products. However, in a sequence of auctions, this risk could be reduced, because the prices that bidders (BSPs) receive for their sales are determined at different points in time.
- *Weak competition*: If competition is not strong in the auction, large-scale BSPs can bid to strengthen their market power in a sequence of auctions, increasing the cost of procuring the frequency balancing and voltage control products. In this case, a single auction might be more preferable.

Annex 12: Balancing responsibility for wind power generators, country example: Italy

Starting from 1 January 2013 the Italian Regulatory Authority for Electricity has introduced the concept of balance responsibility for wind generators (and in general for all variable renewables). The rule has established that wind generators have to pay penalties or receive revenues for the imbalances generated.

The rule has also defined for each variable renewable technology a percentage of error of the forecast for which the imbalances are not penalized through so-called "tolerance bands".

For the years 2013-2014 the tolerance bands for variable renewables units were set at 20% of the volume sold into the market. Starting from 1st January 2015 the tolerance bands are the following:

- Wind farms > 10 MW: 49%;
- PV units > 10 MW: 31%;
- Hydro units > 10 MW: 8%;
- Other units > 10 MW: 1.5%.

The variable renewables units under 10 MW are aggregated and the imbalance settlement is calculated at a portfolio level applying a tolerance band of 8%.

References:

[1] EWEA, "Balancing responsibility and costs of wind power plants", February 2016, http://www.ewea.org/fileadmin/files/library/publications/position-papers/EWEA-position-paper-balancing-responsibility-and-costs.pdf

Annex 13: Approach taken into account when determining the timing of sub-markets

Timing of sub-markets for balancing capacity and balancing energy for the aFCC service is considered and is summarized in Table 18-1 and Table 18-2. In the following a description is provided.

Table 18-1. The fragment of timing of the market for balancing capacity for the aFCC service

Bidding process				Clearance process		Distance to real time of the auction	Balancing capacity resolution in time	Market time unit: balancing capacity availability time
Gate opening time (GOT)	Gate closure time (GCT)	Bidding session	Frequency of bid-ding	Time	Frequency of clearance			
09.00 (21 January)	17.00 (21 January)	8 hours	Hourly	18.00 (21 January)	Hourly	Day	Quarter - hourly	00.00-01.00 (22 January)
10.00 (21 January)	18.00 (21 January)	8 hours	Hourly	19.00 (21 January)	Hourly	Day	Quarter - hourly	01.00-02.00 (22 January)
…	…	…	…	…	…	…	…	…
09.00 (22 January)	17.00 (22 January)	8 hours	Hourly	18.00 (22 January)	Hourly	Day	Quarter - hourly	23.00-00.00 (22 January)

Table 18-2. The fragment of timing of the market for balancing energy for the aFCC service

Bidding process				Clearance process		Distance to real time of the activation	Balancing energy resolution in time	Market time unit: balancing energy delivery time
Gate opening time (GOT)	Gate closure time (GCT)	Bidding session	Frequency of bidding	Time	Frequency of clearance			
17.15 (21 January)	23.30 (21 January)	6.25 hours	Hourly	23.30-23.45 (21 January)	Hourly	15 min	Quarter - hourly	00.00-01.00 (22 January)
18.15 (21 January)	00.30 (22 January)	6.25 hours	Hourly	00.30-00.45 (22 January)	Hourly	15 min	Quarter - hourly	01.00-02.00 (22 January)
…	…	…	…	…	…	…	…	…
16.15 (22 January)	22.30 (22 January)	6.25 hours	Hourly	22.30-22.45 (22 January)	Hourly	15 min	Quarter - hourly	23.00-00.00 (22 January)

Bidding session. This is a period of time during which the BSPs can bid balancing product into the market. The length of the bidding session depends on GOT and GCT of the market for balancing and voltage control products. Within the bidding session, all orders are placed by the BSP who can submit, modify and / or cancel them.

The WoC concept considers (Table 18-1 and Table 18-2):

- Fixed number of hours for bidding capacity for inertia and balancing capacity, i.e. 8 h could be considered as a sufficient time for inertia capacity and balancing capacity bidding;
- Time available for balancing energy bidding depends on the class of balancing energy product, i.e. this is 8.25 h in case of the BCS service, 7.25 h – the BRC service and 6.25 h – aFCC service.
- Fixed number of hours for bidding reactive power, i.e. 4 h could be considered as a sufficient time for reactive bidding.

Gate opening time (GOT). The GOTs for inertia capacity and inertia, as well as balancing capacity and balancing energy bidding are set fixed by linking them to the market time units of inertia capacity and balancing capacity availability; and the market time units of inertia and balancing energy delivery:

- The GOT for inertia capacity for the IRPC service and for balancing capacity for the BSC service bidding is 18 h ahead from real time. 18 h are set considering to the assumption that the auction for the inertia capacity and balancing capacity availability is finished 9 h ahead from real time, the clearing process takes 1 h and bidding session is additional 8 h. This means that if the BSPs will hold inertia capacity or will keep balancing capacity for the BSC service during 00.00-01.00 (of 22 January 2017), the GOT of balancing product will be at 06.00 (of 21 January 2017). The GOT for balancing capacity for the BRC and aFCC services bidding is set by 1 h later, respectively.

- The GOT for inertia for the IRPC service and balancing energy for the BSC service bidding is 8.75 h ahead from real time. 8.75 h consist of 8.25 h for bidding session, 15 min for clearing process and 15 min to real time of balancing energy auction. The GOT for the BRC and aFCC services is set by 1 h later from the GOT for the BSC service, respectively.
- The GOT for reactive power for the PPVC service bidding shall be 11 h before real time. For the market time unit of 00.00-01.00 it is set approximately half an hour later than an announcement of DA market information (at 12.42 o'clock).

Final gate closure time (GCT). The WoC concept sets the GCT for balancing and voltage control product bidding based on the following principles:

- *It is as close as possible to real time*. The implementation of the principle improves price efficiency, because the BSPs submit, update or cancel their bids considering to the latest available information. Thus, risk premium added to the price at which the BSPs wish to sell the balancing and voltage control product is reduced, therefore cost-reflectivity in price is achieved better. In case of balancing capacity bidding, the GCT for BRC and aFCC services is set closer to real time compared to the BSC product. This contributes to limitation of emergence of "price reversal" effect in relation between quality and price of the respective balancing capacity;
- *It ensures sufficient time for necessary balancing processes*. The implementation of the principal improves operational efficiency because leaving sufficient time for balancing process may not require additional personnel, infrastructure or other capacities, which increase administrative cost compared to the situation when little time is left for the performance of balancing process.
- *It is not set before the cross-zonal gate closure time (IDCZGCT)*. The implementation of the principal improves operational and price efficiency because the sequential approach in market organization is kept. Violation of the principle means that trade in ID market continuous, but the CO does not take care seriously of its consequences and closes the gate of balancing energy bidding earlier. In case the market actors will not balance their position by themselves in the ID market, the CO will do this. If energy imbalances are high, the CO could be in shortage of balancing energy because it takes decision having no final information from the ID market. Thus, price of balancing products is high. Moreover, by closing gate early serves as an entry barrier to the market for balancing products. In addition, the design of IDCZGCT itself is relevant for the determination of the GCT for balancing products. Concerning design of the IDCZGCT, two main aspects are understood as relevant for the WoC concept:
  - Level of harmonization of IDCZGCT;
  - Time span needed for the COs and market participants to perform scheduling and balancing processes before real time.

Three options for the harmonization of the IDCZGCT are identified:

- *A single IDCZGCT to be applied in the whole single intraday coupled region*. The option ensures that all market participants have equal access to cross-zonal capacity for the intraday timeframe until the same point in time providing them with a level playing field. However, in order to ensure that all system operation needs are covered, the IDCZGCT is set taking into account the longest time span needed by all the COs to perform balancing and scheduling processes. This solution provides the furthest IDCZGCT from real time, i.e. for example, 60 minutes.

- *A single IDCZGCT to be applied on a regional basis*. This option considers, if possible, to harmonize the IDCZGCT depending on the time span needed to the CSOs for balancing and scheduling processes. In those areas where the CSOs and market participants need less time for these processes, the IDCZGCT is set closer to real time. This regional solution allows for a partially harmonized IDCZGCT, but does not provide the same level playing field for the market participants compared to the first option.
- *An IDCZGCT set per bidding zone border*. This solution allows market participants trading as close as possible to real time depending on the characteristics of the power system where they are active. It does not provide harmonization and cannot be seen as an improvement to the status quo.

With regards to the point in time when to set the single IDCZGCT, all the TSOs have explored the time span needed across Europe for scheduling and balancing processes and the forecasts on whether these time spans can be shortened. The result is that the vast majority of the TSOs need 60 minutes before real time for running their scheduling and balancing processes, although some TSOs are of the opinion that in the future this timing may be shortened after the harmonization of balancing mechanisms is implemented. The TSOs argue that a single IDCZGCT is a great improvement compared to the current situation of large differences in the final GCTs for cross-zonal intraday trading in Europe. With implementing a single platform for cross-zonal intraday trading, a single IDCZGCT is fitting. However, stakeholders disagree with setting the IDCZGCT at 60 minutes before the start of the market time unit. They request for an IDCZGCT closer to the start of the market time unit to be able to better balance their portfolios taking into account flexible resources.

From the perspective of the CSOs, all three options are feasible. However, taking into account an objective of non-discriminatory access, the single intraday coupling solution should be considered as a priority. This shall mean that the GCT of the intraday cross-zonal trading shall be around 1 h before the time of electricity delivery. Thus, the statement that GCT for balancing energy bidding should not be before the IDCZGCT means that it has to be set at a time point, which is later than t-60 min, for example, at t-30 min before balancing electricity delivery (market time unit).

Moreover, within the WoC concept the GCT is tightly linked to the GOT for balancing product bidding. It is expected that by linking the GCT to the GOT improves equity and operational efficiency. Equity is improved because duration of balancing product bidding is the same for all balancing products, i.e. from the perspective of bidding, all the market time units are treated equally. Operational efficiency improves because principle of harmonization of the GCT is implemented which requires that administrative activities related to the balancing products bidding are performed during clearly established time period. Thus, no one has exceptional conditions. Within the WoC concept, the GCT is harmonized in a way that for each following market time unit it is set different but always the same for the particular market time unit. For instance, the GCT for the availability of balancing capacity for the aFCC service during 00.00-01.00 (22 January 2017) is 16.00 (21 January 2017), but for the availability of balancing capacity for the aFCC service during 01.00-02.00 (22 January 2017) it is by one hour later (i.e. 17.00, 20 January 2017). The same principle is applied for the GCT of balancing energy bidding.

Time horizon or frequency of bidding and frequency of clearance. The WoC concept assumes that the frequency of bidding process is equal to the frequency of market clearance and on overall the time horizon is reduced. This means that bidding and clearing processes are performed hourly. The BSPs submit bids for a particular balancing and voltage control product, which must be available for a particular market time unit on hourly basis. The statement that “time horizon is reduced” means that clearing process is organized on short (hourly) instead of long (yearly) basis, since this have sense in terms of improved utilization and price efficiency. For instance, if the sub-market for the balancing capacity is cleared yearly, then only those BSPs who have balancing resources, which are available across whole year, could offer balancing resources. Indeed, this is an entry barrier for many RES & DER BSPs since they cannot offer capacity for the whole year. Thus, utilization efficiency reduces. Because of limited supply, the price efficiency will reduce too. However, yearly clearance increases certainty to the BSPs. They are willing to participate in the market. Thus, availability of balancing resources improves [2].

Distance to real time of the auction. Thus far, European countries have no experience regarding inertia auction organization. Therefore, little is known about the distance to real time of the inertia capacity and inertia auction organization. Within the WoC concept, inertia capacity and inertia auctions are organized a day-ahead from real time after the closure of DA market.

The general existing practice in Europe is that the TSOs organize auctions or enter into the agreement for the procurement of the balancing capacity for the provision of the primary control services day- or week-ahead from real time (market time unit) while auctions / agreements for the provision of services for the secondary and tertiary control are signed from day- to year-ahead from real time (Table 18-3).

Table 18-3. Options for distance to real time of the balancing capacity auction

Balancing product	Day	Week	Month	Year or more
Primary control service	√	√		
Secondary control service	√	√	√	√
Tertiary control service	√	√	√	√

The practice was dictated by the structure of conventional balancing capacity dominated by several large therefore almost not competing power plants providing balancing capacity for national purposes. Moreover, the national practices were acquired subject to stable or little changing conditions in the balancing market for many years. Long distance to real time was favourable to the TSOs since reduced the risk of balancing capacity availability. However, the risk could increase the risk premium added to the balancing capacity procurement price. During the long time many events (including new lower cost potential balancing capacity providers could come) could happen, which influence was not considered into the price of balancing capacity. Thus, the real value of the balancing capacity was rarely reflected in its price. The distance to real time was closely linked to the product resolution (in time) meaning that long-term contracts were agreed far ahead from real time. Indeed, this proclaimed that market was “locked” for new BSPs even for several years forward because old annual contracts were still valid and additional contracts for the whole following year have been already agreed. Thus, new BSPs even hadn’t possibility to enter the market. Moreover, it has to be taken into account technical requirements for the BSPs, which were prepared for particular old and flexibility lacking power generators.

What could happen if the existing practice was hold for future? Let’s consider the case of the aggregator. Long distance to real time have an impact due to the uncertainty it may induce in decision making. Indeed, if the procurement is made long before delivery, aggregator must make assumptions that have an impact on the amount of reserve they can provide (behaviour of consumers, number of aggregated units, etc.). For instance, if procurement is made one year in advance, the aggregator will bid based on the number of units at the time of the bid, and it will not be able to take into account all the potential new aggregated units.

Thus, for future market design the distance to real time is reviewed and shortened, as it is proposed in the “Winter Package”. The “Winter Package” sets a requirement regarding the distance of the balancing capacity procurement to real time. The “Winter Package” determines that irrespective of the control function contracting should be performed for not longer than one day before the provision of the balancing capacity. This means that capacity should be reserved in advance, i.e. in a forward market one day ahead. If this is true, the markets for procurement of balancing capacity will have to be coordinated with wholesale energy markets with the aim do not overlap in time. If a sequential approach to the organization of markets is kept, then markets for balancing capacity should be set out among the energy markets, i.e. after DA market.

The WoC concept sets the distance of balancing capacity procurement to real time based on the European practice, recommendations of the “Winter Package” and the following several factors. Firstly, the abundance of production capacity in the power sector and its availability for the balancing purposes influences on the distance. Under the conditions of production capacity abundance, it is more likely that the CSO will seek to reserve capacity close to real time and agree to pay lower prices for keeping the capacities. Secondly, stability in regulatory environment impacts on the distance. Little changes in electricity sector related regulations are understood as certainty; therefore, the CSO could wish to reserve balancing capacity close to real time. Thus, the distance to real time of the auction is set one day ahead from real time.

The general existing practice in Europe is that the TSOs activates secondary control services very quickly up to 5 min ahead from real time, while tertiary control services usually are activated from 5 min to 1 hour ahead from real time (Table 18-4).

Table 18-4. Options for distance to real time of the balancing energy activation

Balancing product	Less than 1 min	1-5 min	5-15 min	15 min-1 h	More than 1 hour
Primary control service	N/A	N/A	N/A	N/A	N/A
Secondary control service	√	√			
Tertiary control service			√	√	√

The distance to real time of the inertia and balancing energy activation is 15 min within the WoC concept.

DA approach regarding the distance to real time of the reactive power auction organization is taken. However, the reactive power auction is organized closer to real time compared to the inertia capacity and balancing capacity auctions.

Balancing and voltage control product resolution in time (or market time unit). Short and long procurement cycles are considered. Short procurement cycles (quarter-hourly, 15 min) allow new entrants and enable providers with a small portfolio of either generation units and/or schedulable load participating in the market for balancing and voltage control products. The BSPs owning RES units prefer short procurement cycle because RES capacity can be used only for a limited time, for example, 4500 h a year whereas traditional fossil fuel-based power plants can run for approximately the whole year. Therefore, if balancing and voltage control product resolution is set long, the BSPs owning RES units will not be technically capable to provide the required capacities. Therefore, utilization efficiency reduces. Since an entry barrier for cheap technologies is created, the price efficiency reduces too, because cheap technologies do not take part in price setting process. The BSPs operating peak / marginal plants as well some large consumers are interested in longer procurement cycles to capture fixed revenues [1].

The market design variable is essential for the BSPs, especially for the aggregators, demand response, RES and storage technologies.

The relevance for the BSPs who aggregate consumption units or electric vehicles is based on the fact that availability of reserves is highly dependent on the habits of consumers. Thus, the amount of reserve they are able to provide is highly variable and they will be precluded from a market where the time is too long. Demand response technologies are smaller than traditional generators, and may be limited in the contiguous period in which they deliver balancing and voltage control product. With the aim to increase the number of demand response related actors and competition, shorter balancing and voltage control product resolution (in time) should be set. However, short balancing and voltage control product resolution (establishment of short-term markets) alone could be too volatile and risky to support procurement of balancing and voltage control products. Thus, long product resolution (long-term contracts) could be considered. It is justified for the purpose to protect relationship-specific investments. Moreover, long-term markets could give the BSPs the opportunity to better control risks by fixing the contracted volume and price for long-term. Such "hedging" could reduce barriers to entry, making markets more contestable. However, longer product resolution (in time) potentially come with some drawbacks, for example:

- It reduces competition in future bidding processes since the CSOs who are beneficiaries holding long-term contracts will effectively be out of the market for the duration of the contract;
- It transfers risks to the BSPs (both the risk that prices of balancing products will rise in future and capacity prices fall, and – as more contracts are signed – the risk that contracted capacity will not be required in future).
- It increases the costs of any future market design transition (operational efficiency reduces), since long-term contracts would in principle need to be honoured if in future a new market design was adopted.

In Europe, both short- and long-term markets for the provision of balancing products are established (Table 18-5). The balancing products (capacity and energy) for primary control are acquired by the TSOs in both short- and long-term markets by entering into hourly, daily, weekly, monthly or annually contracts with the BSPs. The general practice is that the balancing products for secondary and tertiary control are purchased in the long-term markets by entering into contracts the duration of which varies from week to year or more [3]. Certainly, in some countries both short- and long-term markets for provision of secondary and tertiary services are established.

Table 18-5. Options for balancing product resolution (in time)

Type of market	Short-term market		Long-term market		
Duration of the contract	**Hour**	**Day**	**Week**	**Month**	**Year or more**
Primary control services	√	√	√	√	√
Secondary control services		√	√	√	√
Tertiary control services	√		√		√

The “Winter Package” sets that contracting should be performed for not longer than one day before the provision of the balancing capacity and the contracting period should have a maximum of one day. This means that capacity shall be reserved in advance (i.e., in a DA market) for a maximum of one day.

Considering to advantages and disadvantages of different length of the frequency balancing product resolution, EU practice and requirements set in “Winter Package” for future power systems, the WoC concept establishes short-term markets for balancing and voltage control product trading with the product resolution in time of 15 min.

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Annex 14: Multiperiod Security-Constrained Direct Current OPF

For electricity market design simulations MATPOWER Optimal Scheduling Tool (MOST) [1], [2] was used. MOST can be used to solve problems as simple as a deterministic, single period economic dispatch problem with no transmission constraints or as complex as a stochastic, security-constrained, combined unit-commitment and multiperiod optimal power flow problem with locational contingency and load-following reserves, ramping costs and constraints, deferrable demands, storage resources and uncertain renewable generation. While the problem formulation is general and incorporates a full nonlinear AC network model, the current implementation is limited to DC power flow modelling of the network.

When using DC network modelling assumptions, the standard ACOPF problem is simplified to a quadratic program, with linear constraints. In this case, the dc power flow greatly simplifies the power flow by making a number of approximations including 1) completely ignoring the reactive power balance equations, 2) assuming all voltage magnitudes are identically one per unit, 3) ignoring line losses and 4) ignoring tap dependence in the transformer reactance [3]-[5].

The optimization variables are for multiperiod:

$$x = [\Theta^t; P_G^{ti}; P_L^{ti}; \mathrm{u}^{ti}] \tag{18.1}$$

Where Θ^t - Voltage angles and magnitudes, active injections for power flow at time t.

P_G^{ti} - Active injection for unit i at time t, MW

P_L^{ti} - Active consumption for unit i at time t, MW

u^{ti} - Binary commitment state for unit i in period t, 1 if unit is on-line, 0 otherwise and the overall problem reduces to the following form – Social Welfare maximization:

$$SW(P_G^t, P_L^t) = \sum_{t=1}^{period} \left\{ \sum_{i=1}^{n_c} B_L^{ti}(P_L^{ti}) - \sum_{j=1}^{n_g} C_G^{tj}(P_G^{tj}) \right\} \to \max_{\Theta^t, P_G^t, P_L^t} \tag{18.2}$$

The objective function (18.2) is a consumers' utility minus producers' cost (represented by function $B_L^i(P_L^i)$ and $C_G^j(P_G^j)$, respectively) shall be maximised subject to equality and inequality constraints:

$$g_P^t(\Theta^t, P_G^t, P_L^t) = 0 \tag{18.3}$$

$$h^t(\Theta^t, P_G^t, P_L^t) \le 0 \tag{18.4}$$

$$\theta_{ref} \le \theta_i \le \theta_{ref}, \qquad i = i_{ref} \tag{18.5}$$

$$P_{G,\min}^{tj} \le P_G^{tj} \le P_{G,\max}^{tj}, \qquad j = 1...n_g \tag{18.6}$$

$$0 \le P_L^{ti} \le P_{L,\max}^{ti}, \qquad i = 1...n_c \tag{18.7}$$

OPF development has been closely following the progress in numerical optimization techniques and computer technology. Many different approaches have been proposed to solve the OPF problem. These techniques include nonlinear programming, quadratic programming, linear programming, mixed programming, as well as interior point and artificial intelligence algorithms etc. [6]-[8].

The SCOPF problem is an extension of the OPF problem and contains important features of reliability in the optimization model. It guarantees the stable work for the whole power system, without changing active power generation, when some predetermined contingencies occur (such as outages of transmission line) [9]. The efficient solution of SCOPF is crucial for system operators, in the context of planning, operational planning and real-time operation.

Flowchart of the iterative multiperiod SCOPF algorithm is provided in Fig. 18-1, which starts by solving an OPF with (N-0) constraints. Having solved the contingency analysis, it identifies the critical group of lines and selects lines according to these criteria:

$$K^*_{L,re} = \chi_L \cdot Ps_{L,re}, \tag{18.8}$$

where L power system element ordinal number (lines, transformers etc.); $Ps_{L,re}$ power flow throughout element in operational state re; χ_L interruption probability of element L;

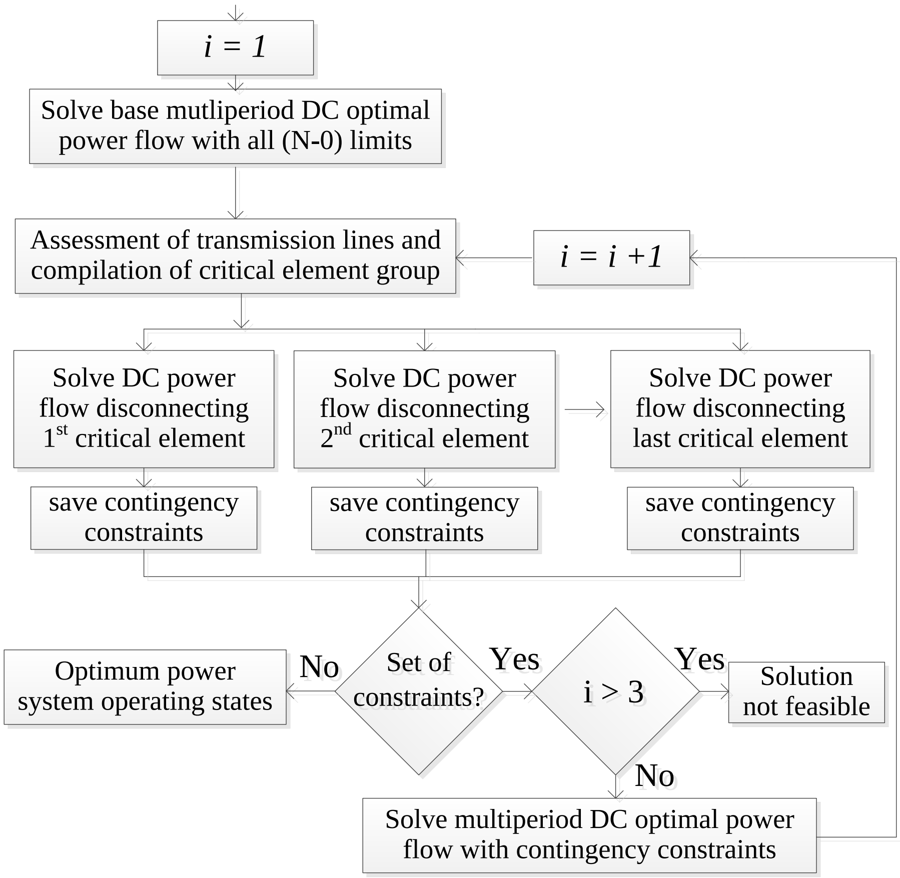

Figure 18-1. Principal block scheme of multiperiod security-constrained OPF

In electricity market tasks for optimal steady-state operation determination, only critical electric elements can be taken into consideration in which element flow: element interruption probability and therefore criteria K* are the highest values. This criterion is necessary in order to select a critical group of elements, subsequently reducing the size of optimization problem and calculation time.

9 bus system with 3 cell sample

In this section, a full 9 bus system (Fig. 18-2) is studied and the simulation results are demonstrated. The 9-bus system has 15 existing lines, 6 inelastic loads and 29 generators. The system parameters are listed in Tables 18-2 and 18-3.

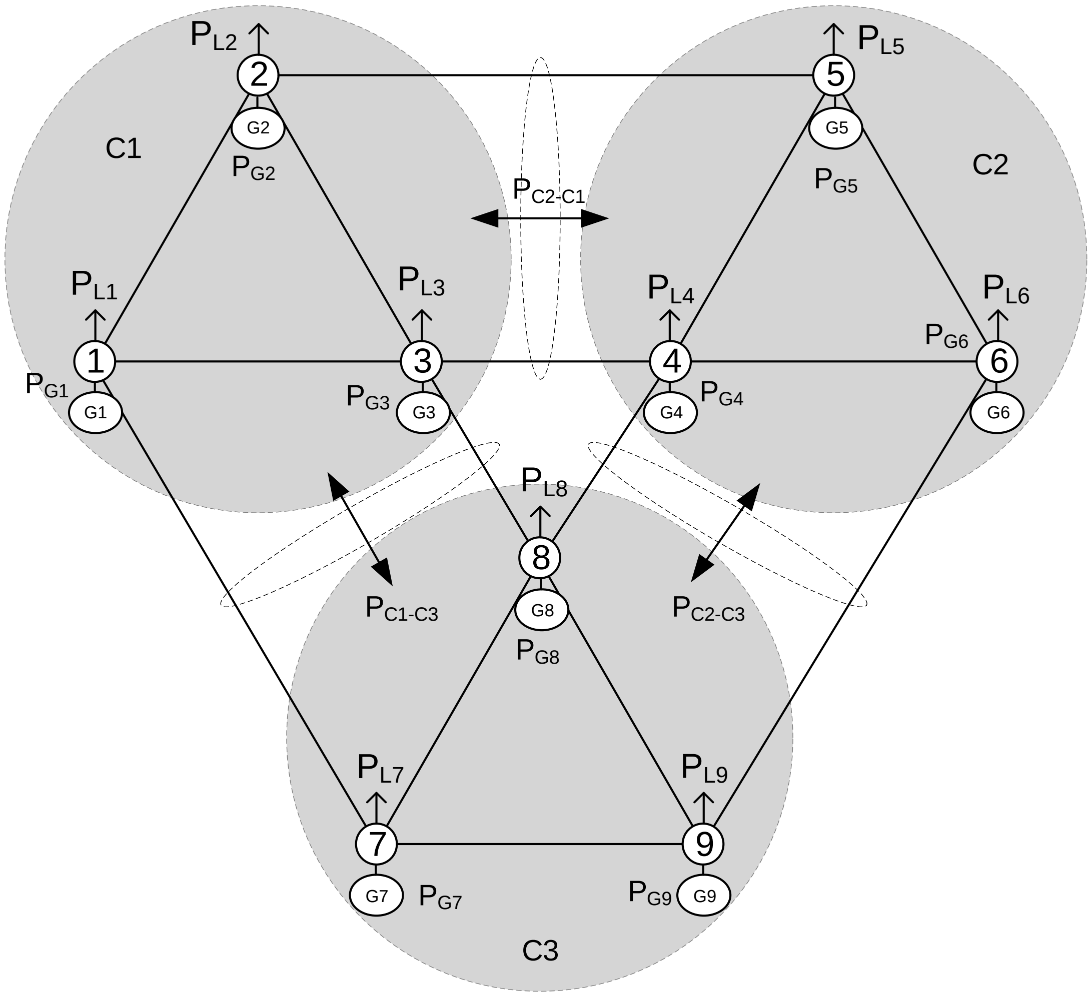

Figure 18-2. Principal block scheme of multiperiod security-constrained OPF

Table 18-6. Line data for 9 bus system

Branch	r_{ij}, p.u.	x_{ij}, p.u.	b_{ij}, p.u.	Capacity	
				MW	MVA
All	0.01	0.1	0.01	40	40

Tab. 18-7. Generator and load data for 9 bus system

Type	Bus No.	P_{GMAX} MW	P_{GMIN} MW	Ramping, MW/min	Bid&Offer Prices EUR/MWh
Load	1	0	-100	0	3000
CHP	1	200	30	10	51
HPP	1	50	10	25	5.1
HPP	1	50	10	25	5.2
HPP	1	50	10	25	5.3
HPP	1	50	10	25	5.4
Load	2	0	-100	0	3000
GT	2	200	30	20	42
Wind	2	100	0	15	1
Load	3	0	-100	0	3000
GT	3	200	30	20	30
Wind	3	100	0	15	2
Load	4	0	-100	0	3000
CHP	4	200	30	10	50
HPP	4	100	20	50	4.1
HPP	4	100	20	50	4.2
Load	5	0	-100	0	3000
CHP	5	200	30	10	55
GT	5	200	30	20	39
Load	6	0	-100	0	3000
ST	6	300	60	6	76
HPP	6	100	20	50	6.1
Load	7	0	-100	0	3000
GT	7	200	30	20	36
HPP	7	20	5	10	7.1
HPP	7	20	5	10	7.2
HPP	7	20	5	10	7.3
HPP	7	20	5	10	7.4
HPP	7	20	5	10	7.5
Load	8	0	-100	0	3000
CHP	8	200	30	10	58
ST	8	200	60	6	78
Load	9	0	-100	0	3000
GT	9	100	30	10	45
Wind	9	100	0	30	3

For the present structure of the network loads was defined by an individual demand pattern with wind production curve for 100 MW power plants (see Fig. 18-3). The production curve is fixed for each step and does not participate in the automatic generation control.

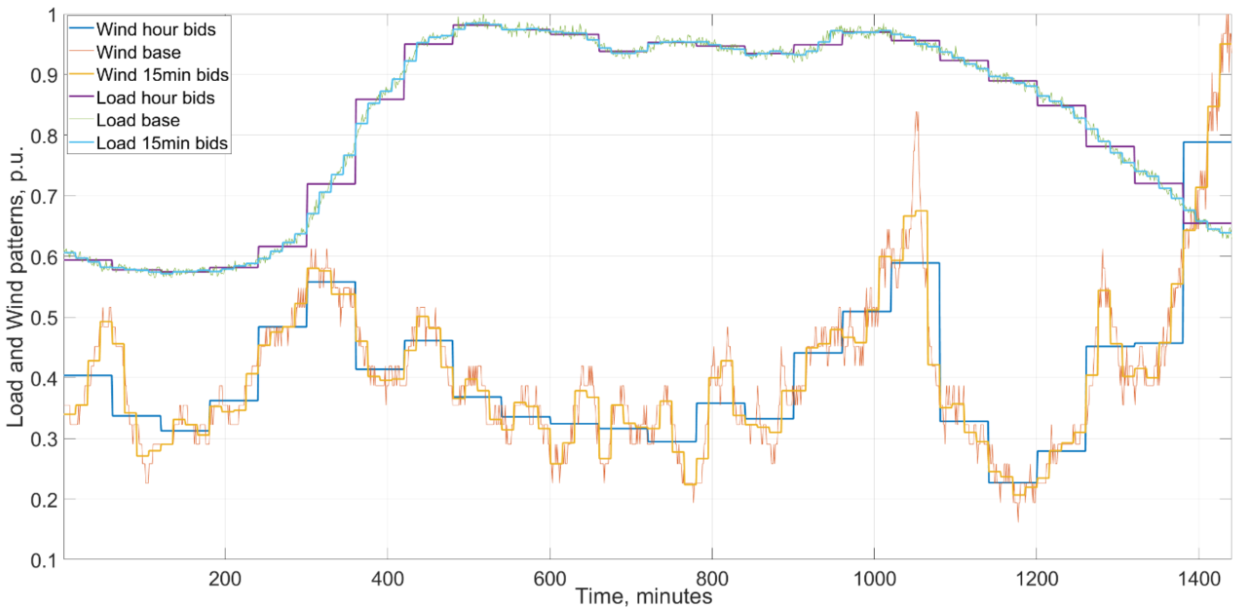

Figure 18-3. Load and Wind patterns for 24 hour time period

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