A TRANSPARENT MARKET DESIGN FOR BALANCING AND VOLTAGE CONTROL PRODUCTS

Irina OLEINIKOVA
NTNU – Norway
irina.oleinikova@ntnu.no

Luciano MARTINI
RSE – Italy
luciano.martini@rse-web.it

J. Emilio RODRIGUEZ-SECO
TECNALIA - Spain
jemilio.rodriguez@tecnalia.com

ABSTRACT

This paper illustrates the results achieved by the European ELECTRA project and in particular the detailed analysis that has been made on market implications related to the deployment of the novel decentralized control architecture for 2030+ power systems, namely the Web-of-Cells. Within this research a high-level market design to support the new proposed control framework was developed. Particular emphasis was given to the analysis of market mechanisms that must be implemented to perform the needed trading for the balancing and voltage control services. In particular, the "power exchange", where balancing and voltage control products are traded between the Balance Service Providers and the Cell System Operators, was considered and analysed.

INTRODUCTION

The European power sector will undergo significant developments beyond 2020. Electricity production is progressively shifting from traditional fossil fuel-based units to distributed intermittent Renewable Energy Sources (RES) units. Hence, energy production significantly moves from a central transmission to a decentralized distribution network connected scenario.

In this research, a decentralized managed approach, called Web-of-Cells (WoC), is considered as a reasonable solution to the expected needed developments [1, 2]. In the WoC, the power system is decomposed into grid areas, called Cells, which are capable to self-providing (local) balance (to maintain cell power export at an agreed set-point) and voltage control services.

The WoC concept must comply with high-level EU regulations, which are related to the general principles regarding the operation of wholesale electricity markets, including market for system balancing products. Therefore, electricity market structure for the architecture of frequency (balancing) and voltage control is developed with 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 [3].

The proposed electricity market design is not related to a specific power system development scenario, but it is related to a number of clear and indisputable trends and the need for an organized marketplace, that fits multiple future scenarios and system needs in normal power system operation, such as cost-effective solutions for offering ancillary services based on large amount of fast reacting Distributed Energy Resources (DER), and the usage of large amount of Cell internal flexibility and load variability [4, 5].

CELL–BASED ARCHITECTURE FOR DECENTRALIZED SYSTEM BALANCING AND VOLTAGE CONTROL

Power system control architecture structured as WoC means that each Cell is assigned to a ***Cell System Operator*** (CSO) who takes the responsibility of balancing capacity activation in real time, based on local observables (see Figure 1). In this way, local imbalance problems are addressed within the Cell, locally, quickly, securely and limiting complexity of the rest of the network.

Figure1. Schematic example of WoC architecture.

The WoC power grid, developed as a solution to future challenges, encompasses a group of interconnected loads, concentrated production units, DER and storage units within defined grid boundaries corresponding to a physical portion of the grid and corresponding to a confined geographical area [1, 2], [6].

The solution starts from the current Transmission System Operator (TSO) balancing approach, based on control area concept, and applies it at any voltage level/power size with enhanced control through concurrent service deployment and greater autonomy and collaboration at local levels.

An ELECTRA Cell has several specific characteristics:

– Local problems are usually solved within a Cell where local observables are used to decide on local corrective actions to handle local issues; there is no need to expose local problems at system level.

– Communication and computational complexities are minimised since they are handled at Cell level; this is more efficient than collecting the data of all system devices, aggregate them, send them upwards to the entire system control centre, process them and send all set-points back to the individual devices downwards.
– Local grid conditions are explicitly taken into consideration when deciding what kind of resources are used.
– Provision of a distributed bottom-up approach for the restoring of the system balance, which is performed as an aggregated effect of the cell balances.
– Focus more on balance restoration, and thereby restoring frequency as well.
– The total amount of internal flexibility in each Cell has to be at least enough to compensate the Cell generation and load uncertainties in normal operation, in such a way that each Cell can follow its initial set-points.

A detailed description of rules, which define the Cell is given in [2].

MARKET DESIGN WITHIN THE WOC CONCEPT

To ensure the operation and functioning of the new WoC architecture for frequency and voltage control, new market mechanisms and conditions are required in order to make possible the trading of balancing and voltage control products involved in the real-time operation of the WoC [3], [7]. The market for balancing and voltage control services is established considering the following principles, elements and products.

Products and market design elements

When designing the market for balancing and voltage control products the following principles shall be considered:
– Development of a reference market model 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.

A reference model of a market for balancing and voltage control products is developed to define the market concepts, main actors and their roles in the market during different stages of market organization/ operation/ functioning.
The problem of transparency of the markets for balancing and voltage control products is solved by establishing following regulating provisions:
– 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, data placement and information publication.

System balancing products

A variety of system balancing products, which are procured by the CSO and supplied by the ***Balance Service Providers*** (BSPs) to assure the balance between electricity production and consumption in real time, is suggested within the WoC architecture. They differ in the balancing control functions, technical characteristics, procurement schemes and other requirements. In Figure 2, the list of system balancing products traded within the WoC architecture is given by categorizing them into classes, directions and types.

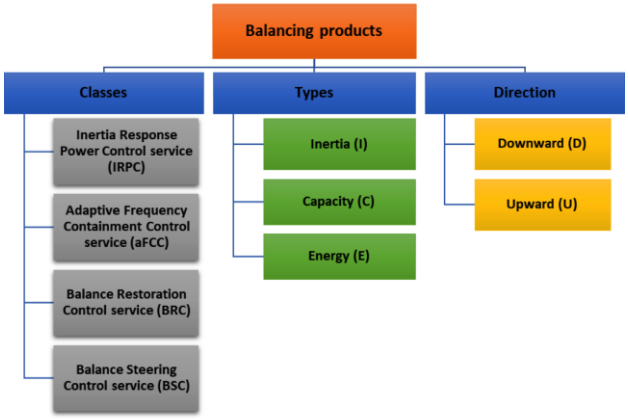

Figure 2. System balancing products.

In the WoC framework, four classes of system balancing products are traded in separate sub-markets with the purpose to keep the system frequency within certain limits [4], [6]:

i) Inertia Response Power Control (IRPC) service where each unit able to provide synthetic inertia automatically changes its level of inertia power response depending on market outcomes.
ii) 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 within each Cell. These will react to frequency deviations to contain any frequency change and stabilize frequency to a steady-state value.
iii) Balance Restoration Control (BRC) service initiates the restoration of the Cell balance 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 or by local storage. BRC is aimed to react to frequency deviations in conjunction with the Cells tie-line power flow

deviations from the scheduled in order to restore both quantities to their initial values.

iv) Balance Steering Control (BSC) service will replace the BRC in a more economic manner if this can be done safely or adjust the balance set points. It can as well have pro-active activation. This control deploys resources not only within the Cell but also from neighboring Cells (imbalance netting).

Based on today's operation a clear direct link between the quality of system balancing products and their price is established, showing that the quality of system balancing products 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 are priced at higher prices. In the WoC architecture, the relationship between the quality of system balancing products and their price could be kept too.

Market actors

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

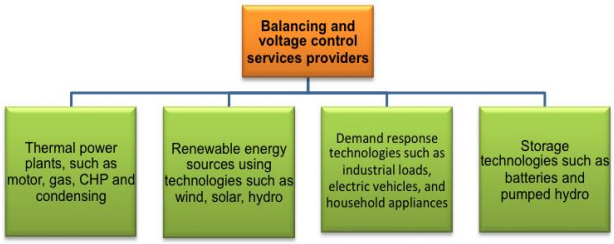

Figure 3. Balancing and voltage control services providers.

As the share of intermittent RES will significantly increase 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 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. They will be at the distribution level and will be represented by RES, demand response and storage technologies. 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.

The CSO is then responsible for the procurement of capacity reserves in the appropriate markets of balancing and voltage control services. The CSO will buy inertia capacity, balancing capacity and reactive power products from the BSPs, and will activate them in real-time when necessary.

The roles and responsibilities of the BSPs in the market for frequency and voltage control products are in line with the following requirements [4]:

- 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 CSO 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 with a valid balance agreement with the CSO and is responsible for its imbalances: manages a balance obligation on its own behalf as a producer (conventional or RES-based), consumer or trader of electricity, or on the behalf of other producers, consumers or traders of electricity. During the stage of balance planning the BRPs are obliged to provide to the CSO the planned energy production, consumption and trade schedules (separately). The roles and responsibilities of the BRPs in the market for frequency and voltage control products are in line with the following requirements [4]:

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

During the real-time operation of the cell, the CSO activates the balancing energy, inertia and reactive power reserves, if needed. The CSO recovers the cost of these services provision from the BRPs who were in imbalance during the particular market time unit, i.e. the CSO sells the procured balancing and voltage control products to the BRPs who are in imbalance.

In the market, the balancing and voltage control products are traded between the BSPs and CSOs at intra-cell and inter-cell levels, and settlements are carried out between the CSOs and the BRPs. The interactions between these market actors split the market into a procurement side and settlement sides are seen in Figure 4.

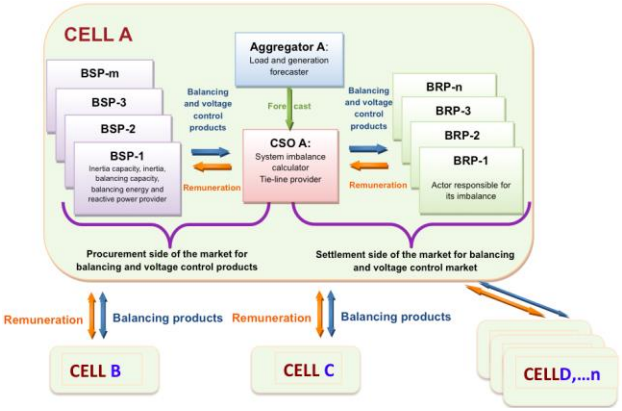

Figure 4. Interactions of the market actors for balancing and voltage control services.

REFERENCE MODEL

The market for balancing and voltage control products is a constituent part of the wholesale electricity market. In addition to the capacity markets for the procurement of reserves (balancing and voltage control services) to be activated if necessary in each cell during the real-time operation by the CSO, the set-points of all cells will be established through energy-only markets. (Figure 5.)

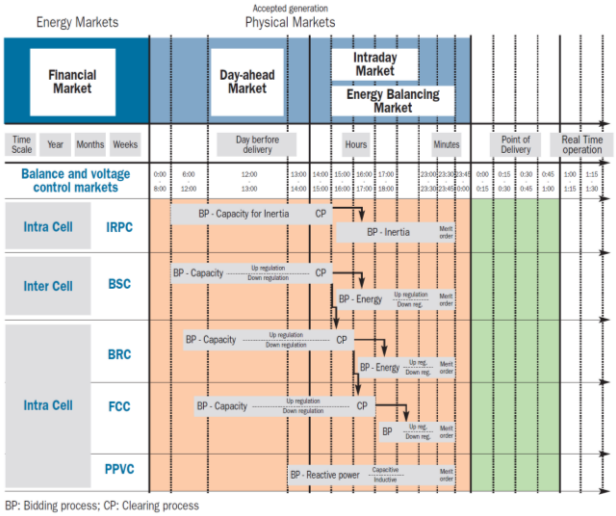

Figure 5. Market sequence organisation for the balancing and voltage control services.

Each balancing and voltage control product 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. For each balancing product there are established two main types of sub-markets: balancing capacity (the BSPs are compensated for availability of reserves) and balancing energy (the BSPs are compensated for the actual delivery of electricity (i.e. utilization of balancing capacity), or inertia capacity and inertia. In the sub-market for voltage control products reactive power is traded.

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 capacity or balancing capacity – they take part in, see Figure 6.

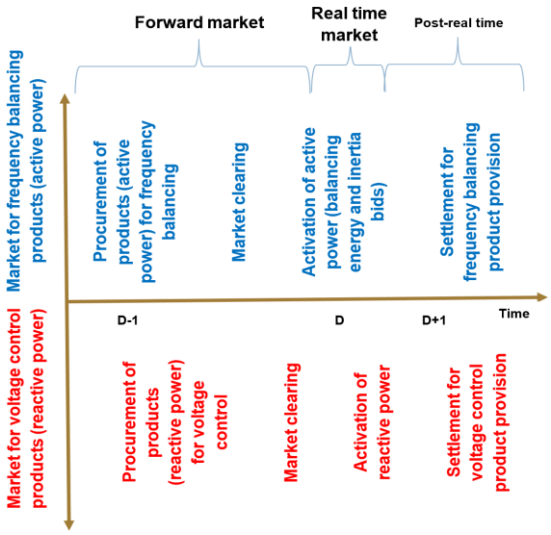

Figure 6. The timing of submarkets.

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). The TSOs select the cheapest energy bids based on the merit order (merit order activation). Considering the European practice, the CSO may apply two types of activation schemes for the BSPs. These are pro-rata and merit order schemes. (see Figure 7, 8.)

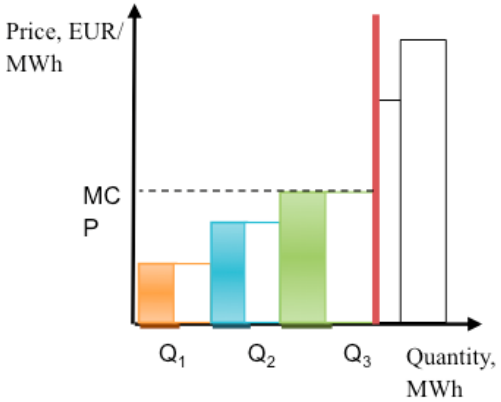

Figure 7. Pro-rata activation scheme.

In the pro-rata activation scheme, all balancing products providing units are activated simultaneously, which ensures that all available ramping speed is used. 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. Two different methods may be applied by the CSO to activate the balancing services.

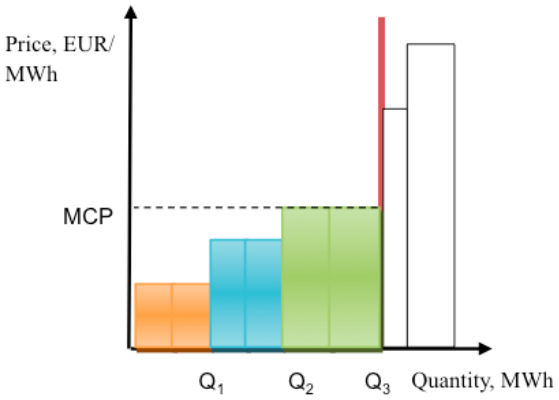

Figure 8. Merit Order.

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.

CONCLUSIONS

An integrated approach, 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 when proposing the market design supporting the functioning of the WoC decentralized architecture for balancing/frequency and voltage control of the grid of the future (2030+). During the research the core elements of the market were analyzed and a market place was designed. The results showed that with an increasing volume of intermittent RES integrated into the power markets, new types of BSPs are requested. Thus, in addition to centralized thermal power plants, small-scale RES, demand response and storage technologies are available at the distribution level to provide the needed balancing and voltage control services. With the purpose to increase the size of the BSPs, aggregators 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 and described in this paper. 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.

Acknowledgments

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007–2013) ELECTRA IRP, under grant agreement No. 609687. The Authors would like to thank Carlo Tornelli and Mattia Cabiati from RSE for their support to this paper.

REFERENCES

[1] Martini, L.; Radaelli, L.; H. Brunner, Caerts, C.; Morch, A.; Hanninen, S.; Tornelli, C. "ELECTRA IRP Approach to Voltage and Frequency Control for Future Power Systems with High DER Penetration*"*. *Proceedings CIRED conference*, Session3: Operation, Control and Protection, Lyone, France, 15-18 June 2015.

[2] Martini, L.; Brunner, H.; Rodriguez, E.; Caerts, C.; Strasser, T.I.; Burt, G. "Grid of the future and need for a decentralized control architecture: The web-of-cells concept. *Proceedings CIRED conference*, Session3: Operation, Control and Protection, Glasgow, UK, 12–15 June 2017.

[3] Bobinaite,V., Obushevs, A., Oleinikova, I., Morch, A. "Economically Efficient Design of Market for System Services under the Web-of-Cells Architecture". *Energies 2018*, 11, 729; DOI:10.3390/en11040729

[4] 21st CenturyPower.org (2013). "Market Evolution: Wholesale Electricity Market Design for 21st Century Power Systems": http://www.nrel.gov/docs/fy14osti/57477.pdf

[5] European Commission (2016). Evaluation Report covering the Evaluation of the EU's regulatory framework for electricity market design and consumer protection in the fields of electricity and gas: http://ec.europa.eu/energy/sites/ener/files/documents/2_en_autre_document_travail_service_part1_v2_1.pdf.

[6] C. Caerts, et al. "Description of the detailed functional architecture of the frequency and voltage control solution (functional and information layer)". ELECTRA Deliverable D4.2: WP4 Fully Interoperable systems. 2016.

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