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Scenarios and case studies for future power systems

Deliverable 3.3

Analysis of necessary evolution of the regulatory framework to enable the Web-of-Cells development

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Deliverable D3.3 discusses how the solutions proposed within ELECTRA can be tailored to the typical rules that will be imposed by national/EU regulators, and/or how the regulations can be extended or adapted to cover the new concepts developed in ELECTRA (Web-of-Cells architecture, associated control mechanisms, Cell System Operator role, etc.).

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Executive summary

This deliverable explains how the solutions proposed within ELECTRA can be tailored to typical rules that will be imposed by national regulators. To support the Web-of-Cells development in the 2030+ horizon, an evolution of the regulatory framework and current roles and responsibilities could be needed. The challenge is thus to explain how the Web-of-Cells architecture, high level Use Cases (i.e., balancing and voltage control mechanisms), and the Cell System Operator new role can be tailored to the regulatory framework, and vice versa. In detail, the following items are considered:

- The deliverable defines an adapted legal framework for the Web-of-Cells development, taking into account new stakeholder roles and obligations. In such a context, definitions and constraints are analyzed for the Web-of-Cells architecture and high-level Use Cases, to be adapted to the mandatory regulation. New amendments are also proposed to the applicable regulation to support/promote the Web-of-Cells architecture and Use Cases.
- The deliverable identifies the regulation implications for the development of market design for the Web-of-Cells.

Through its decentralized paradigm, the Web-of-Cells concept results to be in line with the current EU regulatory framework and would allow to achieve a precise regulation at non-transmission level, by promoting a more active role of DSOs. This latter is due to the fact that in the Web-of-Cells both DSO and TSO will be Cell System Operators with the same level of responsibility over their corresponding cells, where the cell set-points explicitly take into account the capacity limitations of the inter-cell tie-line connections. With reference to the Use Cases developed in ELECTRA, there is a clear impact of network codes and established requirements on most of them, thereby defining the need of the amendments proposed to the current regulation to make the Web-of-Cells feasible from the regulatory point of view. However, this new control architecture can be adapted (with the necessary changes) to the requirements of the corresponding Synchronous Area, by customizing the ELECTRA Use Cases in the related geographic area. As for the roles and responsibilities in the Web-of-Cells architecture, the Cell System Operator new role can be interpreted by the traditional DSOs or TSOs. Most of the responsibilities identified in the functioning of the Web-of-Cells, both in the reserve procurement and real-time operation phases, can be allocated to the Cell System Operator. However, beyond the key new Cell System Operator role, other new roles with specific responsibilities (e.g., aggregators) are also needed for the Web-of-Cells development. In such a context, some adaptations of the current relevant regulations are also proposed to be implemented.

The results of the analysis of the Market Design Initiative of the Winter Package and ENTSO-E Network Codes for market design show that the Web-of-Cells concept should respect the high-level EU regulations, which are related to the general principles regarding the operation of wholesale electricity markets, including market for system balancing products. However, new rules are identified for a well-functioning market of frequency and voltage control services under the Web-of-Cells power grid structure, by also improving the market transparency. This latter issue should be addressed by regulating: qualitative requirements for data; minimum data set and its availability for the Merit order collection and the Merit order decision making; roles for the actors regarding data and information collection, provision, aggregation, use and publish; data placement; and data and information publication.

Terminologies

Abbreviations

ACE	Area control error
ACER	Agency for cooperation of energy regulators
aFCC	Adaptive frequency containment control
AS	Ancillary services
AVR	Automatic voltage regulator
BRC	Balance restoration control
BRP	Balance responsible party
BSC	Balance steering control
BSP	Balance service provider
CACM	Capacity allocation and congestion management
CC	Cell controller
CoBA	Coordinated balancing area
CPFC	Cell power frequency characteristics
CSO	Cell system operator
DER	Distributed energy resources
DG	Distributed generation
DC	Direct current
DCC	Demand connection code
DSO	Distribution system operator
EB	Electricity balancing
ED	Energy directive
EED	Energy efficiency directive
ESI	Energy system integration
EV	Electric vehicles
EU	European Union
FCC	Frequency containment control
FCP	Frequency containment process
FCR	Frequency containment reserve
FRC	Frequency restoration control
FRCE	Frequency restoration control error
FRP	Frequency restoration process
FRR	Frequency restoration reserve
HV	High voltage
IEM	Internal energy market
IRPC	Inertia response power control

LFC	Load frequency control
LFCR	Load frequency control and reserves
LOM	Loss of mains
LV	Low voltage
LVRT	Low voltage ride-through
MCP	Market clearing price
MDI	Market design initiative
MOC	Merit order collection
MOD	Merit order decision
MV	Medium voltage
NC	Network code
NC DCC	Network code on demand connection
NC EB	Network code on electricity balancing
NPFC	Network power frequency characteristic
NRA	National regulatory authority
OLTC	On-load tap changer
OS	Operational security
PGM	Power generating module
PMU	Phasor measurement unit
PPM	Power park module
PPVC	Post-primary voltage control
PVC	Primary voltage control
P2G	Power to gas
RED	Renewable energy directive
RES	Renewable energy sources
RfG	Requirements for generators
RoCoF	Rate of change of frequency
RR	Replacement reserves
RRP	Reserve replacement process
SO	System operator
SPGM	Synchronous power-generating module
TPEMI	Transparency platform for electricity market information
TPlat	Transparency platform for balancing and voltage control services market information
TSO	Transmission system operator
TYNDP	Ten-year network development plan
UC	Use case
WoC	Web-of-Cells

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1. Introduction

The current grid management structure and organization for frequency and voltage control, with the transmission system operator (TSO) being responsible for reserves activation in its control area, will not be effective for addressing several emerging challenges essentially related to the increasing penetration of distributed generation (DG) in power systems. According to the several future scenarios identified in D3.1 [1, 2], the main aspects of the future trends include:

- Generation will shift from classical dispatchable units to variable renewables, and this will result in a paradigm shift from generation following load to load following generation, and in the increased need for balancing reserves activations;
- Generation will generally shift from centralized/transmission system connected to decentralized/distribution system connected. This will result in: more generation at LV and MV level increasing the risk of local voltage problems and congestions; resources which can help in solving voltage and balancing problems moving from the central transmission system level (HV) to the distribution system level (MV/LV); a central system operator (SO) at transmission level no longer having the system overview to effectively dispatch reserves; and the distribution and availability of resources varying significantly in different geographical areas;
- Generation will shift from a few large to many smaller DG units connected at distribution level, resulting in: more locations where incidents can happen, which can remain unnoticed at the global system level; and a shift from synchronous generators to power electronics interfaced generation, reducing the power system inertia and causing a higher rate of change of frequency (RoCoF), more spurious tripping of protection relays, and short activation times for frequency containment reserves (FCR);
- Electricity consumption will increase especially due to the electrification of transport and heating/cooling (e.g., through heat pumps), and this results in the increase of the risk of demand peaks, voltage problems and congestions;
- Electrical storage systems will be a cost-effective solution for offering ancillary services (AS), thereby making distributed storage a competitive solution for reserve services compared to traditional resources [3];
- Ubiquitous sensors will vastly increase the power system observability, and this will result in many measurement points at all voltage levels provided by Phasor Measurement Units (PMUs), smart metering infrastructures and other advanced power/energy measurement devices;
- Large amounts of fast reacting distributed energy resources (DER) (can) offer reserve capacity thereby offering capability as a service (e.g., balance restoration, frequency containment) to grid operators and market parties [4].

Based on these scenarios, it is expected that the future frequency and voltage control can no longer be effectively managed in a TSO-centric manner. In such a context, the Web-of-Cells (WoC) concept was born, which is mainly based on a decentralized paradigm, where the power system is divided in grid areas (i.e. Cells), which can provide local balancing and voltage control with the purpose of solving local problems locally. However, with reference to the current European Union (EU) regulatory framework, several questions arise:

- Is the WoC in line with the current regulatory framework or is it a disruptive concept?
- What are the current regulations impacting on the WoC?
- Which are the main constraints to be considered in a WoC architecture? Does the current regulatory framework cover them?
- Are the current responsibilities respected?
- Are the current regulation (including ENTSO-E network codes) adaptable in a WoC architecture? If not, how to amend them?

- What are the regulation implications for the development of the market design for the WoC?

Therefore, the aim of this Deliverable D3.3 is to explain how the WoC architecture, high level Use Cases (i.e., balancing and voltage control mechanisms), and the new Cell System Operator (CSO) role can be tailored to the regulatory framework, and vice versa, thereby answering the above questions.

In the following, Section 1 introduces the aim and scope of the Deliverable D3.3. Section 2 introduces a critical assessment of the European Regulatory framework for the electricity sector including the main Directives and the Winter Package, the ENTSO-E network codes, the integration with non-electrical energy carriers and the regulation at non-transmission level, with the aim of identifying the potential implications for the WoC. Section 3 describes in detail the current regulatory prescription as well as the current involved stakeholders with specific roles and responsibilities, with reference to the WoC and high level Use Cases (i.e., balancing and voltage control mechanisms). The aim is to identify possible barriers and allocate responsibilities, thereby detecting the needed changes to make the WoC feasible from the regulation point of view. Section 4 analyzes the needed modifications in stakeholders roles and responsibilities to enable the WoC development, and proposes possible extensions and/or amendments in the regulatory framework to support/promote the Web of Cells architecture. Section 5 discusses the regulation implications for the development of market design for the WoC. Finally, Section 6 concludes with the learning and new knowledge derived from this analysis.

2. EU regulatory framework and implications for the Web-of-Cells: a general overview

2.1 European Directives for the electricity sector and the Winter Package

The EU has set ambitious goals for designing its whole energy system from 2020 up to the middle of the 21st century. In view of the fundamental transformation needed to deliver a sustainable Europe by 2050, crucial changes are required. Several regulations and European Directives have encouraged such changes, emphasizing electricity as a crucial enabler for economic growth. These Directives refer to four different energy packages addressing the unbundling of the electrical sector (first package), the promotion of renewables and the network access conditions for cross boundary electricity exchanges (second package), common rules for a single electricity market in Europe (third package), and a redesign of the European electricity market, the updating of the energy efficiency labelling, and the revising of the EU Emissions Trading System (energy summer package). Therefore, these Directives support the three European energy policy pillars, which are: the security of supply, sustainability, and market efficiency, as well as the related short-term energy policy targets for 2020.

On 30 November 2016, the Commission published a new energy package, so-called 'Winter Package' of eight proposals to facilitate the transition to a 'clean energy economy' and to reform the design and operation of the European Union's electricity market. This bumper package of proposals can be grouped into three categories: proposals amending existing energy market legislation; proposals amending existing climate change legislation; and proposals for new measures.

The first category of measures is aimed to bringing about a new market design – also known as the market design initiative (MDI) - and includes a new directive amending and repealing Directive 2009/72 (E-Directive), a new regulation on the internal electricity market, amending and repealing Regulation 714/2009 (E-Regulation), as well as a new regulation repealing Regulation 713/2009 on the ACER (ACER Regulation), usually referred to as the third package of electricity market liberalization measures. Certain measures are intended to enter into force and to apply as from 1 January 2020, while for others, such as the recast ED, no timetable for transposition has yet been indicated [5].

The second category of measures aims to better align and integrate climate change goals into this new market design. This category includes a fully revised Renewables Directive 2009/28 (RED) and a fully revised Energy Efficiency Directive 2012/27 (EED), both to enter into force on 1 January 2021. Lastly, the proposal for a new regulation on risk-preparedness in the electricity sector (the Risk Regulation) and a proposed regulation on Governance of the Energy Union (the Governance Regulation) (both to enter into force on 1 January 2021) are entirely new measures.

In more detail, the package includes 8 different legislative proposals, i.e.:

- Proposal for a recast of the Internal Electricity Market Directive;
- Proposal for a recast of the Internal Electricity Market Regulation;
- Proposal for a recast of the ACER Regulation;
- Proposal for a Regulation on Risk-Preparedness in the Electricity Sector and Repealing the Security of Supply Directive;
- Proposal for a recast of the Renewable Energy Directive;
- Proposal for a revised Energy Efficiency Directive;
- Proposal for a revised Energy Performance of Buildings Directive;

- Proposal for a Regulation on the Governance of the Energy Union.

Therefore, the package has three main goals:

- Putting energy efficiency first;
- Achieving global leadership in renewable energies;
- Providing a fair deal for consumers.

The key areas of these proposals, which are considered most relevant for the WoC concept development, are summarized in the following:

- Creating an enabling framework for further deployment of renewables in the Electricity Sector: by 2030, half of European electricity should be renewable. The share of renewable electricity has already increased up to 29%, and accounts for over 85% of Europe's generation investments. The dramatic cost reduction of renewable power technologies (solar modules and wind technology prices have declined respectively by 80% and 30-40% between 2009 and 2015), and the expected further cost reductions will bring additional cost-competitive capacity in the system. A further increase of renewables will make the electricity sector more inclusive, more diverse and more secure. In this context, the approach to renewables deployment should be increasingly market-based, untapped technological and geographical potentials need to be exploited, innovation must continue and investors must be provided with certainty and visibility. All these elements will contribute to the cost-effective deployment of renewable energy. The WoC concept is fully in line with this area of action, since the 2030 EU target can only be reached if solutions are found to keep the electricity system stable while having larger shares of renewable energy connected to the network at all voltage levels. The WoC actually facilitates RES integration through decentralized control aiming to solve local problems locally by also managing the intermittency and uncertainty of RES and efficiently operating this type of generation;
- Putting consumers at the heart of the energy market. In particular, attention is given to local energy communities as an efficient way of managing energy at community level by consuming the electricity they generate either directly for power or for (district) heating and cooling, with or without a connection to distribution systems. These targeted solutions will push self-consumption of local generation to optimal levels that have strong local characteristics, and can be made possible only through an effective distributed control acting at local level, which is the underpinning concept of the WoC;
- Allowing Distribution System Operators (DSOs) to manage some of the challenges associated with variable generation more locally (e.g. by managing local flexibility resources). This concept is the core of the WoC concept based on the paradigm of solving local problems locally (reducing losses, mitigating congestion risks, limiting communication data volume, cost and time), which as well allows for a more optimal use of the available grid capacity thanks to a divide-and-conquer benefit;
- Improving the connection between DSO and TSO by having a legislative framework able to "ensure that all necessary information and data, e.g. regarding the daily operation and long-term planning of the networks, is shared, and that the use of distributed resources is coordinated. The aim is to ensure cost-efficiency and secure and reliable operation of the networks". Based on the concept of local problems solved locally in the cell, complexity and communication issues are limited (e.g., no intensive bidirectional communication between the DSO(s) and conventional centralised TSO is required for reserve activation), and there is no need to expose local problems at global system level. Both DSO and TSO will be CSO with the same level of responsibility over their corresponding cells, where the cell setpoints explicitly take into account the capacity limitations of the inter-cell tie-line connections.

2.2 ENTSO-E Network Codes

Network codes are a set of rules drafted by ENTSO-E, with guidance from ACER, to facilitate the harmonization, integration and efficiency of the European electricity market. Each network code is an integral part of the drive towards completion of the internal energy market, and achieving the European Union's "20-20-20 energy objectives" of [6]:

- At least a 40% cut in greenhouse gas emissions compared to 1990 levels;
- At least a 27% share of renewable energy consumption;
- At least 27% energy savings compared with the business-as-usual scenario.

The codes belong to three families:

- Connection,
- Operations,
- Market.

Figure 1 summarizes the codes that have entered into force in the three families, whereas Table 1 provides the main details of the codes with potential implications for the WoC.

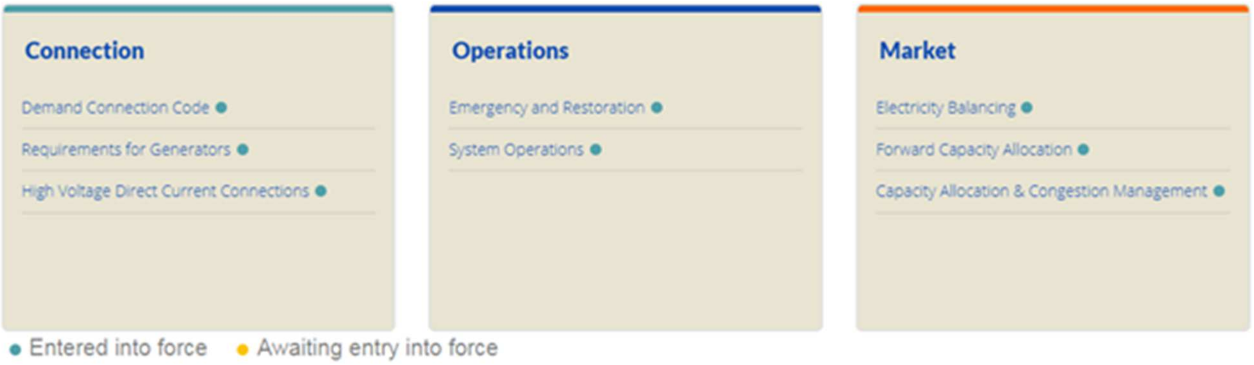

Figure 1: ENTSO-E codes families [6]

Table 1: Overview on main research interest in each ENTSO-E codes families and implications for the Web-of-Cells

Family / Subitem	**Scope/Reference Document**	**Implications for the WoC**
Connection/ Requirements for generators (RfG)	Harmonizes standards that generators must respect to connect to the grid. These harmonized standards across Europe will boost the market of generation technology and increase competitiveness.	At present, the integration of new generators has to be done guaranteeing the system's security and stability. To that end, the generators must comply with some minimum technical and operational requirements for their connection to the system. Each new generator, according to its class (A to D) should be able to fill its own requirements in terms of active/reactive power capability, behaviour in case of abnormal conditions, allowed disconnection, system restoration requirements, etc. The class of a generator is defined by the significance of its impact in the system, the type of generating source (synchronous or converter-coupled), or the specific characteristics of the grid where they are going to be connected.

	Commission Regulation (EU) 2016/631 of 14 April 2016	All these conditions currently existing in the code are compatible with the WoC, but the controllers of the voltage and balance control schemes (aFCC/BRC/BSC/PPVC) must be tuned to fulfil with the requirements of the code for both steady-state and dynamic response. Moreover, the WoC should also be consistent with the update process (each 2 years) to revise the thresholds established in the present document.
Connection/ Demand connection	Sets harmonized requirements for connecting large renewable energy production plants as well as demand response facilities. *Commission Regulation (EU) 2016/1388, of 17 August 2016*	This Regulation establishes a network code which lays down the requirements for grid connection of: a) Transmission-connected demand facilities; b) Transmission-connected distribution facilities; c) Distribution systems, including closed distribution systems; d) Demand units, used by a demand facility or a closed distribution system to provide demand response services to relevant system operators and relevant TSOs. It also defines the responsibilities of the system operators concerning the verification of the code compliance by the demand facilities owners. The TSOs must be aware of the conditions to be fulfilled and must reject the possible connection of facilities not fulfilling the code or which simulation models have not been validated for static and dynamic operation. The demand response services that can be provided include active/reactive power control, frequency control or fast active power control. These responsibilities can be considered easily transferable from TSO to future CSOs in the WoC context. This code poses potential implications for the WoC that has to be considered and matched. For example, the code requires a response time for the very fast active power control of 2 s, and the operation times in WoC framework for the aFCC have been defined with a time response between 2 s - 5 s (that would include also the slower aFCC response of some generators compared to the demand response) [7]. When applying this Regulation, Member States, competent entities and SOs shall apply the principle of optimization between the highest overall efficiency and lowest total costs for all parties involved. This last point could be ensured by a cost-benefit analysis whose details are defined in the document. Accordingly, the cell associated to a CO has to be able to provide all the needed data required in the document to the platform to ensure the objectives established in the code.

Connection/ High voltage direct current connections	Specifies requirements for long distance direct current (DC) connections. *Commission Regulation (EU) 2016/1447, of 26 August 2016*	The HVDC code has a similar structure to the RfG code but focusing on the specific conditions for the connection of HVDC systems. It settles the technical specifications for the active/reactive power control provision, disconnection allowance, obligations to provide synthetic inertia, etc. Additionally, it regulates the information exchanges. Once again, the implications for the WoC are related with the parameters that the voltage and frequency/balance controllers must fulfill in these characteristic systems (droops, normal operating ranges, rampings). However, it is noted that, similarly to what happens in the RfG, the voltage and frequency requirements depend on which is the synchronous area where the HVDC system is connected. For example, the steady state voltage values range from 0.88 p.u. to 1.15 p.u., depending on the synchronous area. The voltage control use case within ELECTRA has considered a safe band of 0.95 p.u.-1.15 p.u. This means that a simple modification of the parameters with no important impact over the original use case definition would make the future WoC voltage control compatible with this Regulation.
Operations/ Emergency and restoration	Fixes the processes that TSOs must follow when they face an incident on their grid. The highest standards and practice in dealing with emergency situations will thus apply in all Europe. *Commission Regulation (EU) 2017/2196 of 24 November 2017*	The code focuses on blackouts, restoration and emergency states, whereas ELECTRA's focus is on normal operation. Therefore, analysis of its implications for the WoC is out of scope of this work.

Operations/ System operations	Sets out the requirements concerning operational security, coordination between TSO/TSO and TSO/DSO and related data exchanges. It also deals with the requirements for the scheduling between the TSO's control areas and the rules aiming at the establishment of the framework for load frequency control and reserves.	The principles gathered in this code are intended to set the minimum and objective requirements to maintain the real-time operational security in the European grid. It also serves to promote the coordination between neighbouring SOs and to determine which are the aspects that are essential for the operational security as well as associated requirements that the SOs, the generation installations and the demand facilities must fulfil. The most relevant aspects in the code are related to the management of frequency control, voltage/reactive power, congestions, dynamic stability, reserve provision and data exchanges. The code is, in summary, a technical framework to cope with the massive integration of RES and the effective development of the IEM ensuring system security. That means that, in order to be applicable to all the synchronous areas, the code gives no concrete values or times for frequency, voltage control, protection settings, etc. It is clear that this Regulation is going to be of major importance and easily transferable to the future WoC, where the current responsibilities of the SOs are going to be shifted to the CSOs and this code will regulate the relationships between them in order to keep the stability and security of the system. This code is going to coordinate the power exchanges in the tie-lines between cells, the definition of the cell voltage and balance set-points (inter-cell and intra-cell), the implications and impacts of remedial actions in one cell over a neighboring cell, the obligation of guaranteeing enough inertia in the system, etc. This means that this code has a direct and strong influence on the voltage and frequency/balance use cases defined within ELECTRA.
Market/ Capacity Allocation & Congestion Management	Sets out the methods for calculating how much space can market participants use on cross border lines without endangering system security. It also harmonises how cross border markets operate in Europe to increase competitiveness but renewables' integration. The capacity allocation and congestion management (CACM) is the cornerstone of a	The CACM code settles the guidelines for the implementation of the pan-European day ahead and intraday markets and the optimal allocation of capacity across different regions. The code also deals with the processes for determining how the capacity in the tie-lines is calculated, how the bidding zones are reviewed and the way the congestions are managed. The pan-European market will increase the liquidity thus favoring the increase of renewable energy sources installed in the system. In the light of this code, the coupled market designed will allow the optimal allocation of the capacity through the WoC. The code also will regulate the mechanisms for the calculation of the clearing prices that will be applicable to the future IRPC, aFCC, BRC and BSC submarkets [7].

	European single market for electricity. *Commission Regulation (EU) 1222/2015, of 24 July 2015*	
Market/ Forward capacity allocation	Deals with rules for long term markets, the forward markets. These have an important role in allowing market participants to secure capacity on cross border lines a long time in advance and therefore have a sort of trade insurance. *Commission Regulation (EU) 2016/1719, of 26 September 2016*	This regulation deals with the mechanisms for the calculation and trading of cross-border capacity in forwards markets (year ahead and month ahead). Similarly to the CACM code, for the implementation of this code it is necessary to have an accurate grid model to effectively calculate the capacity allocation. This calculation is accomplished by using a dedicated platform that allows a clear and fair process and information flows for the market participants. Due to this, there is no need in the future WoC of a dedicated market operator for this forward allocation. The platform has to be developed by the different TSOs. The output of the platform is the volume of allocated long-term transmission rights, the clearing price and the execution status of the bids. This code will mainly impact on the CSOs, as they will be responsible for the forward capacity as well as the owners of the tie-lines in the WoC on behalf of current TSOs. The CSOs will be responsible for the calculation of the long-term capacity in the year-ahead or month-ahead window to ensure the capacity is reliable and the optimal calculation is made available to the market.
Market/ Electricity Balancing	Focuses on creating a market where countries can share the resources used by their TSOs to make generation equal demand always. It is also about allowing new players such as demand response and renewables to take part in this market. All in all, the Balancing Guideline should help increase security of supply, limit emissions and diminish costs to customers. *Commission Regulation (EU)*	This code settles the mechanisms for the harmonization of the electricity balancing markets around Europe, the design process of balancing markets and the imbalance settlement mechanisms and directly impacts on the TSOs, BRPs, BSPs and interconnectors owners. It lays down the guidelines on electricity balancing for the procurement and settlement of FCR, FRR and RR reserves as well as the common rules for the activation of those reserves. The products associated to these reserves differ mainly in the response time and time of delivery. The characteristics to define a product include the preparation period, the full activation time, the ramping period, the minimum and maximum quantity, the deactivation period, the validity period or the mode of activation. All the TSOs have to harmonize their balancing products to adapt them to the FCR/FRR/RR defined in the code and only in specific cases, they can define their own products for their responsibility area. Concerning the differences that may exist between the current standard FCC, FRR and RR and the future needs of the products in the WoC context, the code establishes the possibility to review the standard products every two years as well as the inclusion of new products not previously included. That would be the case of the inertia reserves, that

	2017/2195 of 23 November 2017	would be needed to be incorporated as a new balancing product in future amendments of the balancing code. The proposal of defining new products or modifying the characteristics of existing ones is currently a responsibility of the TSOs that will be accomplished by the CSO in the WoC. Beyond the consideration above, specific details on implications of this code on the WoC, high-level Use Cases and on market design of WoC will be provided in next sections.

2.3 Integration with non-electrical energy carriers

The growing identification of the interdependencies between electricity and other energy carriers has led, in recent years, to the recognition of the need for ‘Energy System Integration’ (ESI) whereby a view of system planning and operation is created which considers all energy interactions. This includes both extant large-scale carriers (such as natural gas, and its associated transmission and distribution), as well as potential new carriers (such as hydrogen and other non-conventional gases), in addition to the inclusion of localised vectors (such as heat networks).

While the majority of such assessment is still in the R&D context, there is a growing recognition by European regulators that the historically separate regulation of energy carriers may not be appropriate under future energy scenarios, and that joint regulation between carriers and sectors may represent a means to a lower-cost energy system in total. This also permits the provision of final demands through different vectors (such as comparing fuel cell to electric vehicles) to be more effectively compared and balanced according to the demands placed on individual carrier infrastructure.

In the draft scenarios prepared for the 2018 ENTSO Ten Year Network Development Plan (TYNDP - [8]), for the first time, joint scenarios have been created which identify the co-dependency between the gas and electricity sectors and the need for a consistent view between the two sets of regulators. Key elements include:

- Assessment of the impact of power-to-gas (P2G) in terms of increasing utilisation of renewable generation and the injection of green gas;
- Alternative trajectories in the decarbonisation of transport, particularly with respect to peak demand in the two sectors;
- The decarbonisation of the domestic heating sector (conversion of fossil fuel heating to electric heat pump heating or hybrid heat pump heating) increasing electricity consumption and decreasing gas consumption in the residential and commercial sectors;
- Changes to gas-fired power plants fuel consumption due to electricity production from renewable energy sources;
- The growth of the ‘prosumer’ and new patterns of energy consumption and generation at all levels.

The TYNDP identifies a concept labelled as the ‘thermal gap’ - a demanded volume of electricity which may be supplied by either coal or gas under different market conditions. This creates a potential for dispatch decisions within the WoC concept, which may require knowledge of the status of the gas system (beyond that communicated indirectly by WoC assets).

Secondly, coordination of WoC actors, under scenarios where heat and transport have undergone increased electrification (through heat pumps and EVs respectively) may require improved forecasting methods to understand the major swings in demand out-turn that will become more pronounced and more frequent. The maintenance of system security (with consequently broader impacts resulting from failure) means that WoC actors might be expected to predict and prepare the system to maintain security considering greater detail in the probability of different line flows and potential outages.

Third, the integration of energy carriers by WoC actors will also permit additional future sources of flexibility which encompass interactions with other carriers (e.g. heating, cooling or vehicle-to-grid), and how they might be regulated within the WoC structure.

The regulatory aspects of Energy Systems Integration are only beginning to be explored, but the growth of interest in this area from European regulators (see for example, the British regulator's scoping for a 'smart flexible energy system' [9] indicates that the WoC concept needs to be introduced with consideration of the mutual visibility and forecasting requirements of actions within other carriers. It should be noted that, at core, the WoC concept is potentially portable to other carriers and extensible to consider multiple vectors in parallel, and that the growth in integrated regulation can be matched by a similar application of parallel carrier-specific cells.

2.4. Regulation at non-transmission level

DSOs have traditionally been passive, leaving TSOs to ensure balance between demand and supply within their zone of coverage. However, as the amount of variable renewable energy (particularly produced by consumers), smart meters, storage and electrical vehicles at distribution level increases, DSOs will need to take on more tasks to make their grids smarter, more flexible and efficient. This includes being able to manage reverse power flows from customers and exporting to transmission networks.

In its proposed Recast Electricity Regulation [10], the Commission aims to create a new EU-level entity for DSOs to enhance cooperation between themselves and with TSOs on planning and operation of their power networks. As proposed, this new 'DSO entity'[1] would have a significant impact - positive or negative - on further deployment and integration of renewables, growth of demand response, decisions on grid tariffs and connection charges for prosumers, and customer data protection and privacy. The DSO entity would have legislatively defined tasks and areas of work.

A brief summary of the missions proposed by the European Commission to the DSO Entity is provided below:

- Coordinated operation and planning of transmission and distribution networks;
- The pace and extent of integration of renewables and storage;
- Deployment of smart grids including digitalization and intelligent smart metering systems;
- How demand response gets developed; and
- Rules around how consumer data are managed and protected, as well as cyber security.

However, the EU DSO entity could work on more issues through the Network Codes process if they relate more to distribution than transmission networks, such as:

- Harmonized rules for how the DSOs themselves impose distribution tariffs and connection

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[1] The DSO entity would be a membership-based body composed of DSOs from across the EU. It would bring DSOs together at EU level to work on issues that affect distribution networks. There are approximately 2,750 DSOs across the EU grouped around 4 main groups: EDSO, GEODE, CEDEC and Eurelectric. In this context, directives similar to those in the Third Energy Package will be more difficult to put in place. [The proposed EU DSO entity: what is it and what's at stake? Client Earth, December 2016]

charges;
- Rules for how DSOs would curtail distributed renewables, demand response and storage;
- Rules on how different market actors can provide non-frequency ancillary services;
- Rules on making more transparent network charges that DSOs impose;
- How DSOs themselves use energy efficiency in their networks;
- Rules allowing DSOs to own storage systems to provide flexibility.

However, there could be two important risks linked to unclear or not well-defined parts in the European Commission proposal:

- The DSOs involved in the codes redaction could be driven by their own priorities (conflicts of interest).
- The ACER is involved twice in the process. It is the instigator of the codes redaction (to insure the coherency with the European Commission guidelines) and it is the organization able to accredit the proposal of the DSO Entity.

In conclusion, it is quite premature to find implications of the current regulation at non-transmission level for the WoC concept as the rules are not currently well defined. Nevertheless, as mentioned earlier, the WoC concept is fully in line with a more active role of DSOs in managing some of the challenges associated with variable generation more locally. In the WoC, both DSOs and TSOs will be CSOs with the same level of responsibility over their corresponding cells, and this would contribute to achieve a well-defined regulation also at distribution level.

3. Impact of the regulatory framework for the Web-of-Cells architecture and high-level Use Cases

In this section, the current regulation aspects for frequency and voltage control, which could impact the WoC deployment and associated high level Use Cases (i.e., proposed balancing and voltage control mechanisms) are analyzed. As already identified in [1], [11-12], in ELECTRA, the EU power grid is decomposed into a WoC structure, where the Cell is a portion of the power grid able to maintain an agreed power exchange at its boundaries by using the internal flexibility of any type available from flexible generators/loads and/or storage systems. The total amount of internal flexibility in each cell shall be at least enough to compensate the cell generation and load uncertainties in normal operation. Each cell is managed by an automated Cell Controller (CC), which is constituted of a set of algorithms for voltage and frequency control. The CC is under the responsibility of a CSO that supervises its operation and, if required, overrides it. A CSO oversees one or multiple CCs, whose corresponding cells do not necessarily need to be adjacent. The CSO is responsible for the real-time reserves activation and dispatching within the cell(s) under his responsibility. Inter-cell reserve exchanges and coordination are included for optimal system-wide management. In each cell, the CSO (through the CC) maintains an accurate view on the overall cell state, and dispatches reserves located in the cell in a secure manner, based on his knowledge of the cell state. In such a context, local problems are solved within the cell in a fast and secure manner, thereby limiting complexity and communication overhead.

In the WoC architecture, by controlling the cell local balance, the CSOs are responsible to contribute to contain and restore system frequency, as well as contain local voltage within secure and stable limits. Tables 2 and 3 show an overview of ELECTRA frequency/balance control and voltage control Use Cases (UCs), respectively, as compared with the current control mechanisms related to control areas/control blocks.

Table 2: Overview of ELECTRA frequency control Use Cases, compared with current control mechanisms [1], [11]

Frequency/Balance Control	
ELECTRA use cases	**Current control mechanisms**
Inertia Response Power Control (IRPC)	
(Adaptive) Frequency containment control (aFCC)	Frequency containment control
Balance restoration control (BRC)	Frequency restoration control
Balance steering control (BSC)	Frequency replacement control

Table 3: Overview of ELECTRA voltage control Use Cases, compared with current control mechanisms [1]

Voltage Control	
ELECTRA use cases	**Current control mechanisms**
Primary voltage control (PVC)	Primary Voltage Control
Post-primary voltage control (PPVC)	Secondary voltage control
	Tertiary voltage control

Based on this general overview, the current regulatory prescriptions for the control mechanisms above, as well as the current involved stakeholders with specific roles and responsibilities, are analyzed in the following sections with the aim of identifying possible barriers and responsibility allocation, thereby detecting the needed changes to make the WoC feasible from a regulatory point of view.

3.1 Impact of the regulatory framework on Use Cases for frequency control

As discussed in D3.1 [1], frequency deviations result from imbalances between consumption/load/export and generation/import. Frequency deviations are seen fast and system-wide. Market parties (Balance Responsible Parties -BRPs- in particular) are responsible for keeping portfolio in balance. Each day is divided into time blocks, and the portfolio of each BRP must be in balance for each of these time blocks. BRPs keep their portfolio in balance by operating on the market (until intraday market gate closure) [1]. After the intraday market gate closure, BRPs submit their production schedules to the CSOs. The day of delivery, the CSO takes care of real-time balancing of residual imbalances by activating the reserves that restore the system balance. Residual imbalances may be caused by remaining imbalances at the intraday market gate closure of the day before delivery, forecast errors causing deviations in the time-window compared to what was scheduled, or incidents. Frequency stability is a fast and global system wide issue. It must be reacted upon quickly, and is therefore addressed in ELECTRA with a cascade (from fast, automatic, expensive to slow, manual and economically optimized) of inertia response power control (to slow down frequency changes), frequency containment control, balance restoration control, and balance steering control (optimization).

It must be said that, in general, in the WoC architecture, the main principles of Load-Frequency Control can be still applied, except for a dedicated inertia control for limitation of RoCoF. However, these principles are applied at Cell level instead of at Control Area level, as shown in Figure 2. As a result, the main control objective within each Cell is to maintain the balance within the Cell, and by this, indirectly restore the system frequency in a bottom-up approach [13].

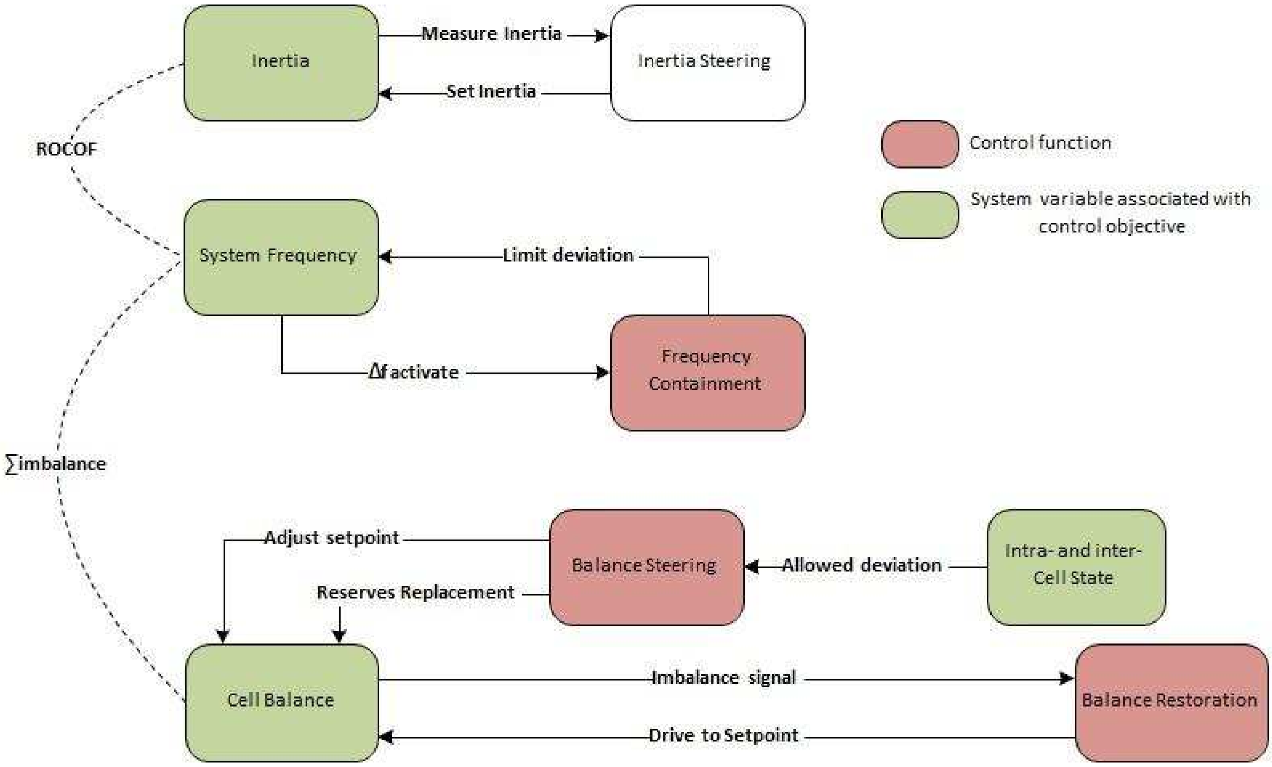


Figure 2: Overview of proposed balance control structure in the Web-of-Cells [13].

If considering the WoC as the future control grid architecture, it is needed to analyze the ENTSO-E Network Code on Load-Frequency Control and Reserves (NC LFCR) [14], which is the main current regulation for frequency control at European level. In the following, a general overview of the NC LFCR, as well as the main responsibilities for TSOs for frequency control processes are discussed in Subsection 3.1.1. The current regulation aspects concerning the frequency control which could impact the Inertia Response Power Control (IRPC), Adaptive Frequency Containment Control (aFCC), Balance Restoration Control (BRC) and Balance Steering Control (BSC), as well as the related responsibilities allocations, are discussed in Subsections 3.1.2, 3.1.3, 3.1.4 and 3.1.5, respectively.

3.1.1 Critical overview of the ENTSO-E Network Code on Load-Frequency Control and Reserves with general implications for the frequency control in the Web-of-Cells

It is known that the system frequency is a common parameter of a Synchronous Area, and has a direct impact on installations connected to the transmission system. This dependence is bi-directional, since also generation and demand facilities connected to the transmission system have an impact on the frequency quality. Therefore, even though each TSO is responsible for the maintenance of frequency quality in its Area, this task is common for all TSOs of the Synchronous Areas, through secure and efficient Load-Frequency Control. In the WoC architecture, the current responsibilities defined in the NC LFCR will be shifted to the CSOs, regardless of the voltage levels included in the cells under their responsibility area.

The aim of the NC LFCR is to ensure a secure Load-Frequency Control based on a close coordination and cooperation of TSOs of the Synchronous Areas, and an efficient system operation based on a close collaboration between all stakeholders at EU level in the electricity sector, through an efficient usage of the available resources for balancing [15].

The NC LFCR ensures Operational Security with respect to System Frequency stability by providing:

- Harmonized System Frequency quality targets;
- Harmonized control processes and operational procedures;
- Harmonized minimum technical requirements for organization of Reserve provision by TSOs;
- Harmonized minimum technical requirements for Reserve Providing Units and Groups;
- Harmonized procedures related to cross-border exchange, sharing and activation of Active Power Reserves within and between different Synchronous Areas improving the overall efficiency of operation.

It must be said that the NC LFCR sets the boundary conditions for products and cross-border coordination of the NC EB, as shown in Figure 3.

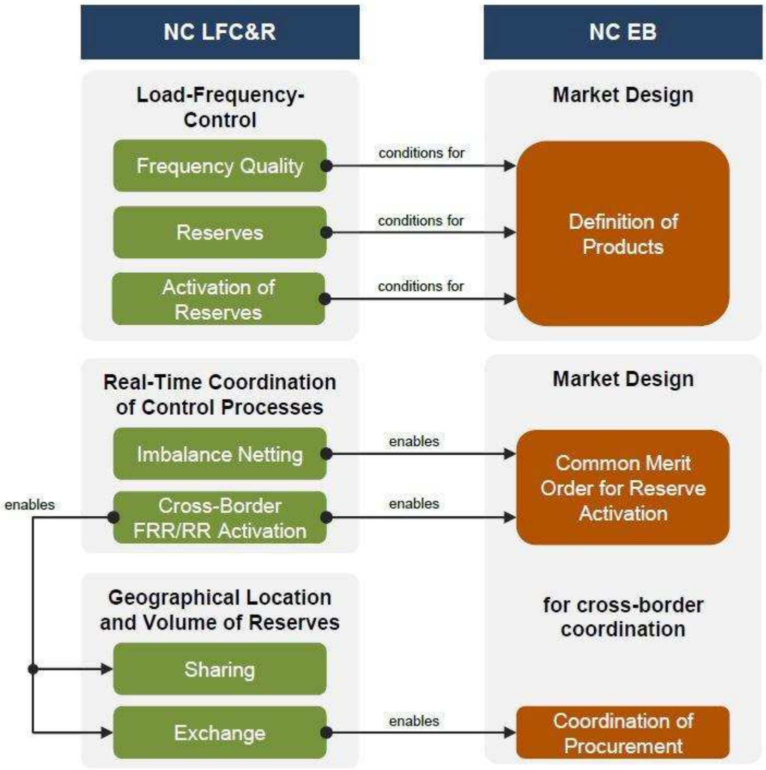


Figure 3: Relationship between the Network Code on Load-Frequency Control and Reserves and Network Code on Electricity Balancing [15]

All stakeholders, including TSOs, should respect the common requirements for control processes and active power reserves presented in the NC LFCR to maintain the frequency quality and stability in the Synchronous Areas and to support the efficient functioning of the European Internal Energy Market (IEM).

The harmonization principles defined in NC LFCR are handled through a global framework consisting of the three following levels:

- European level: Definition of the common control processes for Frequency Containment, Frequency Restoration and Reserve Replacement as well as the according Active Power Reserves and rules for cross-border cooperation;
- Synchronous Area level: Establishment of the control structure, definition of a common frequency quality target and application of the Frequency Containment Process;
- LFC Block level: Definition of a frequency restoration target and application of the Frequency Restoration Reserves (FRR) and Replacement Reserves (RR) Dimensioning Rules;
- LFC Area level: Application of the Frequency Restoration and Reserve Replacement Processes.

The crucial parameters and methodologies of Load-Frequency Control explicitly defined in the NC LFCR includes:

1. Main parameters defining the System Frequency quality and targets for TSOs;
2. Load-Frequency Control processes and their implementation;
3. Cross-border Load-Frequency Control processes;
4. Dimensioning Rules;
5. Minimum Technical Requirements for Reserve Providing Units and Reserve Providing Groups;
6. Limits for Exchange and Sharing of Reserves;
7. Transparency requirements.

All these aspects need to be considered in UCs for frequency control defined in the ELECTRA context.

With reference to point 1, the Frequency Quality Defining Parameters, defined in Article 19 of the NC LFCR [14], represent the values which are used for the design of control processes and reserve dimensioning, and are aligned with emergency procedures and operation ranges for generators [15]. The operation of Synchronous Area has been designed to guarantee that, after a disturbance of the Active Power balance, Frequency Deviations are kept within a certain range. For large Synchronous Areas, this implies that large imbalances do not lead to Frequency Deviations that would trigger under-frequency load-shedding. The largest imbalance which by design shall not cause a violation of admissible System Frequency ranges, is defined as the Reference Incident (it also serves as input to the dimensioning of FCR). The Frequency Quality Defining Parameters define these acceptable ranges for System Frequency after an occurrence of the Reference Incident (Figure 4). These parameters do not only include ranges but also the time durations (Time To Recover and Time To Restore Frequency), where the respective ranges should be reached.

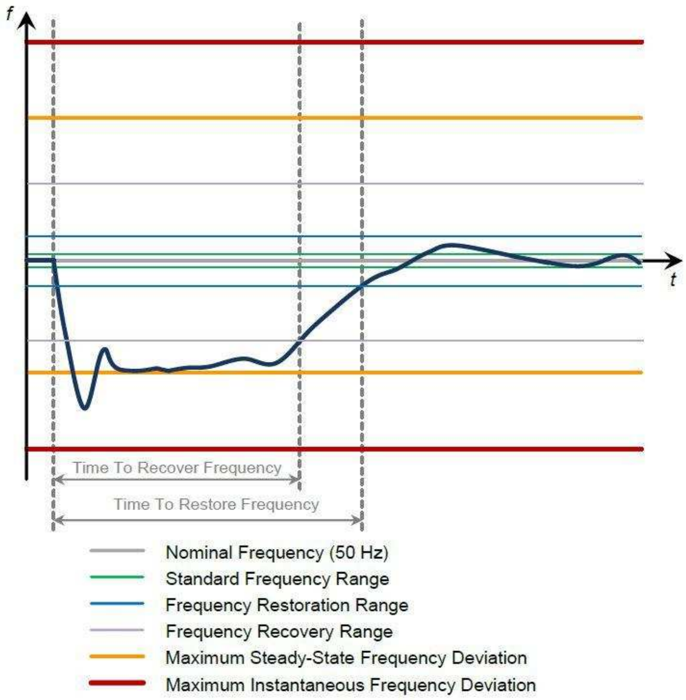


Figure 4: Frequency Quality Defining Parameters [15]

According to Article 19 [14], the Frequency Quality Defining Parameters of the Synchronous Areas with relative default values are summarized in Table 4.

Table 4: Default values of the Frequency Quality Defining Parameters [14]

	CE	GB	IRE	NE
Standard Frequency Range	±50 mHz	±200 mHz	±200 mHz	±100 mHz
Maximum Instantaneous Frequency Deviation	800 mHz	800 mHz	1000 mHz	1000 mHz
Maximum Steady-state Frequency Deviation	200 mHz	500 mHz	500 mHz	500 mHz
Time to Recover Frequency	not used	1 minute	1 minute	not used
Frequency Recovery Range	not used	±500 mHz	±500 mHz	not used

Time to Restore Frequency	15 minutes	10 minutes	20 minutes	15 minutes
Frequency Restoration Range	Not used	±200 mHz	±200 mHz	±100 mHz
Alert State Trigger Time	5 minutes	10 minutes	10 minutes	5 minutes

These Frequency Quality Defining Parameters shall be coordinated between all TSOs of a Synchronous Area in order to ensure proper Synchronous Area behaviour. They shall fulfil the requirements that are set to generators and loads, which are included in the NC RfG and in the NC DCC [16-17].

The Frequency Quality Target Parameter shall be the maximum number of minutes outside the Standard Frequency Range per year per Synchronous Area, and its default value per Synchronous Area shall be the value given in Table 5 (Article 19).

Table 5: Frequency Quality Target Parameters of the Synchronous Area

	CE	**GB**	**IRE**	**NE**
Maximum number of minutes outside the Standard Frequency Range	15000	15000	10500	15000

These requirements need to be respected in the WoC for frequency control, in terms of operation times of the new controllers, maximum limits of the frequency observable, frequency quality characteristics to be achieved, etc.

As for points 2 – 7 above, they will be discussed in the following subsections, by also analyzing the related impact on the ELECTRA UCs for frequency control.

In general, the framework for Load-Frequency Control Processes regulated by NC LFCR is based on the current best practices and control engineering. The three processes addressed are summarized in the following:

- Frequency Containment Process (FCP) as the process stabilizing the frequency after the disturbance at a steady-state value within the permissible maximum steady-state deviation (defined in Table 4), through a joint action of Frequency Containment Reserves (FCR) within the whole Synchronous Area.
- Frequency Restoration Process (FRP) as the process controlling the frequency towards its set-point value through the activation of Frequency Restoration Reserves (FRR), and replacing the activated FCR. This process is implemented by the disturbed LFC Area.
- The Reserve Replacement Process (RRP) as the process replacing the activated FRR

and/or supports the FRR through the activation of Replacement Reserves (RR). Similar to FRP, RRP is also implemented by the disturbed LFC Area.

Therefore, the operation of Load-Frequency Control processes are attached to operational areas. The area hierarchy is shown in Figure 5 [15]. Each Synchronous Area consists of one or more LFC Blocks, each LFC Block consists of one or more LFC Areas, each LFC Area consists of one or more Monitoring Areas, and each Monitoring Area consists of one or more Scheduling Areas.

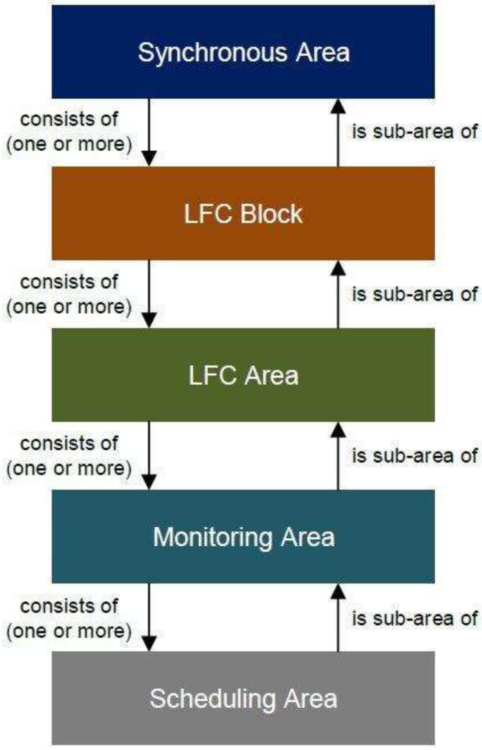


Figure 5: Types and hierarchy of geographical areas operated by TSOs [15].

The different areas are needed to define responsibilities of single TSOs in the common task of system frequency quality, allowing a harmonized approach for all Synchronous Areas. The entire process responsibility structure is regulated by Article 32 of NC LFCR. For instance, a TSO operating an LFC Area has several obligations, such as collecting and calculating the schedules for the area; measuring and monitoring the actual power interchange; calculating (or measuring) the Frequency Restoration Control Error (discussed below); and operating a FRP. On the other hand, all TSOs operating LFC Areas within the same LFC Block have the obligation to cooperate with other TSOs of the LFC Block to fulfil the area process obligations, i.e., to fulfil the frequency restoration quality target parameters (to be discussed later).

According to the process responsibility structure defined, Table 6 summarizes the different area process obligations defined in NC LFCR.

Table 6: TSOs obligations related to areas [15]

Obligations	**Scheduling Area**	**Monitoring Area**	**LFC Area**	**LFC Block**	**Synchronous Area**
Scheduling	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Online calculation and monitoring of actual power interchange	NA	Mandatory	Mandatory	Mandatory	Mandatory
FRP	NA	NA	Mandatory	Mandatory	Mandatory
Frequency Restoration Quality Parameters	NA	NA	Mandatory	Mandatory	Mandatory
FRR/RR Dimensioning	NA	NA	NA	Mandatory	Mandatory
FCP	NA	NA	NA	NA	Mandatory
Frequency Quality Target and FCR Dimensioning	NA	NA	NA	NA	Mandatory
RRP	NA	NA	Optional	NA	NA
Imbalance netting process	NA	NA	Optional	NA	NA
Cross-border FRR activation process	NA	NA	Optional	NA	NA
Cross-border RR activation process	NA	NA	Optional	NA	NA
Time control process	NA	NA	Optional	NA	NA

Mandatory cooperation to fulfill obligations of	Monitoring Area	LFC Area	LFC Block	Synchronous Area	NA

In contrast to the current control scheme where system level TSOs operate in a centralistic manner for their respective Control Area, in the WoC architecture, which is based on a decentralized real-time control, CSOs operate in a decentralized manner with reference, for instance, to detection of the need for reserves activations as well as the activations themselves - in a similar manner to what is done today at transmission level, but applied at small geographic areas. The key difference is that Cells can provide local balancing and voltage control with the purpose of solving local problems locally through self-responsibilization; there is no “master-CSO” hierarchically above the CSOs. By following this approach, local problems are solved locally within the cell, thereby limiting complexity and communication overhead (i.e., no bidirectional communication between the DSO(s) and conventional centralised TSO is required for reserve activation), and there is no need to expose local problems at global system level.

3.1.2 Inertia Response Power Control (IRPC)

The Renewable Energy Directive [18] requires the EU to fulfill at least 20% of its final energy consumption with renewable sources by 2020. Future electricity networks incorporating such a large proportion of renewable sources will be subject to intermittent generation, characterized by high variability and unpredictability and by low mechanical inertia (since it is often connected to the grid via decoupling electronic power devices and often composed of static generators). Therefore they will require new control approaches, together with new rules in the regulatory framework and in the energy market, that can successfully deal with the problem of balancing supply and demand to prevent blackouts and poor power quality. In particular, the decrease of system inertia will be a critical issue.

System inertia mainly consists of the intrinsic reaction of rotating masses connected to the grid. The variation of their angular momentum, in fact, opposes to system frequency variations (i.e. gradients), so it helps to keep frequency stable. System inertia is especially useful when a large infeed (a generator or an importing interconnector) or consumption (a load or an exporting interconnector) unexpectedly disconnects from the system: the system inertia resists the frequency from falling too quickly and gives the automatic and manual regulations time enough to intervene.

System inertia primarily comes from synchronous generators. Due to the changing demand and generation mix and the significant increase of non-synchronous generation, the inertia is decreasing and will continue to decrease. As it decreases, the rate at which frequency falls – the rate of change of frequency, RoCoF, measured in Hz/s and usually considered an absolute value – following the loss of an infeed or consumption is likely to increase. Such effects are depicted in Figure 6 and Figure 7, which show simulation results for the Irish system, in Table 7 and Table 8, which show simulation results for the Great Britain system, and in Figure 8, which shows simulation results for the Continental Europe system.

In particular, Figure 7 plots the magnitude of the initial RoCoF following the loss of the largest single infeed/outfeed (i.e. both low and high frequency events are considered), calculated from the simplified overall swing equation for the Irish system; the initial value of the RoCoF is considered to be the largest value in the transient following the event; such an estimation of the initial RoCoF has been carried out for each hour of a reference 2020 scenario, and the figure reports the results in each day of the week in each season. One can observe that most periods in which the RoCoF is high (RoCoF>0.5 Hz/s) occur during the weekend (inherently low-load periods), anyway on Sundays the RoCoF is often high in spring (and sometimes in the oher seasons) while on saturdays the RoCoF is sometimes high in spring and winter (and marginally in autumn). During the week, a sort of “V-shaped” behaviour, with respect to the seasons, can be observed, with Mandays similar to Fridays (and also to Saturdays): on Tuesdays, Wednesdays and Thursdays, less high- RoCoF values are present, probably due to the higher system load and to the presence of more conventional plants online.

One possible effect of the increasing system RoCoF experienced after a large infeed or consumption is the loss of synchronism of synchronous machines; another possible effect is the trigger of RoCoF Loss of Mains (LOM) protection used by some DG, so the disconnection of this DG from the system. These events may cause the frequency to vary further in the same direction, thus vanishing efforts from regulation to recover frequency.

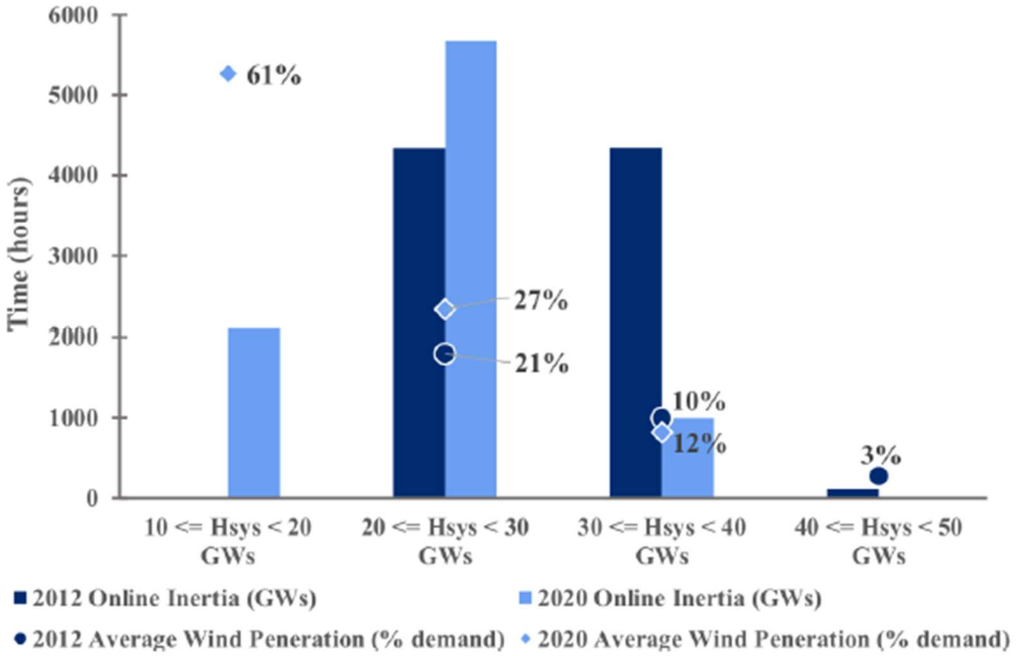


Figure 6: Frequency distribution of rotational energy (inertia) stored in the Irish system in 2012 and 2020, with corresponding average wind penetration (% demand) [19]

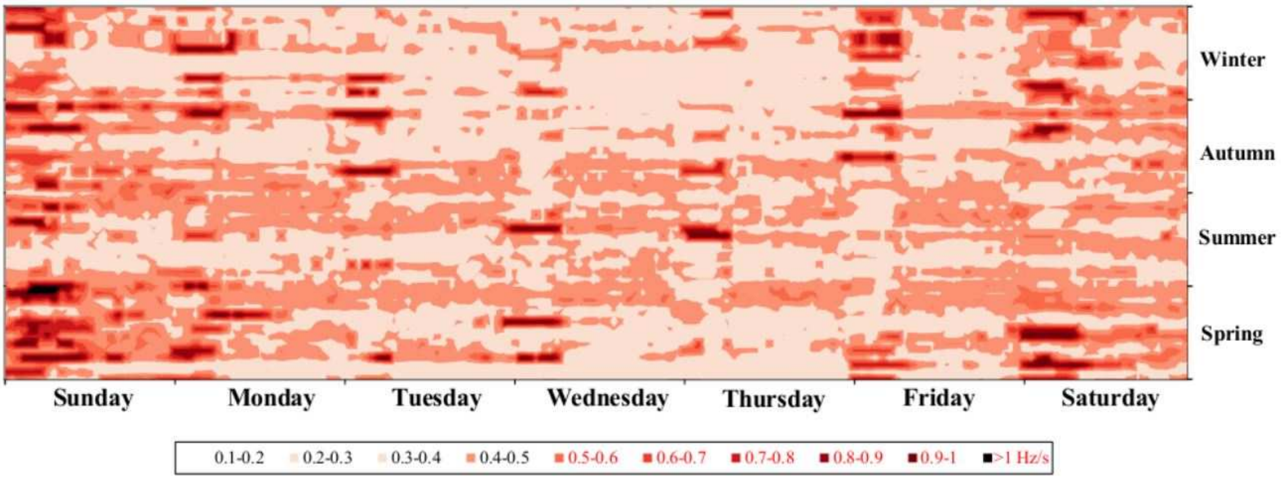


Figure 7: Initial RoCoF following the loss of the largest single infeed/outfeed online for each hour of 2020 (base case of unit commitment and economic dispatch schedule in the Irish system) [19]

Table 7: Predicted Average System RoCoF in Great Britain, for high wind conditions [20]

Year	Demand [GW]	1320 MW loss		1800 MW loss	
		RoCoF @ 100 ms [Hz/s]	RoCoF @ 500 ms [Hz/s]	RoCoF @ 100 ms [Hz/s]	RoCoF @ 500 ms [Hz/s]
2014	20	-0.24	-0.24	-0.34	-0.33
	35	-0.13	-0.13	-0.18	-0.17
2016	20	-0.25	-0.24	-0.35	-0.34
	35	-0.13	-0.13	-0.19	-0.18
2018	20	-0.3	-0.29	-0.43	-0.42
	35	-0.16	-0.16	-0.23	-0.22
2020	20	-0.36	-0.35	-0.5	-0.49
	35	-0.19	-0.19	-0.27	-0.26

Table 8: Predicted Average System RoCoF in Great Britain, for high wind and high imports conditions [20]

Year	Demand [GW]	1320 MW loss		1800 MW loss	
		RoCoF @ 100 ms [Hz/s]	RoCoF @ 500 ms [Hz/s]	RoCoF @ 100 ms [Hz/s]	RoCoF @ 500 ms [Hz/s]
2014	20	-0.26	-0.26	-0.36	-0.36
	35	-0.14	-0.13	-0.19	-0.18
2016	20	-0.27	-0.27	-0.38	-0.37
	35	-0.14	-0.14	-0.2	-0.19
2018	20	-0.33	-0.32	-0.47	-0.45
	35	-0.17	-0.17	-0.24	-0.24
2020	20	-0.42	-0.4	-0.57	-0.56
	35	-0.21	-0.2	-0.29	-0.28

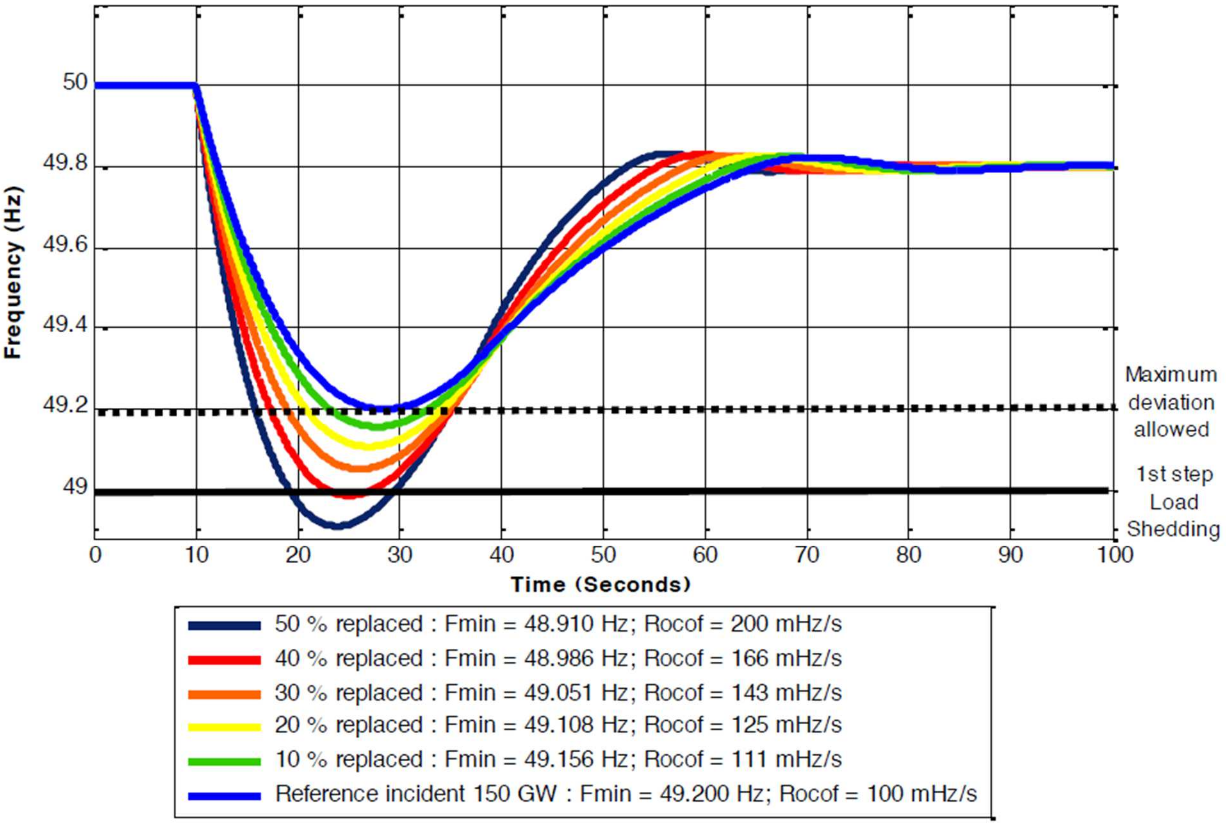


Figure 8: Frequency transients and initial RoCoF values for a sudden loss of 3000 MW under extreme conditions in the former UCTE system [21]

The SO has to manage the system so that the RoCoF after a large balance perturbation is not too large. Therefore, the SO often takes pre-emptive actions to do this. For instance, it can:

- Reconfigure the generating mix so as to increase system inertia – this can be as simple as constraining synchronous generators to be on, but as the requirement for reconfiguration increases it can imply to constrain non-synchronous wind generation, which is undesired;
- Limit the possible value of the maximum instantaneous imbalance – if an infeed or consumption suddenly and unexpectedly disconnects, the smaller the disconnection the smaller the RoCoF.

Such actions translate to the activation of ancillary service resources in real time; these are procured and activated via one or more markets and the related costs ultimately transferred to end users.

As far as RoCoF settings are concerned, so far only a few countries in Europe (Belgium, Spain, UK, Ireland and Denmark) have given values; each such country has selected different admissible ranges according to the national grid characteristics and generator inventory. For Belgium and Spain those values are only outlined, but UK, Ireland and Denmark have defined them in a clearer way. In particular, a study by National Grid in the Great Britain has estimated the risk of mass tripping of distributed generation on their RoCoF due to the loss of one and more large generators.

For this reason, UK, Ireland and Denmark could be defined as models for the future development of grid managing; as detailed in the following.

United Kingdom

In the UK, before September 2015, the prescribed setting for RoCoF LOM protection was ≥ 0.125 Hz/s. The presence of DG caused many troubles that were solved via ‘desensitising’ the settings of the RoCoF LOM protection on DG so that a higher RoCoF was needed to activate them. The DSO Licensees proposed this solution in a modification call to the national authority, to change the Distribution Code. The results were included in the so-called Engineering Recommendation G59 (ER G59), enforced in September 2015. The main details about the new RoCoF setting values are shown in Table 9, extracted from ER G59/3-1.

Table 9: RoCoF setting values in Great Britain; “small” in the table means below 50 MW [22]

RoCoF settings for Power Stations ≥ 5 MW				
Date of Commissioning		**Small Power Stations**		**Medium Power Stations**
		Asynchronous	**Synchronous**	
Generating Plant Commissioned before 01/08/14	Settings permitted until 01/08/16	Not to be less than K2§ x 0.125 Hz/s and not to be greater than 1Hz/s¶, time delay 0.5s	Not to be less than K2 x 0.125 Hz/s and not to be greater than 0.5Hz/s¶Ω, time delay 0.5s	Intertripping Expected
	Settings permitted on or after 01/08/16	1Hz/s¶, time delay 0.5s	0.5Hz/s¶Ω, time delay 0.5s	Intertripping expected
Generating Plant commissioned between 01/08/14 and 31/07/16 inclusive		1Hz/s¶, time delay 0.5s	0.5Hz/s¶Ω, time delay 0.5s	Intertripping expected
Generating Plant commissioned on or after 01/08/16		1Hz/s¶, time delay 0.5s	1Hz/s¶, time delay 0.5s	Intertripping expected

§ K2: = 1.0 (for low impedance networks) or 1.6 (for high impedance networks)

¶: the time delay should begin when the measured RoCof exceeds the threshold expressed in Hz/s, and it should be reset if the measured RoCoF falls below that threshold. The relay must not trip unless the measured RoCoF remains above the threshold expressed in Hz/s continuously for 500 ms.

Ω: the minimum setting is 0.5 Hz/s. For overall system security reasons, settings closer to 1.0 Hz/s are desirable, subject to the capability of the generating plant to work to higher settings.

Ireland

The current RoCoF capability required of all units in Ireland is 0.5 Hz/s and is set out in the Irish Grid Code. Detailed technical studies undertaken by EirGrid have indicated that, during times of high wind generation following the loss of the single largest credible unit, RoCoF values greater than 0.5 Hz/s but no greater than 1 Hz/s could be experienced on the island power system. In addition, TSO studies have shown that instantaneous RoCoF values in excess of 2 Hz/s could be experienced in Northern Ireland if system separation were to occur on the island.

EirGrid has proposed a modification of the mentioned RoCoF threshold, to 1 Hz/s, in order to facilitate the delivery of the 2020 renewables targets, whilst maintaining operational security of the power system. Specifically, a higher RoCoF standard is expected to allow EirGrid to operate the system at a higher operational limit of 50%. Therefore, without this higher RoCoF standard, the curtailment of wind is expected to be higher and the overall 40% target may not be achieved by 2020. A similar modification has been proposed by SONI in Northern Ireland and has been consulted by the Regional Regulator.

Denmark

In 2015, Denmark sourced 42% of electricity from wind generation, and is among the world's top 20 countries for non-hydro renewable power capacity per inhabitant. In 2013, Energinet.dk in Denmark purchased two 200 MVA synchronous condensers to support the power system, at a cost of 340m DKK. Synchronous condensers provide a range of system services, including synchronous inertia. However, these units are likely to have been primarily installed to address system strength and other relatively localized grid support issues, rather than synchronous inertia and RoCoF challenges. Like Germany, Denmark is highly interconnected with neighboring regions via AC interconnectors, and therefore has access to considerable amounts of synchronous inertia from other jurisdictions. Denmark requires new thermal generators connecting to be able to withstand a RoCoF of ±2.5 Hz/s [23] (increased from a previous value of 2 Hz/s). Also for wind and PV generation above 11 kW, the regulations state that generators must be able to withstand a change of frequency (df/dt) of ±2.5 Hz/s.

European Grid

Finally, ENTSO-E, the European TSOs consortium, has carried out analyses of the general behaviour of the European grid in case of large imbalances, without or with subsequent network splitting [24]. For example, in normal operation after 1 GW power plant outages, system load frequency gradients of 5-10 mHz/s are presently observed in the Continental European (CE) power system. In emergency operating conditions, instead, such as in the three serious disturbances occurred in the last 15 years, frequency gradients in a range between 100 mHz/s up to 1 Hz/s have been recorded, which have accompanied network splitting. The simulated reference scenario for the future indicates that the CE system must be able to resist, under split conditions, imbalances up to 40% of load of the largest remaining island, and with a maximum frequency gradient of 2 Hz/s.

The ENTSO-E Network Code requires that each TSO has to specify the df/dt (RoCoF) which a power generating module or a demand unit shall at least be capable of withstanding (for the loads, in particular, the value of the RoCoF shall be calculated over a 500 ms time frame); besides, it prescribes that [25]:

- "An HVDC system shall be capable of staying connected to the network and operable if the network frequency changes at a rate between –2.5 and +2.5 Hz/s (measured at any point in time as an average of the rate of change of frequency for the previous 1 s)".

- “A DC-connected power park module shall be capable of staying connected to the remote-end HVDC converter station network and operable if the system frequency changes at a rate up to +/– 2 Hz/s (measured at any point in time as an average of the rate of change of frequency for the previous 1 s) at the HVDC interface point of the DC-connected power park module at the remote end HVDC converter station for the 50 Hz nominal system”.

ENTSO-E also remarks [25] that the RoCoF withstand capability can be considered as “an important input to calculate the essential minimum inertia (provided by the synchronous power generating machines with inherent inertia and by power park modules with synthetic inertia) for system stability in case of outage or system split, including asynchronous operation of control blocks. Therefore, there is a direct link between RoCoF and inertia related requirements”.

These last concepts in particular have been transferred to the WoC scheme with reference to the IRPC use case (UC), in that each CSO, whose role is similar to the current TSO role, determines the overall (i.e. physical plus synthetic) requirement for (minimum) inertia in its cell or cells, and similarly, at the highest control topology level, i.e. at inter-cell level, the overall requirement for (minimum) inertia is determined by coordination mechanisms among CSOs. Inside each cell and in real time, the overall inertia requirement is then translated into a request, to be sent to individual devices or aggregations of devices, for inertial support availability and inertial response power supply. Inertial response from individual devices or aggregations of devices can be typically supplied as an intrinsic power variation due to the speed variation of a rotating mass, or as a control-driven power variation proportional to the RoCoF measured locally in real time. As hinted at in Figure 2 (See Subsection 3.1), these last power variations should indeed be able to support the Frequency Containment Control UC especially in case of limited presence of synchronous machines and of physical/kinetic inertia. On the whole, the IRPC should of course guarantee the provision of a minimal inertia level independently of the energy mix (day/night, sunny/cloud, windy/calm day).

3.1.3 Adaptive Frequency Containment Control (aFCC)

In the WoC, the Adaptive Frequency Containment Control (aFCC) functionality ensures that each cell adapts its amount of provided dP/df droop in response to a CPFC (Cell Power Frequency Characteristic) set-point received from a (system-level) process [11]. The actual droop that a cell actually provides is further scaled to reduce the activation of FCC resources in cells that are not causing the deviation (this is the Adaptive aspect).

The rationale for the ”adaptive” aspect is to make cells responsible for solving the deviations they are causing, by ensuring that each cell adapts the amount of provided dP/df droop in response to real-time frequency and tie-line deviations from their nominal values. Each unit (generation and load) is able to provide the FCC mechanism at control cell level. Moreover, much more distributed reserves across the power grid and within each cell, may allow to solve local problems locally, also improving FCC flexibility. In contrast to ‘traditional’ frequency control (Load Frequency Control), this adaptive FCC is not a primary response that is followed by a slower secondary response that takes over from this primary response. The aFCC is acting on a system level observable (frequency deviation) but its actions are scaled in relation to its local state.

Regulatory Constraints on the FCC Activation Process

As discussed in detail in Subsection 3.1.1, in the current architecture for large scale electric power system at European level, the frequency control is performed by Load Frequency-Control (LFC) process. The dynamic hierarchy of Load-Frequency Control processes is shown in Figure 9.

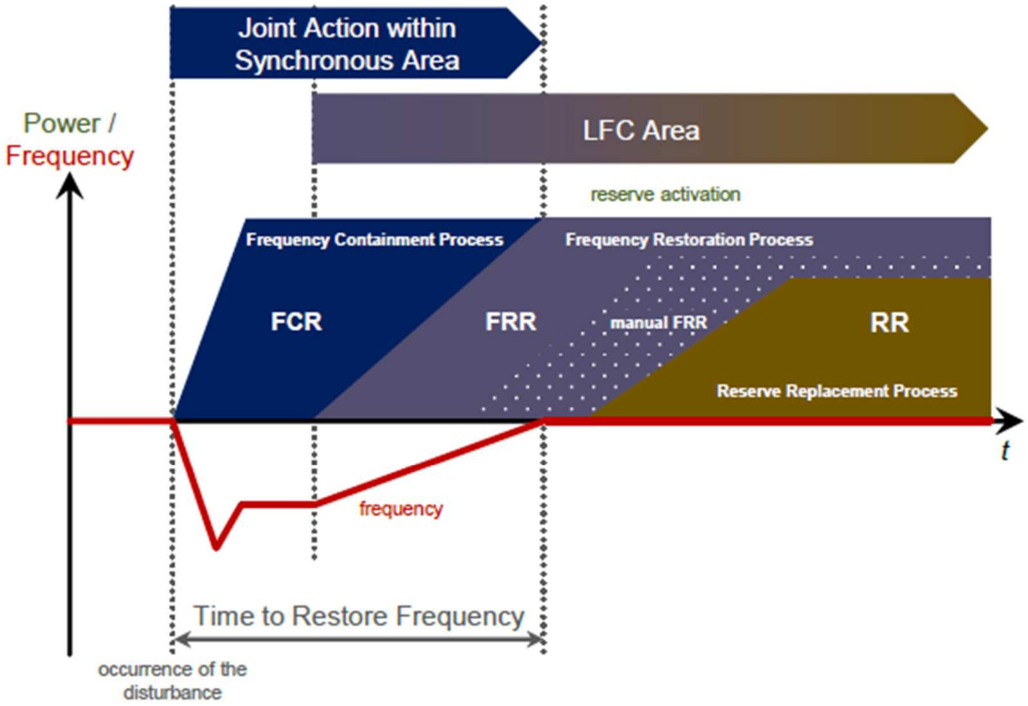


Figure 9: Dynamic hierarchy of Load-Frequency Control processes [15]

The first process, i.e., FCP is a primary control. In the primary control action, only active power is balanced. It should be noted that the aFCC control shows some similarities to the traditional FCP control. However, due to the differences between the current architecture of large power system and the WoC, also mechanisms for the process and resources activation show some differences.

In the current European power grid architecture, the FCR is activated by a joint action of FCR Providing Units and FCR Providing Groups within the whole Synchronous Area with respect to the frequency deviation. Depending on the best practices for a Synchronous Area the activation requirements for single FCR Providing Units and FCR Providing Groups may differ, nonetheless, the overall behavior shall follow two principles:

- The overall FCR activation is characterized by a monotonically decreasing function of the frequency deviation.
- The total FCR capacity shall be activated at the maximum steady-state frequency deviation.

The NC LFCR provides a European harmonization of FCP design, while allowing the necessary flexibility for different Synchronous Areas and types of FCR Providers. The objective of the FCP is to maintain a balance between generation and consumption within the Synchronous Area and to stabilize the electrical system by means of the joint action of respectively equipped FCR Providing Units and FCR Providing Groups. Appropriate activation of FCR results consequently in stabilization of the system frequency at a stationary value after an imbalance in the time frame of seconds.

In contrast with the current FCP stabilizing the frequency after the disturbance at a steady-state value by a joint action of FCR within the whole Synchronous Area, in the WoC, the aFCC functionality aims at locally (i.e., at cell level) observing and responding to frequency changes by modifying active power to support the containment of frequency under normal operation or after incidents. Each cell is assigned a portion of frequency droop responsibility (CPFC), but actual reserves (droop) activations are dynamically scaled so that reserves activations are prioritized in cells that are causing deviations, and are minimized in cells that are not causing activations. This should mitigate the effect of causing cell imbalances (with subsequent BRC activations) in cells that otherwise would be in balance because of a blind reaction on a global observable (frequency deviation). This scaling factor is determined based on a combined observable of frequency deviation and cell balance error. This scaling behavior is highly configurable and can take the form of a basic 0/1 factor to a value provided by a fuzzy logic controller. In the WoC, aFCC is running at the same timescale as BRC, so both join forces in containing frequency deviations.

In detail, the cell central Frequency Droop Parameter Determination function receives the cell's CPFC set-point (cell's contribution to the system Network Power Frequency Characteristic (NPFC)) for the next timestep. The Merit Order Decision (MOD) function, through the Merit Order Collection (MOC) function, orders the available Frequency Droop devices based on cost and location. This is done based on availability and cost information received from these Frequency Droop devices, and load and generation forecasts of all busses (nodes), and a local grid model. The resulting ordered list is sent to the Frequency Droop Parameter Determination function that determines the requested dP/df droop setting (can be 0) for each Frequency Droop device. Each Frequency Droop device receives its droop setting (droop slope and deadband) for the next time-step, and will continuously monitor df and activate/absorb active power in accordance to its droop setting.

This droop setting is continuously adapted by the Adaptive CPFC Determination function by means of a scaling factor that is determined based on the cell's imbalance state. Based on frequency and cell imbalance error signals, this function calculates a scaling factor to achieve that most FCC activations are done in cells that cause the deviation, and less in cells that do not cause the deviation. The CPFC is a WoC related concept similar to the NPFC. The main difference is that the CPFC can be adjusted in the moments subsequent to a disturbance affecting the power-frequency control mechanism, depending if the incident occurred inside or outside a given cell.

Regulatory Constraints for Frequency Containment Reserves

According to Article 44(1) [14], each Reserve Connecting TSO shall ensure that the FCR corresponds to the following properties listed for its Synchronous Area applying to all FCR Providing Units and FCR Providing Groups consistent with the values in [NC RfG Article 10 (2) (c)]:

Table 10: Frequency Containment Reserves properties in the different Synchronous Areas [14]

Minimum accuracy of frequency measurement	CE, GB, IRE and NE	10 mHz or the industrial standard if better
Maximum combined effect of inherent Frequency Response Insensitivity and possible intentional Frequency Response Dead band of the governor of the FCR Providing Units or FCR Providing Groups.	CE	10 mHz
	GB	15 mHz
	IRE	15 mHz
	NE	10 mHz

FCR Full Activation Time	CE	30 s
	GB	10 s
	IRE	15 s
	NE	30 s if System Frequency is outside Standard Frequency Range
FCR Full Activation Frequency Deviation	CE	±200 mHz
	GB	±500 mHz
	IRE	Dynamic FCR ±500 mHz Static FCR ±1000 mHz
	NE	±500 mHz

The accuracy requirements include:

- The minimum accuracy of System Frequency measurement;
- Inherent Frequency Response Insensitivity and possible intentional Frequency Response Deadband.

The implications of the accuracy requirements are demonstrated in Figure 10 on a simplified control scheme for calculation of FCR activation for a FCR Providing Unit or a FCR Providing Group.

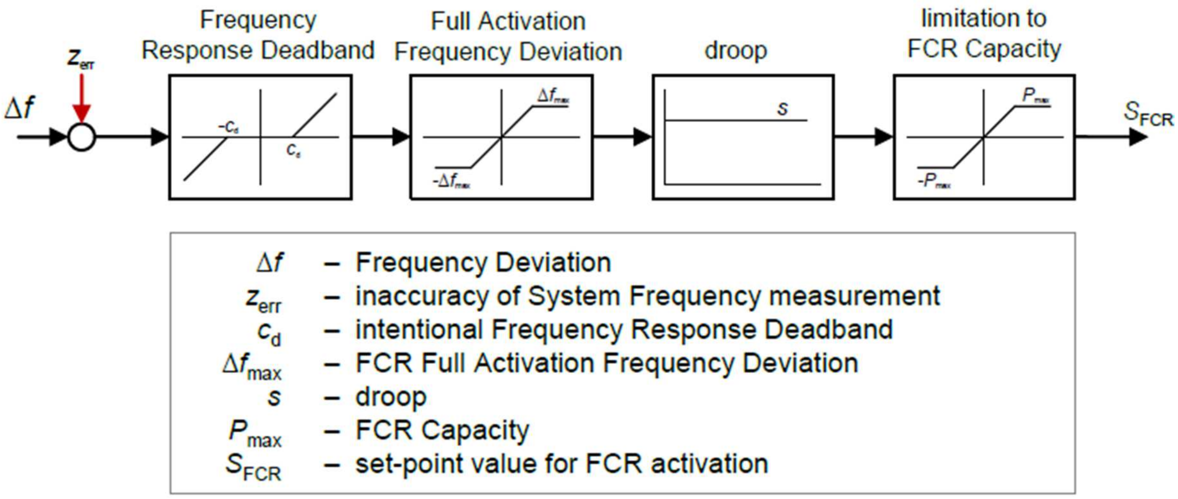


Figure 10: Implications of accuracy requirements – simplified control scheme [15]

The resources activation is linked to the measurement error (Zerr). Therefore, it is essential to have the measurement error within the safety limits to allow proper activation of the FRC phase. The NC LFCR defines a harmonized value of ≤10 mHz for all Synchronous Areas. This value can be used as the reference in the WoC architecture.

The second requirement of Article 44(1) [14] allows an intentional Frequency Response Deadband (c_d), but at the same time limits its combined effect with the inherent Frequency Response Insensitivity in order to ensure that also small Frequency Deviations are controlled and the Frequency Quality Target Parameters can be fulfilled. Furthermore, the requirement ensures that the activation of FCR does not start too late after a Frequency Deviation.

The Full Activation Deviation defines a requirement for activation in terms of Frequency Deviation and ensures that the Maximum Steady-State Frequency Deviation is not violated.

The Full Activation Time of FCR defines a requirement for activation in terms of time by guaranteeing a sufficient activation gradient in order to achieve the necessary frequency quality and to ensure that the Maximum Instantaneous Frequency Deviation is not violated.

It is important that the FCR minimum technical requirements defined at Article 44(1) [14] need to be considered in the WoC, even though responsibilities of TSOs will be covered at cell level by the CSOs.

As for dimensioning of the FCR, the basic criterion is to withstand the Reference Incident in the Synchronous Area by containing the System Frequency within the Maximum Frequency Deviation and stabilizing the System Frequency within the Maximum Steady-State Frequency Deviation.

The Reference Incident has to take into account the maximum expected instantaneous power deviation between generation and demand in the Synchronous Area.

Under the WoC concept, the situation remains similar but at a smaller grid area (i.e., cell level) and under the responsibility of the CSOs which can be interpreted by TSOs in such a context. The main difference is that there is more focus on solving local problems locally through self-responsibilisation and self-balance. In the WoC, since the frequency containment process in a problematic cell tries to minimize the activation of reserves in neighbour cells, presumably the aFCC reserves of each cell should be dimensioned higher to compensate the “missing collaboration”.

As for availability rules, the reference taken into account is Article 45 [14]. For CE, the FCR Capacity which can be provided by a single FCR Providing Unit is limited to 5% of the total FCR Capacity (currently 150 MW). For GB, IRE and NE due to higher volatility of the systems the loss of a FCR shall be taken into account by the continuous FCR dimensioning. Moreover, requirements are also specified for:

- FCR provision by a single FCR Providing Unit in order to limit the consequences of a loss of a Power Generating Module, Demand Unit or a Connection Point;
- The ability to activate FCR in case of persisting Frequency Deviations.

Regarding the ability to activate FCR three aspects need to be considered:

- Expected activation of FRR and corresponding relief of FCR within Time To Restore Frequency;
- Possibly limited energy reservoirs in FCR Providing Units and FCR Providing Groups;
- Possibility of time periods with Frequency Deviations occurring mainly in one direction.

All these aspects are covered by the NC LFCR, with the respective requirements for activating FCR as long as the Frequency Deviation exists but also allowing FCR Providing Units and FCR

Providing Groups with limited storage as long as certain conditions can be fulfilled (Article 45(6)). In particular:

- Each FCR Providing Unit or FCR Providing Group with energy reserves which are not limited (e.g. fossil-fuelled power plants) shall activate FCR as long as the Frequency Deviation persists or, as it is the case for GB and IRE, until the same Providing Unit or Providing Group has activated FRR.
- If the energy reservoir is limited, the FCR Providing Unit or FCR Providing Group shall also activate FCR as long as the Frequency Deviation persists or the energy reservoir is exhausted (or in case of GB and IRE until it has activated FRR).

These two aspects result to be in contrast with the WoC concept, where there is no a 2-phased approach as done today (containment followed by restoration). Conversely, these two latter run at the same time-scale and fast reserves are used for restoration immediately. Therefore, the WoC benefits from the existence of fast reserves that favour the local activation. Obviously, the FCR properties in the Synchronous Area (activation times, frequency deviations, etc.) must be considered as reference values for the WoC frequency control process.

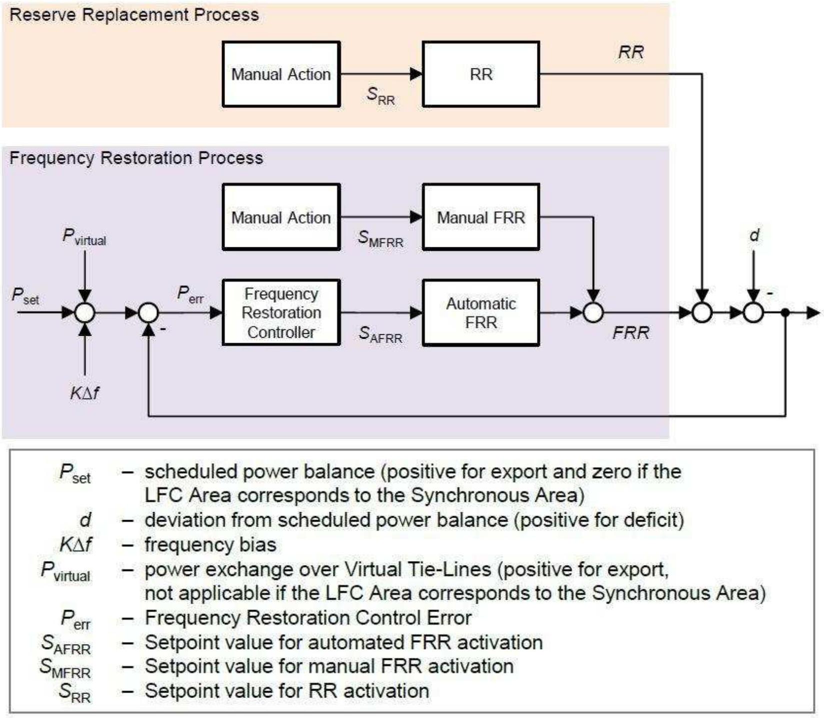
3.1.4 Balance Restoration Control

In the WoC, the goal of BRC is to restore cell balance and by doing so: restoring inter-cell load flows to their scheduled secure values. Based on the difference between scheduled power flow and measured/actual power flow across the cell borders, also referred to as the Balance Restoration control error, the Balance Restoration reserves available within the cell are activated. Restoration Reserves may be offered by loads, production units as well as storage units. The combination of resources offered through flexible loads, and possibly local storage as balance restoration reserve capacity, will give the CSO a sufficient amount of restoration reserve capacity. In the WoC, BRC acts as a primary frequency control helped by the aFCC control. Some containment mechanism is still necessary to enter into operation when the BRC is not enough to restore the balance. In a WoC architecture, each CSO is thus responsible for activating balance restoration reserves when an imbalance within his cell is detected. Within the balance restoration control layer, only resources from within the cell can be procured as balance restoration reserves. When deviations are observed, the corrective actions are taken using local (intra-cell) reserves. Dispatching the reserves by the CSO is based on an ordered list taking into account economic factors, but potentially others as well (e.g., fairness,…). Before activation, the local grid status is checked so that activating reserves does not cause congestion or voltage issues within the Cell. Therefore, as also discussed in D4.2 [11], the BRC functionality in a WoC architecture monitors instantaneous active power import/export profile that was received. In response of observed deviations, i.e., cell imbalances, active power is controlled to correct these deviations. In this way, the system balance, as well as the frequency, is restored in a bottom-up approach based on local observables (cell tie-line power flows). The Cell set-point corresponds to a system balance, and if each Cell adheres to its set-point, then the system balance is kept.

Regulatory Constraints on the BRC Activation Process

The BRC UC shows resemblance to the current Frequency Restoration Control (FRC), with a fundamental difference: BRC is not a slower (secondary) control, but instead is a fast primary control – using many local fast ramping resources like flexible loads or storage – that runs at the same time as the aFCC control (instead of taking over from FCC). Deviations that are observed by a cell can be caused by the cell itself, but also by neighboring cells, so there is a level of local collaborative balance (and frequency) restoration. It should be noted that BRC acts on a pure local observable, whereas the aFCC UC acts on a system level observable (frequency deviation).

Currently, the frequency restoration process (FRP) - as the process that aims at restoring frequency to the nominal frequency, and for Synchronous Areas consisting of more than one LFC Area, the process that aims at bringing the power balance to the scheduled value (from NC OS [26]) - is regulated by the NC LFCR [14] at transmission level. Figure 11 shows the implementation of the FRP from perspective of a LFC Area as a general control scheme.



P_{set} – scheduled power balance (positive for export and zero if the LFC Area corresponds to the Synchronous Area)
d – deviation from scheduled power balance (positive for deficit)
$K\Delta f$ – frequency bias
$P_{virtual}$ – power exchange over Virtual Tie-Lines (positive for export, not applicable if the LFC Area corresponds to the Synchronous Area)
P_{err} – Frequency Restoration Control Error
S_{AFRR} – Setpoint value for automated FRR activation
S_{MFRR} – Setpoint value for manual FRR activation
S_{RR} – Setpoint value for RR activation

Figure 11: Frequency Restoration Process and Reserve Replacement Process from a perspective of a Load-Frequency Control Area as a general control scheme [15].

The FRP is thus designed to control the Frequency Restoration Control Error (FRCE) towards zero by activation of manual and automated FRR within the Time to Restore Frequency. In this way, the frequency is controlled to its set-point value and the activated FCR are replaced. According to the NC LFCR [14], this is triggered by the disturbed LFC Area, under the responsibility of TSOs. Under the WoC concept, this current responsibility will be shifted to the CSO, regardless the voltage levels included in the cells under their responsibility area, thereby assuming responsibility similar to former TSO responsibility in its Control Area.

In general, there are several aspects defined in the current regulation which need to be taken into account in the BRC functionality developed in ELECTRA: the frequency restoration target parameters, the allowable timing to be outside FRCE ranges, evaluation of the dynamic behaviour, provision and activation of restoration reserves, as well as dimensioning rules.

In article 20 [14], the NC LFCR defines the FRCE Target Parameters, which provide a harmonised consideration of the FRP as part of the quality framework, while taking into account the physical differences between the Synchronous Areas. In detail, there are two FRCE Ranges, Level 1 and Level 2. For TSOs of the Synchronous Areas CE and NE:

- The values of the Level 1 FRCE Range and the Level 2 FRCE Range shall be defined in the Synchronous Area Operational Agreement by all the TSOs of the relative Synchronous Areas, for each LFC Block at least every year, with the goal of respecting the provisions of Article 19 i.e., frequency quality target parameters.
- In case of more than one LFC block, TSOs of the relative Synchronous Areas shall ensure that Level 1 FRCE Ranges and the Level 2 FRCE Ranges of the LFC Blocks are proportional to the square root of the sum of the Initial FCR Obligations, according to Article 43 for FCR dimensioning of the TSOs constituting the LFC Blocks.

Regarding the FRCE target parameters, the TSOs of the Synchronous Areas CE and NE shall use the values shown in Table 11 (Article 20 (2) [14]), for each LFC Block of the Synchronous Area.

Table 11: Frequency Restoration Control Error target parameters for the Synchronous Areas CE and NE [14]

	Level 1 FRCE	Level 2 FRCE
Number of time intervals per year outside the level FRCE Range within a time interval equal to the Time to Restore Frequency	< 30%	< 5%

If a LFC Block consists of more than one LFC Area, the values of the Level 1 FRCE Range and the Level 2 FRCE Range, as well as the FRCE Target parameters shall be defined in the Synchronous Area Operational Agreement, by all the TSOs of the LFC Block, for each LFC Area complying with Article 20 [14]. On the other hand, for the Synchronous Areas GB and IRE, the Level 1 FRCE Range shall be ±200 mHz and the Level 2 FRCE Range shall be ±500 mHz (Article 20 of NC LFCR [14]). Regarding the FRCE target parameters, the TSOs of the Synchronous Areas CE and NE shall use the values shown in Table 12 (Article 20 (5) [14]) of a Synchronous Area, and the fulfillment of these target parameters should be done on annual basis.

Table 12: Frequency Restoration Control Error target parameters for the Synchronous Areas GB and IRE [14]

	Level 1 FRCE		Level 2 FRCE	
	GB	**IRE**	**GB**	**IRE**
Maximum number of time intervals outside the level FRCE Range	≤ 3%	≤ 2%	≤ 1%	≤ 1%

According to the Article 34(2) of NC LFCR [14], the FRCE is the Area Control Error (ACE) of a LFC Area where there are more than one LFC Area in a Synchronous Area; or, the Frequency Deviation where one LFC Area corresponds to the LFC Block and the Synchronous Area. In particular, according to the Article 34(3) of NC LFCR [14], the ACE of a LFC Area shall be calculated from the deviation between the scheduled and actual power interchange of a LFC Area (including Virtual Tie-Lines if any) corrected by the frequency bias (K-Factor of the LFC Area multiplied by the Frequency Deviation). This shows similarity to the BRC functionality, focusing on local inter-cell tie-line power flow deviations but at cell level rather than system frequency, where the responsibility for detecting and correcting such real-time deviations is delegated to local (i.e.cell) operators. The main principles defined by the NC LFCR [14] at control area are still applicable within the WoC instead at control cell level.

As for the dynamic behaviour of the system frequency or the FRCE, several criteria are used to evaluate it when a bigger disturbance causes the respective parameter to exceed a range (e.g. Standard Frequency Range) and must be returned to the lower range. The respective criteria can be seen as different forms of “trumpet curve” evaluation. The quality of BRC is assessed in a similar manner to the assessment of current secondary control in control areas, where trumpet-shaped curves are defined on the basis of values obtained from experience and the monitoring of system frequency over a period of years [27]. When the frequency is maintained within the trumpet-shaped curve during the BRC process it is considered effective in terms of technical control.

With reference to the FRR activation, the set-point value can be determined manually by the operator (feed-forward control) and/or in an automated way (feed-back control). The latter requires a Frequency Restoration Controller with proportional-integral behaviour implemented in the control system of the TSO (Article 34 of NC LFCR [14]). In particular, as stated at Article 34(4) [14], this controller shall:

- be an automatic control device designed to reduce the FRCE to zero;
- be operated in a closed-loop manner with FRCE as input and set-point value for FRR activation as output;
- have proportional-integral behaviour; and have a control algorithm which prevents the integral term of a proportional-integral controller from accumulating the control error and overshooting.

In the WoC, the CSO will provide autonomous control of balance/frequency, and this could radically change the present paradigm, involving a central TSO control room/centre, to instead require significantly reduced manual operator interaction for real-time control. In particular for BRC functionality, each CSO is responsible for activating BRC reserves when an imbalance within his cell is detected, and for dispatching the reserves based on an ordered list.

The FRP process described above is based on the assumption that active power reserves are instructed by the same TSO that operates the LFC Area to which the reserves are connected, similar to the WoC environment with the CSO operating its cells. The NC LFCR [14] also enables and regulates the cross-border reserve activation and Imbalance Netting. However, as discussed above, within the balance restoration control layer of BRC Use Case, only resources from within the cell can be procured as balance restoration reserves. When deviations are observed, corrective actions are taken using local (intra-cell) reserves. To compensate for the missing Imbalance Netting effect in a bottom-up restoration approach, a balance steering control (BSC) is added, to be discussed later.

Regulatory Constraints for Balance Restoration Reserves

According to the control mechanisms in the current grid, any imbalance between active power generation and consumption leads to a persisting rise or fall of the system frequency and therefore to a frequency deviation which has to be countered by FCR activation. Therefore, there is a direct physical relationship between the amount of FCR, FRR and RR, since if any imbalance amount is not covered by FRR or RR, the frequency deviation is followed by joint and automatic activation of FCR in the whole Synchronous Area. NC LFCR defines rules (Article 46 [14]) for TSOs to be followed on the level of LFC block for FRR dimensioning. In summary, the minimum values for FRR required for CE and NE shall be based on a combination of:

- A deterministic assessment based on the positive and negative Dimensioning Incident (Article 46(2).e and Article 46(2).f [14]);
- A probabilistic assessment of historical records for at least one full year (Article 46(2).a and Article 46(2).b [14]).

According to the deterministic approach, the FRR Capacity shall not be smaller than the Dimensioning Incident, which is the highest expected instantaneously occurring Active Power Imbalance within a LFC Block in both positive and negative direction. In general, this is the tripping of the largest generation unit for the positive direction and the largest demand facility for the negative direction. As for the probabilistic approach, the NC LFCR defines a minimum value for the sum of FRR and RR capacities (Article 46(2).h and Article 46(2).i) which is defined by the 99% quantile of the LFC Block Imbalances (separate for positive and negative direction). The 99% quantile is a minimum value and thus can be harmonised for all LFC Blocks. Moreover, for a specific LFC Block, it is necessary to exceed the minimum values defined by the NC LFCR [14] :

- To comply with FRCE Target Parameters (Article 46(2).b and Article 48(3).c);
- To respect network constraints within a LFC Block (Article 46(2).g);
- To take all factors into account which may lead to unavailability of FRR or RR (for instance, in case of unavailability of reserves provided from a different LFC Area or Sharing).

The different response times of both Automatic and Manual FRR must be also considered in the dimensioning and lead to the respective shares. It must be said that for GB and IRE, only the deterministic approach is applied due to the volatility of the systems [15]. For Ireland, FRR reserves are dimensioned to exactly cover the Reference Incident which is the largest single infeed. So, after 90 seconds, the FCR with additional MWs become FRR. As these combined MWs only sum to the largest single infeed it means that for the Reference Incident FRR cannot replace FCR and the TSO must rely on RR to replace the FCR.

Under the WoC concept, situation remains similar but the dimensioning process should occur at cell level by considering BRC faster acting resources and under the responsibility of the CSO which can be interpreted by TSOs in such a context. This is because the key difference is that there is more focus on solving the problems locally through a self-responsibilization process. This avoids the 2-phased approach where containment is followed by restoration, thereby allowing to start restoring immediately based on faster acting resources (aFCC and BRC operating in the same timeframe).

As for reserves provision and activation, according to NC LFCR [14], there are two main harmonized requirements for all Synchronous Areas, i.e.:

- The full FRR Activation Time, which shall be at most equal to Time-To-Restore-Frequency (Article 46(2).c).
- The delay for Automatic FRR Activation, which shall be at most equal to 30 s (Article 47(1).c).

The FRR Minimum Requirements take into account the different boundary conditions of the single LFC Areas and LFC Blocks (structure of generation and load, renewables, typical imbalance patterns). Therefore, the NC LFCR [14] defines a harmonised framework for the requirements and leaves room for further details which must be defined on the LFC Block and LFC Area level in order to ensure efficiency. The FRR Minimum Requirements shall [15]:

- Ensure Operational Security;
- Enable the fulfillment of FRCE target parameters;
- Be based on transparent technical arguments;
- Respect the values provided by NC RfG [16];
- Enable an efficient FRR monitoring;
- Be approved by the responsible NRAs.

The fulfilment of the requirements shall be evaluated during the Prequalification phase, where each potential Reserve Provider shall have the right to apply for Prequalification at the Reserve Connecting TSO, and the TSO shall evaluate the fulfilment of the technical requirements and declare the Prequalification as passed or propose amendments which can be implemented by the potential Reserve Provider.

Requirements defined at Article 47 still remain in the WoC architecture both for reserves providers and for reserve providing units, even though responsibilities of TSOs will be covered at cell level by the CSOs. In detail, balance restoration reserves are procured within a cell and ordered in a merit order, based on the costs for reservation as well as the physical state of the network. When a cell imbalance occurs, the required reserves are activated according to the merit order, and reserves are activated for a maximum period of time. In such a context, aggregators, which aggregate the flexibility from a portfolio of many (different) resources, can act as a restoration reserve provider. In order to comply with a reserve activation request, the aggregators must ensure that the required reserves are activated within the agreed ramp-up time. Therefore, each aggregator has to be aware of the overall flexibility of its combined portfolio, and thus needs to know the availability and state of the resources within its portfolio. In the WoC, resources for restoration reserves are flexible resources in its broadest interpretation: synchronous generators, renewable resources, curtailable load, shiftable load, electricity storage, etc.

3.1.5 Balance Steering Control

The objective of Balance Steering Control is to compensate for the missing Imbalance Netting effect in a bottom-up restoration approach [11]. This counters the excessive amount of bottom-up BRC activations that are based on local observables and which lose the benefits of Imbalance Netting – that is, the optimal dispatch of reserves considering the availability of reserves in neighboring cells, considering the availability of transfer between cells across tie-lines.

This can be activated under two different scenarios:

- Reactive substitution of Balance Restoration Reserves by Replacement Reserves, and thereby achieving the most economical dispatch of reserves;
- Proactive activation of Balance Steering Resources based on short-term forecasting.

The traditional approach to deployment of such reserves is for Frequency Containment followed by Frequency Restoration. The new approach of BRC and BSC focuses more on Balance Restoration (BRC) at the same timescale as frequency containment, with subsequent application of BSC on the 15 minute to 1 hour timescale, from which point conventional market-based deployment is expected to respond to imbalances.

Failure to implement BSC as part of the WoC concept would result in higher demand for Reserve Capacity than is necessarily needed, and so would entail significant addition costs to system operation. However, BSC should not be considered as a potential contributor to LFC, and all Cells should be capable of management of frequency under the assumption that no such balance management is possible (such as in the case of adverse network congestion).

Under the status quo, where there is only one FRP in a Synchronous Area and the Frequency Restoration Control Error is based on Frequency Deviation (e.g. IRE, GB or NE), the Imbalance Netting Process is implemented implicitly in the control error calculation. Introduction of additional cells with autonomous frequency restoration processes and reserves causes additional boundaries across which imbalance netting may occur.

The transfer of balancing services between Cells through BSC, allows the exchange of reserve capacity, thereby reducing the amounts of reserves activated as well as opening-up the market and thereby increasing competition between balancing service providers.

Regulatory Constraints on the BSC Activation Process

Within the BSC Use Case [11] new set-points for tie-line dispatch are determined, resulting in the deactivation of previously activated reserves in a co-ordinated peer-to-peer manner, countering the excessive amount of bottom-up BRC activations that are based on local observables and so gaining the benefits of imbalance netting.

A distributed/decentralized control scheme is utilized, whereby neighboring cells mutually agree on changing their tie-line active powerflow set-points – without violating operating limits – and so reduce the amount of BRC reserves that would be activated in each cell. The Use Case implements a corrective BSC functionality which determines new set-points for the BRC controller.

To summarise the specific processes required:

1. The use of a central ‘Tie-line Limits Calculation Function’ which calculates acceptable tie-line deviations based on information received from the ‘Load and Generation Forecaster’;
2. If an imbalance error signal is received that is larger than a static threshold, the ‘Cell Set-point Adjusting Function’ calculates for each neighbour a proposed tie-line set-point change, taking into account previously calculated allowed deviations;
3. The neighbour’s ‘Cell Set-point Adjusting Function’ uses that information to calculate an acceptable set-point change which may be the same as proposed, an alternative value, or a zero (i.e. no change is made);
4. On receipt of this response, the originating cell’s ‘Cell Set-point Adjusting Function’ calculates the aggregated balance set-point change and sends this to the ‘Imbalance Determination Function’ as previously determined in the BRC process.

The key elements of this process which would fall within the scope of existing/proposed regulation are:

a. The determination of acceptable tie-line deviations which would be acceptable within further assessment of system security;
b. Limits on permitted exchange of reserves in synchronous areas consisting of more than one LFC block;
c. The economic determination of the optimum tie-line deviation on an independent and market-led basis, including competition regulation;
d. The process of BSC activation of BRC deactivation acting within accepted frequency management limits;
e. The mechanism for data exchange between cells, and considerations around data privacy and retention;
f. The rights of TSOs of LFC areas to define internal limits for the exchange of reserves;

The Proposal for a Directive on Common Rules for the Internal Electricity Market [28] sets out the broad concepts behind the IEM and has Articles relating to the above in the following manner:

- Article 3 has general provisions on discrimination and competition which relate to c);
- Articles 15-17 determining the roles and activities relating to demand-side response, local energy systems active consumers, which relate to e) and f);
- Article 41 concerning confidentiality and transparency, relating to e);
- Article 58 concerning market entry and restrictions on trade (as well at 59 concerning the regulatory oversight of such matters), relating to c) and f);

The technical provisions a) and b) described relate to security-constrained dispatch of power between LFCs, and so are primarily governed by the ENTSO-E Network Code on Load Frequency Control & Reserves [14].

The aspects related to proactive BSC deployment are covered within the Network Code on Operational Planning and Scheduling. Each of these technical relations are explored more fully in the following subsections.

Relation of Balance Steering Control to Frequency Regulation

The primary objective for defining the level of BSC activation is to minimize and optimize the activated balancing reserves, in terms of (de)activation of active power resources, considering the availability of reserves within neighboring cells – this is in contrast to the above Balance Restoration Control where only resources within the cell are dispatched and considered, which ignores the benefits of imbalance netting between cells. The opportunity for imbalance netting through activation of BSC is considered within the constraint that tie-line power flow constraints are not exceeded.

Within the Network Code, the Imbalance Netting Process is designed to reduce the amount of simultaneous and counteracting FRR activation of different participating and adjacent LFC Areas by Imbalance Netting Power exchange. The Imbalance Netting Process is applicable between LFC Areas which are part of one or more LFC Blocks within one Synchronous Area or between LFC Areas of different Synchronous Areas.

However, the Network Code on LFCR deals only with technical requirements. From this technical perspective, the implementation of control processes relating to Imbalance Netting is not a precondition for the maintenance of operational security in each case. In case of exchange and/or sharing of reserves or joint dimensioning for several LFC Areas the implementation of the respective cross-border activation processes is required explicitly. Hence, in contrast to the regulatory requirements governing frequency restoration, the objective should be principally set by the economic benefits of removing such imbalance netting within the constraints that any actions should not adversely affect operational security. Treatment of imbalance netting is hence seen as an optional requirement to operators of LFCs. This may not be the case, if the management of Imbalance Netting may be related to fulfilment of the quality target as defined in the Winter Package.

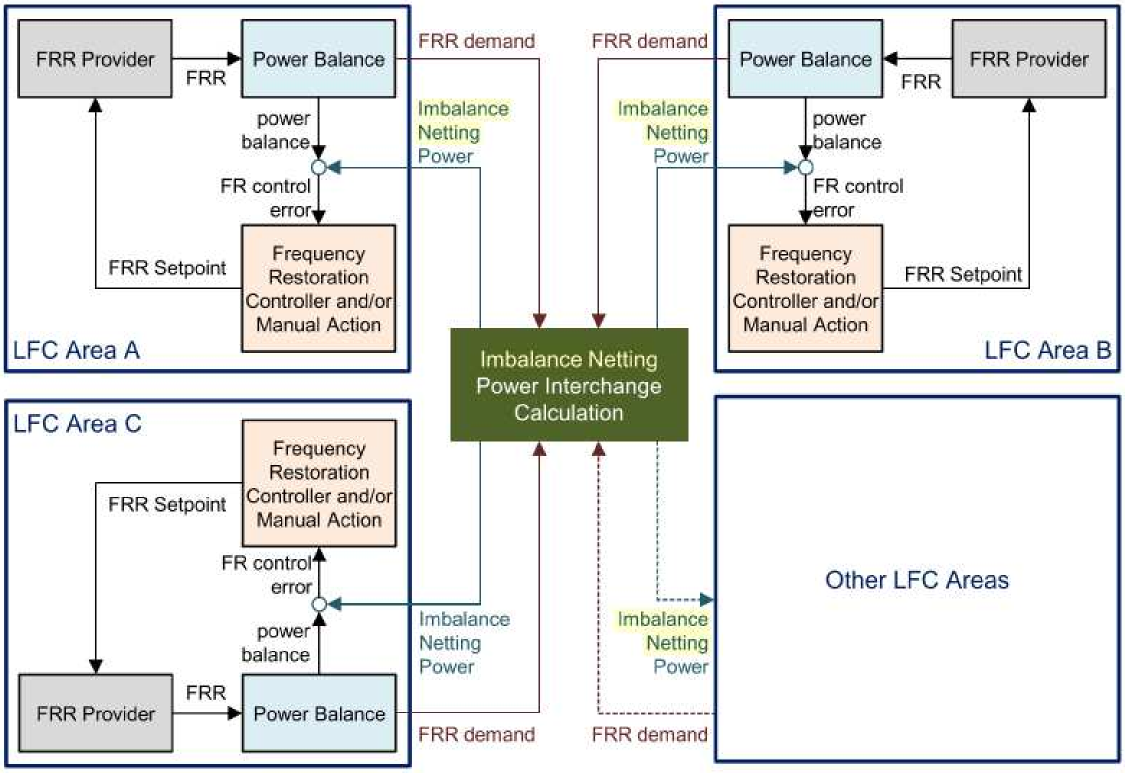


Figure 12: Imbalance netting calculation process within the Network Code on Load-Frequency Control and Reserves [14, 15]

Figure 12 illustrates the intended Imbalance Netting calculation between LFC Areas as defined by the NC LCFR. This incorporates the calculation into the FRR activation process:

- The participating TSOs calculate in real time the demand for FRR activation based on the power balance of the LFC Area. This value represents the total amount of FRR needed to reduce the FRCE to zero (as required in Article 36(5), the Imbalance Netting Power Interchange shall not exceed this value).
- These values are transmitted to an algorithm which nets the single FRR demands and calculates the Imbalance Netting Power Interchange for each participating LFC Area. Where the participating LFC Areas are located in the same Synchronous Area the Imbalance Netting Power Interchange is implemented by a Virtual Tie-Line. The term Virtual Tie-Line is used for a real-time control signal which is exchanged between two LFC Areas for adjustment of ACE.

Within the WoC concept, the use of BSC to correct for Imbalance Netting is separated from the use of FRR. However, the requirement of Article 36(5) remains that the process of activating RR should not allow the FRCE to deviate from zero.

Primarily the dimensioning of replacement reserves should seek to maintain the same principles of frequency regulation as defined within the BRC. The dimensioning of replacement reserves should be determined by the economic objective – in other words, the use of replacement should allow the achievement of the least-cost use of dispatch taking into account the available reserves *across all coordinated cells* within the constraint defined by tie-line limits. This economic objective is currently stated within the high-level design of the IEM as well as the Network Code on Operational Planning and Scheduling.

Relation of Balance Steering Control to Operational Planning

Any change in flows to manage Imbalance Netting shall not result in load-flows which lead to violation of Operational Security Limits (cf. Article 36(6), Article 37(5) and Article 38(5)). This implies two requirements:

- The physical result in terms of load-flows caused by the Imbalance Netting Process or cross-border activation of FRR or RR must be made transparent in real-time operation in order to enable an understanding of the system state. This places an onus on the relevant operators to have a clear and timely mechanism for undertaking the BRC process, which is complicated by the potential for there to be a large number of cells within a synchronous area.
- A procedure to limit the interchange between LFC Areas, in real-time, must be implemented by the TSOs. The limits for the interchange must respect ex-ante planned values and observations of the real-time Operational Security Analysis.

If there is an issue with the enactment of BSC, such as due unforeseen restrictions of transmission capacity or problems with the communication infrastructure, the operators should have in place appropriate fall-back procedures, starting with detection and alarming of the operational staff and ending with limitation or deactivation of BSC, and including local re-activation of FRR where deactivations have already occurred as part of the BRC process. The NC LFCR defines data provision requirements which must be harmonised for all Synchronous Areas in order to assist in this goal.

Application to Current Synchronous Areas

Although there is no current analogue to BSC currently active in the same time frames as that proposed in the WoC architecture, there has been development of cooperative instruments for the management of imbalance netting between cooperative TSOs.

The Network Code on Electricity Balancing (NC EB) [29] contains the concept of a ‘Coordinated Balancing Area’ (CoBA) which means an area within which cooperation occurs with respect to the Exchange of Balancing Services, Sharing of Reserves or operation of the Imbalance Netting Process between two or more TSOs. Every EU TSO is obliged to cooperate with two or more TSOs in a CoBA by exchanging one or more Standard Product or through implementation of an Imbalance Netting Process. Figure 13 below illustrates some of the proposed configurations of CoBA currently under consideration, and within which imbalance netting management may occur. ENTSO-E has indicated preference towards an ‘organic’ approach towards determining the configuration of CoBAs.

Figure 13: Proposed Coordinated Balancing Area scenarios proposed by ENTSO-E [29]

Some current areas lack management of imbalance netting due to the absence of zonal pricing - for example, as the GB and Ireland Synchronous Areas are currently dispatched under single market mechanisms, with single zonal procurement of reserves, there is currently no possibility of Imbalance Netting. Further, no reserve capacity is currently contracted across HVDC interconnection for either synchronous area. However, as these regions are co-opted into wider CoBA then management of imbalance netting will become required.

The NC EB guidelines foresee an Imbalance Netting Regional Integration Model for the whole CE synchronous area. Any TSOs of the Central European area that have not yet implemented a cross-border imbalance netting process will progressively join the Imbalance Netting CoBA based on the International Grid Control Cooperation collaboration to comply with regional integration obligations.

Imbalance Netting is also seen as a first step towards implementation of automatic FRR activation between TSOs within CoBAs (on the basis that it is a natural first step which delivers important benefits without high technical complexity). It is considered unlikely that a TSO would become part of an aFRR CoBA without joining first an Imbalance Netting CoBA. TSOs which are netting their imbalances successfully will then progress to implementation of exchange of aFRR energy. This is a fundamental difference with the WoC frequency control mechanisms, which benefits from the implementation of the BSC imbalance netting but does not consider an exchange of FRR (BRC) energy between cells in normal conditions. It is considered inefficient to develop aFRR CoBAs in parallel with Imbalance Netting CoBAs. The ‘organic’ approach towards CoBA development identifies this convergence to be likely to occur first via bilateral cooperation between DE/AT and/or AT/BE/DE/NL.

Economic and Competitive Considerations

ACER identifies [30] that a risk of balancing market integration is that, due to regional implementation (prior to EU-wide integration) being a necessary evolutionary step, there is a risk of development of incompatible regions lacking mutual harmonisation and standardisation. Attempts to integrate such poorly-harmonised regions would lead to distortions and biases in dispatch actions taken to deliver cross-border flows, and the economic optimal management of imbalance netting would not be achieved.

For this reason, it has been identified that there are a number of key standards that must be applied to ensure economic parity between participants within TSOs coordinating balancing:

- Standard products for imbalance netting should be defined prior to implementation;
- Principles underlying these products and algorithms must be rigorously respected;
- The pricing method for balancing energy must be applied in all CoBAs;
- Gate closure times must be harmonised within each CoBA;
- The imbalance settlement period must be the same in all CoBAs;
- TSO-TSO settlement rules for the exchanges of balancing energy must be the same in all CoBAs.

While the WoC concept provides a set of algorithms which may achieve the above harmonisation, any introduction of WoC will require that it integrates with the existing CoBA development that has already occurred - otherwise distortions may occur between areas which have adopted existing CoBA products and those which have adopted WoC. For this reason, the introduction of WoC is likely to require transitional arrangements, such as a secondary settlement process which can adjust for any economic inefficiencies due to disharmonization of algorithms between regions.

3.2 Impact of the regulatory framework on Use Cases for voltage control

The stability of the grid voltage is essential for the safe and stable operation of the electricity network. Due to this, voltage control is a critical ancillary service for the power system. To maintain the voltages in the nodes within allowable limits, CSOs will need to procure services from units connected to its grid to fulfill the self-sufficiency of resources required for controlling the cell voltages in real-time. In normal operation the balance of reactive power must be kept in a way all the voltages in the nodes are within acceptable limits; in case of a disturbance, the voltages must be restored to the optimal values as soon as possible. In D3.1 [1], it was stated that the future control mechanism designed for the WoC roots on two layers: primary voltage control (PVC) and post-primary voltage control (PPVC) in opposition to the three current layers considered nowadays (primary, secondary and tertiary) [31]. The proposed voltage control structure within ELECTRA is shown in Figure 14, where the main information flows have been represented. In case of MV/LV levels, where there is a high R/X ratio, the activation of the voltage control mechanisms may impact on the system balance, leading to the subsequent activation of the balance control.

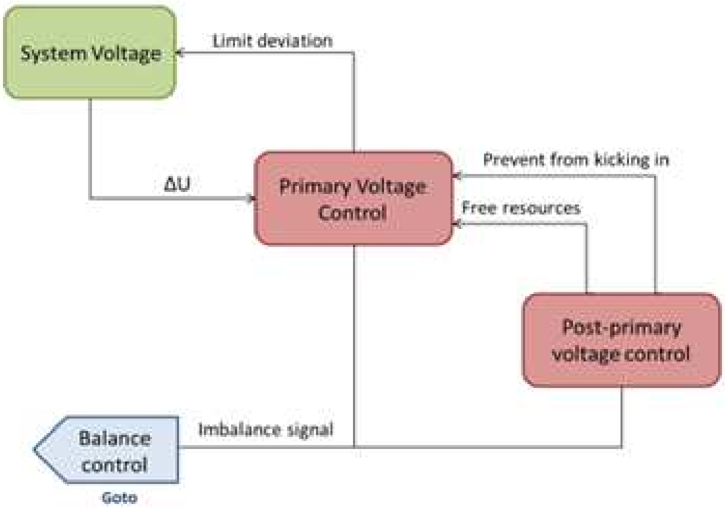


Figure 14: Overview of proposed voltage control structure of a cell [13]

The analysis that is going to be made along this subchapter focuses on the current regulation aspects concerning to voltage control that could impact in the deployment of the WoC, in order to identify the barriers and allocation of responsibilities with the aim of determining the required changes to make the WoC feasible from a regulatory point of view.

According to the standard EN 50160:2010 [32], the voltage disturbances can be classified depending on their magnitude and duration, as shown in Figure 15. The regulations set different conditions for the generators for any of these disturbances, excluding the definition of the bands where the system is in a normal operation state. According to the scope of the different voltage control layers defined for the WoC, the requirements for withstanding voltage dips/sags/swells fall under the umbrella of the PVC, while the requirements for the longer disturbances will be of interest for the PPVC.

Being strict with the requirements in the abovementioned standards that have a direct impact over the deployment of the PPVC, the most important is the definition of the safe band that poses the limits for the PPVC proactive resolution while triggering the operation of the PPVC corrective (steady-state limits). Additional requirements, such as the need to supply reactive power, the allowable operation modes, the controllers' deadbands, the P/Q diagrams, etc. are linked to the development of the local controllers of the generation sources. Even though the impact on the UC is indirect, it can be seen that the need to ensure compliance with the codes is essential to match the requirements of the regulations itself with the operation timeframes defined in the UC.

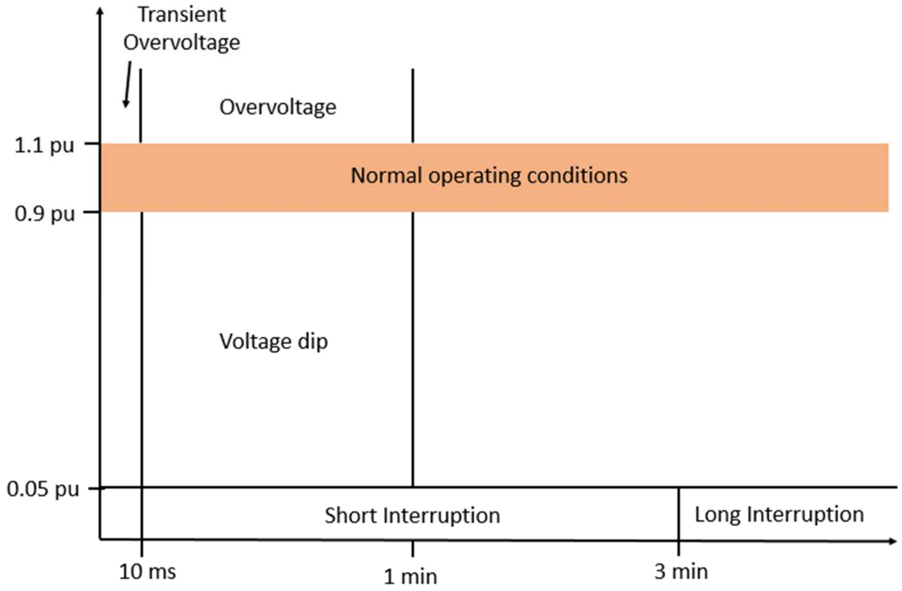


Figure 15: Classification of voltage disturbances according to EN 50160:2010

Depending on the voltage levels, there are four main regulations considered relevant to this analysis currently in force at a European level:

- HV: ENTSO-E Network Code on Requirements for Generators (2017) [16]
- MV: CLC/TS 50549-2 (2015) [33]
- LV: CLC/TS 50549-1 (2015). For generators above 16A [34]
- LV: EN 50438 (2013). For generators up to 16A. [35]
- EN 50160 (2010) [32]

If considering the WoC as the future grid architecture with all the voltage levels included, and with a focus on the impact of the distributed generation, it is appropriate to analyze all the above mentioned regulations. The ENTSO-E NC RfG [16] establishes the rules applicable to the transmission grid. The Technical Specification from CENELEC CLC/TS 50549-2 focuses on the requirements for the connection of generators above 16 A per phase [33]. This means it settles the requirements for connecting to MV grids. Lastly, CENELEC CLC/EN 50438, titled "Requirements for micro-generating plants to be connected in parallel with public low-voltage distribution networks" is applicable to generators that have to be connected in LV grids [35]. If the generators provide above 16 A and are connected to a LV grid, they fall in the scope of CLC/TS 50549-1 [34]. All these standards at European level are a benchmark that are usually completed with country-specific regulations. This is the case of the ENTSO-E NC RfG [16] that gives non-exhaustive requirements with flexible operating limits which has to be later adapted and supplemented by each TSO.

3.2.1 Primary Voltage Control

The goal of the PVC is to maintain the voltage set-point locally at the connection point of a flexibility resource by an automatic voltage control process based on a given set-point, local measurements and control algorithms. It is also in charge to minimize transient voltage deviations. This automatic mechanism is launched when a difference between the measured voltage and the voltage set-point is detected, and leads to the activation of the rapid automatic voltage regulators (AVRs) operating in timeframes that are in the order of milliseconds. Controllers in synchronous generators or the control systems of inverter-coupled resources / FACTS may also be equipped with AVR capabilities. They are able to control the reactive power output, keeping the output voltage magnitudes at the specified values.

The PVC UC developed within ELECTRA does not raise noticeable differences over the current practices established nowadays. The voltage magnitude has a local character and the fast response required to stabilize the grid and to correct the voltage deviations during major disturbances is already requested by the regulations. In the ENTSO-E Operation Handbook [36], it is stated that the TSOs are committed to keep enough reserves of fast reactive power to ensure normal operation with a continuous and normal evolution of the load, and to prevent voltage collapse in case of any contingency. According to the implications derived from the WoC concept, this current responsibility will be shifted to the CSOs, regardless the voltage levels included in the cells under their responsibility area. The main difference in the 2030+ horizon of ELECTRA interest will be the devices that could be massively deployed in the future grid architectures, such as storage or EVs that could also be requested to surrender to the same regulations. Also the DSO current responsibilities concerning the maintenance of power quality and grid security will be accomplished by the CSOs in the future WoC architecture.

The NC RfG [16] that became a binding regulation in May 17th of 2017 sets the rules for the allowable disconnection of Power Generating Modules (PGMs)[2] under several conditions. They can, according to their category, disconnect or remain connected (according to a LVRT curve) in case of major disturbances. Type B can disconnect according to a LVRT curve, Type C are allowed to disconnect at certain voltage levels and Type D PGMs have to respect a LVRT curve enclosed between certain limits. For type D the disconnection is allowed if the voltage level is below the minimum. Table 13 shows a summary of the PGM classification as a function of their type within the European power system. PGM comprises all the generation plants that can depend on a synchronous generator (SPGM) or if they are connected through power electronics converters, called power park modules (PPM). According to the rated power of the PGMs, the bigger the size of the power plant, the more demanding the requirements, because the impact of the PGM over the full power system also noticeably increases. Type A - those PGMs which rated power is up to 0.8 kW and whose impact in the total system is negligible - do not have defined dedicated requirements within the ENTSO-E NC RfG. In Figure 16, the summary of maximum and minimum LVRT curves that must be withstood by the PGMs depending on their type is shown. It must be noted there is freedom for the system operators to define a specific curve if it is included between these extreme limits. Bigger PGMs (Type D) must comply with zero voltage ride-through, while that stringent requisite is not compulsory for types B and C.

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[2] PGM - Power generating module: generation facility that can be either a synchronous power-generating module (SPGM) or a power park module (PPM).

Table 13: Classification of the Power Generating Modules according to their size and location

	Maximum capacity for Type B PGMs	Maximum capacity for Type C PGMs	Maximum capacity for Type D PGMs
Continental Europe	1 MW	50 MW	75 MW
Great Britain	1 MW	50 MW	75 MW
Nordic	1.5 MW	10 MW	30 MW
Ireland and Northern Ireland	0.1 MW	5 MW	10 MW
Baltic	0.5 MW	10 MW	15 MW

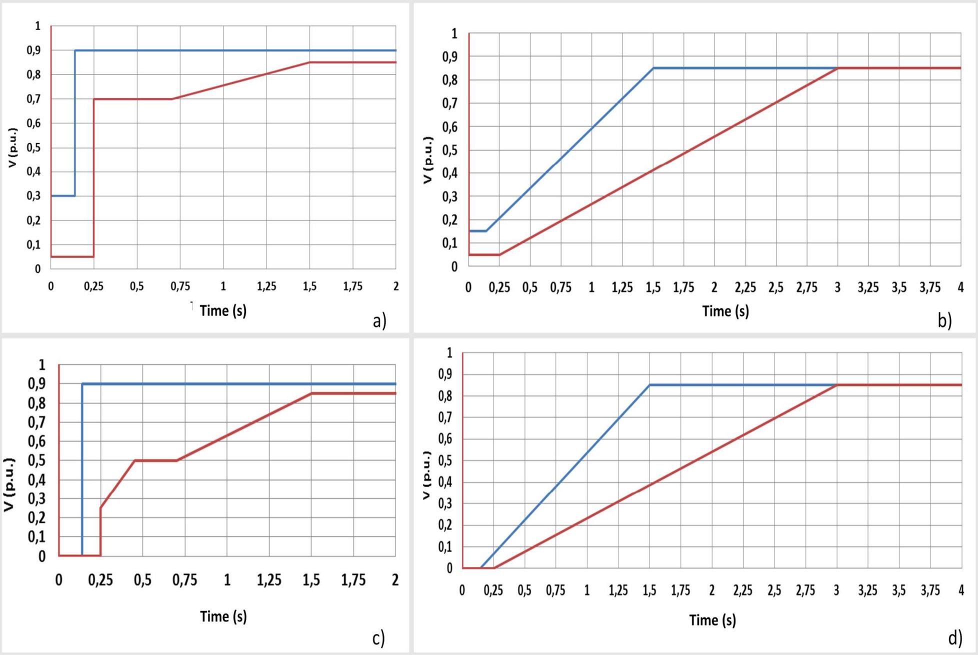
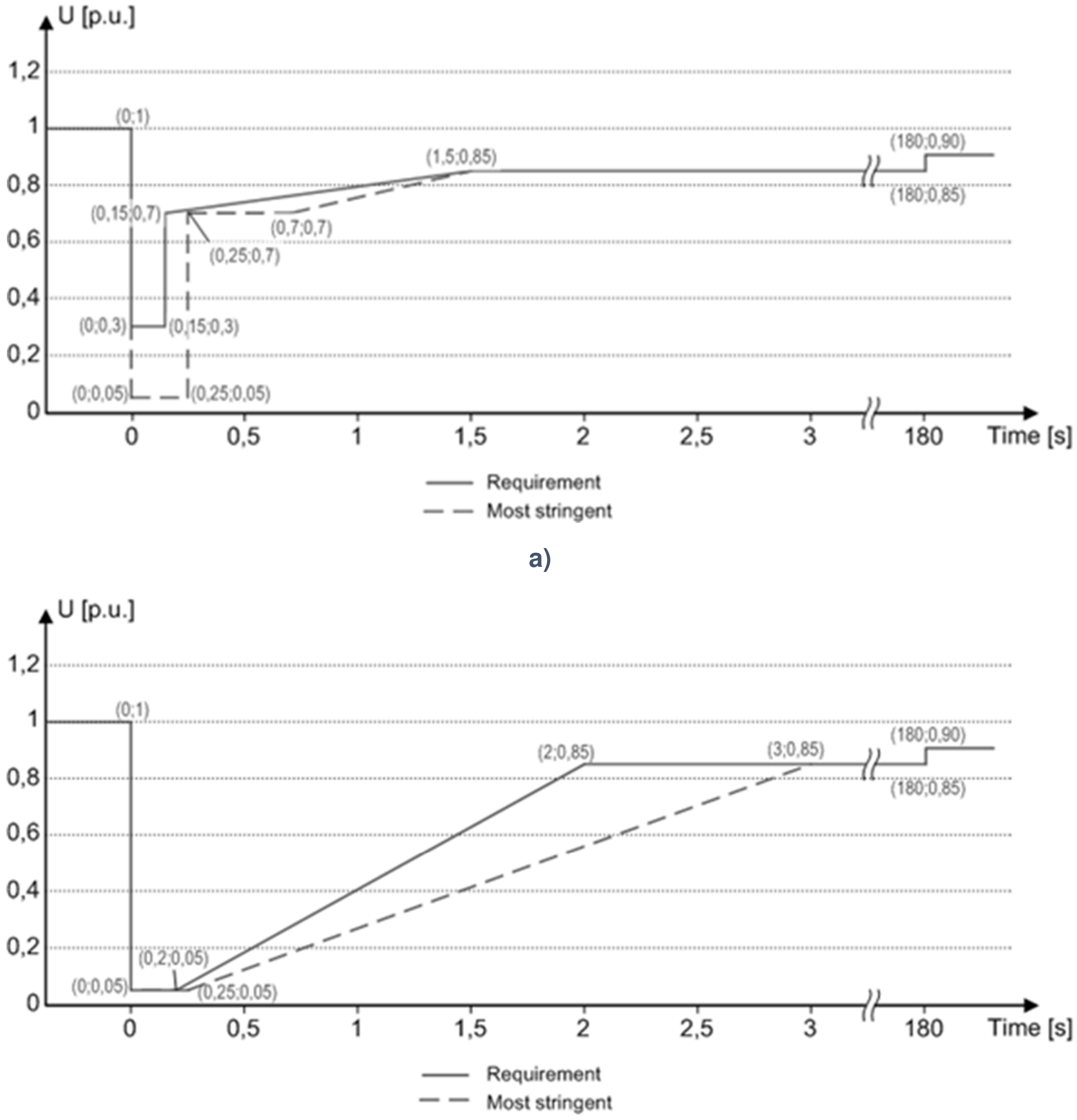


Figure 16: Summary of LVRT capabilities minimum (blue) and maximum (red) that has to be withstood by the PGMs in the ENTSO-e NC RfG. a) curves for type B and type C SPGMs; b) Type B and Type C PPMs; c) Type D SPGMs; d) Type D PPMs.

In CLC/TS 50549-2, there are also LVRT profiles defined for the synchronous and converter-coupled generation, as shown in Figure 17. For voltage swells HVRT requirements force the generators to remain connected if the voltage level goes up to 120% during 100 ms and to 115% during 1 s.



a)

b)

Figure 17: Summary of LVRT capabilities that has to be withstood by the generating plants according to CLC/TS 50549-2. a) Synchronous generation. b) Converter-coupled generation.

In case of a disturbance, when the PPVC corrective mode entries into operation, the units must be able to supply additional reactive power up to their maximum. At minimum the provision of the reactive power must be done according to Figure 18. The gradient of the curve k must be adjusted between 0 and 10 for both the positive and negative voltage sequences. The additional reactive current step response time shall be no greater than 30 ms.

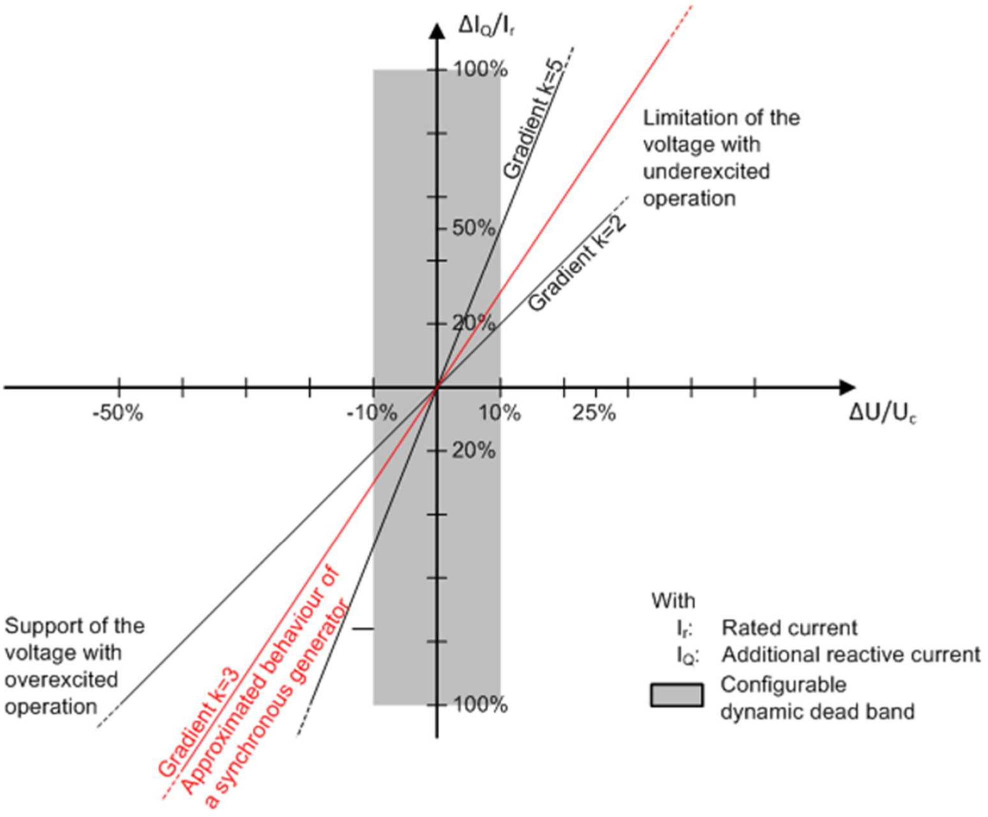


Figure 18: Reactive power supply dynamic capability required for the generation.

CLC/TS 50549-1 applies to the generation up to 16 A connected to LV. The LVRT requirements, only required for PV plants in this version of the regulation (even the code sets out the possibility to further extend it to the other technologies) are the same in CLC/TS 50549-2 for converter-coupled generators. The HVRT capabilities and the reactive power supply capabilities in dynamic mode are required for all the generators, also with equal limits/timings to the ones in CLC/TS 50549-2. Minor differences, out of the interest of this work appear in the ratio between Q/P supplied as a function of the voltage deviation. The small generators connected to the LV grids with a rated current below 16 A are not subject to LVRT requirements, because their impact over the global system is negligible and thus, they usually disconnect when the voltage in the terminals go below a certain limit.

3.2.2 Post-Primary Voltage Control

The PPVC has the commitment to restore the voltages in the nodes of the cells to the optimal set-points and keep the voltage within the safe bands that are defined by the regulations. The PPVC will be operating over two types of nodes: nodes with continuous voltage control (synchronous generators, inverter-coupled generators, etc.), and nodes with discrete voltage control (status/position of transformers with on-load tap changers -OLTC-, capacitor banks, shifting transformers or interruptible loads). The optimization objective is the minimization of the power losses in the systems. There are many aspects gathered in the regulations that directly impact the PPVC strategy, as defined in the ELECTRA context:

- Voltage bands that define the steady-state system operation;
- Allowable timings to withstand out of voltage bands events, depending on the voltage level

itself;
- Reactive power capabilities of the available DERs;
- Reactive power provision character: compulsory vs. non-compulsory obligations;
- Power factor to be kept by the installations in the point of common coupling;
- Definition of controller parameters: dead-bands, droops, limits, etc.

The regulatory voltage safe bands define the limits for the triggering of the corrective PPVC mode. These bands in the ENTSO-e RfG Network Code are different depending on the synchronous area, the type of PGM (ABCD or if it is an offshore PPM) and the voltage level. Table 14 shows the voltage bands defined for Type D PGMs connected at voltage levels between 110 kV and 400 kV. Additional requirements can be requested by the Spanish TSO due to the specific characteristic of the Spanish power system that is weakly linked to the rest of the European power grid. For the Baltic system, the PGMs may be required to keep connected at 400 kV with the bands limits and timings defined for the Continental Europe synchronous area. Additional requirements are also requested for offshore PPMs connected at 300 kV or 400 kV, as shown in Table 15, where the values in p.u. are calculated for the rated voltages. It should be highlighted that PPMs are required to behave/respond in the case of undervoltages in the same manner as is required for the synchronous generation in most of the synchronous areas (with the exception of Ireland, where the PPMs must cope with overvoltages higher than those for synchronous generation). Wider voltage ranges or longer time periods, as well as the possibility of automatic disconnection can be agreed between the TSO and the owners of the facilities.

Table 14: Voltage bands defined in the ENTSO-E grid code for Type D PGMs.

	110 kV – 300 kV		300 kV – 400 kV	
	Voltage range	**Time period for operation**	**Voltage range**	**Time period for operation**
Continental Europe	0.85 p.u. – 0.9 p.u.	60 min	0.85 p.u. – 0.9 p.u.	60 min
	0.9 p.u. – 1.118 p.u.	Unlimited	0.9 p.u. – 1.05 p.u.	Unlimited
	1.118 p.u. – 1.15 p.u.	Not less than 20 min and not more than 60 min	1.05 p.u. – 1.10 p.u.	Not less than 20 min and not more than 60 min
	Spain: 1.05 p.u. – 1.0875 p,u.	Unlimited	Spain: 1.05 p.u. – 1.0875 p,u.	Unlimited
Great Britain	0.9 p.u. – 1.10 p.u.	Unlimited	0.9 p.u. – 1.05 p.u.	Unlimited
			1.05 p.u. – 1.10 p.u.	15 min

Nordic	0.9 p.u. – 1.05 p.u.	Unlimited	0.9 p.u. – 1.05 p.u.	Unlimited
	1.05 p.u. – 1.10 p.u.	60 min	1.05 p.u. – 1.10 p.u.	Not more than 60 min
Ireland/Northern Ireland	0.9 p.u. – 1.118 p.u.	Unlimited	0.9 p.u. – 1.05 p.u.	Unlimited
Baltic	0.85 p.u. - 0.9 p.u.	30 min	0.88 p.u. – 0.9 p.u.	20 min
	0.9 p.u. – 1.118 p.u.	Unlimited	0.9 p.u. – 1.097 p.u.	Unlimited
	1.118 p.u. – 1.15 p.u.	20 min	1.097 p.u. – 1.15 p.u.	20 min

Table 15: Voltage bands defined in the ENTSO-E grid code for offshore PPMs.

	300 kV		**400 kV**	
	Voltage range	**Time period for operation**	**Voltage range**	**Time period for operation**
Continental Europe	0.85 p.u. – 0.9 p.u.	60 min	0.85 p.u. – 0.9 p.u.	60 min
	0.9 p.u. – 1.118 p.u.	Unlimited	0.9 p.u. – 1.05 p.u.	Unlimited
	1.118 p.u. – 1.15 p.u.	Not less than 20 min and not more than 60 min	1.05 p.u. – 1.10 p.u.	Not less than 20 min and not more than 60 min
Great Britain	0.9 p.u. – 1.10 p.u.	Unlimited	0.9 p.u. – 1.05 p.u.	Unlimited
			1.05 p.u. – 1.10 p.u.	15 min
Nordic	0.9 p.u. – 1.05 p.u.	Unlimited	0.9 p.u. – 1.05 p.u.	Unlimited

	1.05 p.u. – 1.10 p.u.	60 min	1.05 p.u. – 1.10 p.u.	Not more than 60 min
Ireland/Northern Ireland	0.9 p.u. – 1.10 p.u.	Unlimited	0.9 p.u. – 1.10 p.u.	Unlimited
Baltic	0.85 p.u. – 0.9 p.u.	30 min	0.88 p.u. – 0.9 p.u.	20 min
	0.9 p.u. – 1.118 p.u.	Unlimited	0.9 p.u. – 1.097 p.u.	Unlimited
	1.118 p.u. – 1.15 p.u.	20 min	1.097 p.u. – 1.15 p.u.	20 min

Without prejudice to the foregoing, there are additional requirements for Type B, Type C and Type D SPGMs, concerning to their dynamic behaviour. Even though they are not directly dependent on the PPVC, they have impact on the voltage control strategy, since they define the characteristics of the controllers that must act in case of the corrective operation to recover voltage levels after disturbances. Type B SPGMs must be equipped with a permanent AVR that allows the generator to provide the reactive requested by the relevant TSO. Also, considering application of the general voltage bands defined for the PGMs, additional requirements are defined for Type C PPMs concerning voltage control capabilities. Type C PPMs must have the capacity to supply extra reactive power in the connection point to compensate the voltage drop in the HV line. They must also fulfill compliance with a U-Q/Pmax curve agreed with the relevant TSO, similar to the one required for SPGMs, where the capacity to supply reactive power must be at the maximum (see Figure 19). However, in the case of PPMs, if the reactive power capability is below the maximum, it is also necessary to agree a P-Q/Pmáx curve between the facility owner and the relevant TSO. Even if the active power injected is at maximum, the PPM must still have capacity to supply more than 50% of that maximum active power value as reactive power to contribute to the voltage restoration in the PPVC corrective mode.

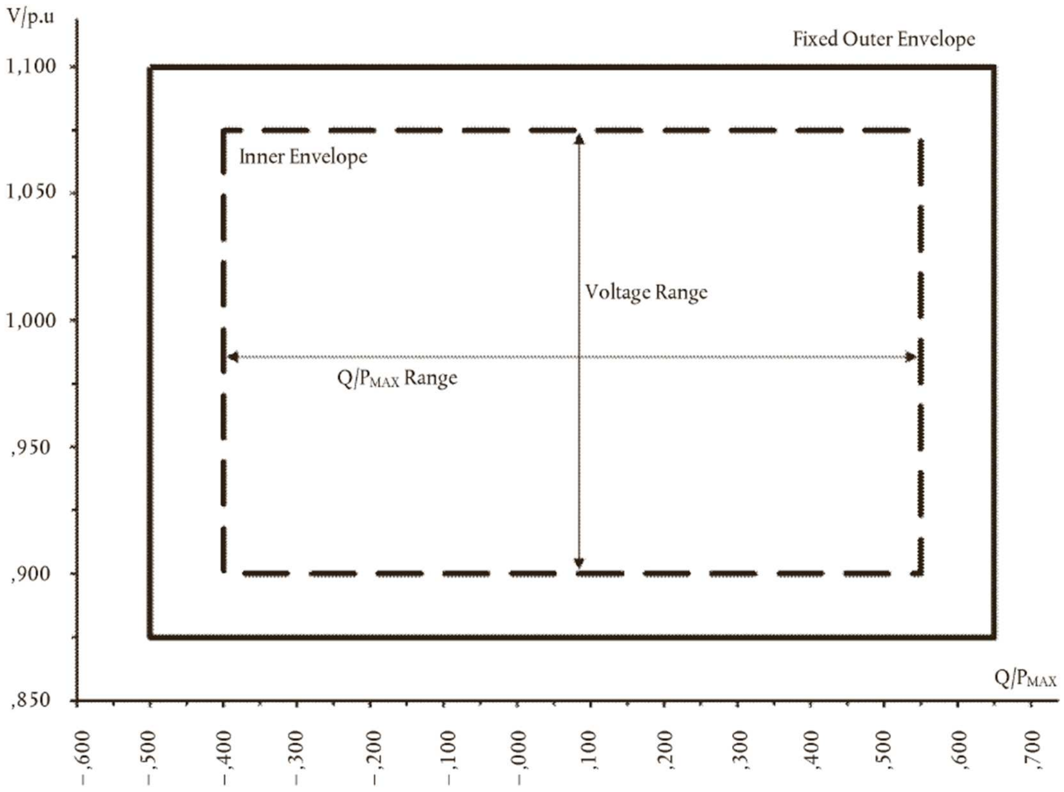


Figure 19: U-Q/Pmax boundaries for SPGMs [16]

CLC/TS 50549-2 is of application for each generating plant type. The default voltage band that defines the normal operation of the system is defined between 0.9 p.u. and 1.1 p.u., where all the equipment must remain connected continuously. This band must be adjusted up to 0.8 p.u. and 1.2 p.u. Concerning the reactive power provision capabilities requested for the generation groups, during normal operation conditions where the generators are injecting or absorbing the maximum rated active power (Pmax), there is the necessity to guarantee the possibility to supply/absorb Q=±0.484 Pmax. For operation outwith the normal safe band, there is no obligation to fulfill these injection/absorption conditions even where the generators should help to the system restoration as much as their technical capabilities allow them. Additional requirements, such as continuous VAR compensation could be provided by the generation facility in agreement with the DSO. Each generation plant must be able to operate in 6 different control modes:

- Fixed Q;
- Q(U);
- Q(P);
- Fixed power factor (cosphi);
- Cosphi (U);
- Cosphi (P).

Generating units connected to the grid through converters shall have the capability to reduce their current as fast as technically feasible down to or below 10% of the rated current when the voltage is outside of the steady-state voltage range. According to CLC/TS 50549-1, applicable to generators connected at LV grids up to 16 A, the voltage safe band that define the normal operation state for the PPVC is settled between 0.85 p.u. and 1.10 p.u. The other requirements that could potentially impact the PPVC deployment are equal to those in CLC/TS 50549-2.

Lastly, EN 50438 gathers the requirements for the connection of microgenerators to LV grids, up to 16 A. The normal operating voltage band for this standard settle the limits between 0.85 and 1.1 p.u. For the converter-coupled generators, the DSO establishes a curve for the reactive power provision of the generators, with power factors that vary from 0.9 underexcited to 0.9 overexcited, as long as the active power injected surpasses 20%. If the active power is below 20%, the reactive power should not be higher than 10% of the nominal active power. If the generator is directly coupled to the grid, the power factor must be always higher to 0.95 if the active power is over 20%. Otherwise, the requisite is the same that for the converter-coupled groups. Three control modes must be guaranteed:

- Q(U);
- Fixed power factor (cosphi);
- Cosphi (P).

In the case of a voltage increase in the grid, and in order to avoid the tripping of the voltage protections, the generators are allowed to reduce their active power supply in accordance with the manufacturers' settings.

4. Definition of adapted legal frameworks for the Web-of-Cells development

In this section, modifications in current roles and responsibilities - as well as the possible extensions and/or amendments in the regulatory framework - which can enable the WoC development, are discussed. Today, roles and responsibilities in the power system are well defined, and they are implemented in very different ways both across Europe and in a centralistic manner. On the other hand, it is expected that, due to the forthcoming changes, the future frequency and voltage control can no longer be effectively managed in a TSO-centric manner. Under the WoC concept, each CSO is responsible for establishing and maintaining automatic control mechanisms as well as procuring sufficient reserves (i.e. assuming responsibility similar to former TSO responsibility in its Control Area), thereby contributing to stability and security of system operation. In such a decentralized paradigm, local problems are solved within the cell where local observables are used to take decisions on local corrections, i.e., localization and local responsibilization. This decentralized frequency and voltage control implies a change in current roles and responsibilities as well as in regulatory framework.

Based on this premise, the needed changes in current roles and responsibilities, as well as the proposed extensions and/or amendments in the regulatory framework, including Network Codes, are discussed in the following.

4.1 Roles and responsibilities for the Web-of-Cells architecture

In this subsection, CSO roles and responsibilities are analyzed in order to identify regulatory barriers and to define the needed changes for the WoC concept. To achieve this goal, responsibilities are splitted over multiple roles, with reference to the different phases belonging to the timeline of Balancing Procedure in the WoC concept shown in Figure 20 [1], i.e.:

- Pre-T0 ("time of delivery") phase;
- After-T0 (real-time control phase).

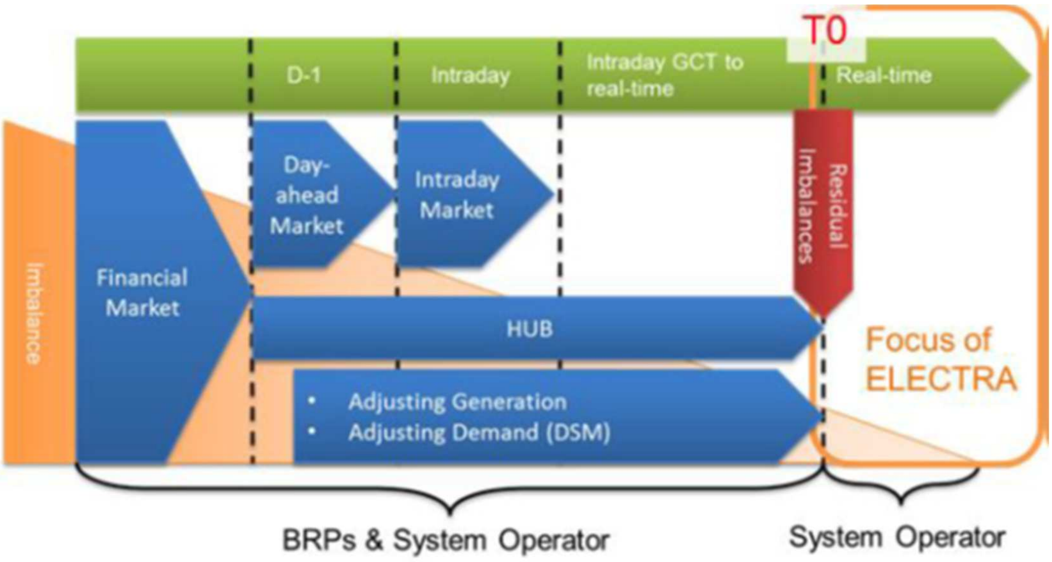


Figure 20: Timeline of Balancing Procedure in the Web-of-Cells concept [1]

More general aspects are also addressed, such as settlement of activations, and information distribution by the CSOs.

4.1.1 Roles and responsibilities in procurement phase

The responsibilities identified in the procurement phase (pre-T0 phase) with the related roles in the WoC are shown in Table 16, whereas the details are discussed in the following.

Table 16: Responsibilities and roles in the Web-of-Cells in pre-T0 phase

Responsibility in the WoC	Key role in the WoC	Other roles needed for the WoC
Provision of generation/load forecast information for cell balance set-points	Allocated under the responsibility of CSOs (current TSOs/DSOs)	Generation/load forecasts are made by entities, such as the large-scale BRPs, receiving all necessary information from their large-scale generating and load units, and the aggregators, who collect all necessary information from the small-scale BRPs who themselves are supplied with data by small-scale generating and load units
Provision of information on cell tie-line constraints	Allocated under the responsibility of CSOs with some specific requirements (current TSOs/DSOs)	-
Procurement of flexibilities for the next time-step	Allocated under the responsibility of CSOs (current TSOs/DSOs). Requirements for the procurement of balancing services (guidelines on electricity balancing) could be tailored to the WoC concept with some adaptations	-
Collection of grid model and grid status information	Allocated under the responsibility of CSOs (current TSOs/DSOs) with specific tasks	The process of metering itself as well as the roles involved for doing it could follow different approaches, where there are three main options: (1) the metering infrastructure is directly managed by the CSO, who is also the responsible for collecting the data itself and sending it to the market via a data hub; (2) to dump the data to a

		centralized data hub, owned by any other party different than the CSO - in this case, the role of Meter Data Responsible party is accomplished by other actor different from the CSO itself, such as a supplier or an aggregator; (3) the provision of data via an independent and certified body who provides data access to any market player.
Combination of grid model/status and generation/load forecast information	Allocated under the responsibility of CSOs (current TSOs/DSOs) with specific tasks	BSP as the party responsible of providing the balancing and voltage control reserves, can be acted by an aggregator
Decision on PVC, PPVC and CPFC (for aFCC) settings for the next time-step	Allocated under the responsibility of CSOs (current TSOs/DSOs) with specific tasks	-

Provision of generation/load forecast information for cell balance set-points

With reference to Regulation No 543/2013 on submission and publication of data in electricity markets [37], for their control areas, the TSOs calculate day-ahead, week-ahead, month-ahead and year-ahead forecasts of total load, estimate of the total scheduled generation (MW) and forecast wind and solar power generation (MW) per bidding zone, per each market time unit of the following day. Generation units and DSOs located within a TSO's control area provide that TSO with all the relevant information required to calculate the load and generation forecasts. The proposed timing of load and generation forecasts provision is determined in the Regulation No 543/2013.

In the WoC architecture, the provision of generation/load forecast information for the Cell balance set-points - MODs - is under the responsibility of the CSO (TSO/DSO). However, generation/load forecasts are made by entities, such as the large-scale BRPs, receiving all necessary information from their large-scale generating and load units, and the aggregator, who collects all necessary information for this task from the small-scale BRPs who themselves are supplied with data by small-scale generating and load units (Figure 21).

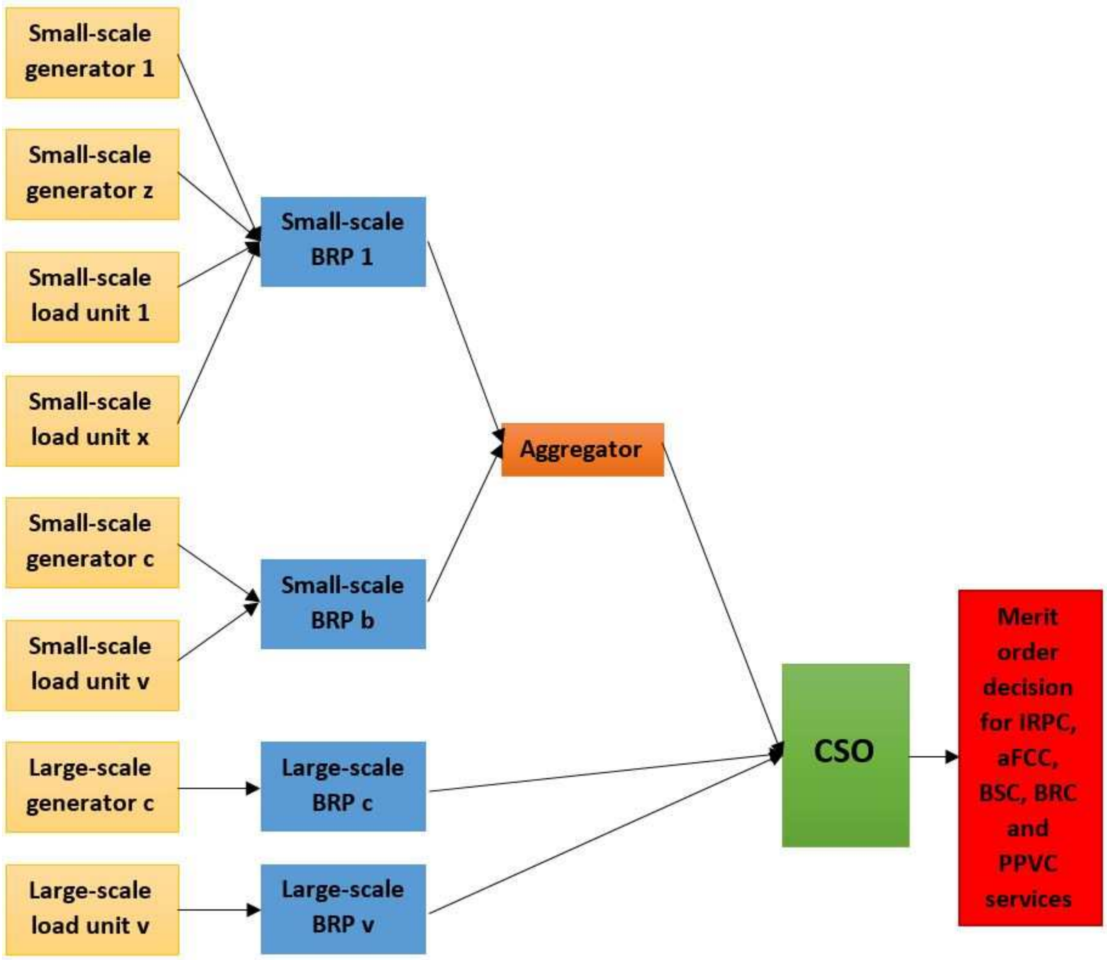


Figure 21: The proposed actors of load / generation forecaster within the Web-of-Cells architecture

Although the large scale BRPs and the aggregator are capable to prepare generation and load forecasts for long-, medium- and short-term (as required by the Regulation No 543/2013), for setting the MODs for balancing and voltage control products, short-term load and generation forecasts are of high importance, therefore are considered within the WoC architecture. Specifically, the large-scale BRPs and the aggregator supply load and generation forecasts to the CSO who uses them for determination of the optimal volume of capacity for inertia, inertia, balancing capacity, balancing energy and reactive power, and for setting prices. The following types of load and generation forecasts are requested for setting the MOD:

- A day-ahead forecast of total load and generation per market time unit, which is one hour consisting of four quarter-hours (4*15 minutes). Total load and generation forecasts are provided between the gate opening and closure times of the sub-market for inertia (IRPC service) and is updated when significant changes occur. The forecasts are used for determination of the required volume of inertia, balancing capacity and reactive power.
- An improved day-ahead forecast of total load and generation per market time unit, which is one hour consisting of four quarter-hours (4*15 minutes). An improved total load and generation forecast is provided between the gate opening and closure times of the sub-market for balancing energy of balancing products and is updated when significant changes occur. The forecasts are used for determining the volume of balancing energy.
- A forecast of wind and solar power generation (MW) per Cell, per each market time unit of the following day. Presently, information is published one day before actual delivery takes

place. The information is regularly updated and published during intra-day trading with at least one update published on the day of actual delivery. In future, information shall be provided twice for a particular market time unit, i.e. between the gate opening and closure times of the sub-market for inertia and sub-market for balancing energy, and shall be updated when significant changes shall occur.

Load and generation forecasts shall be made 48 times a day based on a rolling schedule, i.e. load and generation forecasts for the market time unit $t+1$ shall be provided by the CSO at time $t+1-n$ and $t+1-m$, and for the market time unit $t+k$, at $t+k-n$ *and* $t+k-m$, where n and m are chosen to provide forecasts close to real time with $n>m$.

These roles and mechanisms are further discussed in Deliverable D3.2 [7].

Provision of information on cell tie-line constraints

In the WoC architecture, the CSO is responsible for management of grid model information. Under the Network Code on Operational Security (NCOS) [26] there is an obligation among TSOs and DSOs to communicate ‘without undue delay’ any changes in protection settings, thermal limits and technical capacities at the interconnectors between their responsibility areas. Neighbouring TSOs are required to exchange structural information regarding transmission lines between areas, and real-time information on power exchange over virtual and real tie-lines. Transmission connected DSOs shall similar be entitled to gather relevant structural, scheduled and real-time information from neighbouring DSOs. Hence, the necessary information exchange mechanisms previously established to ensure operational security can be mapped directly across to the CSO case, whereby each CSO is required to mutually exchange and agree both structural and real-time information about the status and protection limitations of any tie-lines between cells.

If the tie-line is not owned by a TSO or DSO, such as in the case of a merchant HVDC Interconnector, then the same reporting responsibilities (both structural and real-time) should be carried over to the owner/operator of the tie-line.

The NCOS also requires neighbouring TSOs and DSOs to ‘exchange operational experiences’ and to perform joint operational testing – these same requirements should be mapped across to CSOs.

In total, this requires CSOs to:

a) Maintain, via mutual exchange of structural data between connected CSOs, a consistent view of tie-line capacities and protection restrictions;
b) Mutually exchange real-time information between connected CSOs including data which may cause time-variance of the tie-line capacities;
c) To cross-check that the exchange leads to a consistent view of capacities by CSOs on either end of a tie-line;
d) Institute the same mechanisms with any non-CSO transmission owner.

Procurement of flexibilities for the next time-step

In the WoC architecture, the CSO will be responsible for the procurement of balancing and voltage control services. These are capacity for inertia, balancing capacity and balancing energy for upward and downward regulation, and reactive power.

The European practice demonstrates a great variety of procurement schemes for balancing and voltage control services [38], but there is no valid Regulation dealing with the issue of procurement of services.

Under the Commission Regulation (2017) establishing guidelines on electricity balancing, each TSO shall be responsible for procuring balancing services from balancing service providers (BSPs) to ensure operational security and each DSO shall provide, in due time, all necessary information to perform the imbalance settlement to the connecting TSO. All TSOs will have an obligation to prepare a proposal regarding establishment of the European platform for the exchange of balancing energy from replacement reserves, frequency restoration reserves with manual and automatic activation, and imbalance netting processes based on common governance principles and business processes. This European platform shall apply a multilateral TSO-TSO model with common merit order lists to share and exchange all balancing energy bids from all standard products. Each TSO shall use cost-effective balancing energy bids available for delivery in its control area based on common merit order lists. Also, each TSO shall define the rules for the procurement of balancing capacity following the principles that the procurement method is market-based for (at least) the frequency restoration reserves and replacement reserves; the procurement process is performed close to real time; the contracted volume can be divided into several contracting periods, and the procurement of upward and downward balancing capacity for (at least) the frequency restoration reserves and the replacement reserves is carried out separately. Moreover, two or more TSOs can develop a proposal for the establishment of common and harmonized rules regarding exchange of balancing capacity.

The requirements for the procurement of balancing services determined in the guidelines on electricity balancing could be tailored to the WoC concept with some adaptations. Firstly, it is the CSO (TSO/DSO) who is responsible for the procurement of flexibilities. Secondly, to assure economic efficiency and transparency of the procurement process, a common platform for the exchange of balancing energy and balancing capacity for upward and downward regulation for all types of balancing services and inertia shall be established. Each CSO shall procure balancing services via the centralized marketplace (exchange, where harmonized trading rules are applied), which is a common platform (i.e. is developed at the WoC architecture level) and which employs an auction as a mechanism for efficient allocation of resources and efficient pricing of balancing services. The CSO shall organize auctions for balancing services on daily basis one day ahead from real time, and the auction shall be cleared based on price of bids submitted by the BSPs to the capacity markets open separately for each cell by the corresponding CSO. The market clearing price (MCP), which is a single price for all the local (cell) BSPs, shall be established. In case of trading the BSC service (inter-cell trade), auction is organized for all CSOs and BSPs using this platform. The cascading procurement principle shall be used. The CSO will remunerate BSPs for availability of capacity for inertia, balancing capacity and their utilization based on the MCP. Thirdly, via the exchange standardized balancing services are traded in a sequential manner. Fourthly, procurement process is non-discriminating (it is technology- and fuel- neutral), but creating a level playing field for all technologies.

Voltage control is a mandatory service in many European countries subject to certain technical parameters (for instance, volume of installed capacity or transmission level). Thus, it is provided by generators, industrial consumers, DSOs and others to the TSOs for free (Germany) or, is contracted and paid at the regulated price (Lithuania, Ireland, Norway or Estonia) or via pay-as-bid (Poland, G. Britain, Belgium, the Netherlands). The WoC concept assumes that at the WoC level the CSOs shall establish a common platform - centralized marketplace, which is an auction-based exchange, to procure voltage control services. However, each CSO will organize procurement of voltage control services for its Cell only from local BSPs. Voltage control services shall be paid by the CSO at MCP. Procurement contracts shall be short-term to better reflect market conditions in the price and do not lock from new entries.

Collection of grid model and grid status information

In the WoC, the CSO will be the responsible for the collection of data regarding the grid model information, as currently fulfilled nowadays by TSOs/DSOs. The CSO will be also the in charge of applying the market clearing algorithm with the network model for the procurement of frequency/balance and voltage reserves. This network model must be selected by the CSO by finding a tradeoff between minimum accuracy required to detect the balancing and voltage congestion issues and the data complexity that can be managed by the algorithms. The grid model includes the grid topology and components' parameters but also many other metrics such as the number of customers per feeder, the capacity of substation per consumer, etc. This grid model is later combined with the measurements registered by the metering infrastructure to evaluate the grid status. These measurements needed for estimating the grid status and, consequently, for the market algorithms within the WoC are going to be more easily and widely registered in in the 2035+ horizon due to the massive roll out of advanced smart metering infrastructure in LV distribution networks [39].

However, the process of metering itself as well as the roles involved for doing it could follow different approaches, where there are three main options according to the literature [36]: (1) the metering infrastructure is directly managed by the CSO, who is also the responsible for collecting the data itself and sending it to the market via a data hub; (2) to dump the data to a centralized data hub, owned by any other party different than the CSO - in this case, the role of Meter Data Responsible party is accomplished by other actor different from the CSO itself, such as a supplier or an aggregator; and (3) the provision of data via an independent and certified body who provides data access to any market player. The prevalence of any model over the other will be linked to the market design of the WoC as well as the associated incentives. Presently, the Meter Data Responsible party is the owner of the measurement device who has the responsibility on the installation, maintenance and operation of the measurement equipment.

Combination of grid model/status and generation/load forecast information for the merit order list

The function for collecting data on the grid model information as well as on generation/load forecast is currently done by TSOs/DSOs. In the WoC architecture, the merit order of the procured reserves is a function indicating which reserves will be activated at a certain measured imbalance. This list is set up based on costs of the reserves activation [40]. The cell system state or a prediction of the cell system state can also be taken into account in order to avoid grid congestion issues in case of reserves activation. Moreover, the merit order could also include other objectives such as maximal reliability and efficiency. The observables or inputs for this controller are the cell system state as well as the reserve capacity bids which were previously sent by the BSPs to the CSO. Bids indicate the volume that is available for balance reserve, as well as the related activation price. The output of this function is a merit order list of reserves to be activated (which on and how much and/or according to what profile). As for timing, the merit order should be available at least 15 minutes before the possible activation time (T0). The function is performed by the CSO, which can be the TSO or DSO CSO. In such a context, the BSP is a party responsible of providing restoration reserves, which can be a load, production or storage unit. Therefore, a BSP may group or aggregate a combination of different units to provide reserves. In such a context, aggregators, in their role of aggregating the flexibility from a portfolio of DERs, can act as BSPs.

Decision on PVC, PPVC and CPFC settings for the next time-step

For the accomplishment of the calculation of PPVC (proactive mode) and PVC set-points, the CSO has retrieved the information from the forecasting system, also under the responsibility of the CSO.

This includes the load and generation forecast profiles for the window of interest together with the information given by the reserves providers (DERs owners, aggregators, etc.) concerning the available capabilities for the provision of reactive power on the next period, as well as the allocation of the resources (of major importance in the case of voltage control). The CSO, for its part, has collected the knowledge concerning the grid topology and the grid status. With all this information, the CSO, before T0, calculates the optimal voltage set-points for the subsequent operation window (15 min) with a sampling time of 1 min (forecast sampling time). The information must be available to the CSO sufficiently in advance to allow time to perform the calculation. The CSO is also responsible for establishing the procedures for the exchange information with the PPVC participants as well as the characteristics of the exchanges itself. The PPVC sends the set-points to the PVC devices and adjust them in case of disturbances for a proper action on voltage control at a local level.

The determination of the CPFC in the aFCC control mechanisms also relies on the CSO. For that purpose, the CSO estimates the imbalance location based on the received voltage and frequency measurements. The fuzzy-logic CPFC controller calculates the CPFC settings for the next time-step. The CPFC ratio (between 0 and 1) that comes out from the controller is used as input for any of the DERs in the cells, which then adjust their droops automatically by multiplying the droops by the CPFC value for the next time step.

4.1.2 Roles and responsibilities in real-time control phase

The responsibilities identified in the real-time operation phase with the related roles in the WoC are shown in Table 17, whereas the details are discussed in the following.

Table 17: Responsibilities and roles in the Web-of-Cells in real-time control phase

Responsibility in the WoC	Key role in the WoC
Detecting the need of a balancing control service + Activation	Allocated under the responsibility of CSOs (current TSOs) based on the cell imbalance observation and event location
Detecting need of a corrective PPVC service + Activation	Allocated under responsibility of CSOs based on the measurements from the metering devices
Decision on adaptation of cell tie-line set-points + Doing it	Allocated under the responsibility of CSOs. Neighbouring CSOs require a coordinated decision process whereby the optimal tie-line set-point is determined independently and confirmed between CSOs via the ‘Cell Set-point Adjusting Function’ based on information previously exchanged.

Detecting the need of a balancing control service and Activation

In the WoC, the CSO is responsible for contributing to containing and restoring system frequency through real-time reserve activation and dispatch in its own cell. This responsibility is currently enacted by each TSO in its Control Area. In detail, the BRC continuously observes the state of the cell. When a cell power imbalance occurs, the control evaluates, if it depends on an internal or external cell event and issues this information to the aFCC. Furthermore, the BRC sends a signal to modify the active power of the cell resources. Based on the obtained information and its internal control logic, the aFCC determines the frequency response for each cell resource. The resource activation depends on the location of the instability event. Therefore, BRC and aFCC employ a synergistic approach, at the same timescale, in order to ensure the WoC stability.

During the real-time control phase, the main element defining the need of a balancing control service activation is the cell imbalance observation and event location, which is under the responsibility of the CSO. Activation commands then achieve the imbalance correction as well as the adaptive CPFC determination.

Detecting need of a corrective PPVC service and Activation

The CSO is responsible for maintaining the voltage levels within the safe bands defined by the Regulations as well as ensuring the required reactive reserves to deal with the voltage deviations. Aligned with this, the CSO receives the measurements from the metering devices, compares them with the safe-band voltages mandatory by regulation, and detects the need for corrective actions. The activation commands are directly sent to the devices or to the aggregators downstream.

Decision on adaptation of cell tie-line set-points and Doing it

Neighbouring CSOs require a coordinated decision process whereby the optimal tie-line set-point is determined independently and confirmed between CSOs via the 'Cell Set-point Adjusting Function' based on information previously exchanged. As with the activation of e.g. PPVC and Balancing Control described above, the actual change in tie-line set-point is achieved via activation commands directly imposed upon downstream devices and aggregators. Under the WoC architecture, no third-party actor is required.

4.1.3 Roles and responsibilities with reference to general aspects related to the WoC

The responsibilities identified for general aspects related to the WoC with the related roles are shown in Table 18, whereas the details are discussed in the following.

Table 18: Responsibilities and roles for general aspects related to the Web-of-Cells

Responsibility in the WoC	Key role in the WoC	Other roles needed for the WoC
Settlement of activation	Allocable under responsibility of a third-party organization with a specific regulatory licence to conduct the settlement process, and to take on the responsibilities for measurement and calculation of activations, cross-checking of records with CSOs, and dispute resolution.	Specific settlement calculations shall be subject to design and approval by the NRAs and transparent to all participants.

Information distribution by the CSOs	The CSOs should provide specific information to market participants via a specific platform to improve transparency in information distribution. New regulatory rules are required.	-

Settlement of activations

Within the NC EB, TSOs are allowed to delegate some or all of the functions assigned to them to one or more third parties, and this may be encouraged in order to ensure the financial neutrality required by the settlement process overseen by National Regulatory Authorities (NRAs). Within the WoC architecture, it may be desirable for a third party organisation with a specific regulatory licence to conduct the settlement process, and to take on the responsibilities for measurement and calculation of activations, cross-checking of records with CSOs, and dispute resolution. The specific settlement calculations shall be subject to design and approval by the NRAs and transparent to all participants.

Information distribution by the Cell System Operators

Transparency is a core principle of a well-functioning market. It is essential for the implementation of the internal market for electricity and for the creation of efficient, liquid and competitive market for balancing and voltage control services. Transparency refers to the conditions, subject to which market participants possess complete information on the nature of the transaction and where available information is symmetrically concentrated on the CSO and balancing and voltage control service providers. Recognizing that the presence of information asymmetries[3] between the market participants (i.e., unfair distribution of available market information among actors) could be the source of large economic inefficiencies, the issue of a so-called “Transparency Platform for Balancing and Voltage Control Services Market Information” (TPlat) should be addressed within the WoC concept. The equivalent of such a type of platform already exists: the Transparency Platform for Electricity Market Information (TPEMI). The TPlat should be developed as an expanded version and integral part of the TPEMI. The CSOs should at least provide the following information to market participants via the TPlat:

- Rules on balancing and information sharing;
- Accepted offers and activated balancing capacity per each balancing service, cell, market time unit; type of BSP (traditional generators, RES, storage, demand response, etc):
    - Offered volume, MW;
    - Accepted volume, MW;
    - Activated volume, MWh;
    - Price of activated volume, EUR/MWh.
- Volume of contracted balancing capacity per each balancing service, cell, market time unit, contract type (quarter-hourly) and source of balancing capacity (generation, load);
- Price of reserved balancing capacity per each balancing service, cell, market time unit and contract type;
- Imbalance price per cell, EUR/MWh;

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[3] Asymmetric information, also known as information failure, occurs when one party to an economic transaction possesses greater material knowledge than the other party. This normally manifests when the seller of a good or service has greater knowledge than the buyer, although the reverse is possible. Almost all economic transactions involve information asymmetries [https://www.investopedia.com/terms/a/asymmetricinformation.asp].

- Cross-Cell balancing:
    - Aggregated offers, MW;
    - Activated offers, MW;
    - Min price, EUR/MWh;
    - Max price, EUR/MWh.
- Contracted and used volume of reactive power per each cell, market time unit, source of reactive power;
- Price of used reactive power:
    - Min price;
    - Max price.
- Financial expenditures and income per market time unit and cell.

4.2 Proposal of possible extensions and amendments in the regulatory framework including Network Codes

4.2.1 Frequency control

In the framework of frequency control, the proposed extensions and/or amendments in the regulatory framework needed to support/promote the related ELECTRA Use Cases are summarized in Table 19.

Table 19: Proposes extensions/amendments in the regulatory framework for the ELECTRA Use Cases for frequency control

ELECTRA Use Case	Proposed extensions/amendments in the regulatory framework
IRPC	Currently, the IRPC is not regulated. It is necessary to establish: ● Dimensioning rules; ● Procurement rules; ● Activation rules; ● Monitoring rules.
aFCC+BRC	● Amendment to Article 153 (FCR dimensioning) of COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation [41]: new reference incidents must be necessarily defined at cell level and dimensioning rules need to be applied at cell level under the responsibility of the CSO. (Valid for aFCC) ● Amendment to Art. 156 (7-8) (FCR provision) [41]: in the WoC architecture, there is no a 2-phased approach as done today (containment followed by restoration). Conversely, the aFCC + BRC run at the same time-scale and fast reserves are used for restoration immediately (fast “primary control mechanism”). (Valid for both aFCC and BRC).

BSC	● The current 'organic' approach to Coordinated Balancing Area (CoBA) evolution within the Network Code on Electricity Balancing will require further detail on transitional arrangements, as TSOs / Cell Controllers progressively join Imbalance Netting CoBAs. ● The WoC parameters for BSC management (specifically with the exchange of tie-line constraint information and structural information) should be utilised as Standard Instruments in Imbalance Netting CoBAs. ● The role of CCs should be specifically covered within the structural and real-time information exchange, and the role of non-CC/CSO transmission owners be clarified. ● Standard products for Imbalance Netting will require definition based on economic principles, with the pricing method for balancing energy, gate closure times and settlement periods harmonised within and across CoBAs. ● For settlement processes following BSC activation, it may be desirable for a third-party organisation to be granted a specific regulatory licence, carrying out the independent functions of measurement and calculation of activations, validation and dispute resolution.

A key issue in the suggested regulatory framework evolution, with reference to the IRPC UC regards dimensioning rules, i.e., determine the minimal inertia requirement for a whole WoC and for each cell inside it. Some considerations can be drawn starting from the similarity between the TSO role and the CSO role, and from an analogy between the current FCR procurement and a possible future "inertial response power reserve" procurement. More precisely, one can refer to the mechanism currently indicated to TSOs by ENTSO-E Network Code [41], for the determination of the minimal FCR. In this way, the minimal inertia required to be guaranteed in order to face a defined maximal imbalance, with a maximal tolerable absolute value of the RoCoF, can be determined, for a whole synchronous interconnected system within a WoC. This overall minimal inertia requirement has then to be "split" into minimal inertia requirements for individual cells inside that system. A possible mechanism to partition the overall inertia requirement into cell inertia requirements could be based on the amount of energy exchanged (in absorption and in injection) by each cell, exactly as happens today for FCR ([41], Art. 153). In this way, a uniform distribution of inertia supplying resources can be sought, which would be beneficial for frequency stability. The mentioned requirements, of course, can vary with time; for instance, they could be computed on a yearly, monthly, or even daily basis.

Then, on an hourly or quarter-of-an-hourly basis e.g., each CSO will have to procure the availability of Cell devices so as to guarantee that the defined minimal inertia is always supplied.

Synthetic inertia may be integrated in the cells to get faster responses. The use of synthetic inertia is not a new concept but is already being discussed as part of the ENTSO-E [42]; however, new amendments are required to adapt the concept at WoC architecture.

Finally, in real-time operation, the procured resources inside cells will be activated to compensate for the power variations requested by local IRPC control in relation to the measured RoCoF. The CSOs will also have to check if the IRPC control actions in their cells have been delivered correctly: therefore, suitable monitoring rules will be needed, based on measures collected from single devices or groups of devices or at suitable network nodes (similar to "pilot nodes"); measurement collection will require an increased level of system observability. The collected information can also be useful in an offline post-processing analysis, aimed at assessing the effectiveness of the IRPC actions, assessing the minimal inertia requirement and, if necessary, correcting it, so as to improve the inertia commitment process.

From an economic point of view, the procurement of inner resources for inertia supply can be carried out, as already mentioned, via a suitable market; it may be easier and less expensive in the case where enough synchronous rotating masses are present, while it may be critical if a cell is endowed with large amounts of power electronic devices. In either case, the monitoring system adopted to check for inertia supply may also be exploited in the remuneration process.

With reference to the key issues of the needed evolution of the regulatory framework for aFCC and BRC, in the restructured perspective of the WoC, new roles and control mechanisms need to be defined. Firstly, CSOs become responsible for the stability control in cells under their responsibility and for the frequency sensors network management. Furthermore, current Synchronous Area dimensions are clearly defined as well as their resources and the relative Reference Incident (e.g., in the Synchronous Area, the CE Reference Incident is currently equivalent to 3000 MW - two biggest nuclear power units of 1500 MW each). On the contrary, since cell dimensions are not standard but they depend on specific characteristics, for dimensioning of FCR under the WoC concept, new reference incidents must be necessarily defined at cell level (as an amendment of Art.153 [41]), and dimensioning rules need to be applied to smaller grid areas (i.e., cell) and under the responsibility of the CSO.

With reference to FCR provision, another amendment relates to Art. 156 (7-8) [41] since, in the WoC architecture, there is no a 2-phased approach as done today (containment followed by restoration). Conversely, aFCC and BRC run at the same time-scale and fast reserves are used for restoration immediately (fast “primary control mechanism”). Finally, cells do not need to be autonomous energetic systems (matching demand with supply) but instead are self-reliant in terms of local voltage control and real-time balancing using local resources (local problems have to be solved locally based on local observables), and able to keep the agreed power exchanges with neighbour cells over the tie-lines. Therefore, new Frequency Quality Parameters are not necessary for the WoC architecture and the ones already adopted in the different Synchronous Areas can be considered still valid (Nominal Frequency, Standard Frequency Range, Frequency Restoration Range, Frequency Recovery Range, Maximum Steady-State Frequency Deviation, Maximum Instantaneous Frequency Deviation).

The management of BSC requires coordination of new entrants into areas within which Imbalance Netting is managed. The current ‘organic’ approach to Coordinated Balancing Area (CoBA) evolution within the Network Code on Electricity Balancing will require further detail on transitional arrangements, as TSOs / CCs progressively join Imbalance Netting CoBAs. This can be achieved through regulatory guidelines as opposed to codification, but will require greater coordination than the initial bilateral approach proposed. Further, the WoC parameters for BSC management (specifically with the exchange of tie line constraint information and structural information) should be utilised as Standard Instruments in Imbalance Netting CoBAs. The role of CCs should be specifically covered within the structural and real-time information exchange, and the role of non-CC/CSO transmission owners be clarified. This should be supported by a mechanism for the confirmation of optimal tie-line set-points between CSOs following the Imbalance Netting process.

In order to maintain economic parity between participants in BSC, standard products for Imbalance Netting will require definition based on economic principles, with the pricing method for balancing energy, gate closure times and settlement periods harmonised within and across CoBAs.

With regards Settlement processes following BSC activation, it may be desirable for a third-party organisation to be granted a specific regulatory licence, carrying out the independent functions of measurement and calculation of activations, validation and dispute resolution.

4.2.2 Voltage control

In the framework of voltage control, the proposed extensions and/or amendments in the regulatory framework needed to support/promote the related ELECTRA Use Cases are summarized in Table 20.

Table 20: Proposes extensions/amendments in the regulatory framework for the ELECTRA Use Cases for voltage control

ELECTRA Use Case	Proposed extensions/amendments in the regulatory framework
PVC	No amendments of the current regulation are needed.
PPVC	● Higher observability in the MV and LV grids is the main requirement that should be addressed in future regulations to allow the PPVC to become a reality in the WoC. ● The use of the smart meters in LV would imply the need to increase their acquisition ratio (5 min-60 min, nowadays used for billing purposes) to much higher ratios needed for control.

The PVC is an automatic voltage control that is intended to keep the voltages set-points in the output of the generators by controlling the excitation systems of the AVRs. However, PVC is a local control that has a time response in the order of ms up to a few seconds. As no disruptive changes are expected in the WoC framework, there are also no noticeable new amendments in the network codes that could impact on the PVC, and the requirements for PVC will be kept very similar to the ones requested nowadays and previously collected in Subsection 3.2.

However, some regulatory modifications are necessary to perform the PPVC. Higher observability in the MV and LV grids is the main requirement that should be addressed in future regulation to allow the PPVC to become a reality in the WoC. In the LV distribution grid, current data concentrators and meters usually send hourly energy measurements that are used only for billing purposes. The widely spread meters register only the energy from the PQ measurements, because the DSOs considers these sufficient for the distribution grid operation on the LV side of the secondary transformer. However, they are able to register measurements faster with typical reporting rates as 5-15-30-60 min [43]. These sampling rates are still too slow to integrate the smart meters measurements in the PPVC control, which works with measurements and forecasts that have to be received/updated every minute. However, fast progress is being made in the field of smart metering, e.g. advanced smart meters are able to register not only the energy consumption but also the instantaneous voltage, instantaneous frequency, voltage waveform or harmonic distortion. This will help towards the use of smart meter data for planning and operation of the WoC in general and, in particular, for the implementation of the PPVC.

5. Regulation implications for the development of market design for the Web-of-Cells

In this section, the regulation implications (Third Energy Package, Market Design Initiative of the Winter Package and ENTSO-E Network codes) for the development of the electricity market design in the WoC are analyzed (see ELECTRA Deliverable D3.2 for further details [7]).

5.1 The Third Energy Package regulations

In 2011, the Third Energy Package came into force, aiming at removing the obstacles to cross-border competition, making the electricity market fully effective and creating a single EU electricity market which functions based on competitive principles, with prices kept as low as possible, high standards of service and increased security of supply. Within the Third Energy Package three legislations were approved in the area of the internal electricity market development. They are Directive 2009/72/EC Concerning Common Rules for the Internal Market in Electricity (Electricity Directive (No 2009/72/EC)) [44], Regulation No 714/2009 on Conditions for Access to the Network for Cross-Border Exchanges in Electricity (Electricity Regulation (No 714/2009)) [45] and Regulation No 713/2009 Establishing an ACER (Regulation establishing ACER (No 713/2009)) [46].

Electricity Directive (No 2009/72/EC) [44] was published to establish common rules for the generation, transmission, distribution and supply of electricity. It provides provisions aiming at protecting consumers and forms an approach which contributes to the improvement and integration of the competitive electricity markets. It lays down the rules relating to the organization and functioning of the electricity sector, open access to the market, the criteria and procedures applicable to calls for tenders and the granting of authorizations and the operation of systems. It also lays down universal service obligations and the rights of electricity consumers and clarifies competition requirements. The provisions of Electricity Directive (No 2009/72/EC [44]) are relevant when developing the electricity market design for WoC concept. However, some provisions are found to be outdated - they serve as undesirable limitations and do not strongly support the undergoing processes, which must be addressed by the new market design, and for which solutions must be found within the WoC concept. Therefore, they should be updated or replaced. A critical review of provisions, which are relevant for the WoC concept development, is given below:

- Article 15 on dispatching and balancing sets that "…TSOs procure the energy they use to cover energy losses and reserve capacity in their system according to transparent, non-discriminatory and market-based procedures, whenever they have such a function…". and Article 25 on DSOs roles and responsibilities sets that "…each DSO shall procure the energy it uses to cover energy losses and reserve capacity in its system according to transparent, non-discriminatory and market based procedures, whenever it has such a function…". The provisions are relevant for the WoC concept development because of criteria set for the procurement of balancing services. The WoC concept refers to these criteria and, in particular, attention is given to implementation of market-based mechanisms for the supply and purchase of electricity, needed in the framework of balancing requirements.
- Article 15 sets that "… TSOs adopt rules for balancing the electricity system. The rules, including rules for charging system users of their networks for energy imbalance, are objective, transparent and non-discriminatory…". The same is applicable to DSO in reference to Article 25. The provision gives an insight on the subject who is responsible for development of balancing rules and the criteria, which have to be taken into account when

developing qualitative rules and a market design within the WoC concept. However, the Electricity Directive does not provide measures on how to decide about the quality of rules, thus from this point much latitude is left for the WoC concept to decide on how objectivity, transparency and non-discrimination should be assured in the new market design of the WoC concept.

- Furthermore, Article 15 and Article 25 set that the "…terms and conditions, including the rules and tariffs, for the provision of balancing services by TSOs [DSOs] are established pursuant to a methodology compatible with Article 37(6) in a non-discriminatory and cost-reflective way and are published…". The provisions are relevant for the WoC concept from the point that a clear methodological background should be established for terms and conditions of balancing services provision. Tariffs should be set in a way that they reflect true cost of balancing service provision. Provision of public information is required to assure transparency of applied methodology, terms, conditions, etc.
- Article 37(6) sets that "…the regulatory authorities shall be responsible for fixing or approving sufficiently in advance of their entry into force at least the methodologies used to calculate or establish the terms and conditions for the provision of balancing services which shall be performed in the most economic manner possible and provide appropriate incentives for network users to balance their input and off-takes. The balancing services shall be provided in a fair and non-discriminatory manner and be based on objective criteria…" and "…in fixing or approving the tariffs or methodologies and the balancing services, the NRAs shall ensure that TSOs and DSOs are granted appropriate incentive, over both the short and long term, to increase efficiencies, foster market integration and security of supply and support the related research activities…". The provisions showing that the NRAs play an active role to ensure that balancing tariffs are non-discriminatory and cost-reflective, are observed by the WoC concept.
- Article 15 sets that "…the dispatching of generating installations and the use of interconnectors shall be determined on the basis of criteria which shall be approved by NRAs where competent and which must be objective, published and applied in a non-discriminatory manner, ensuring the proper functioning of the internal market in electricity…". The provision raises the issue of non-discrimination in dispatching and is compatible with the WoC concept. However, later in Article 15 and 25 an exemption is provided to RES in accordance with Article 16 of the Directive 2009/28/EC [18]. In accordance to Article 16 of Directive 2009/28/EC [18], TSOs and DSOs give priority to generating installations using RES when dispatching electricity generating installations in so far as the secure operation of the national electricity system permits and based on transparent and non-discriminatory criteria. The WoC concept assumes that subject to significantly increased volume of RES in electricity market, RES-using installations should be treated equally to fossil fuel power plants when dispatched and no priority lists should be created.
- Article 12 proclaims that "…the TSO shall be responsible for ensuring a secure, reliable and efficient electricity system and, in that context, for ensuring the availability of all necessary ancillary services, including those provided by demand response, insofar as such availability is independent from any other transmission system with which its system is interconnected…" is also observed by the WoC concept as a provision on CSOs responsibilities regarding provision of balancing services.
- Article 16 on confidentiality for TSOs and transmission system owners determines the requirement for information, i.e. "…information necessary for effective competition and the efficient functioning of the market shall be made public…". The WoC concept assumes that, seeking to avoid consequences caused by information asymmetry (i.e. market failures),

information should be available to all market participants, and thus, it has to be publicly published. However, the Article 16 does not specify what information should be published and how often market participants should be supplied with this information.
- Article 23 on decision-making powers regarding the connection of new power plant to the transmission system proclaims that the TSOs should establish and publish transparent and efficient procedures for non-discriminatory connection of new power plants to the transmission system, and that they should not be entitled to refuse the connection of a new power plant on the grounds of possible future limitations to available network capacities. The provision is a relevant condition for generators within the WoC concept, since it eliminates the barrier of entering the power sector.

Electricity Regulation (No 714/2009) [45] provides a harmonized framework for cross-border exchanges of electricity. It was announced as a response to the obstacles when selling electricity on equal terms, without discrimination or disadvantage. In particular, non-discriminatory network access and an equally effective level of regulatory supervision did not exist in Member States and isolated markets persisted. The existing rules and measures did not provide the required framework for the creation of interconnection capacities to achieve the objective of a well-functioning, efficient and open internal market. The Electricity Regulation (No 714/2009) aimed at addressing these issues. Moreover, it addressed issues such non-discriminatory and transparent charges for network use, transparency for market participants concerning available transfer capacities and the security, planning and operational standards that affect the available transfer capacities, equal access to information on the physical status and efficiency of the system, enhancement of the trust in the market through the effective, proportionate and dissuasive penalties. These are the preconditions for effective competition in the internal electricity market, however, the issues raised and solved by the Electricity Regulation (No 714/2009) are out of the scope of ELECTRA project when dealing with the electricity market design for future.

Regulation establishing ACER (No 713/2009) [46] was prepared as a measure improving the regulatory framework at EU level with the objective to complete the internal electricity market. It was developed as a response to a proposal that a voluntary cooperation between NRAs should take place within the EU by setting clear competences, and with the power to adopt individual regulatory decisions in a number of specific cases. The Regulation establishing ACER (No 713/2009) determines areas where NRAs closely cooperate:

- Eliminating obstacles to cross-border exchanges of electricity;
- Ensuring that regulatory functions performed by the national regulatory authorities are in accordance with Electricity Directive (No 2009/72/EC);
- Monitoring regional cooperation between TSOs in the electricity sectors as well as the execution of the tasks of the European Network of Transmission System Operators for Electricity (ENTSO-E);
- Monitoring the internal markets in electricity and informing the European Parliament, the Commission and national authorities of its findings where appropriate;
- Developing framework guidelines which are non-binding by nature (framework guidelines) with which network codes must be in line. It is also considered appropriate for the Agency, and consistent with its purpose, to have a role in reviewing network codes (both when created and upon modification) to ensure that they are in line with the framework guidelines, before it may recommend them to the Commission for adoption;
- Making recommendations to assist regulatory authorities and market players in sharing good practices;
- Contributing to the efforts of enhancing energy security;

The roles and responsibilities of ACER are relevant for the development of the internal electricity market, however, are not analyzed in deep within the ELECTRA project, only as much as they are relevant for the establishment of a transparent market for balancing and voltage control products within WoC concept in [7].

Enforcement of the legislation – Electricity Regulation (No 714/2009), the Electricity Directive (No 2009/72/EC) and the Regulation establishing ACER (No 713/2009) – made a significant contribution towards the creation of an internal market for electricity and led to positive results both for electricity markets and consumers. Electricity markets became less concentrated and more integrated and the set of new consumer rights introduced by the Third Energy Package improved the position of consumers. However, the legislation was developed in view of the predominant generation technologies – centralized, large-scale fossil fuel- and nuclear-based power plants with limited participation of consumers – but now European power systems are in the process of fundamental developments. Namely, the transition to zero-carbon energy systems, the cost-efficient integration of variable RES, the tendency towards decentralized renewable energy production, the evolving role and stronger participation of energy customers and the requirements to ensure the security of supply in short and long terms efficiently and at affordable costs [47], create new business opportunities and challenges for market participants and require that existing electricity market rules would be adapted and new rules set in order to reflect all the emerging tendencies and comply with the undergoing fundamental processes. The market design for the WoC concept will cover these emerging trends and challenges.

5.2 “Market Design Initiative” of “Winter Package”

Responding to the challenges the market participants will have to deal with in future, on 30 November 2016, the EC announced a “Winter Package”. In relation to the development of the internal market for electricity, five legislative proposals - which if bundled into a single package are known as a “Market Design Initiative” (MDI) [48] - were prepared. They were developed as a timely response to challenges the internal electricity market in EU faces and as a support to fundamental developments taking place. In particular, the proposals for the new electricity market design create a market-based framework that supports and relies on RES & DER, energy efficiency measures and decentralization. The proposals reveal that both a competitive, non-discriminatory and, particularly, consumer-centered and flexible electricity market is a target of the Union [49]. The MDI proposals significantly expands the content of up to now valid legislation on the internal electricity market. If until the publication of MDI proposals, the requirements for particular markets and their design were determined fragmentary through the whole legislation package, then now the market design issues and requirements for the market design are set out concentrated and discussed more consistently.

Overall, the EC proposes a very promising and challenging framework of a new market design. It suggests to include at least the following elements into the new market design [50]:

- 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.

Actually, the framework of a new market design proposed within the MDI proposals is a very close environment for a WoC concept development too. Namely, in the framework of MDI proposals, the

WoC concept is being developed and solutions are searched. Table 21 summarizes the content of the MDI proposals by emphasizing their relevance for the WoC concept development.

Table 21: Summary of proposals of "Market Design Initiative" and their importance for the development of Web-of-Cell concept

Proposal	**Aim**	**Articles of proposal relevant for Web-of-Cell concept development**
Proposal for a Directive on Common Rules for the Internal Electricity Market (recast Directive No 2009/72/EC) [51]	This Directive establishes common rules for the generation, transmission, distribution, storage and supply of electricity, together with consumer protection provisions, with a view to creating truly integrated competitive, consumer centered and flexible electricity markets in the Union. Using the advantages of an integrated market, the Directive aims at ensuring affordable energy prices for consumers, a high degree of security of supply and a smooth transition towards a decarbonized energy system. It lays down the key rules relating to the organization and functioning of the European electricity sector, in particular rules on consumer empowerment and protection, on open access to the integrated market, on third party access to transmission and distribution infrastructure, unbundling rules, and on independent national energy regulators.	3, 15–17, 31, 32, 36, 40–42, 54, 58–59
Proposal for a Regulation on the Internal Electricity Market (recast regulation No 714/2009) [10]	It aims at: • Setting the basis for an efficient achievement of the objectives of the European Energy Union and in particular the climate and energy framework for 2030 by enabling market signals to be delivered for increased flexibility, decarbonization and innovation; • Setting fundamental principles for well-functioning, integrated electricity markets, which allow non-discriminatory market access for all resource providers and electricity customers, empower consumers, enable demand response and energy efficiency, facilitate aggregation of distributed demand and supply, and contribute to the decarbonisation of the economy by enabling market integration and market-based remuneration of electricity	3–5, 9–13, 15, 34, 47, 51, 53–55, 60, 61

	generated from renewable sources; - Setting fair rules for cross-border exchanges in electricity, thus enhancing competition within the internal market in electricity, taking into account the particular characteristics of national and regional markets. This includes the establishment of a compensation mechanism for cross-border flows of electricity and the setting of harmonised principles on cross-border transmission charges and the allocation of available capacities of interconnections between national transmission systems; - Facilitating the emergence of a well-functioning and transparent wholesale market with a high level of security of supply in electricity. It provides for mechanisms to harmonize the rules for cross-border exchanges in electricity.	
Proposal for a revised Regulation Establishing a European Union Agency for the Cooperation of Energy Regulators [52]	This Regulation establishes a European Union Agency for the Cooperation of Energy Regulators. The purpose of the Agency shall be to assist the regulatory authorities in exercising, at Union level, the regulatory tasks performed in the Member States and, where necessary, to coordinate their action.	–
Proposal for new regulation on Risk Preparedness in the Electricity Sector [53]	This Regulation lays down rules for the cooperation between Member States in view of preventing, preparing for and handling electricity crises in a spirit of solidarity and transparency and in full regard for the requirements of a competitive internal market for electricity.	–
Proposal for a revised Renewable Energy Directive [54]	This Directive establishes a common framework for the promotion of energy from renewable sources. It sets a binding Union targets for the overall share of energy from RES in gross final consumption of energy in 2030. It lays down rules on financial support to electricity produced from RES, self-consumption of renewable electricity, and renewable energy use in the heating and cooling and transport sectors, regional cooperation between Member States and with third countries, guarantees of origin, administrative procedures, information and training. It establishes sustainability and greenhouse gas emissions saving criteria for	20–22

	biofuels, and bio-liquids and biomass fuels.	

As seen in Table 21, 2 out of 5 MDI proposals are critically relevant for the WoC concept development. Namely, a Proposal for a Directive on Common Rules for the Internal Electricity Market and a Proposal for a Regulation on the Internal Electricity Market have far-reaching implications for WoC concept development. The MDI is also linked to the proposal for a revised Renewable Energy Directive. Although the revised Renewable Energy Directive provides a framework how to achieve the 2030 renewable target, the measures aimed at integration of RES in the market – such as provisions on dispatching, market-related barriers to self-consumption and other market access rules – have a direct link to an internal electricity market development and are also addressed by the WoC concept.

The analysis of the MDI proposals reveals that provisions are generally compatible with the WoC concept, especially those, which are related to market organization and market principles, roles and responsibilities of TSOs and DSOs, rules on balancing markets and dispatching of power generation and demand-response, transmission and distribution systems operations, network codes and guidelines. It is worth noting that some of the provisions of the MDI proposals are rather loosely defined, their content is abstract and broad in the sense that a huge space is left for the formation and derivation of technical- and market-based solutions for the WoC concept. Indeed, the proposals of MDI cover much broader spectrum of issues, which, although important for the internal electricity market development, are out of the scope of the ELECTRA project and are not directly applicable to the WoC concept. These are provisions regarding reinforcement and expansion of consumer rights and consumer protection (except those which are dedicated to activities of active consumers and demand response), unbundling of transmission system (except those which are related to storage and provision of ancillary services by the TSOs), duties of national regulatory authorities, etc. Below a brief and concentrated review of the critically relevant MDI proposals is given by emphasizing the areas, which are the most actual for the development of the market design for the WoC concept.

The areas of the Proposal for a Directive on Common Rules for the Internal Electricity Market, which are the most relevant for the WoC concept development, are the following:

- General provisions regarding competitive, consumer-centered, flexible and non-discriminatory electricity market (Article 3) since they determine requirements for actions which could not be taken in relation to market development;
- Provisions on active consumers (Article 15), since they determine a list of allowed actions for

the final consumers by disclosing active role of final consumers when generating, storing and selling self-generated electricity to all organized markets in future;

- Provisions on the role of local energy communities (Article 16) to have access to all organized markets either directly or through aggregators or suppliers in a non-discriminatory manner;
- Provisions on demand response (Article 17), since provisions recognize the demand response and the aggregators as important participants in all organized markets. Provisions foresee the participation of demand response alongside generators in a non-discriminatory manner in all organized markets, in procurement of ancillary services on equally basis;
- Provisions regarding the general tasks of DSOs (Article 31) and tasks in relation to the use of flexibility (Article 32). The DSOs are responsible for the procurement of energy they use to cover energy losses, non-frequency ancillary services in its system according to transparent, non-discriminatory and market based procedures, ensuring effective participation of all market participants including RES, demand response, energy storage facilities and aggregators. In addition, in relation to flexibility, DSOs should define standardized market products for the services procured ensuring effective participation of all market participants including RES, demand response and aggregators. DSOs should exchange all necessary information and coordinate with TSO in order to ensure the optimal utilization of resources, ensure the secure and efficient operation of the system and facilitate market development. DSOs should be adequately remunerated for the procurement of such services in order to recover at least the corresponding expenses, including the necessary information and communication technologies and infrastructure expenses.
- Provision on DSOs and TSOs ownership of storage facilities (Article 36 and Article 54). DSOs and TSOs should not be allowed to own, develop, manage or operate energy storage facilities;
- Provisions on tasks of TSO (Article 40), in particular, to procure ancillary services from market participants to ensure operational security. Procurement of ancillary services should be transparent, non-discriminatory and market-based. TSOs should not own assets that provide ancillary services;
- Provisions on confidentiality and transparency requirements for TSOs and transmission system owners (Article 41), particularly, provision that information necessary for the effective competition and the efficient functioning of the market should be made public;
- Provisions on decision-making powers regarding the connection of new power plants to the transmission system (Article 42);
- Provisions on general objectives of the regulatory authority (Article 58), in particular, eliminating restrictions on trade in electricity between Member States; facilitating access to the network for new generation capacity and energy storage facilities, in particular removing barriers that prevent access for new market entrants and of electricity from RES;
- Provisions on duties and powers of the regulatory authority (Article 59), in particular approving products and procurement process for non-frequency ancillary services; monitoring the level and effectiveness of market opening and competition at wholesale and retail levels.

The Proposal for a Regulation on the Internal Electricity Market aims at making the electricity market fit for more flexibility, decarbonization and innovation by providing undistorted market signals. For this purpose it sets out rules for the balancing markets, day-ahead and intraday markets, sets out a process for defining regional electricity markets (bidding zones), updates rules on network charges, and sets out design principles for national capacity mechanisms. The proposal clarifies the responsibilities of the market participants, introduces regional operational centers and establishes a new European entity for DSOs.

The WoC concept takes into account the principles regarding the operation of electricity markets (Article 3), the balancing responsibilities set for market participants (Article 4), the critical elements of balancing market (Article 5), the applied price restrictions and their methodological background (Articles 9-10), the principle of dispatching of generation and demand response (Article 11), the principle of re-dispatching and curtailment (Article 12), the application of definition of bidding zones to an imbalance price area (Article 13), the principle of allocation of cross-zonal capacity across timeframes and for the exchange of the balancing capacity, as well the use the cross-zonal capacity for the exchange of balancing energy (Article 15), the tasks of regional operational centers (Article 34), the responsibility of TSOs to provide relevant information to market participants and NRAs (Article 47), the tasks of the EU DSO entity (Article 51), the cooperation between DSOs and TSOs (Article 53), the adoption of network codes and guidelines (Article 54), the establishment of network codes (Article 55), the provision of information and confidentiality (Article 60), the penalties (Article 61). The identified provisions form the scope within which the solutions for the new market design for the WoC concept are searched.

5.3 Implications of the “Market Design Initiative” for market design of Web-of-Cell concept

The WoC concept should consider a lot of peculiarities of a new market design suggested by the EC for further development of the internal electricity market. Namely, the WoC concept should take into account the principles regarding the operation of electricity markets. In particular, it should keep the idea that procurement in the wholesale markets should be organized based on market principles; 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. In addition, the WoC concept should assume that prices should reflect the true value of electricity and price caps should be removed, except where they reflect the value of lost load. Seeking to establish an efficient market, all generation, storage and demand resources should participate on equal basis in the market supporting the WoC concept. The electricity market design should allow free entry and exit of electricity generation and electricity supply undertakings the electricity market based only on their assessments of the economic and financial viability of their operations and no barriers (through regulatory limitations, etc.) should be established.

The MDI-specific requirements for the establishment of the balancing market should be of high importance in the WoC concept. Within the framework of a new market design, the EC provides a valuable interpretation of the future direction, by not only having a very strong focus on making markets for the ancillary services, but also by ensuring that these markets are driven by competition between market participants and not gradually becoming included in the realm of TSOs. The WoC concept should be in an agreement with this notion. Namely, the WoC concept should keep an idea that all products which are needed to operate the power system – frequency or non-frequency – should be procured in the market places based on the principles of competitive market. Electricity prices should be determined based on demand and supply. This should also include rules on trading preventing the introduction of capping or floors on prices, except in cases when the price caps are set in a view of the economic background – for example, the maximum price is based on the value of lost load. The WoC concept should consider that all market participants should have access to the balancing market, be it individually or through aggregation. This would contribute to increased number of market participants and an establishing of an efficient market. The market should be organized in such a way as to ensure effective non-discrimination between the market participants taking into account of the different technical capability of generation from variable RES and demand side response and storage.

The WoC concept should support the idea that balancing energy and balancing capacity should be traded separately by establishing sub-markets for each. The procurement processes of balancing energy should be transparent while at the same time confidential. The principles of procurement process should be implemented by choosing market-based procurement methods, such as auctions. Marginal pricing as an advanced method of pricing should be used for the settlement of balancing energy instead of pay-as-bid pricing. Market participants should be allowed to bid as close to real time as possible. The procurement of balancing capacity should be facilitated on a regional level and it should be organized in such a way as to be non-discriminatory between market participants. The procurement of upward balancing capacity and downward balancing capacity should be carried out separately too. The WoC concept should keep the provision 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. Seeking to avoid issues of asymmetric information in the market and as a result market failure, the SO should publish close to real-time information on the current balancing state of their control areas, the imbalance price and the balancing energy price.

In agreement with the MDI proposals, the WoC concept should foresee that generators, consumers, aggregators, demand response, high, medium and low voltage network operators and national regulatory authorities are the main market participants, and that they perform the critical roles in the wholesale (including balancing) market.

With their reinforced and expanded rights, the consumers should be provided with a critical role in the market. The WoC concept should allow consumers to adjust consumption to price signals and to receive income by consuming or saving electricity at favorable for this time. Furthermore, consumers should be encouraged to both produce and sell electricity. Recognition of the ability for active consumers to produce, store, consume and sell self-produced electricity would show an increasing number of households and businesses owning renewable installations and operating storage assets. The rights of active consumers to carry out these activities without disproportionate cost and to contract with aggregators without the consent from a retailer, would send a clear statement that consumers are expected to interact with and participate in the electricity markets in the future.

Because of their possibilities to create fundamental, transitory, and opportunistic value in power system [55], aggregators should also be recognized as relevant players in the WoC concept. They could participate in the market by combining the electricity load of multiple customers and offering them for sale, purchase or auction in the market. They should be provided with a role of intermediary between customers and the electricity market, making it less complicated for the customers to profit from the electricity system and helping saving money.

With the aim to enable the market to better deal with shifting energy consumption and generation, a critical attention should be drawn to demand response in the WoC concept. Through the demand response, the customers should be incentivized financially to lower or shift their electricity use at peak times.

Medium and low voltage system operators (DSOs) should take roles that are more important in the power system than before. The CSO should set requirement to connect new production capacity, enable spot market trading, demand side response, participation of the prosumers, etc. Moreover, the CSO should be obliged to accommodate electric mobility and charging points. The new market design and the WoC concept should recognize the importance of electricity storage, but with the aim to guarantee competition, the CSOs should not be allowed to own, develop, manage or operate energy storage facilities. CSOs should provide services in a transparent, non-discriminatory and market-based way by ensuring effective participation of all market participants including RES, aggregators and demand response. In order to guarantee an efficient use of the grids medium and low voltage CSOs should cooperate with high voltage CSOs in a new market design of the WoC concept.

The provisions that are set in the Third Energy Package and the MDI and applicable to the TSOs should remain largely maintained in a new market design of the WoC concept. In a new market design of the WoC concept, the high voltage CSOs should be obliged to perform tasks related to the procurement of (balancing and non-frequency) ancillary services from market participants to ensure operational security in a way that is transparent, non-discriminatory and market-based, to ensure effective participation of all market participants.

The WoC concept (particularly, a market design of the WoC architecture) should take into a view the provisions which acknowledge that RES need to be more integrated into the wholesale markets and the wholesale markets need to be more coordinated with each other. For the development of the market design for the WoC concept, the following MDI provisions are critically relevant. Renewables should participate in wholesale markets on a “level playing field” with other technologies. In particular, the WoC concept should keep the MDI requirement to remove for renewables a dispatch priority over other generation types. Renewable power should be treated in the same way as fossil fuel power when it comes to the order in which it is dispatched to the grid. The dispatch is “non-discriminatory and market-based”, with a few exceptions such as small-scale renewables (<500 kW) (a threshold that shrinks to 250 kW from 2026). Priority dispatch could be allowed for small renewables or high-efficiency cogeneration installations with an installed capacity of less than 500 kW, for demonstration projects, for innovative technologies and for existing installations (unless they are modified or expanded). The move to integrate renewables into balancing markets should mean that they compete with other energy sources to balance the system such as storage and demand-side measures. These flexibility options should benefit from the price signals. Renewables should face the balancing risk. The principle should be implemented in line with the MDI provision 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 balance responsible parties or delegate their responsibility to a balance responsible party of their choice.

5.4 Implications of ENTSO-E Network Codes for market design of Web-of-Cell concept

By continuing the discussion on the implications of EU regulations on the WoC concept development, attention must be paid to the preparation of efficient balancing rules, which contribute to ensuring operational security. Such rules have to provide incentives for market participants solving the system scarcities for which they are responsible. In particular, it is necessary to set up rules related to the technical and operational aspects of system balancing and energy trading, while supporting the achievement of targets for penetration of renewable production and providing benefits for consumers. In this respect, the European Commission’s Regulation Establishing a Guideline on Electricity Balancing is perhaps the most serious legislation in relation to established minimum principles on making harmonized and integrated electricity-balancing markets. The WoC concepts could refer to the provisions of the Regulation at least in areas of electricity balancing market design and its elements.

Specifically, the WoC concept could refer to high-level functions and responsibilities of high voltage network operators, BRPs and BSPs in the electricity balancing market (Articles 14-17). The Regulation determines that high voltage network operator (TSO) should be responsible for procuring balancing services from BSPs in order to ensure operation security. The WoC concept should look at the problem in more depth in a sense that the CSO, who could be a high, medium or low voltage network operator, should be responsible for the procurement of balancing services and solving local problems locally. The Regulation foresees an application of a self-dispatching model for determining generation and consumption schedules, which is in line with the WoC concept.

Cooperation issues, described in Article 15, are of less importance in the WoC concept, because no global system information is required and no bidirectional communication between DSO and TSO is needed for reserve activation in a WoC concept. However, the WoC concept keeps an idea of cooperation between the network operator, BSPs and BRPs for efficient and effective balancing. Role of BSPs to be qualified for providing bids for balancing energy and balancing capacity, their rights to participate in the procurement process on non-discriminatory manner, submit and update balancing capacity bids from standardized products before the gate closure time of the procurement process remain relevant in the WoC concept. Again, the roles of BRPs to be financially responsible for the imbalances, rights to change the schedules required to calculate their positions prior to determined time are kept in the WoC concept too.

The Regulation foresees the establishment of platforms for the exchange of balancing energy from at least secondary (replacement) and tertiary (frequency restoration with manual activation and automatic activation) reserves, and determines required actions and works to be done for this. The Regulations says that the platforms should apply a common merit order list to exchange all balancing energy bids from all standard products. The WoC concept assumes that for maintaining of the balance CSO should be allowed to procure reserves from “cross cell borders”, meaning the availability of exchange of balancing energy via the particular platform. Moreover, WoC concept takes over an approach of establishment of a common merit list for the exchange of energy. Besides, the WoC concept takes into view of the following two aspects of market design when exchanging balancing energy via the particular platform – balancing energy gate closure time and requirements for standards products. Namely, the requirement to establish balancing energy gate closure time as close as possible to real time and not before the intraday gate closure time. The WoC concept accepts the minimum requirements for the standard product bid, which are determined in Article 25.

Indeed the most significant implications of the Regulation on the WoC concept is in the scope of procurement of balancing services. In compliance with Article 29 on activation of balancing energy bids from common merit order list, each CSO should use cost-effective balancing energy bids available for delivery in its cell based on common merit order list. In compliance to Article 30 on pricing for balancing energy and cross-zonal capacity used for exchange of balancing energy for operating the imbalance netting process, the CSO shall refer to the provision that marginal pricing (pay-as-cleared) should be applied at least in cases when balancing energy bids are activated for BRC and BSC control services.

Balancing capacity procurement rules (Article 32) should be taken into account by the CSO. Namely, the provisions that procurement method should be market based, procurement process should be performed on a short-term basis and the procurement of upward and downward balancing capacity should be carried out separately for at least BRC and BSC services. The WoC concept foresees the exchange of balancing capacity (the issue is presented in Article 33).

The WoC concept addresses the general settlement principles (Article 44) and principles for settlement of balancing energy (Article 45–49), including principles of balancing energy calculation and payment for balancing energy. Non-discriminatory, fair, objective and transparent rules on imbalance settlement (Articles 52–55) are considered by the WoC concept. Namely, the CSO shall apply the imbalance settlement period of 15 minutes. CSO shall calculate the imbalance for each BRP, for each imbalance settlement period and in each imbalance area. The CSO shall determine the imbalance price for each imbalance settlement period, imbalance price area and for each imbalance direction.

6. Conclusions and final remarks

Since Regulation can shape and prescribe the development of the technical solutions proposed in ELECTRA, an analysis on regulatory aspects is carried out in this Deliverable D3.3 to explain how the WoC architecture, balancing and voltage control mechanisms, and the new CSO role can be tailored to the regulatory framework, and vice versa, what aspects of the current regulation could be adapted or extended to cover the WoC requirements. To support the WoC development in the 2030+ horizon and to tailor the developed high-level Use Cases to the regulatory framework, potential barriers are first identified and responsibilities are allocated with the aim to detect the needed changes to make the WoC feasible from the regulation point of view. Based on this analysis, the needed modifications in stakeholders roles and responsibilities as well as the possible extensions and amendments in the regulatory framework are defined to enable the WoC development. In parallel, the regulation implications for the development of market design for the WoC are also discussed. The key findings of Deliverable D3.3 are defined in the following paragraphs.

Through its decentralized paradigm, the WoC results to be in line with the key areas proposed in the Winter Package. With reference to the further deployment of renewables, the WoC concept is fully aligned with this area of action, since the 2030 EU target can only be reached if solutions are found to keep the electricity system stable while having larger shares of renewable energy connected to the network at all voltage levels, which is one of the main assumptions for the development of this new control architecture in ELECTRA. As for the attention given to local energy communities as an efficient way of managing energy at community level by consuming the electricity they generate either directly for power or for (district) heating and cooling, with or without a connection to distribution systems, these targeted solutions can be made possible only through an effective distributed control acting at local level, which is the underpinning concept of the WoC. Moreover, the concept of allowing DSOs to manage some of the challenges associated with variable generation more locally (e.g. by managing local flexibility resources), is also fully in line with the WoC, which is based on the paradigm of solving local problems locally (reducing losses, mitigating congestion risks, limiting communication data volume, cost and time). In the WoC, both DSOs and TSOs will be CSOs with the same level of responsibility over their corresponding cells, inherently giving a more active role to DSOs, which are currently under the absence of a precise regulation at non-transmission level. With reference to the regulatory aspects of European System Integration (ESI), it is found that the WoC concept is being developed against a background of ESI (such as between electricity and gas) and may in future require additional information exchange between energy vectors beyond that currently in use for electrical instruments. It is noted that the WoC concept is potentially portable to other non-electrical energy carriers.

With reference to the Use Cases developed in ELECTRA, there is a clear impact of network codes and established requirements on most of the them. For the IRPC functionality, from the regulatory framework point of view, procedures and rules will be needed to:

- Determine the minimal inertia requirement for a whole WoC and for each cell inside it (dimensioning rules), for instance by starting from the mechanism, currently indicated to TSOs for the determination of the minimal FCR;
- Determine how much inertia a CSO has/can collect from available devices in its cell(s) (procurement rules), in order to guarantee that the inertia set-point in its cell(s) is met in each time slot;
- Determine which devices, and with which control gain, to activate in real time for inertia provision (activation rules);

- Collect information, from distributed resources or from selected network nodes, in order to assess the effectiveness of individual devices contribution to IRPC or of the overall IRPC functionality (monitoring rules).

In contrast to ‘traditional’ frequency control (Load Frequency Control), the aFCC is not a primary response that is followed by a slower secondary response that takes over from this primary response. Moreover, in contrast with the current FCP stabilizing the frequency after the disturbance at a steady-state value by a joint action of FCR within the whole Synchronous Area, in the WoC, the aFCC functionality aims at locally (i.e., at cell level) observing and responding to frequency changes by modifying active power to support the containment of frequency under normal operation or after incidents. Therefore, in the analysis of the current FCR regulatory constraints, it is found that for dimensioning rules under the WoC concept, new reference incidents must be necessarily defined at cell level. Moreover, dimensioning rules need to be applied to that smaller grid area (i.e., cell) and under the responsibility of the CSO, which can be interpreted by TSO in such a context. With reference to availability rules, current regulatory aspects covered by the NC LFCR seem to be in contrast with the WoC, where there is no a 2-phased approach as done today (containment followed by restoration). Conversely, these two latter run at the same time-scale and fast reserves are used for restoration immediately. The BRC shows resemblance to the current FRC, except that BRC is not a slower (secondary) control, but instead is a fast primary control at cell level – using many local fast ramping resources like flexible loads or storage – that runs at the same time as the aFCC control (instead of taking over from FCC). The main principles defined by the NC LFCR at Control Area level are still applicable within the WoC at control cell level, with the CSO being responsible for the reserves activation process in cells under his responsibility. The dimensioning process should occur at cell level by considering BRC faster acting resources and under the responsibility of the CSO.

As for BSC, a failure to correctly manage Imbalance Netting through BSC due to a regulatory gap would increase the volume of reserves activated (aFCC, BRC) at significant additional cost, but such management requires the definition of competitive and non-discriminatory mechanisms for tie-line constraint calculation, information exchange, activation and deactivation. Currently, there is no mechanism analogous to BSC, active within the same time frames as that defined in the WoC concept. Instead, to date there has been an 'organic' development of cooperative instruments between neighbouring TSOs. Moreover, the dimensioning of replacement reserves within BSC should firstly respect Operational Security Limits and secondly be determined by the economic objective across all coordinated cells within a Coordinated Balancing Area (CoBA). The coordination of new entrants into areas within which Imbalance Netting is managed will require greater coordination than under current bilateral arrangements in order to achieve the economic objective across a CoBA. A set of standard products for Imbalance Netting will require definition, based on sound economic principles, in order to ensure harmonisation within and across CoBAs.

As a general concept in the framework of frequency control, although structure, procedures and related responsibilities are generally harmonized at EU level, implementation details (e.g., activation time-frames) are different between Synchronous Areas. With reference to the WoC, it is found that the current structure can be adapted (with necessary changes) to the requirements of the corresponding Synchronous Area (i.e. customize UCs in the geographic area).

In the framework of voltage control, the stability of the grid voltage is essential for the secure operation of the power system. The PVC developed in ELECTRA does not raise noticeable differences over the current practices accomplished nowadays, since the voltage magnitude has a local character and the fast response required to stabilize the grid in case of major disturbances and to correct the voltage deviations is already requested by the regulations. Therefore, the requirements for PVC will be kept very similar to the ones requested nowadays, and amendments of the current regulation are not needed. Responsibilities of TSOs to keep enough reserves of fast reactive power to ensure normal operation with a continuous and normal evolution of the load and to prevent voltage collapse in case of any contingency will be covered by CSOs. Also, the DSO current responsibilities concerning the maintenance of power quality and grid security will be covered by CSOs. As for the PPVC, there is a clear impact of the current regulations since they specify the safe band for the triggering of this control mechanism, and fix the parameters (dead-bands, activation times, response times, etc.) for the local controllers of the generators at the different voltage levels that must fulfil the timeframes required by the PPVC.

With reference to the definition of roles and responsibilities for the WoC architecture, the CSO role can be interpreted by the traditional DSOs or TSOs. Clearly, most of the responsibilities identified in the functioning of the WoC, both in the reserve procurement and real-time operation phases can be allocated to the CSO. However, new roles and adaptations of the current regulations could be required. For instance, in the procurement phase (before the “time of delivery”), the provision of generation/load forecast information for the cell balance set-point - MOD – can be allocated under the responsibility of the CSO, based on the generation/load forecasts provided by large BRPs and aggregators who collect all necessary information for this task from smaller BRPs, who themselves are supplied with data by generating and load units. The requirements for the procurement of balancing services from BSPs determined in the guidelines on electricity balancing could be tailored to the WoC concept with some adaptations on responsibilities of CSOs. For the real-time operation phase, the detection of the need of balancing control services and corrective PPVC services together with their activations are allocated under responsibility of CSO, based on the cell imbalance observation and event location, and on the measurements from the metering devices. The decision on adaptation of cell tie-line set-points can be also allocated under responsibility of CSO, and no third-party actor is required. As for settlement of activations, it could be allocated under responsibility of a third-party organization with a specific regulatory licence to conduct the settlement process, and to take on the responsibilities for measurement and calculation of activations, cross-checking of records with CSOs, and dispute resolution. With reference to the issue related to the information distribution by the CSOs, based on the concept of transparency, the set-up of a so-called “Transparency Platform for Balancing and Voltage Control Services Market Information” should be addressed within the WoC concept.

The results of analysis of MDI and ENTSO-E Network Codes for market design showed that WoC concept should respect the high-level EU regulations, which are related to the general principles regarding the operation of wholesale electricity markets, including market for system balancing products. Among others, the WoC concept should support the principle that a variety of roles (balance and voltage control service providers, BRPs, load and generation forecaster, aggregators, consumers, CSOs, market operators and regulatory authority) should be established in the market for system balancing products with the purpose to develop a competitive, flexible, consumer-oriented, non-discriminatory and transparent market. These established roles should be provided with the WoC architecture specific responsibilities. Moreover, no entry barrier should be created for market actors, i.e., the WoC concept should consider that all market actors, be it individually or through the aggregation, have access to the market for system balancing products on equal basis. In addition, new rules are needed to be established for a well-functioning market of frequency and voltage control services under the WoC power grid structure, by also improving the market transparency:

- Regulatory rules for the provision of generation and load forecast information for the cell Merit Order Decision function by obliging large scale BRPs and aggregators to take this responsibility in the cell.

- Regulatory rules for the process of intra-cell and inter-cell procurement of flexibilities via the auction-based exchange by employing marginal pricing method for price setting and BSPs remuneration based on short-term flexible, non-discriminating, transparent and competitive market principles.
- Regulatory rules for the information distribution performed by the CSO to improve the transparency of the market for frequency and voltage control services. At least, the qualitative requirements for data and information should be set, minimum data set and its availability for the MOC and the MOD making should be determined, roles for the market actors regarding data and information collection and publication should be established, data and information placement should be proposed, data and information publication problem considered.

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