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ELECTRA

European Liaison on Electricity Committed Towards long-term Research Activities for Smart Grids

WP 3

Scenarios and case studies for future power system

Deliverable D3.1

Specification of Smart Grids high level functional architecture for frequency and voltage control

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This deliverable proposes a new control architecture for reserves activation that better addresses the changes of the future power system. In the proposal, the power grid is decomposed into a web-of-cells structure, each cell is managed by a Cell System Operator, who takes responsibility for the reserves activation and dispatching in his cell.

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Executive Summary

In this deliverable a high level functional architecture for frequency and voltage control for the future (2030+) power system is proposed.

The need for a transition towards a new functional architecture is based on a number of scenario assumptions regarding the 2030+ power system. It is assumed that in the future power system, generation will shift from classical dispatchable units to more intermittent renewables, and related to this. A significant part of the generation will shift from central transmission system connected generation to decentralized distribution system connected generation. As a consequence, a significant part of the generation will shift from few large units to many smaller units. However, they will continue existing some big and centralized power plants, mainly composed by RES generation and placed in both onshore and offshore locations. At the load side it is assumed that electricity consumption will increase significantly. Electrical storage is assumed to be a cost-effective solution for offering reserve services. In addition to this, the large amounts of fast reacting distributed resources (production as well as loads and storage) will be able to offer reserves capacity. Next to this, it is assumed that the power system's observability will increase due to more ubiquitous sensors.

This deliverable proposes a new control architecture for reserves activation that better, technically as well as economically, addresses the fundamental changes of the future power system. The document focuses on reserve activation to correct real-time imbalances –frequency deviations- caused by residual imbalances left over by the BRPs, forecast errors or incidents, as well as to regulate voltages.

In the proposal, the EU power grid is decomposed into a ***Web-of-Cells*** structure, where the "cells" are defined as a group of interconnected loads, concentrated generation plants and/or distributed energy resources and storage units within well-defined grid boundaries corresponding to a physical portion of the grid and corresponding to a confined geographical area. Cells have adequate monitoring infrastructure installed, as well as local reserves capacity enabling them to resolve voltage and cell balancing problems locally. Each cell is managed by a single system operator, who takes responsibility for the real-time reserves activation and dispatching in his cell. Inter-cell reserve exchanges and coordination is included for optimal system-wide management. In each cell, the Cell System Operator 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 principle, no global system state information is required for this. In this way, a 'divide and conquer' way of tackling voltage and balancing issues is implemented. Thus, local problems are resolved in the cell in a fast and secure manner, limiting complexity and communication overhead. There is no need to expose local problems at global system level. Still, inter-cell coordination is possible to support global optimization if needed.

In the proposed cell-based architecture, the main principles of Load-Frequency Control still apply. These principles are however applied at cell level instead of at control area level, requiring novel observables and a novel control architecture. A Cell System Operator is responsible for the balance within his own cell. For maintaining that balance he can procure reserves from within his cell but also 'cross cell border' reserves from neighbouring cells. The proposed mechanism for frequency control in a Web-of-Cells based system consists of the

following parts: inertia steering control, frequency containment, Balance Restoration and balance steering control.

Voltage stability is a local issue, therefore it is appropriate to solve these issues using resources located as close as possible to the occurring problem, i.e. using as many resource providers as possible within each cell. To maintain the voltages in the nodes within allowable limits, Cell System Operators will need to procure services from units connected within its cell or from neighbouring cells by coordination with the neighbouring Cell System Operators. Two control layers are identified within voltage control: primary voltage control and post-primary voltage control.

This proposed high level functional architecture lays the foundation for the development of innovative monitoring systems that will be developed in WP5, and dynamic autonomous distributed control function that will be developed in WP6. A subset of these will subsequently be implemented for lab integration and testing in WP7.

Terminologies

Definitions

See ELECTRA Glossary

Abbreviations

AVC	Automatic Voltage Controller
BRC	Balance Restoration Control
BRP	Balance Responsible Party
BSC	Balance Steering Control
BSR	Balance Steering Resources
CA	Control Area
CAPEX	Capital expenditures
CSO	Cell System Operator
DER	Distributed Energy Resources
DSO	Distribution System Operator
EV	Electric Vehicle
FACTS	flexible alternating current transmission system
FCC	Frequency Containment Control
FCR	Frequency Containment Reserves
FRR	Frequency Restoration Reserves
GHG	Greenhouse Gas
ICT	Information and Communications Technology
IP	Internet Protocol
KPI	Key Performance Indicator
LV	Low Voltage
MV	Medium Voltage
OPF	Optimal Power Flow
PMU	Phase Measurement Unit
PPVC	Post-primary voltage control
PV	Photovoltaic
PVC	Primary Voltage Control

RES	Renewable Energy Resource
ROCOF	Rate of change of frequency
RR	Replacement Reserves
SVC	Secondary voltage control
SVR	Secondary Voltage Regulation
TSO	Transmission System Operator
UC	Use Case

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1. Introduction

1.1 Scope of the document

This deliverable proposes a high level functional architecture for frequency and voltage control for the future (2030+) power system. Based on a number of scenario assumptions regarding the 2030+ power system, a new control architecture for reserves activation that better address the fundamental changes of the future power system is proposed.

Hence, this document focuses on the high-level functional control architecture related to the **real-time reserves activation** by the system operator. Both to correct for real-time imbalances –and thus frequency deviations- caused by residual imbalances left over by the BRPs, forecast errors or incidents, as well as to regulate voltages. To emphasize: the scope of the ELECTRA IRP is the control that takes place AFTER the market parties ended their balancing activities (t_0), and it addresses real-time deviations compared to the scheduled balance resulting from forecast errors (in load or generation) or incidents (Figure 1).

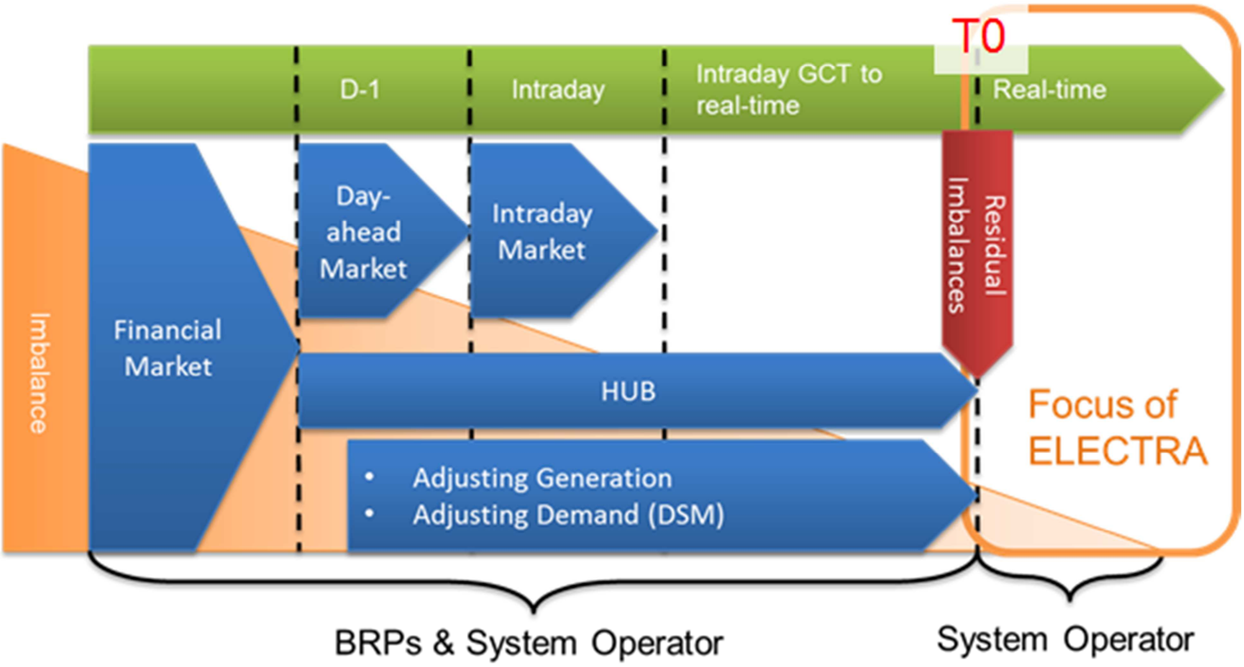


Figure 1: Timeline of Balancing Procedure

It is expected that due to the forthcoming changes, the future frequency and voltage control can no longer be effectively managed in a TSO-central manner. Instead, a radical new approach is required, that leverages innovative monitoring systems based on a fully instrumented network, and dynamic autonomous distributed control functions.

In order to regain reliable control over the power grid, also distributed generators and loads should be controlled in a way that increases the predictability of the maximum power imbalance as perceived system-wide by the TSO’s.

One could view the real time operation of future power systems as composed of “vertical integration” of control schemes reinforced by “horizontal integration” of distributed control schemes. This is depicted in Figure 2.

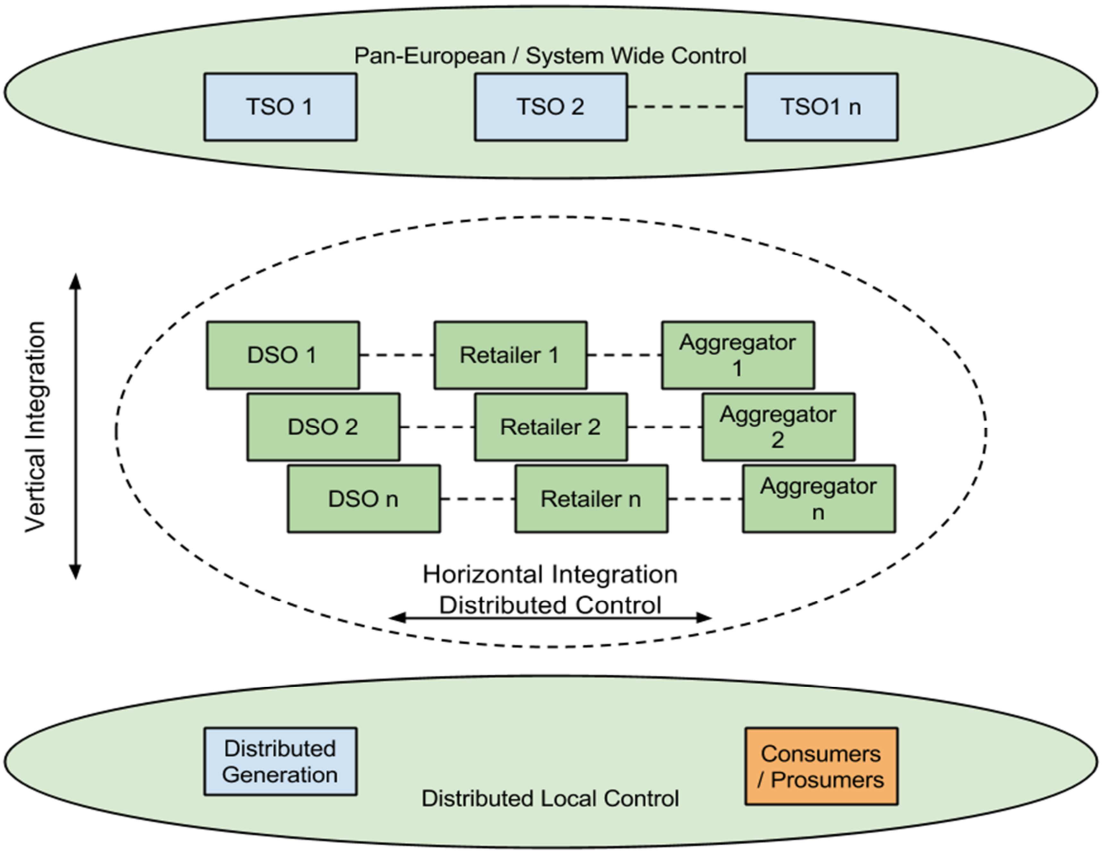


Figure 2: Vertical as well as horizontal integration of distributed control schemes

These vertically-integrated control schemes reinforced with horizontally-distributed control schemes are expected to provide for a dynamic power balance that is closer to its equilibrium value than a conventional central control scheme. This enables grid operators to regain control in a future power system with a high share of decentralized generators.

This high level functional architecture lays the foundation for the development of innovative monitoring systems that will be developed in WP5, and dynamic autonomous distributed control functions that will be developed in WP6. In WP6 control cycles are defined with flexible resources, based on so-called “Control Triples” developed in WP5 which in essence define basic control loops. The proper set-points of the basic control loops also need to be defined in WP6. A subset of the developed control loops will subsequently be implemented for lab integration and testing in WP7.

The focus of this deliverable is on the functional architecture. Reserves must be contracted through a market party (BSP) taking into account (regulatory) requirements related to amounts, types, characteristics, location,… but this procurement itself is out of scope for this deliverable.

1.2 Structure of the document

This document is organized as follows. In chapter 2, an overview of the ELECTRA scenario assumptions related to the 2030+ power system –and the consequences- is given.

Based on this, a cell-based architecture for frequency and voltage control is introduced in chapter 3. After a description of the cell concept, the main impact of the proposed architecture on the frequency and voltage control operation is shortly outlined.

At the end, a high-level Use Case description of the proposed Frequency and voltage controls is given. This constitutes the foundations for the subsequent detailing of these use cases, as well as the definition of needed observables and control loops that will be later developed in WP4, WP5 and WP6.

2. ELECTRA scenario assumptions for the 2030+ power system

2.1 Introduction

Development of scenarios in energy domain is a fairly new approach for predicting, exploring and anticipating the future energy perspectives. Today a great number of energy scenarios is developed and presented every year. These are developed with different purposes, by different institutions (Governmental and Non-governmental Organizations, Energy Companies etc.) using various techniques and concentrating on various segments of the energy sector. Therefore it becomes very challenging to analyse/compare various scenarios and derive meaningful conclusions. Scenarios are basically tools for taking a long view in a world of great uncertainty, which usually describe hypothetical possible futures and corresponding pathways that may lead from the present to that particular future [1]. Scenario approach has been frequently applied in the energy sector due to necessity for a long term planning mostly caused by capital-intensive and lengthy investment cycle for energy infrastructure.

Traditional scenario approaches have demonstrated several shortcomings caused by various reasons, where the most common is lack of transparency and the alignment with the predictions with overall goals of a company or organization developing the scenario.

ELECTRA has tried to find the traceability from the well-known scenario analysis performed in the eHighway2050 project (www.e-highway2050.eu/e-highway2050/). This is not an arbitrary decision. There are several reasons for using the selection of e-Highway scenarios as a starting point in ELECTRA project. The first and main reason is the high overall quality of the study, based on the following factors:

- E-Highway 2050 analysis is one of the few publically available bottom-up scenario studies, which are available at the moment. The scenario is not a black-box type of study, but a fairly transparent analysis; with very few exceptions (results from one of ENTSO-E questionnaires are confidential).
- The fact that study has been developed by a broad international consortium under FP7 umbrella considerably reduces possibility of being biased, compared to studies developed by specific energy companies, interest organizations or other NGOs.
- The study resides on a comprehensive review of numerous existing scenarios and received an input from the key stakeholders via two questionnaire iterations with ENTSO-E.
- Applying the bottom-up approach, the study is built on multitude of uncertainty and opportunity parameters, which are carefully evaluated and structured into a comprehensive set of boundary conditions, setting the scope of the analysis.

The second reason is the wide scope of the results. Unlike several other studies, generating one or several single predictions, the e-Highway 2050 project develops a field of scenarios. The field is enveloped by the five equally probable scenarios, where each of these meets the 2050 goals of the European Union.

2.2 e-Highway project scenario analysis

The e-Highway 2050 study started with a detailed review of national studies and policies within the EC, which was based on results of two questionnaires distributed among ENTSO-E members. The first referred to national data related to load, generation and transmission development. The second one was related to national policies and studies and was divided into the following major parts:

- Energy demand and efficiency.
- Generation.
- Storage.
- General framework.

Further the study did a review of the existing scenario studies, comprising 16 studies, which resulted in more than 40 scenarios. Based on this a set of recommendations to the further work was developed.

The next step was setting of boundary conditions, by definition of a set uncertainties and options, where:

- Uncertainties are factors, which cannot be directly influenced by decision-makers. Combinations of uncertainties constitute futures.
- Options introduce controllable factors (choices) into the scenario. Combination of the options in a scenario creates a strategy.

The identified uncertainties and options were ranked from most important to less important, based on their relevance. Combination of Futures and Strategies create a number of Scenarios as it is shown in Figure 3.

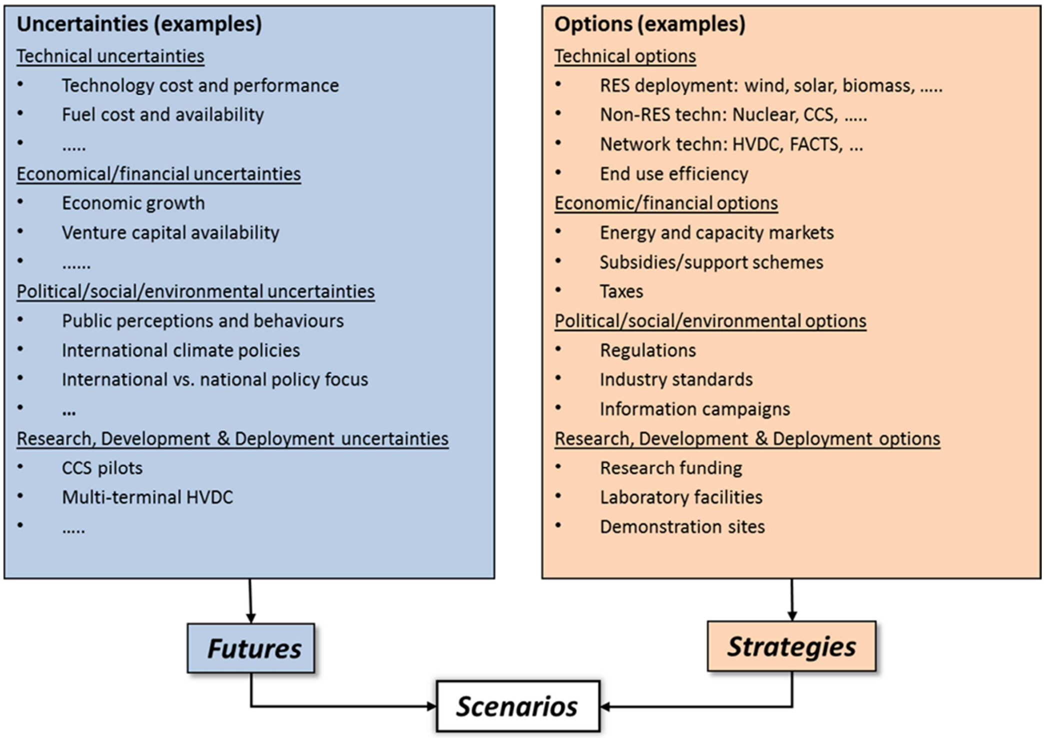
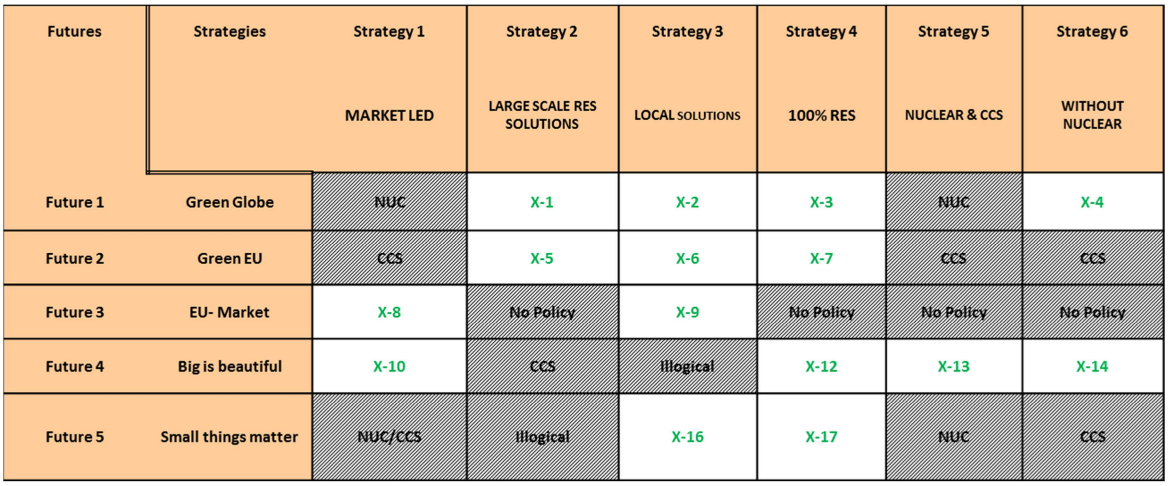


Figure 3: Methodology for scenario set-up [2]

Based on this methodology the study identified altogether five possible futures, which can be achieved by pursuing six relevant strategies. Combination of these generates in total 30 scenarios as it is presented in Figure 4.



Futures	Strategies	Strategy 1 MARKET LED	Strategy 2 LARGE SCALE RES SOLUTIONS	Strategy 3 LOCAL SOLUTIONS	Strategy 4 100% RES	Strategy 5 NUCLEAR & CCS	Strategy 6 WITHOUT NUCLEAR
Future 1	Green Globe	NUC	X-1	X-2	X-3	NUC	X-4
Future 2	Green EU	CCS	X-5	X-6	X-7	CCS	CCS
Future 3	EU- Market	X-8	No Policy	X-9	No Policy	No Policy	No Policy
Future 4	Big is beautiful	X-10	CCS	Illogical	X-12	X-13	X-14
Future 5	Small things matter	NUC/CCS	Illogical	X-16	X-17	NUC	CCS

Figure 4: Generation of scenarios [2]

The next step was elimination of spurious scenarios that involve contradictions between the defined futures and strategies. This reduced the number of scenarios from 30 to 15 (these are marked with green in Figure 4.

The following step was to identify representative scenarios, which will be challenging enough in order to cover a wide scope of possible futures in a set of limited cases to study for the Pan-European transmission grid. The following 5 scenarios were selected:

- Big and market (x-10).
- Large fossil fuel with CCS and nuclear (x-13).
- Large scale RES & no emission (x-5).
- 100%RES (x-7).
- Small and local (x-16).

Figure 5 shows a summary of the five selected scenarios, presented as radar diagrams.

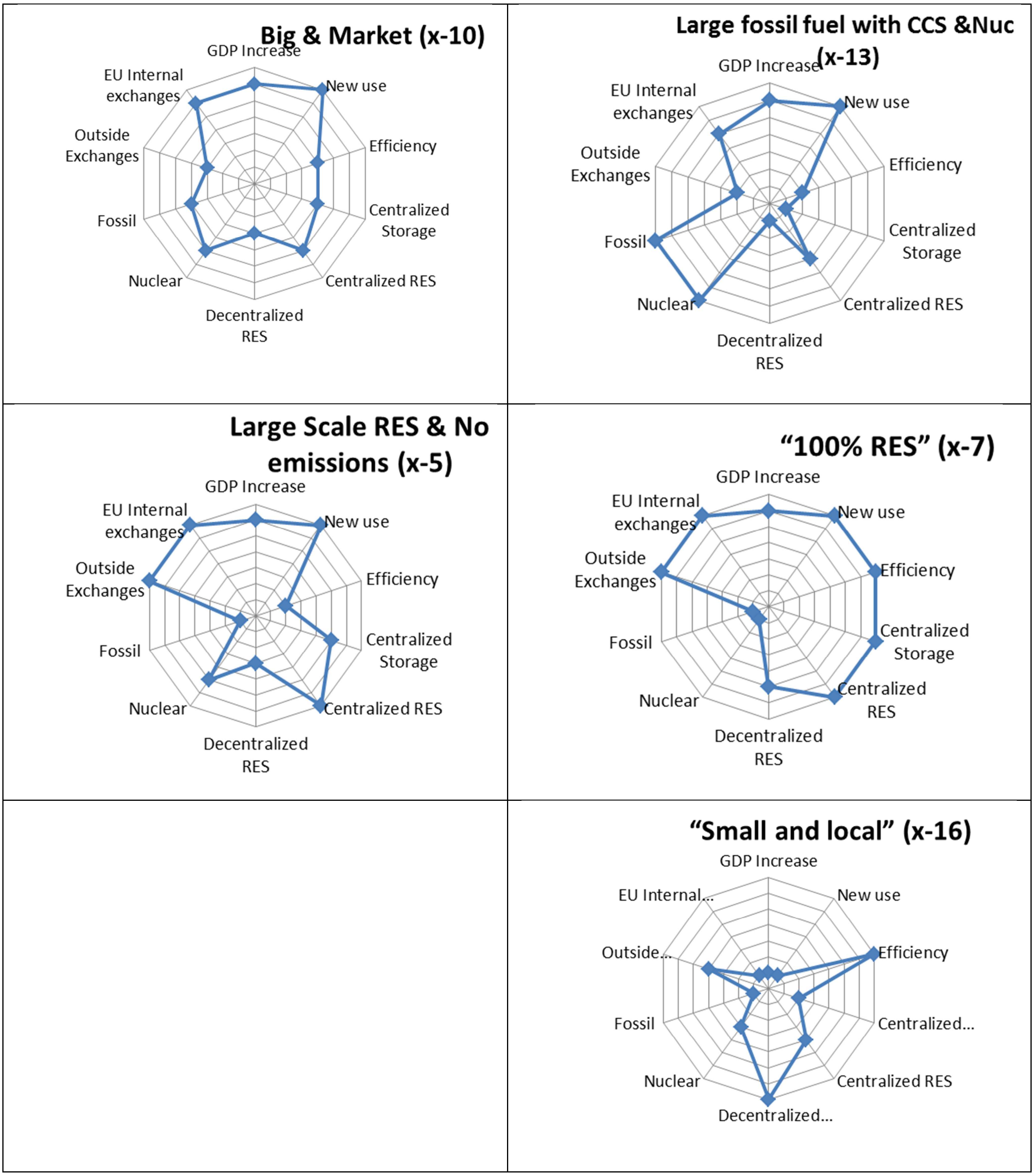


Figure 5: Summary of the selected scenarios [2]

It was specifically stated in e-Highway 2050 project that the selected scenarios are neither predictions nor forecasts about the future. It was not concluded that one single scenario will be more likely to happen than another, nor that one scenario is more preferred or "better" than another. Rather each e-Highway2050 scenario is one alternative image of how the future of

European Electricity Highways (EHS) could unfold.

For this purpose the study kept scenarios, which had contrasted impacts i.e. differ from each other, assessed the impacts of the different scenarios on the transmission grid and pinpointed the most impacting trends which the pan-European transmission system may face up to 2050.

It is necessary to mention that the chosen scenarios in practice set an envelope for all equally possible ways to achieve the 2050 targets (see Figure 6). Based on the previous, it is reasonable to assume that any scenario achieving the 2050 goals, like the one assumed in ELECTRA, will land within the stipulated envelope of the eHighway analysis.

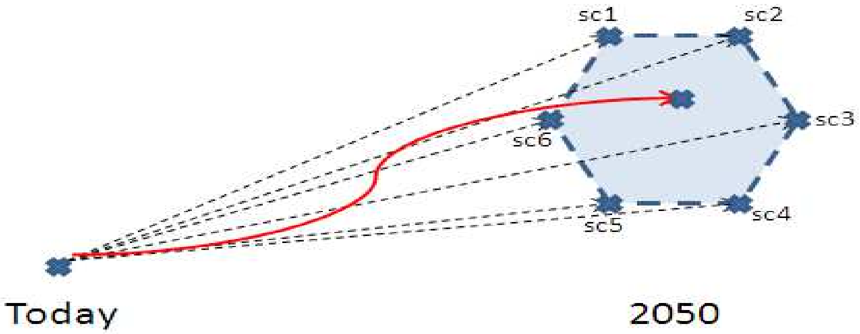


Figure 6: "ELECTRA scenario" landing within the envelope formed by the eHighway representative scenarios

2.3 Key trends and assumptions that impact the future (2030+) voltage and frequency control

The e-Highway2050 project has investigated into the different possible scenarios that could meet the objectives put forward by the EU for the reduction of CO_2 emissions and the reduction of the energy dependency. It is the main objective of ELECTRA to build solutions to operational problems that will have to be faced by the kind of scenarios described in the e-Highway2050 project and which could be expected to occur in the future.

The Web-of-Cells concept specified in future chapters of this document is flexible enough to cope with the operational problems that presumably will arise in many scenarios. In other words, ELECTRA will propose control solutions not related to a specific scenario, but instead related to **a number of clear and indisputable trends that fit multiple future scenarios**. Main aspects of these trends are described in the following paragraphs, and constitute the set of assumptions for the so-called "ELECTRA scenario". This identified possible future is far from being conservative and reflects the technical challenges to be tackled by ELECTRA.

The European energy strategy, through its Directive 2009/28/EC sets ambitious goals for the energy systems of the future. This strategy implies a substantial increase of the share of renewable electricity production in the EU, which can only be achieved 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.

According to the European Commission Energy Roadmap 2050 [3] for long-term plans, by the year 2030, around 25% of the primary energy will come from RES and the percentage will increase until up to 60% by 2050. If comparing these forecasts with the results by 2005 (Figure 7), it is clear than the commitment of the European Union with a low-carbon energy future is a one-way journey.

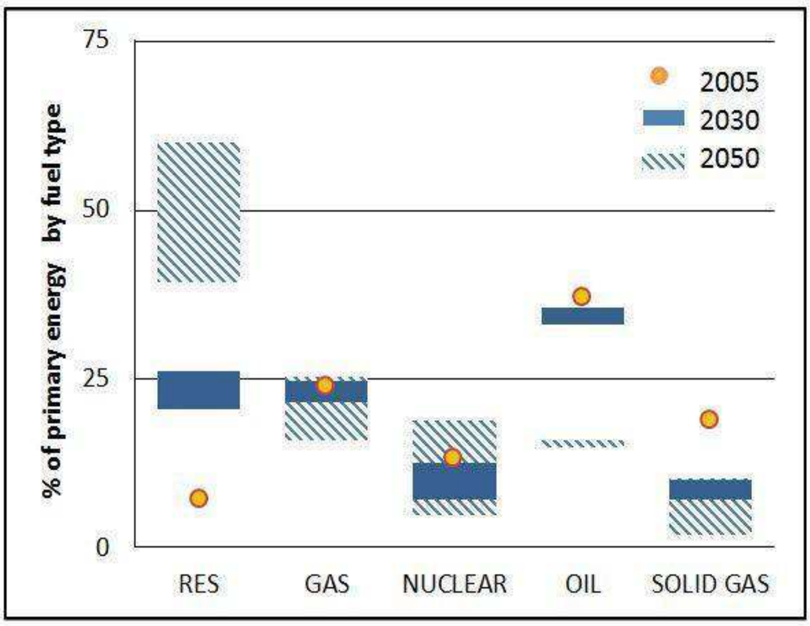


Figure 7: Percentage of primary energy by fuel in 2030 and 2050 horizons

From the previously detailed scenarios of the e-Highway2050, some trends have been derived. They will be used as assumptions in ELECTRA for further developments within the project.

2.3.1 Generation will shift from classical dispatchable units to intermittent renewables

Based on various reports and outlooks, it is expected that by 2030, between 52% and 89% of electricity production will stem from RES [4-5]. The scenarios are still more aggressive under the 2050 scope, where the European Commission foresees a 97% of the electricity generation from RES. RES deployment in the electricity sector is well spread across the EU. Country-specific differences are applicable, mainly as a consequence of the uneven starting point but also reflecting differences in nationally or regionally available RES potential[2] and regulation.

Consequences:

- Paradigm shift needed from generation following load to load following generation.
- Increased need for balancing reserves activations to correct in real-time the residual imbalances caused by forecast errors of intermittent generation and (flexible) loads.
- Even though on a global system level these forecast errors may partially balance each other, they may cause significant local imbalances resulting in insecure load flows that deviate from the planned and scheduled ones.
- The replacement of a significant portion of large synchronous rotor based generation by RES causes a reduced power system inertia in turn resulting in a much higher rate of

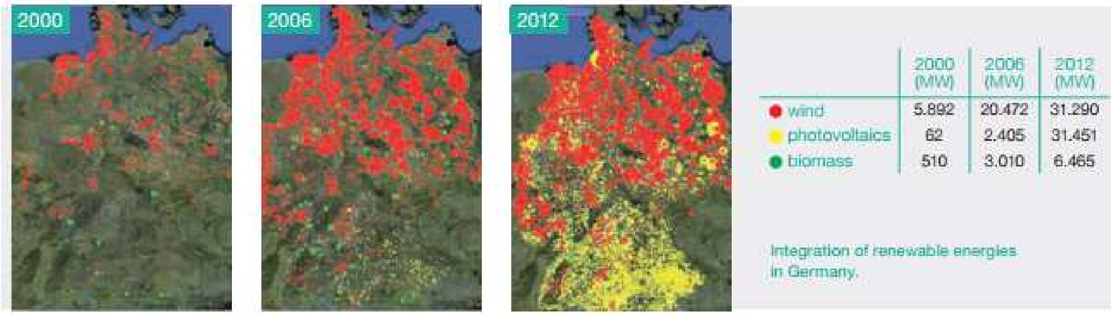
change of frequency (ROCOF) that has to be controlled by means of corrective action.

- Due to their intermittent nature and limited dispatchability (because of the weather dependency of their production), RES resources are less adequate for providing balancing reserves services. Therefore such reserves capacity will be provided by peaking power plants (more adequate than large CCGT), flexible loads and/or storage. Storage is expected to be a competitive alternative for peaking power plants for offering ancillary services as early as 2020 [6].

2.3.2 Generation will substantially shift from central transmission system connected generation to decentralized distribution system connected generation

The share production of RES connected to distribution grids will increase. This foreseen increment shows important differences between countries and no average values can be easily obtained since not equivalent comparisons can be accomplished. One important key factor when examining the statistics is the diverse voltage levels grouped under the heading of “distribution”. Distribution gathers voltage levels up to 33 kV in France, 60 kV in Portugal, 70 kV in Belgium or 132 kV in the UK. This means that, as an example, greater proportion of fossil fuel power plants are connected to distribution levels in countries with higher distribution voltages. This results in noticeable differences in the 2030 forecast of RES connected to distribution grids, which can vary from 76% in Portugal to 100%, as in Italy or Ireland [7].

The German case is analysed as an example. Germany has a big potential of solar and wind power that will be almost tripled in the long-term horizon (2030). This new RES generation injected at distribution levels will suppose an increase from the current levels (68%) to ~83% by 2030. The trend of displacement the generation to distribution levels started several years ago and important advances have already been accomplished, as shown in Figure 8.



	2000 (MW)	2006 (MW)	2012 (MW)
🟥 wind	5.892	20.472	31.290
🟨 photovoltaics	62	2.405	31.451
🟩 biomass	510	3.010	6.465

Integration of renewable energies in Germany.

Figure 8: Example of the explosive growth of distributed RES generation (in Germany) [4]

Consequences:

- More injection at LV distribution grid increases the risk of local voltage problems and congestions (especially given the expected increase in electricity consumption: see scenario assumption 2.4)
- The location of the sources of voltage issues and balancing problems that require reserves activation, will partially shift from central transmission system level (HV) to distribution

system level (MV/LV)

- Also the resources that can help to address voltage and balancing problems, i.e. resources that can provide ancillary reserves support will move, in a high percentage, from central transmission system level (HV) to distribution system level (MV/LV).
- A (HV located) central system operator no longer has the system overview to effectively dispatch reserves so coordination between operators of different voltage levels will be essential, taking into account the full distribution system state.
- The distribution and availability of resources (production as well as storage) may vary significantly from location to location.

2.3.3 Generation will shift from few large units to many smaller units

Electricity production units connected to the distribution grid are typically much smaller than large central power plants. There will be a shift towards more electricity production connected to the distribution grid, since electricity generation will shift from a few large plants to many smaller units. Next to the smaller units, there will still remain large central power generators, be it increasingly more of a RES nature (e.g. large wind-power plants (onshore and offshore), hydro-electric power plants, marine energy parks, etc.)

Moreover, a transition is going on within electricity production investments from an “OPEX” -driven model towards a model that is more “CAPEX” driven, leading to an increase in investments in smaller production units as opposed to larger (classic) production plants [8].

Consequences:

- There will be more locations –and chances– where incidents (like generation outages) can happen, but each individual incident will have a smaller –local– impact.
- Local –distribution system level- incidents may have a local impact that goes unnoticed at a system global level
- There will be a shift from synchronous generators to power electronics interfaced generation. Power electronics interfaces lead to specific problems, such as harmonic pollution and lack of inertia response capability, which both influence the electricity system.
- Since the production portfolio within the overall power system will be subjected to changes throughout the day (e.g. renewable generators are weather dependent), the electromechanical time constant (and system response time) of the power system will depend on the time of the day.

2.3.4 Electricity consumption will increase significantly

Due to the GHG emission reduction targets, there is a drive towards the electrification of transport and heating/cooling, resulting in an expected increase of the electricity consumption of around 43% [9]. The EV massive integration into electrical networks is expected to happen between 2030 and 2050. By the year 2050, it is schedule a rate of 80% of hybrid and pure electric vehicles [10]. This will have an impact mainly at distribution level. This increase will be partially compensated by the electricity consumption reduction resulting from energy efficiency measures and targets.

Consequences:

- The load on the grid infrastructure will raise, increasing (the risk for) congestion and local voltage problems.
- This will happen, in particular, in the distribution grid, where the majority of additional load resulting from the electrification of heating (domestic and tertiary sector) and transport will be situated, and where as well the distributed RES generation is located.
- Due to increased share of space heating and EVs, the consumption becomes much more temperature-dependent and thus less predictable and volatile. On the other hand, these loads represent a large potential of flexibility in the grid.
- An increase in consumption, increases the risk for coinciding consumption peaks, in turn causing large power flows. Power peaks are especially expected if consumers will be encouraged to consume electricity following the production pattern of renewable production plants (that are not necessarily connected to the same grid segment).

2.3.5 Electrical storage will be a cost-effective solution for offering ancillary services

Higher penetration of RES into distribution networks will increase the needs of reserves for ensuring system stability. Storage can help to decrease the requirements of back-up conventional energy with security of supply purposes. The excess energy proceeding from RES during high generation periods can be transformed back to electricity for balancing the power system in low-demand periods.

According to the recommendations for a European Energy Storage Technology Development Roadmap [11], prices of (electrical) storage are projected to drop, making distributed storage a competitive solution compared to traditional resources for reserve services. Next to that, the energy storage roadmap claims that distributed storage located at a utility substation on the distribution grid has a much higher value than central storage because it offers distribution upgrade deferral and circuit stability control. The forecast in the 2030 horizon for energy storage by its application is displayed in Figure 9.

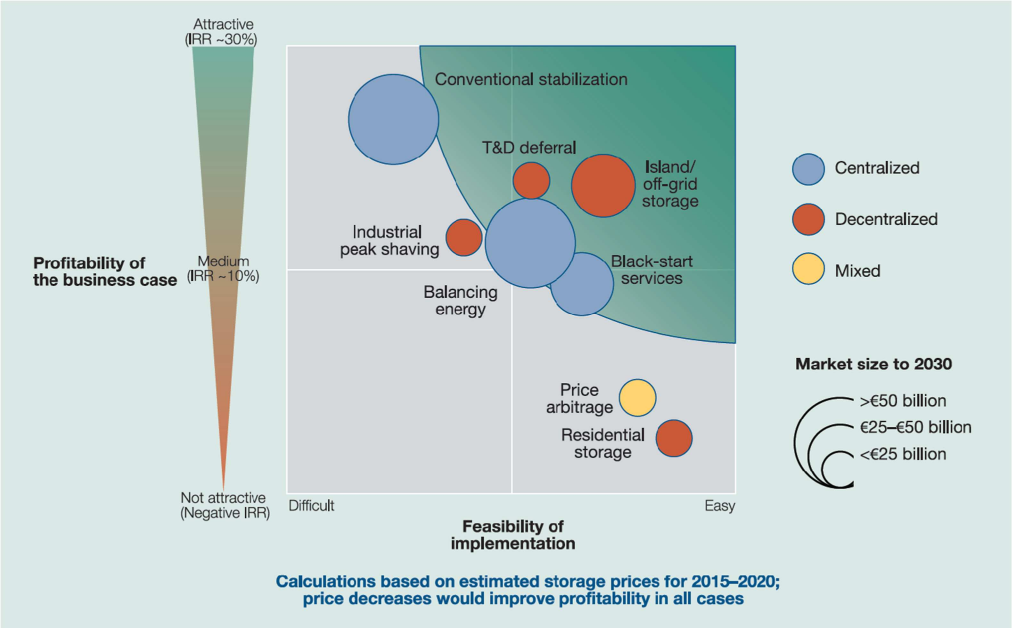
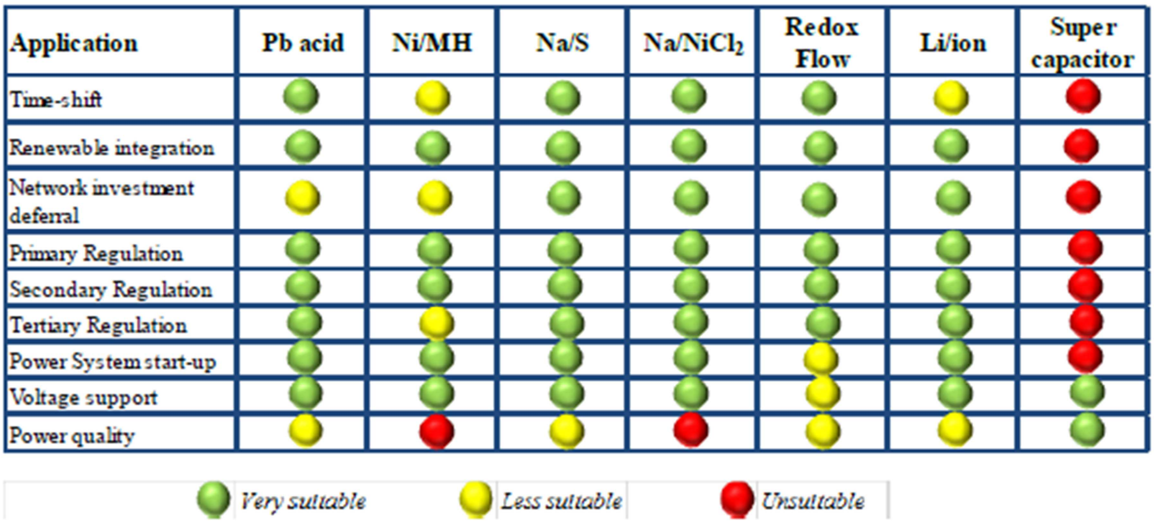


Figure 9: Electrical Energy Storage market forecast by application for 2030 [12]

Consequences:

- Local Electrical storage will be a common source for reserve services for balancing and voltage control. Storage is well suited to deal with continuous small up and down fluctuations caused by intermittency and forecast errors. Moreover, it has a larger flexibility range in both directions and fast reaction time. Some technologies are commercially available nowadays and its used is extended for its use in power networks. As an example, Figure 10 shows a comparison of the suitability of diverse battery technologies for grid operation applications.



Application	Pb acid	Ni/MH	Na/S	Na/NiCl$_2$	Redox Flow	Li/ion	Super capacitor
Time-shift	🟢	🟡	🟢	🟢	🟢	🟡	🔴
Renewable integration	🟢	🟢	🟢	🟢	🟢	🟢	🔴
Network investment deferral	🟡	🟡	🟢	🟢	🟢	🟢	🔴
Primary Regulation	🟢	🟢	🟢	🟢	🟢	🟢	🔴
Secondary Regulation	🟢	🟢	🟢	🟢	🟢	🟢	🔴
Tertiary Regulation	🟢	🟡	🟢	🟢	🟢	🟢	🔴
Power System start-up	🟢	🟢	🟢	🟢	🟡	🟢	🔴
Voltage support	🟢	🟢	🟢	🟢	🟡	🟢	🟢
Power quality	🟡	🔴	🟡	🔴	🟡	🟡	🟢

🟢 *Very suitable* 🟡 *Less suitable* 🔴 *Unsuitable*

Figure 10: Comparison among different electrochemical storage systems for the key grid applications [11]

- Storage at distribution level can provide voltage support control, improve voltage quality or favour the distributed generation insertion thanks to reactive power compensation.

2.3.6 Ubiquitous sensors will vastly increase the power system's observability

With the proliferation of distributed generation, and the price of sensors and solutions set to fall dramatically over the next few years, the inclusion of sensing and monitoring systems is starting to make compelling economic sense. It is essential for providing grid operators with a holistic view of the grid and its critical components [13].

Consequences:

- Many more measurement points at all voltage levels, such as PMU's, smart metering infrastructure, etc.
- In case of many sensors being present, not all information will be relevant to every grid control or other aim. Useful information will have to be extracted by some kind of aggregation algorithm, resulting in new observables and better observability of the power system.
- It must be acknowledged that a challenge with many measurement equipment technologies (such as smart metering) today is its latency and reliability: transfer of data might not always be fast enough for (real-time) control applications, or it may be unavailable or disturbed.

  By way of example, in Figure 11 it is displayed a comparison of the increment in the percentages of smart meters installed in different regions of Europe from 2011 with regards to the expected installations in 2015.

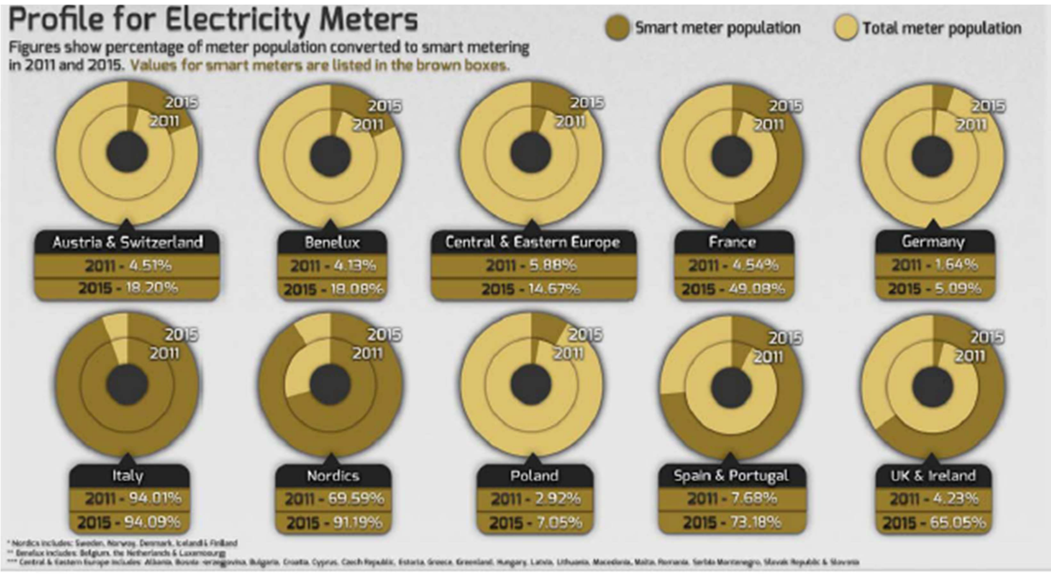


Figure 11: Illustration of increase of smart meter installations in Europe [14]

2.3.7 Large amounts of fast reacting distributed resources (can) offer reserves capacity

Vast amounts of flexible loads will be available at all voltage levels (especially at the low voltage levels). The same holds for local storage. Both of these have very fast reaction and ramp times. Additionally, both of these will be connected –through public ICT infrastructure– to grid operators and market parties offering there flex capabilities as a service.

Consequences:

- There will be a large number of distributed resources with a large variety (production as well as consumption and storage resources) that will be able to provide Frequency Containment Reserves (possibly imposed participation through regulation).
- There will be a large number of distributed resources with a large variety (production as well as consumption and storage resources) that will be able to provide Balance Restoration Reserves.

3. Conceptual functional architecture

Based on the ELECTRA scenario assumptions as outlined in the previous section, the present grid management structure and organization for frequency and voltage control, with the TSO being responsible for reserves activation in its Control Area, is no longer effective [15-16].

The approach today, with the TSO as central actor responsible for the management of ancillary services for voltage and frequency control has proven effective because (and as long as) power flows are mainly unidirectionally downstream and the resources for reserves needed to address frequency (or balance) issues and voltage problems, are (mainly) located centrally at the HV level and their activation hence only impacts this unidirectional downstream power flow. But with the shift to the distribution grid of the problem causes, as well as the reserves resources that must be activated to resolve them, a new control architecture may be more appropriate.

Two future architectures are considered:

1. A (still) centrally managed future, where frequency and voltage control is managed by the TSO who controls reserves located both at distribution grid level and at transmission grid level:
    - The TSO remains responsible for the real-time reserves activation and dispatching within his Control Area / Control Block.
    - To securely dispatch reserves located at the distribution system, ensuring that this does not cause local voltage or congestion problems, the TSO must be informed about the distribution grid state. This requires increased monitoring of the distribution grid by the DSO, as well as bi-directional communication such that the DSO provides the TSO with the desired information.
    - But local problems, related to the larger share of RES generation located at the distribution grid level, will or may not be noticed by the TSO at system level. For example, voltage issues on the local distribution grid due to increased production of RES remain unnoticed by the TSO.
    - With the increasing amount of intermittent RES generation at distribution grid level, there will be an increasing amount of residual local imbalances that may counterbalance each other at system level. Local imbalances caused by forecasting errors may result in insecure local load flows, i.e. 'additional' power flows compared to the scheduled set-point flows may cause congestions or overloading of tie lines without triggering central –restoration- frequency control. But even in case these would not lead to congestions, they would lead to excessive and avoidable losses in case reserves would be activated in an (geographical) area that is at a large distance from where the imbalance (deviation from the scheduled balance) is located.
2. A decentralized managed future, where the power system is divided in grid areas, called Cells, which can provide local balancing and voltage control with the purpose of solving local problems locally.
    - Each cell has assigned a Cell System Operator who takes responsibility for the real-time reserves activation and dispatching in his own cell (i.e. assuming responsibility

similar to former TSO responsibility in its Control Area).

- In each cell, the Cell System Operator maintains an accurate view on the cell state, and dispatches reserves located in the cell in a secure manner based on his knowledge of the cell state. In principle, no global system state information is required for this. In this way, a ‘divide and conquer’ way of tackling voltage and balancing issues is implemented.
- In this way, local problems are resolved locally, in the cell (simple and effective control paradigm) in a fast and secure manner, limiting complexity and communication overhead (i.e. no bidirectional communication between DSO and TSO is required for reserve activation). There is no need to expose local problems at global system level.
- Next to the benefits related to solve local problems locally (reducing losses, mitigating congestion risks, limiting communication data volume, cost and time), this as well allows for a more optimal use of the available grid capacity thanks to a divide-and-conquer benefit. Due to the smaller dimensions and complexity of a cell, load flow checks and optimizations for instance can be done to an extent that would be computationally not affordable for a complete TSO Control
- A Cell System Operator is responsible for the balance within his own cell. For maintaining that balance he can procure reserves from within his cell but also ‘cross cell border’ reserves from neighbouring cells.

First steps towards an architecture following the ‘centrally managed’ philosophy, i.e. option 1 above, were described in the ELECTRA internal report R3.1 [17]. Later was decided, after internal discussions, to opt to develop a control architecture for the second option, mainly because it allows for a more straightforward and flexible control of the power system in the future, as further explained below.

3.1 Cell-based architecture for decentralized frequency and voltage control

In our proposal, the EU power grid is decomposed into a web-of-cells structure, where the cells are defined as follows:

- A group of interconnected loads, concentrated generation plants and/or distributed energy resources and storage units within well-defined grid boundaries corresponding to a physical portion of the grid and corresponding to a confined geographical area.
- A cell is not a micro-grid. In ELECTRA, microgrids are defined as being able to operate in grid-connected as well as “island”-mode [18]. Being able to operate in island mode is not a requirement of a cell. See ANNEX B for a more elaborate comparison.
- A cell is in ‘balance’ when it is able to follow the scheduled consumption/generation schedule that was agreed between the BRPs and TSO at t_0.
- Cells have adequate monitoring infrastructure installed, as well as local reserves capacity enabling them to resolve voltage and cell balancing problems locally.
    - But there is no demand that cells must be able to operate in islanded mode, i.e. they can rely on structural imports or exports for their local BRP market-based balancing

    (micro-grid capabilities are optional).

  - Only for the real-time resolving of local residual imbalances or local voltage regulation, it is expected that sufficient local reserve capacity is available. Cells are dimensioned accordingly (possibly dedicated reserves capacity like local storage is added). The procurement of reserves capacity is out of scope for this document, but it is proposed that guidelines, similar to those currently employed at Control Area level, are used to define the type and amount of reserves capacity required for each cell.

- Cells are connected to neighbouring cells via inter-cell physical tie lines ; there can be multiple physical tie-lines between any two cells. At a given moment of time, any connection can be either open or closed.
- A cell is managed by a Cell System Operator (the TSO or DSO 'Cell Operator').
  - But there may (read: will) be multiple BRPs and aggregators active in a cell.
  - The extension of the responsibilities and role of DSOs in particular is being investigated within other projects as well, such as Grid4EU [www.grid4eu.eu] and evolvDSO [19].
- Examples:
  - The HV part of a TSO Control Area could be a cell
    - The MV and LV parts of the grid belonging to the Control Area may consist of multiple cells

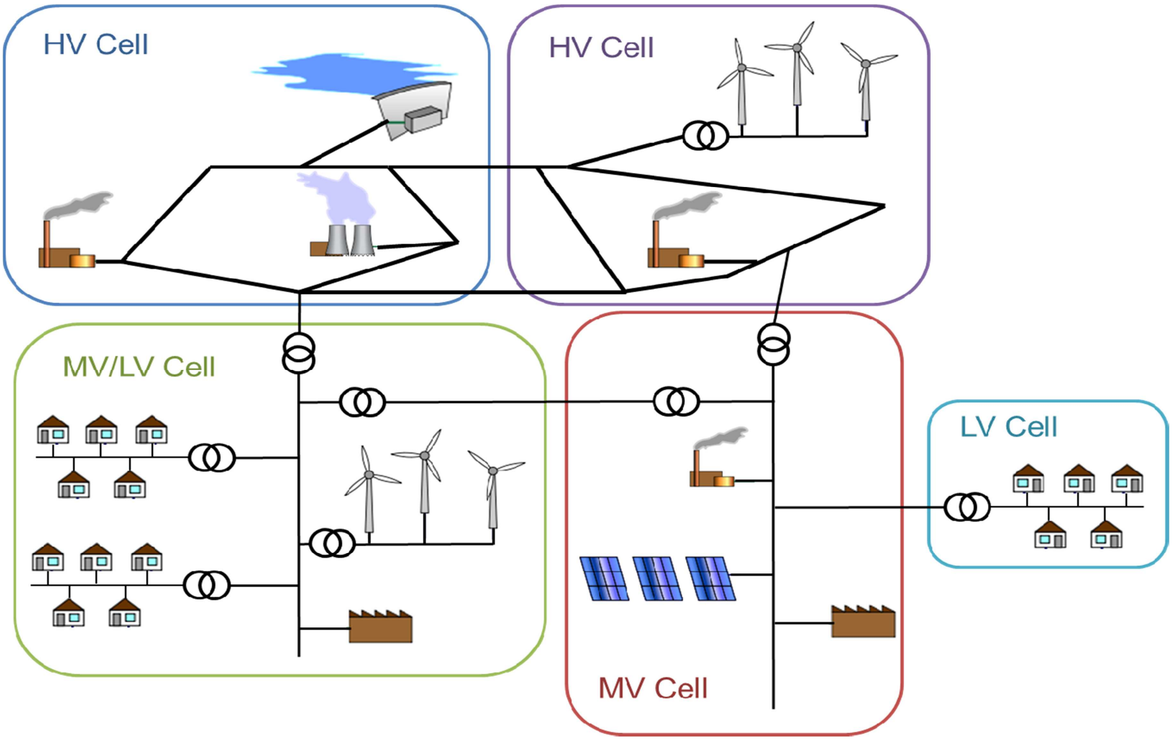


Figure 12: Schematic example of proposed "Web-of-Cells" architecture

While the cell-based ‘solve local problems locally’ in the cell approach is simple and effective, it has the consequence that global reserves activation optimization is disregarded. Examples of such system-wide optimizations are:

- Economic optimization, by replacing (automatically activated) restoration reserves by more cost-effective restoration reserves
- Imbalance netting, system-wide reduction of opposite sign activations

Therefore, the proposed control architecture will add an inter-cell coordination control layer to support system-wide optimized reserves activation if the cell state and system state allows. It must be noted though that by allowing inter-cell coordination, the local cell balance will not necessarily be completely restored by activating balancing reserves in an adjacent cell. Still, on a system-wide scale system balance must be reached.

3.2 Cell System Operator role

Each Cell System Operator is responsible for establishing and maintaining automatic control mechanisms as well as procuring sufficient reserves, contributing to a stable and secure system operation. This is done by:

- Contribution to containing and restoring system frequency and a secured power exchange by maintaining the cell balance under operating schedules by timely activation of local reserves.
- Containing and stabilizing local voltage within secure limits.

In real-time, the operating state of a cell and the whole power system has to be monitored to ensure continuous secure operation and the appropriate response to disturbances. Whereas many systems are automatic, some responses may be manual.

A Cell System Operator has the role of monitoring the system and its interconnections, to initiate control actions in response to critical events in order to maintain secure and stable operation. Further, it is the Cell System Operator's responsibility to coordinate with neighbouring operators regarding control actions that affect them as well.

Due to high amounts of fluctuating RES, it may be beneficial for (groups of connected) cells to cooperate in their balancing efforts, so that natural fluctuations (prevailing wind, PV cloud cover or forecast errors) may be minimised across cell boundaries. Also pooling of balancing resource procurement may be an option for cooperation between cells.

On activations, cells can cooperate to remove the system deviation in a more system-optimized manner (e.g. imbalance netting, system-wide reduction of opposite sign activations). This is only allowed if the system is in a safe (normal) state.

3.2.1 System and cell operation modes

To support the decision-making of operators, a standard framework must be provided that distinguishes normal situations from emergency situations in power system, so that different sets of appropriate control actions can be defined. With respect to operation modes, the terms “secure” and “stable” operation define essential limits with reference to definitions in [3].

In general, three main operating modes can be identified:

3.2.1.1 Secure operation = 'green zone'

- "Security — the ability of the power system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system components."
- "Security of a power system refers to the degree of risk in its ability to survive imminent disturbances (contingencies) without interruption of customer service. It relates to robustness of the system to imminent disturbances and, hence, depends on the system operating condition as well as the contingent probability of disturbances."
- "Observables" are the 'secure operation margins' as defined by probability & scale of disturbances & stability limits.

3.2.1.2 Stable operation = 'yellow zone'

- The yellow zone refers to situation in which the system is stable, but not secure; i.e. it may not be able to absorb further disturbances
- "Stability of a power system, refers to the continuance of intact operation following a disturbance."
    - Stability (and 'intact operation') is defined in several categories, referring to a number of known mechanisms in which stability may be lost.
    - Stability boundaries depend on the present operating state and must be considered through derived observables.
    - Each instability mechanism has its appropriate observables (it cannot be assumed that in general all possible instability mechanisms are known and observable).
- "Security and stability are time-varying attributes which can be judged by studying the performance of the power system under a particular set of conditions."
    - As security is defined in terms of stability boundaries as well as likely disturbances, also security is a time-varying, non-static concept

3.2.1.3 Emergency operation = 'red zone'

- The red zone refers to conditions under which system stability is about to be lost within a projectable evolution of events.
- Emergency operation warrants control actions that are not in coordination with the market, with the objective of avoiding a violation of stability boundaries and / or returning to a safe and stable operating state.

3.2.1.4 Cell operating mode/state

The cell operating state is defined on the basis of observables relating all relevant observables that characterize the cell operating state, in analogy with a traffic light [19]:

- Normal (green): no limits violated, secure with respect to any single foreseeable contingency: objective is to maintain secure operations
- Alert (yellow): no limits violated, not secure: return to secure operating state

- Emergency (red): limits violated, immediate action required

Further operating states can be defined to provide higher granularity of observables and control actions.

3.2.2 Cell cooperation and interconnection operating modes

Operators of adjacent cells and of networks of adjacent cells may cooperate with respect to cell responsibility, partially re-organizing the operation responsibility on the basis of their individual responsibility and their collective responsibility to other cells not part of the cooperation network.

Moreover, operators are jointly responsible for identifying the reserve and control requirements for stability problems that have a larger scope than the cell boundary, e.g. in the case of frequency control, all Cell System Operators of a synchronous area are responsible.

Any mechanism to enable inter-cell cooperation must allow for a cell to procure and activate reserves in another cell if this can be done in a safe way and is economically justifiable. The activation of reserves in an adjacent cell must take into account that the position of a BRP in that adjacent cell may be impacted. Also, deviations of power flows within the cell compared to their scheduled values are increased. Increased deviations may not be a problem in itself, but care must be taken that the cell operation mode is still safe.

While activating reserve resources in any adjacent cell, care must be taken not to jeopardize subsequent reserve activation. Procuring reserves from an adjacent cell should not make the adjacent cell incapable of activating a (local) reserve on the next event.

3.2.2.1 Inter-cell transfer of operating mode

The operating mode of one cell can be transferred to that of a neighbouring cell, depending on the type of collaboration that is in place. Observables that relate to the overall system state (frequency, some stability margins) affect all cells correspondingly.

The ‘state’ of the route (segments and equipment) through which the power will flow between the source in one cell and the sink in another cell needs to be known, as well as how the proposed activation in another cell will change this route. Hence as a result of allowing inter-cell cooperation, the system state may change, and may become less safe. For example, margins will become smaller.

3.2.2.2 Cell interconnection mode

The state of a cell interconnection with respect to operating limits:

- Normal (green): no limits violated, secure with respect to any single foreseeable contingency.
- Alert (yellow): no limits violated, not secure.
- Emergency (red): limits violated, immediate action required

3.3 High level conceptual impact of the cell concept on voltage and frequency control

In the proposed web-of-cell based architecture, Cell System Operators are responsible to contribute to containing and restoring system frequency, as well as containing local voltage within secure and stable limits.

For this purpose, proposals for frequency and voltage control within a Web-of-Cells system are developed, and explained below. It must be noted that by moving to a cell-based architecture, different observables and control aims may be required. Therefore, a sound cell-based architecture is more than the transpose of existing practices from the present TSO to a Cell System Operator.

3.3.1 Frequency/Balance control

Frequency deviations result from imbalances between consumption/load/import and generation/export. Frequency deviations are seen fast and system wide.

Market parties (BRPs in particular) are responsible to keep the balance in their portfolio. Each day is divided in time blocks (e.g. 15') 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 (intraday up to intraday market gate closure t_0). After intraday market gate closure (t_0) BRPs submit their production schedules to the Cell System Operators. After t_0 and during each of the time-blocks the Cell System Operator takes care of real-time balancing of residual imbalances by the activation of reserves that restore the system balance. Residual imbalances may be caused by remaining imbalances at t_0, forecast errors causing deviations in the time-window compared to what was scheduled, or incidents.

When there is an imbalance, the frequency starts to deviate from the set point system frequency.

Frequency stability is a fast and global system wide issue. It must be reacted fast upon and is therefore addressed with a cascade (from fast, automatic, expensive to slow, manual and economically optimized) of inertia response (slow down frequency changes), primary control (containment), secondary control (restoration) and tertiary control (optimization).

In the proposed cell-based architecture, the main principles of Load-Frequency Control still apply (not surprisingly, as the physics does not change). These principles are however applied at cell level instead of at Control Area level, requiring novel observables and a novel control architecture.

The proposed mechanism for frequency control in a web-of-cells based system consists of the following parts: inertia steering control, frequency containment, balance restoration and balance steering control. An overview of the proposed mechanism is shown in Figure 13. Each part is explained in depth below.

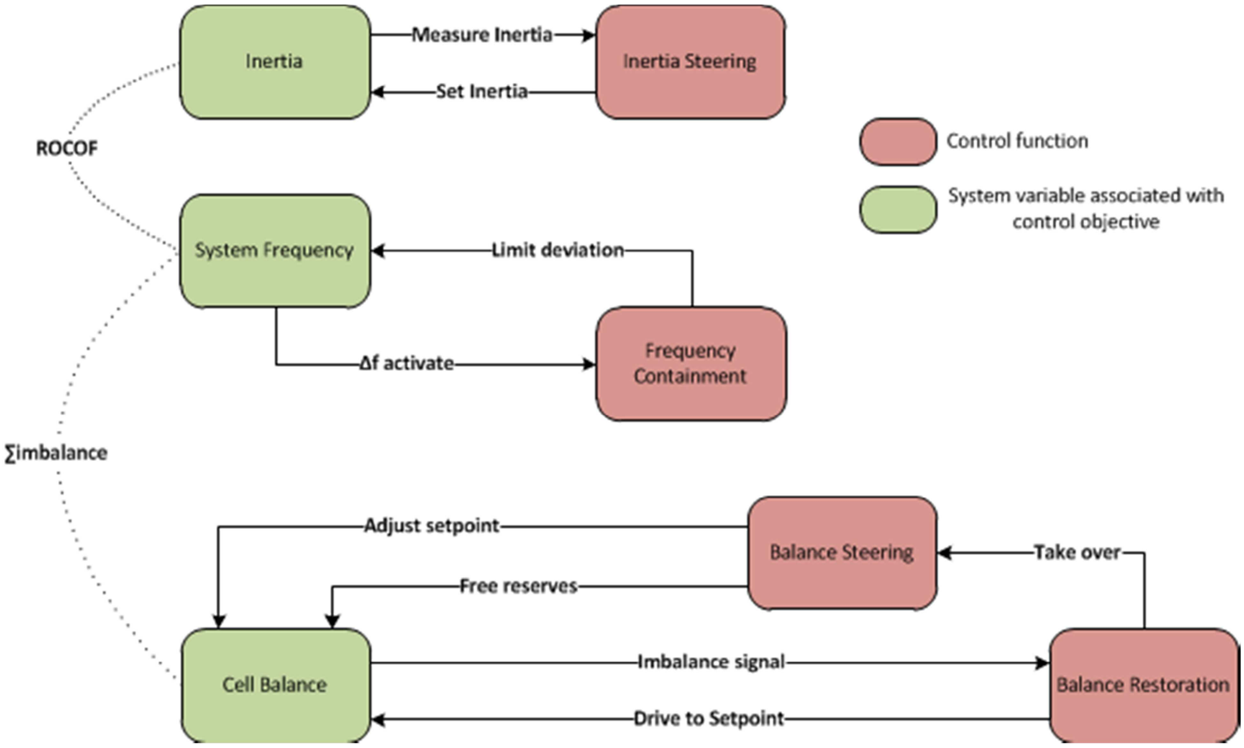


Figure 13: Overview of proposed balancing control structure of a cell[1]

3.3.1.1 Inertia Steering Control

The effect of a change in inertia steering power in a power system is quite different from that of a change in balance power. Adding inertia response power smooths both small and large frequency variations, whereas changing balance power changes the stationary value of frequency itself by virtue of the power-frequency droop curve of the generators. This is shown in the next graphs:

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[1] Balance Control will act on local imbalances even if no frequency deviation that would necessitate frequency control is observed. In case of large (central) incidents that do cause a frequency deviation that requires FCC to be activated, the Balance Control will operate in parallel, and by removing all imbalances implicitly have a *frequency restoration* effect.

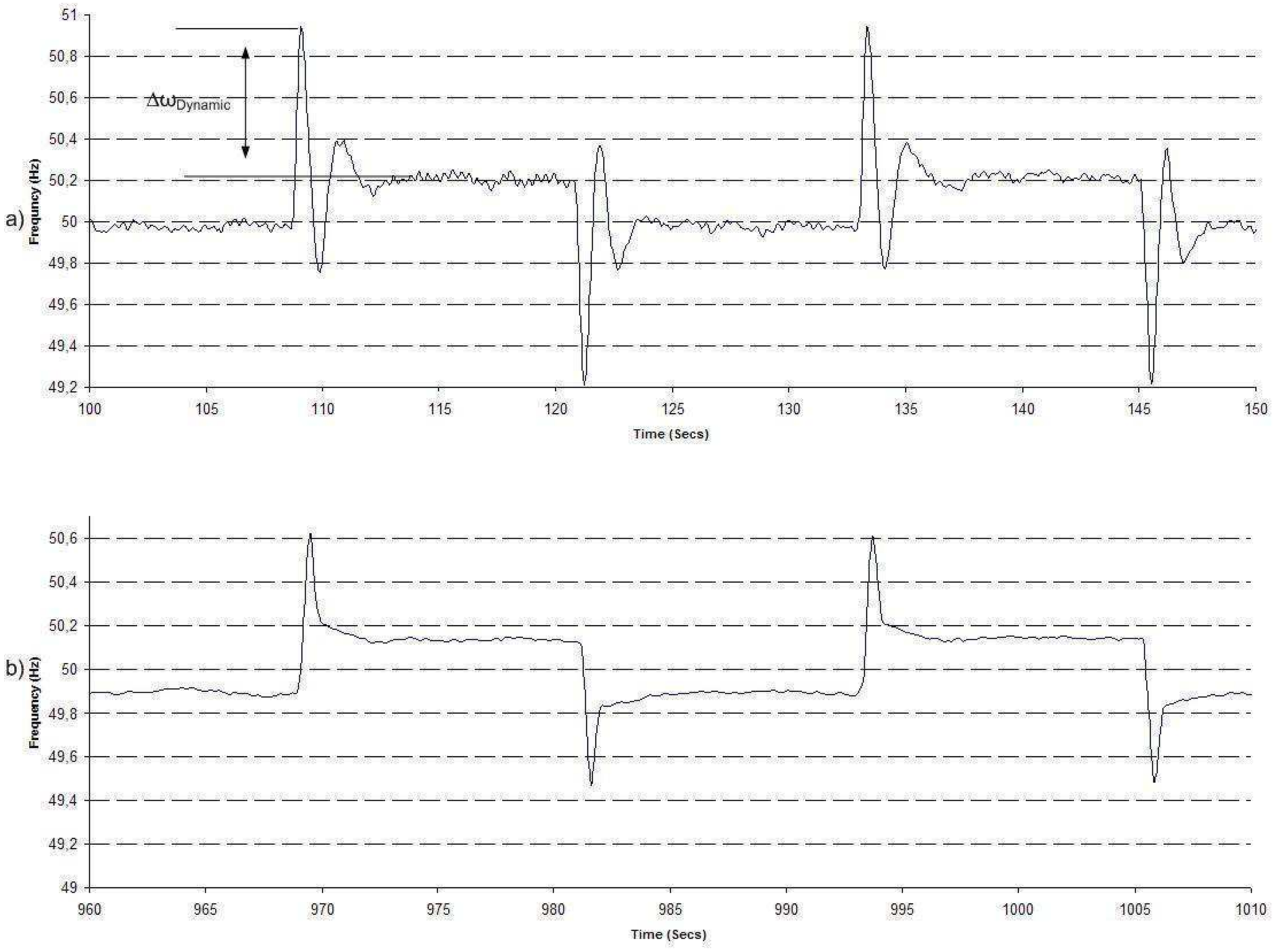

Figure 14: Effect of inertia and balance power on frequency: a) Frequency response of an islanded generator due to significant stepwise load changes, b) With the addition of virtual inertia response power[2]

Inertia response power is needed within the overall power system so that the rate of change of the frequency (ROCOF) after a disturbance and during normal operation is kept within acceptable limits. In today's power system, the ROCOF is limited by inertial response power due to changes in the stored kinetic energy in the synchronous rotating generators, resulting in continuous power exchanges with the grid that counteract frequency changes.

However, in the future power system two challenges will need to be tackled with regard to inertia steering power control:

(1) Increase of converter-coupled generation and load

The installed nominal power of static generators (converters) increases while the installed nominal power of rotating generators decreases. And thus, the direct-coupled inertia response power provided by direct-coupled rotating generators or machines decreases.

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[2] In Figure 14b with the addition of virtual inertia response power, the stationary variations become smaller, and the step response decreases with fewer oscillations. Note that the stationary frequency deviations from 50 Hz are not zero, but keep following the frequency-power droop curve of the generator. Courtesy of the European VSYNC Project, www.vsync.eu (Contract No. TRENI07/FP6EniS07.72935/038584)

Figure 15 gives an overview of inertia response power present in the power system. As can be seen, direct-coupled inertia response power can be replaced by synthetic inertia response power. Synthetic inertia response power is a facility provided to replicate the effect of inertia response power of a synchronous generating unit to a prescribed level of performance, for example:

- Indirect-coupled inertia response power provided by converter-coupled rotating devices (generator or loads, with control algorithms responding to frequency rate of change.)
- Synthetic inertia response power provided by converter-coupled generators with energy storage (with control algorithms responding to frequency rate of change.)

Consequently, the challenge for inertia response power control is that the decrease of direct-coupled inertia response power will have to be substituted by indirect-coupled and/or synthetic inertia response power.

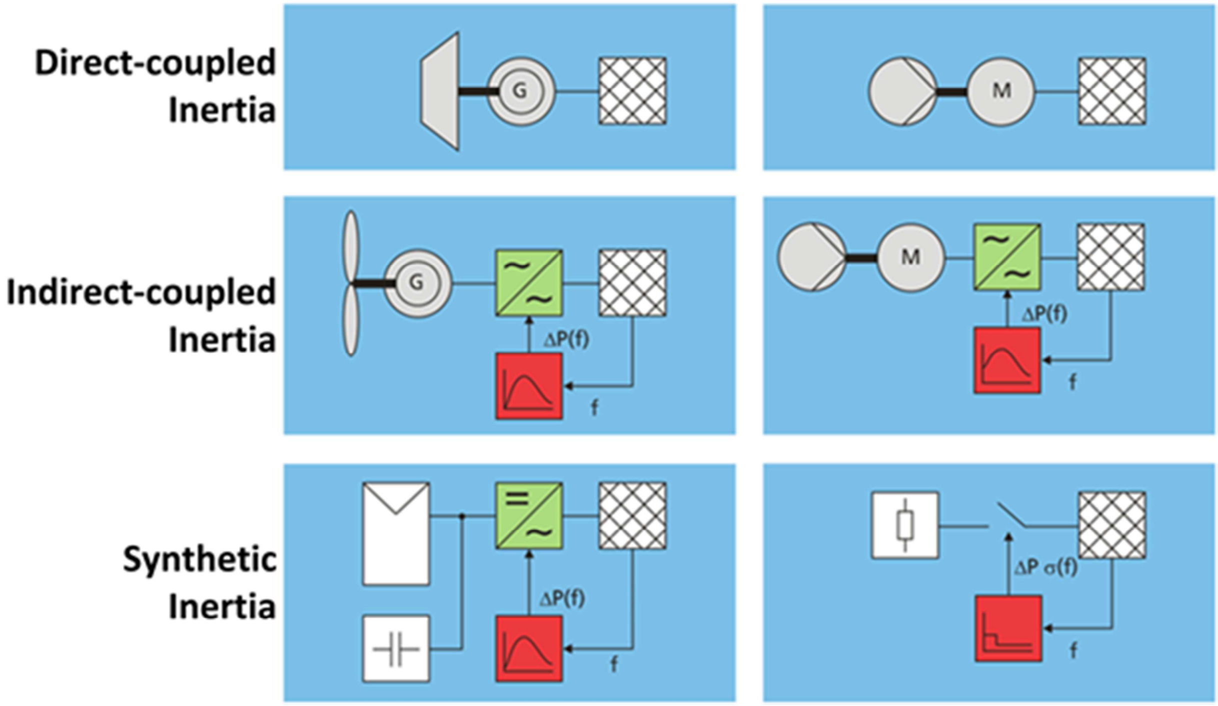

Figure 15: Categories of inertia response power: direct coupled inertia, indirect coupled inertia and synthetic inertia [20]

(2) Time-variant generation mix

In the future power system the ratio between rotating and static generators will change over time. For example during a sunny afternoon the electricity consumption could mainly be covered by PV, i.e. static generation, whereas during a windless night conventional power plants, interfaced with rotating generators, dominate almost exclusively.

Figure 16 exemplary shows the power generation in Germany at the 18th of April 2013. During the afternoon up to about half of the power generation is covered only by wind and

PV. These sources are assumed to be mostly converter-coupled without inertial power response. In contrast during the night the conventional generation with inertial power response clearly dominates.

Consequently the challenge for inertia response power control is that the time-variant ratio of rotating to static generation due to more frequent changes in the generation mix results in time-variant direct coupled inertia.

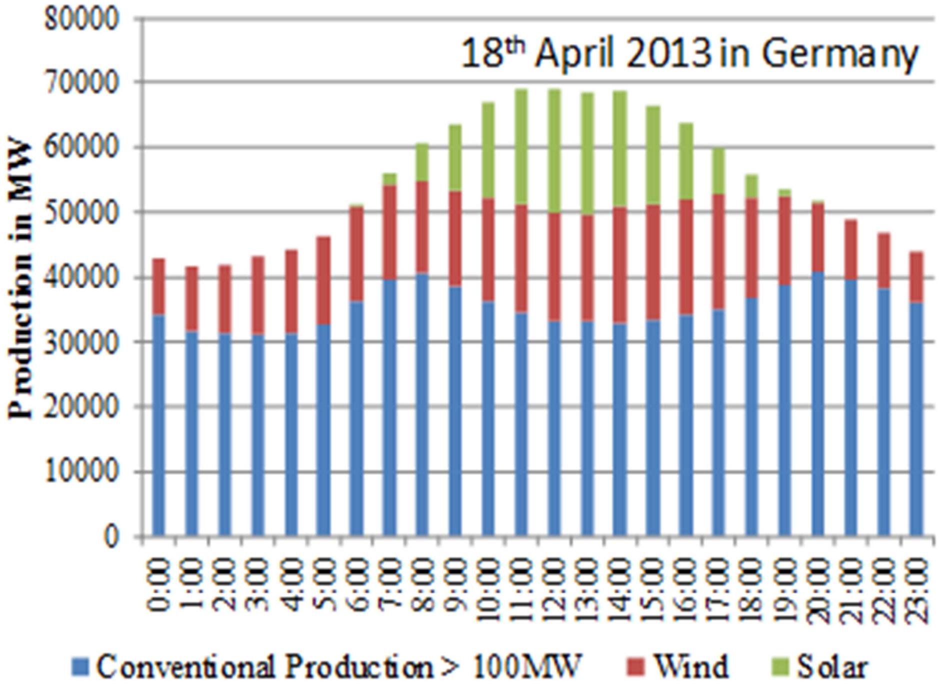

Figure 16: Power generation in Germany at the 18th of April 2013[3]

The control objectives of inertia response power control are:

1. Limitation of rate of change of frequency (df/dt) to a maximum allowed value df_{max}/dt
2. Support to assure a dynamic frequency deviation limit $\Delta f_{dyn,max}$ during normal operation.

Depending on local frequency and rate of change of frequency, each unit involved in inertia response power control, automatically changes its active power contribution or consumption depending on predefined characteristic. It is assumed that an emulation of direct-coupled inertia response power is not an absolute requirement. The basic requirement to be fulfilled is that inertial response power is proportional to the negative time derivative of frequency. Moreover alternative characteristics, not contradicting the former basic requirement, could be implemented in converter-coupled units/loads which are more suitable for them. The requirements will have to be stated in the grid code. Control is implemented within the unit/load itself and therefore reacts on local measurements.

The inertial response power control functionality of each unit is switched on/off by the Cell

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[3] Based on data from www.transparency.eex.com

System Operator. Therefore the Cell System Operator checks on a regular basis if enough inertia response power is present in his system. The parameterization and dimensioning of inertia steering control has to be coordinated with the Frequency Containment process. A schematic overview of the inertia steering control process is shown in Figure 17.

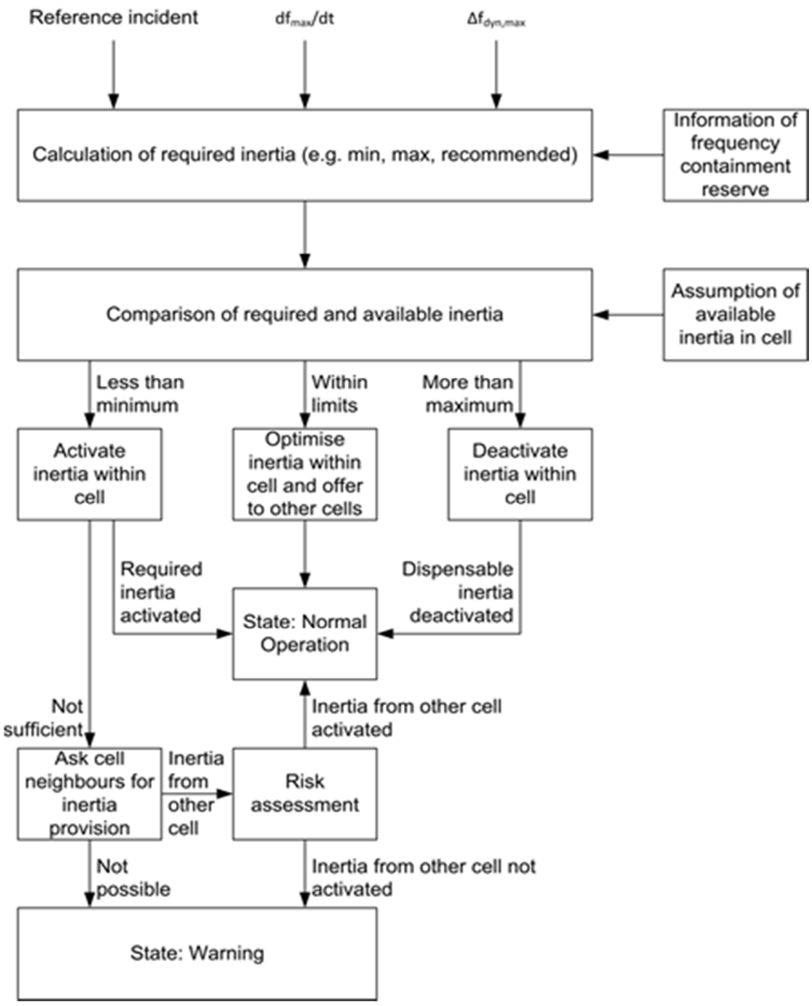


Figure 17: Schematic overview of the inertia control process

3.3.1.2 Frequency Containment Control

The goal of frequency containment control is to stabilize the frequency deviation to a set safe band. The frequency is stabilized by activating the resources providing containment reserves automatically based on local frequency measurements.

Operationally, no fundamental change compared to today's frequency containment control is foreseen, except that the resources providing containment reserves will be different: generating units (in the broadest sense) as well as loads and storage. The reserves will be much more distributed across the power grid (within each cell) and composed of many small contributors instead of few large contributors. Containment reserves will also be delivered by loads and storage solutions which can react very fast and provide very high ramping rates. Consequently, the dynamics of the containment control process will be influenced.

Note that the activation of frequency containment reserves, especially important at low-voltage level, might need to take into account the local grid status, to avoid causing over- or under-voltages.

In conclusion: the main objective of the frequency containment control layer is to stabilize the system frequency while keeping the power balance, until the restoration control layer takes over.

3.3.1.3 Balance Restoration Control

The goal of Balance Restoration control 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, Balance Restoration reserves, available within the cell are activated.

Restoration Reserves may be offered by loads, production units as well as storage units. Response of Balance Restoration Reserves activation orders should be sufficiently fast. The exact timing requirements will be examined in WP5 and WP6 of the ELECTRA project. It is assumed that (almost) all prosumers, that are connected through public IP infrastructure, will be able to offer fast Balance Restoration reserve capacity, e.g. through their flexible loads, and possibly local storage. The combination of all those resources will give the Cell System Operator a sufficient amount of restoration reserve capacity.

By the activation of resources providing Balance Restoration reserves, containment reserves are freed up to deal with subsequent incidents.

Each Cell System Operator is responsible for activating Balance Restoration reserves when an imbalance within his cell is detected. Within the Balance Restoration control layer, it is assumed that only resources from within the cell can be procured as Balance Restoration reserves.

Dispatching the reserves by the Cell System Operator is based on an ordered list taking into account economic factors, but potentially others as well (fairness,…). Before activation the local grid status is checked so that activating reserves does not cause congestion or voltage issues within the cell.

In conclusion: the main objective of Balance Restoration control is to initiate the restoration of the cell balance and load flows based on local information. Seeking global optimization is taken care of by the next control layer.

3.3.1.4 Balance Steering Control

The objective of balance steering control is twofold:

(1) Freeing up the Balance Restoration Reserves:

  - By replacing them by frequency steering control reserves, possibly from other neighbouring cells, and possibly cheaper.
  - By reducing the overall, system wide, amount of Balance Restoration activations by exploiting ‘opposite sign’ imbalances in other cells (= imbalance netting). This means

that the goal to restore the cell balance (and with that : the tie connection load flows to their scheduled values) is relaxed, and that new load flow values are set as new scheduled baselines.

(2) Pro-active activation based on short term forecasts:

- Preventing the activation of frequency containment and restoration reserves. This way, the system becomes more reliable against contingencies and its operating cost is optimized.

As mentioned previously, one major difference between Balance Steering Control and Balance Restoration Control is that the former deploys resources not only within the cell but also from neighbouring cells. The timeframe of activation and operation of frequency steering control will be further examined in WP5 and WP6 of the ELECTRA project. In a first instance it is assumed that the timeframe of activation ranges from 15 min to 1 hour because it is assumed that flexibility and forecasting algorithms used for balance steering control have a granularity on the scale of quarters and hours. Next to that, the assumption is made that (other) market processes will be able to take over any remaining balancing issue after one hour.

The monitoring of power flows across cell tie-lines is an important observable for the frequency steering control effectiveness. Additional indicators such as operating costs of reserves can be used for validation of cost-optimization algorithms deployed by the frequency steering control. Also, similar as with Balance Restoration control, before activation the local grid status is checked so that activating reserves does not cause congestion or voltage issues within the cell or across cell borders.

To obtain a global, system-wide, optimization of the activation of Balance Restoration and balance steering reserves, a (multi-agent) reserve coordination system may be required. This coordination system may be centrally implemented or in a distributed way.

In conclusion: the main objective of balance steering control is to restore the cell balance. Global, system wide, optimization of activation of reserves is aimed for.

3.3.2 Voltage control

The stability of the grid voltage is an absolute requirement for safe and stable operation of the electricity grid. To maintain the voltages in the nodes within allowable limits, Cell System Operators will need to procure services from units connected to its grid or from neighbouring cells by coordination with theirs Cell System Operators.

Voltage stability is a local issue, therefore it is appropriate to solve these issues using resources located as close as possible to the occurring problem, i.e. using as many resource providers as possible within each cell. Furthermore, since it is expected that more generating units will be connected at distribution level, fewer big power plants will be available for voltage control services at transmission level. As a consequence, there will be a displacement of responsibilities from transmission to distribution levels. The obligations concerning voltage control will have to be shared between Cell System Operators at the different voltage levels, since the traditional approach with most of the authority remaining at transmission operators will be no longer valid.

Two control layers are identified within voltage control: primary voltage control and post-primary voltage control.

3.3.2.1 Primary Voltage Control

Primary Voltage Control (PVC) is an automatic control accomplished by fast-acting devices (such as the automatic voltage controllers of the generation groups). It operates in the range of milliseconds. The goal of PVC is to act over the reactive (or active) power injection in the point of interconnection of the device. Based on the measured voltage at the interconnection of the device, the reactive and/or active power flow of the device is regulated so that the voltage in the node sets close to the set-point. The primary voltage control set-point is received from the post-primary voltage control layer. Operationally, no fundamental change compared to today's primary voltage control is foreseen, except that the resources used for primary voltage control will be different: generating units (in the broadest sense) as well as loads, storage devices and FACTS. These resources will be procured within every cell, and will thus be distributed over different voltage levels.

As mentioned above, it is possible that, particular at LV level, the use of active power will be needed to have an adequate effect on the voltage level. One could argue that the use of active power will cause new/additional imbalances. This, however, is not problematic since we rely on the frequency control to correct imbalances. After all, for frequency control it does not make a difference whether an imbalance is caused by a forecast error, an incident or a voltage control action. Basically, this gives voltage control a 'higher priority' over frequency control: voltage issues are fixed before frequency control makes sure that balance is restored.

3.3.2.2 Post Primary Voltage Control

Post-primary voltage control (PPVC) has the commitment to bring the voltage levels in the nodes of the power system back to nominal values while optimizing the reactive power flows in order to reduce the losses in the network. PPVC should be completed in the time frames of current secondary voltage control.

Actually, secondary voltage control is required to recover the voltage levels after a severe disturbance while the goal of the tertiary voltage control is to reach a global system optimization from an economical perspective. Under ELECTRA project it is proposed a new scheme for future networks that will merge the no-longer valid secondary + tertiary schemes into a more efficient control, PPVC, PPVC will allow the calculation of the suitable set-points for system optimization, according to technical and economic criteria in a single step.

Two main facts will made possible the PPVC control scheme in 2030+ horizon:

- It is foreseen an improvement in observability at MV-LV levels —see section 2.6—, due to advances in measurement and monitoring systems and their price drop.
- The shift from a central and big power system under a TSO responsibility to the web-of-cells structure will decrease the size of the power system to be controlled by the operator.

It is clear that mainly reactive power will be used to restore any voltage issue. The required reactive power may be delivered from generating units (of any kind) as well as storage, or any other unit capable of offering reactive power. However, if active power proves to be more effective, and optimal, to be used to control the voltage level (in particular at LV levels), active power may be procured as PPVC resource as well. Then the same comment with respect to impact on balance in PVC applies here as well: frequency control is used to restore the balance.

Each cell is responsible for its own voltage control while a close coordination guarantees the provision of PPVC service between neighbouring cells. Each time a voltage issue is detected, the Cell System Operator determines its necessary PPVC resources by taking into account technical as well as economic constraints. Before activating any PPVC resource, the Cell System Operator determines whether the activation causes congestion issues that could put the cell stability into risk.

Probably many PPVC resources will be located at MV levels, with possibility of service contributions to LV layers as well as HV layers. The PPVC mechanism assures the possibility of supplying Voltage Control resources to e.g. HV cells if there is a lack of self-procured resources within the HV cell.

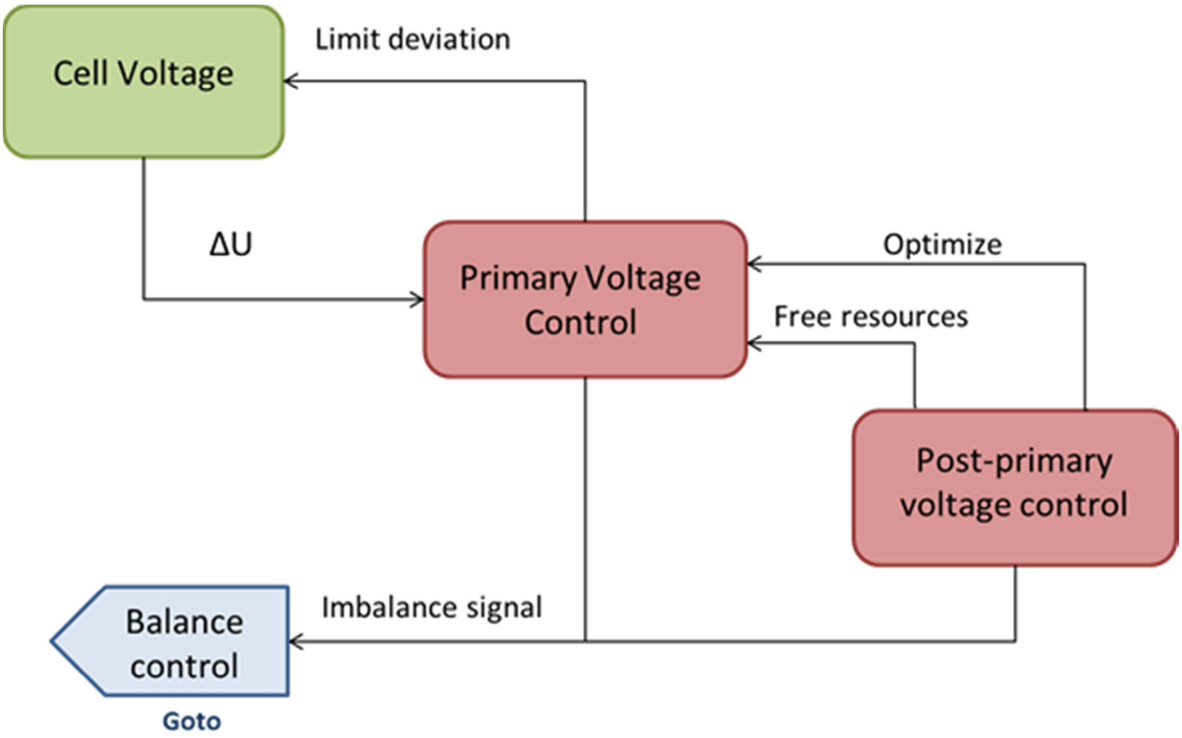


Figure 18: Overview of proposed voltage control structure of a cell

4. Market implications from the Web-of-Cells concept

4.1 Introduction: changes in e-market environment due to massive integration of renewable energy sources (RES)

Significant amounts of variable renewable capacity have been integrated into the networks during last years. A reliable system operation requires an increment of the balancing capabilities in electric power systems with high amounts of RES. This is because the output of renewable energy generation is intermittent and difficult to be predicted (forecast errors), so its variability is added to the typical fluctuations of the electricity demand. Since renewable production generally has feed-in priority, the remaining capacity has to adjust its output to match total electricity production with demand.

The electricity demand as well as the output from RES can change rapidly and not necessarily in the same direction. For example, the wind power plants are commonly able to produce more energy in low-demand periods (at night). System operators therefore need to have enough capacity to quickly respond to these changes.

The impact of RES deployment on electricity markets is severe. Variable RES generates electricity at very low marginal costs and therefore pushes thermal capacity higher up in, or completely out of the merit order. This means a reduction in the operating hours and the cutback of revenues for thermal capacity. In addition, subsidized RES output depresses electricity prices. This makes the feasibility of thermal plants even more challenging. But, obviously, thermal capacity is still needed in high RES system to balance the system, to be used as backup energy supply, etc. However, the profitability of these assets is jeopardized.

Several EU member states have identified a concern that the market may bring forward insufficient capacity under current market arrangements as a result of plant closures and the lack of investment in new capacity. There is a potential market failure associated with a perceived political risk of allowing prices to reach high levels at peak times. Such high prices would be required to remunerate plant running at lower load factors, so that they are able to recover fixed costs whilst operating for only a small number of hours per year (missing money issue). However, there is another issue that must be addressed since it is not simply “capacity” that is required in high RES system. Consideration must be given to delivering the “right types” of capacity, and in particular, that a sufficiently flexible mix is available. Without appropriate price signals, there is an equally important concern around “missing flexibility”.

4.2 Market vision within ELECTRA

The current model for market design at a pan-European level is based on the definition of diverse bidding zones that compete in a wholesale market. Each bidding zone is a large geographical area in which the participants are able to exchange energy without border limitations. The network operators are highly responsible of the enhancement of the market mechanisms.

The new regulations of ENTSO-E set the trend towards the implementation of a new and integrated market design based on the application of two principles: the orientation to “energy only regional markets” in combination with market coupling mechanisms. The “only energy regional market” is a simplified version of a wholesale electricity market, where the price of the energy is equal to the marginal cost of the last unit that has to supply energy in normal operating conditions. In case of scarcity, the prices will be higher. However, additional capacity payments have to be established in order to attract potential investors by reducing their investment risks. Moreover, the market coupling mechanisms allow a better coordination of the different zonal spot markets ensuring the lowest priced bids to be accepted.

These two principles that must govern the future European electricity market will contribute to get a reliable, efficient and environmentally friendly power supply at affordable prices. It will also be useful to increase the system security by allowing the provision of ancillary services from a wider variety of sources and assisting the massive increase of a high percentage of variable RES generation. The integration of the current market structure into a single internal electricity market (IEM) represents an important challenge due to the diversity of market structures presently in use in the Member States. A detailed state of the art in the structures of electricity markets for some relevant EU countries will be presented in the internal report R3.2.

Concerning to ELECTRA, the market mechanisms and the specific market design for the project will be accomplished in Task 3.3: Market Design. Main results of this work will be part of the deliverable D3.2 (Survey of different options for the EU E-market design, M48). Even the development of the project is still far away from reaching this lead time, the proposal of a new functional architecture in this deliverable D3.1 (The Web-of-cells) justifies a first draft approach to a real-time market vision that could be supported by the architecture. It is also convenient to favour the alignment with the ENTSO-E perspective. The orientation within ELECTRA should be the development of an integrated wholesale market for the provision of ancillary services (AS) in real-time, as it is still in progress for the actual balancing markets too.

As it was previously justified in the Section 1.1 of this deliverable (Scope), the focus of ELECTRA concerning to markets is the provision of AS in real-time, after the balancing markets gate closure, with the purpose of correcting the real-time deviations caused by the differences between the schedule balances and the forecast errors. The time horizon where the market design of ELECTRA will be focused it is shown in Figure 19, in the context and with mutual connections to other types of markets:

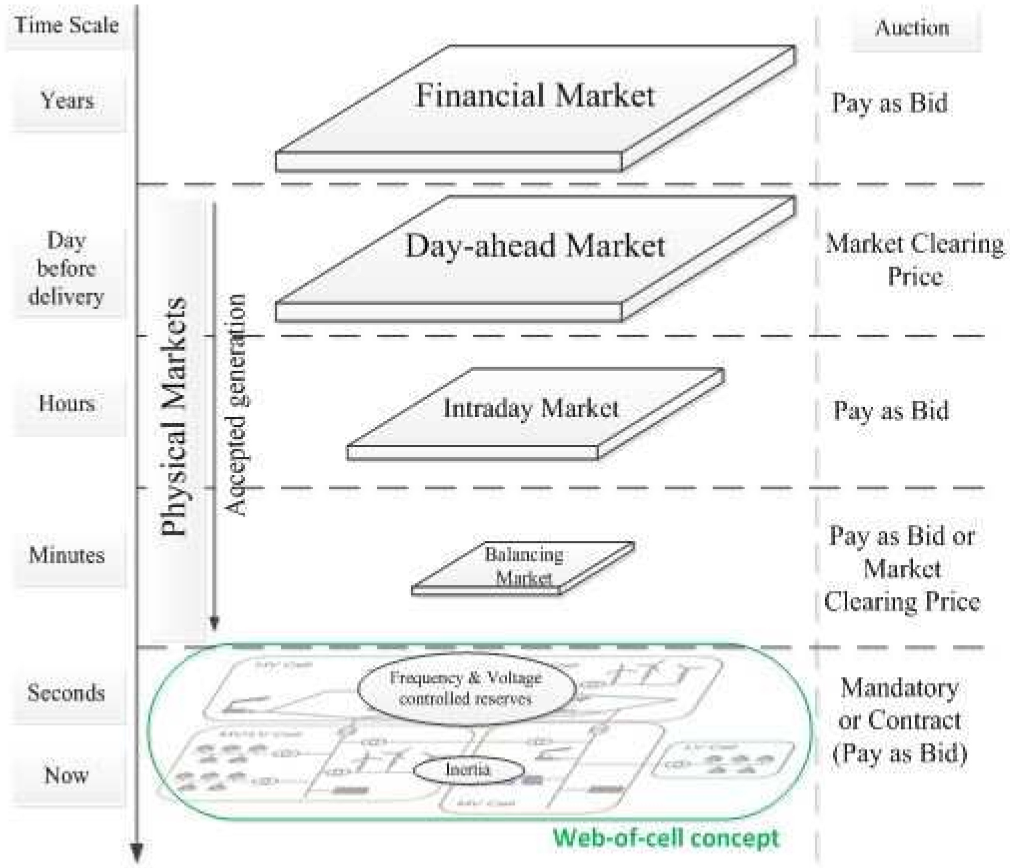


Figure 19: Market design and ELECTRA scope

The final definition of the market structure to be accomplished along the project will need to raise answers to multiple issues such as:

- Which will be the services to be provided (frequency control, voltage control, inertia, …)
- If new services must be included in the portfolios (congestion management, system restoration, contribution to power quality improvement...)
- The type of market model (ranging from fully regulated to fully liberalized)
- Market level: Global/local? Wholesale market/retail market?
- Mandatory or optional provision of the service (and depending on the technology, the size…)
- The time horizon for the negotiation of the contracts (hourly, 15 min, peak load, off peak...)

The future developments of financial, day-ahead and intraday markets are out of the scope of this project. This means that the evolution of these market mechanisms will be according economic principles. The trend towards the global AS markets could also be extendable to the future design of the mechanisms applicable to the real-time markets of the Web-of-Cells.

4.3 Roles and responsibilities

Roles and responsibilities are implemented in very different ways among the European Countries. Analyzing the responsibilities of the diverse market participants some key roles can be identified for the future energy market design within ELECTRA. They are listed below:

- **Producers:** the owners of the generation units, responsible for their operation. The producers inject energy to the cell and they receive the price formed in pool .
- **Consumers/end-users:** They are the customers connected to the cell which pay a price for the energy use. This price has been previously agreed, usually, with a retailer.
- **Prosumers:** the prosumers can act as both consumers and/or producers. They can generate a certain amount of energy for self-supply, exporting the difference to the cell. They can, alternatively, take advantage of the market prices to sell the whole energy they produce and buying the required electricity at a lower price.
- **Aggregators**: The distributed generation and renewable energy sources (producers/consumers/prosumers) usually do not have the minimum participation size to enter as individuals in the markets for provision of ancillary services. Sometimes, the DERs units do not even have enough control capabilities to be able to adapt their operating mode according to the needs. The aggregators are the entities, that gather the flexibility by forming Virtual Power Plants (VPPs), that will enable the participation of those smaller units in the AS markets. Other times, these small resources can enter into the market as part of the portfolio of a retail supplier or an energy service company (ESCO)
- **Market operator:** the entity that is responsible to favour the transparent operation of the market and to bring together all the interests of multiple actors buying and selling products in a non-discriminatory way.
- **Retailer:** The final entity that will establish the contracts directly with the end-users. Its main responsibility is to provide the electricity and, in general, the energy services to its customers.
- **Cell System Operator (CSO):** it is the responsible of the safe and reliable operation of every cell and to manage the interconnection tie-lines with neighbouring cells by agreement with adjacent CSOs. The CSO has to deliver the energy to the users. The role of the CSO in the future market structure for the Web-of-Cells is one of the key points to consider in the ongoing process of Task 3.3. Several possibilities can be taken into account: the behaviour of the CSO as the DSOs nowadays (so the CSO would facilitate the market resolution but without direct participation) or other options such as the active involvement of the CSO as retailer or its operation as a single entity (producer/prosumer) to individually bid in the market.

4.4 Ancillary services provision: from present to future

The ancillary services are all those services required by the network operators to enable them to maintain the integrity and stability of the transmission or distribution system as well as the power quality. These services can be mandatory or they can be subject to competition processes. The system services (SS) are all those services provided by some system function (such as a TSO) to the users connected in the system.

The current structure of the traditional system as well as the flows between the different elements for services provision can be observed in Figure 20. The power system is composed by the interconnection of major grid structures, each one under the supervision of a TSO. In a lower layer, at MV level, each DSO is responsible of a smaller part of the grid. Between HV and MV, the provision of SS is a top-down flow while the ancillary services are supplied from the DSO-managed areas located downstream. Among TSOs located in HV the provision of both AS & SS is peer-to-peer. Every TSO can obtain the required ancillary services by coordination with adjacent TSOs or directly through the big plants connected (usually conventional PP but also, nowadays, renewable energy plants, such as wind power parks).At MV, the DSOs behave as demanders of system services but not as providers.

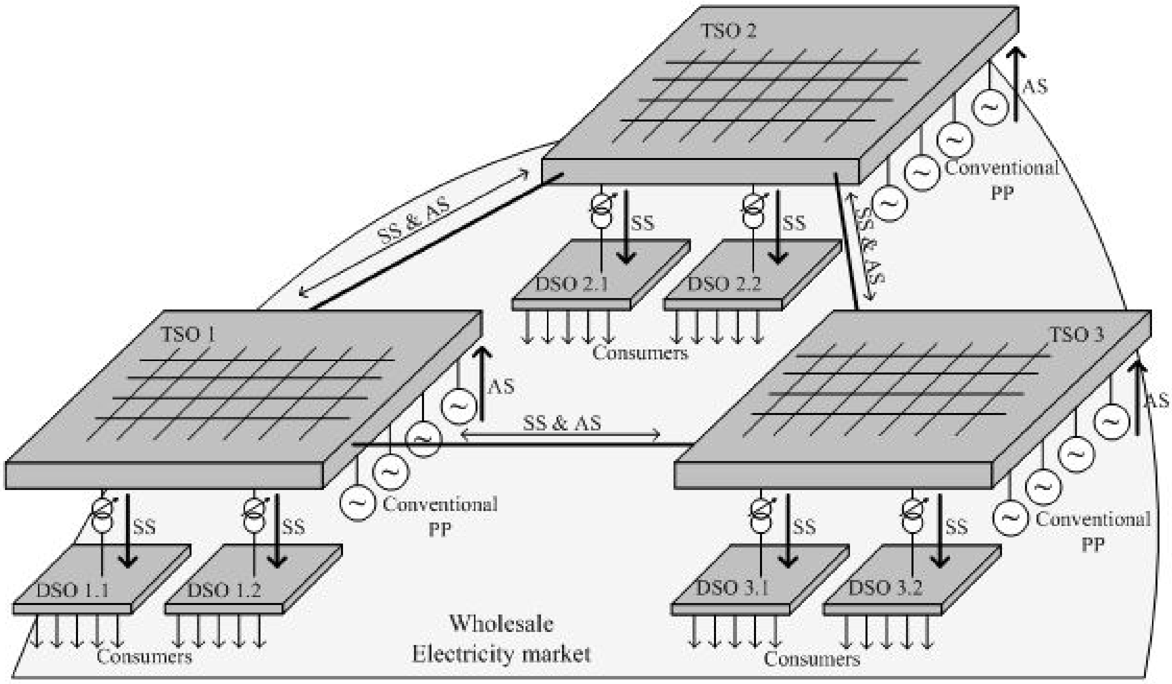


Figure 20: Traditional power system representation and AS/SS providers/consumers

The development of the Web-of-Cells concept as well as the assumptions of the ELECTRA scenario force the redesign of the ancillary services markets for real-time solving of residual imbalances. On the one hand, the inherent fluctuation of the resource has an impact on the requirements for several AS and the prices to be paid for them. On the other hand, the variable characteristics of the system in its different areas, makes troublesome the generalization of requirements across several time scales and systems. Even, the participation of new suppliers in the ancillary services market presents the advantage to enable the competition,it raises challenges related with the specificities linked to every technology.

The traditional power system topology it will necessarily evolve due to the expected trends detailed along this deliverable, so within this project, the Web-of-Cells was proposed as the most promising high-level functional architecture to couple with all these changes. Figure 21 shows a schematic view of the future power system topology (the Web-of-Cells), as well and the flows for AS/SS provision among the different participants.

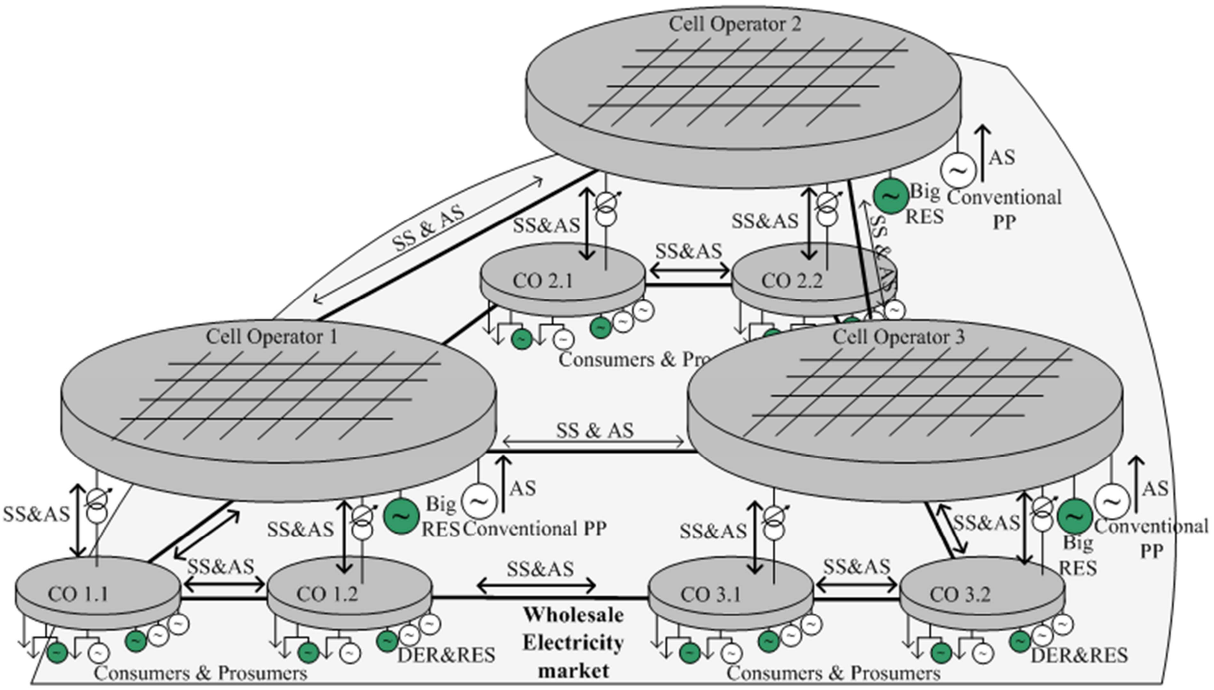


Figure 21: 2030+ power system representation and AS/SS providers/consumers

From the comparison between the AS/SS flows between the traditional power system and the Web-of-Cells, some immediate results can be derived:

- New participants are involved in the provision of AS/SS (Big RES, Cells, VPPs,...)
- All the cells at a different voltage levels are able to provide AS/SS to neighbouring cells, located at the same level, as well as upstream and/or downstream. This way, the top-down/bottom-up approach of the traditional power system is translated into a bidirectional scheme.

5. Use Cases for future (2030+) frequency control

As explained in Section 3, moving towards a cell-based architecture will result in new mechanisms for frequency control.

In WP4 of the ELECTRA was decided to employ a Use Case Methodology to describe functionalities of new developed mechanisms and control concepts [21]. Therefore all developed frequency control mechanisms, as described in section 3, are written down as High-Level Use Cases in the ELECTRA Use Case template, based on IEC 62559-2.

By employing the Use Case methodology, the role of the different actors involved in a certain functionality are made clear. Also, the interactions, needed observables and control aims are specified in each Use Case document. These high level specifications of observables and control aims will subsequently be considered and used for further development within WP5 and WP6 of the ELECTRA project.

5.1 Future Inertia Steering Control

5.1.1 Description of the Use Case

Use Case Identification		
ID	Area/Domain(s)/Zone(s)	Name of Use Case
F-1	Domains: Generation, Transmission, Distribution, DER, Customer Premises Zones: Process, Field, Station, Operation	inertia steering control (InC)

Version Management				
Version No.	Date	Name of Author(s)	Changes	Approval Status
0.1	02/12/2014	Dominik Geibel	--	Draft
0.2	15/01/2015	Dominik Geibel	Section 2: change of figures Section 4 is filled in	Proposed

Scope and Objectives of Use Case	
Scope	Maintain frequency after incidents. Contain dynamic frequency deviations in normal operation. This use case describes the management of the inertial response power characteristics of a cell, so that frequency is maintained after incidents and dynamic frequency deviations are contained during normal operation.
Objective(s)	The objective is to maintain, both in case of a power imbalance (positive or negative) and during normal operation, within the limits of a reference incident the frequency quality parameters of maximum allowed df_{max}/dt and maximum dynamic frequency deviation limit $\Delta f_{dyn,max.}$ For frequency incidents, maintaining is done until downstream functionalities take over to contain and to restore system frequency by means of Frequency Containment Control, Balance Restoration Control and Balance Steering Control. For normal operation, maintaining is done until the dynamic frequency deviations return to nominal or lower without additional inertial response power.
Related business case(s)	--

Narrative of Use Case
Short description
In future power systems the share of converter-coupled generation/load increases. This leads to reduced response power due to changes in stored kinetic energy in the power system since converter-coupled generation/load does not inherently contribute to inertia power response. Comparable active power changes would yield less inertial response power resulting in higher frequency time derivatives and larger dynamic frequency deviations during normal operation. In order to assure that integration and use of converter-coupled generation/load has not to be limited due to frequency stability issues, new concepts for power system control have to be introduced on plant (especially for converter-coupled generation/load) as well as on power system level. This use case describes the interaction and the general sequence of the inertia steering control.
Complete description

Within the following description synchronism between generators within the power system and rotor angle stability (transient and small signal) is assumed.

With regard to the use case inertia steering control it is assumed that the time derivative of the frequency -- mainly given (in the today's power system) by the inertial response power resulting from changes in stored kinetic energy in the rotating generators -- is kept within predefined limits although the power system characteristic will change.

In future power systems the share of converter-coupled generation/load increases. This leads to reduced inertial response power due to changes in stored kinetic energy in the power system since converter-coupled generation/load does not inherently contribute to inertia response power. Comparable active power changes would result in higher frequency time derivatives. In order to assure that integration and use of converter-coupled generation/load has not to be limited due to frequency stability issues new concepts for power system control have to be introduced on plant (especially for converter-coupled generation/load) as well as on power system level.

The challenges of the future power system with regard to inertia steering control are the following:

1. Categories of inertia at plant level: The provision of inertia can be grouped as follows:
    - Direct-coupled inertia
    - Indirect-coupled inertia provided by converter-coupled rotating devices (generator or loads)
    - Synthetic inertia provided by converter-coupled generators with energy storage or by discrete load changes

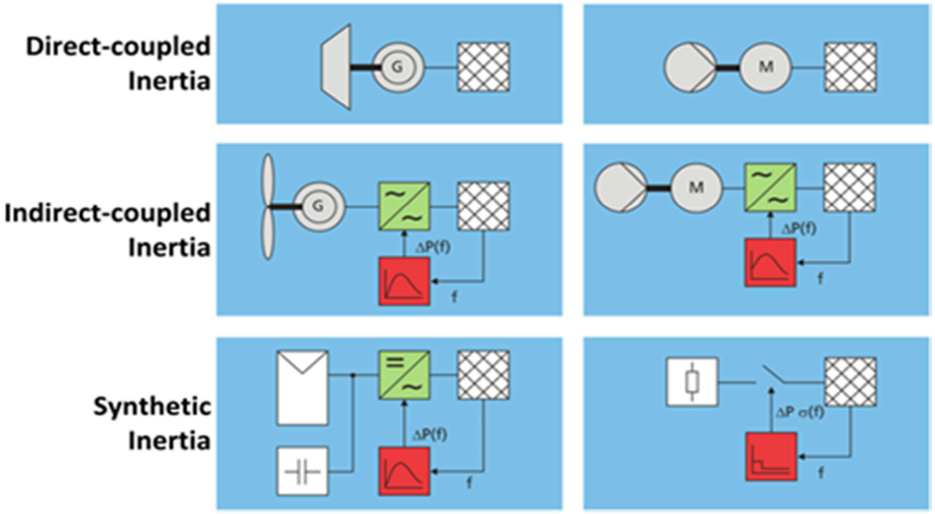


Figure 22: Categories of inertia: Direct coupled inertia, indirect coupled inertia and synthetic inertia [22]

The category direct-coupled inertia contributes to inertia control inherently. Devices which are grouped in the categories indirect-coupled and synthetic inertia do not inherently contribute to inertia steering control, but due to the power electronic interface their behaviour can be influenced explicitly. Therefore the requirements for inertia steering control provided by indirect-coupled or synthetic inertia have to be described precisely in grid codes. The inertia steering control can be described in general by applying a sufficient fast change in active power contribution or consumption of generating units/plants and/or loads based on the rate of change of frequency, which is measured locally. The activation (switch on/off) of the functionality including parameterisation is done by the cell responsible. The expected -- perhaps different -- behaviour of the devices has to be taken into account during the inertia response power control process on the power system level.

2. Increase of converter-coupled generation and load: The installed nominal power of static generators (converters) increases as well as the installed nominal power of rotating generators decreases. By trend the direct-coupled inertia provided by direct-coupled rotating generators or machines decrease. This decrease of direct-coupled inertia has to be substituted by indirect-coupled and/or synthetic inertia in order to guarantee a secure power system operation. Since retro-fit of installed generation and load with inertia steering control should be avoided, an introduction of this grid code requirement has to be realized accurately timed.
3. Time-variant generation mix: In future power systems the generation mix expressed mainly by the ratio of rotating and static generators will be more time-variant especially if the trend towards converter-dominated power systems is taken into account. For example during a sunny afternoon the electricity consumption could mainly be covered by PV, in contrast during a windless night conventional power plants, interfaced with rotating generators, dominate almost exclusively. Therefore the responsible actor for power system stability has to assure that enough inertia is available at any time although the generation mix changes faster than nowadays.
4. Determination of inertia response power within power system: depending on the actual system state the available inertia response power has to be determined and used as input for the inertia control on power system level. Reliable methods have to be developed and introduced.

These challenges require an introduction of an inertia steering control which affects the unit, plant and power system level. Therefore the use case describes the interaction and the general sequence of the inertia steering control.

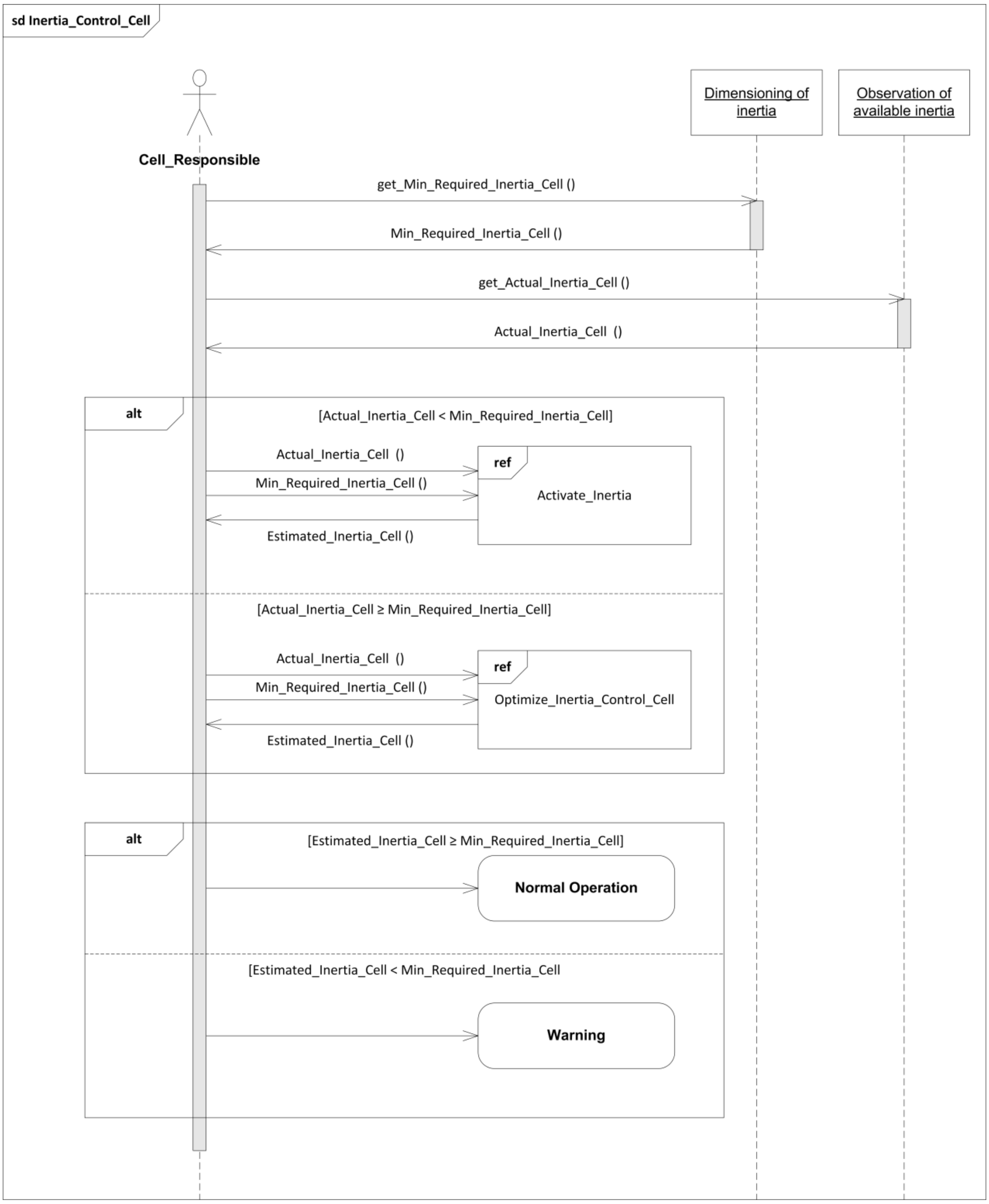
	Key Performance Indicators			
ID	Name	Calculation	Scope	Objective
KPI_01	Contribution of cell to grid stability	Time the inertia response power requirements are fulfilled in relation to total time.	Observation of inertia response power in cell	Contribution to frequency stability

Classification Information
Relation to Other Use Cases
Frequency Containment Control Use Case (F-2).
Level of Depth
High-Level
Prioritisation
Generic, Regional or National Relation
Generic
Viewpoint
System operation
Further Keywords for Classification

General Remarks

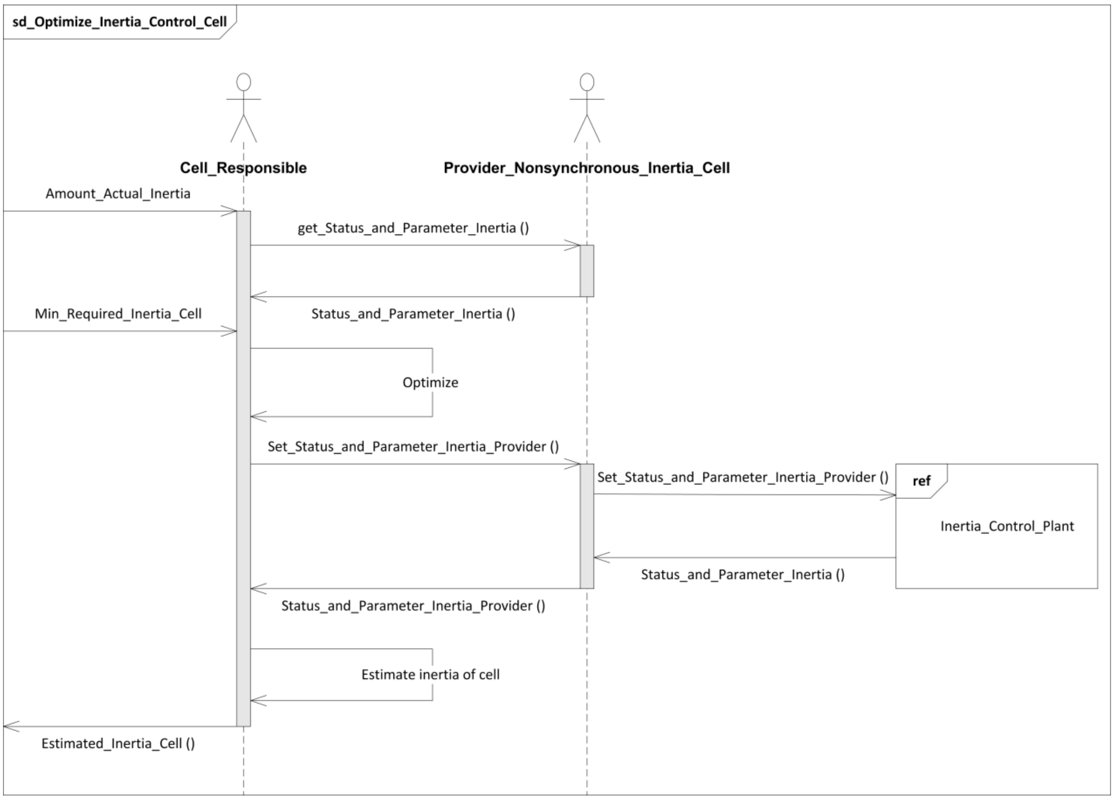
5.1.2 Diagrams of Use Case

Diagram(s) of Use Case
Sequence Diagrams: Inertia response power control of Cell

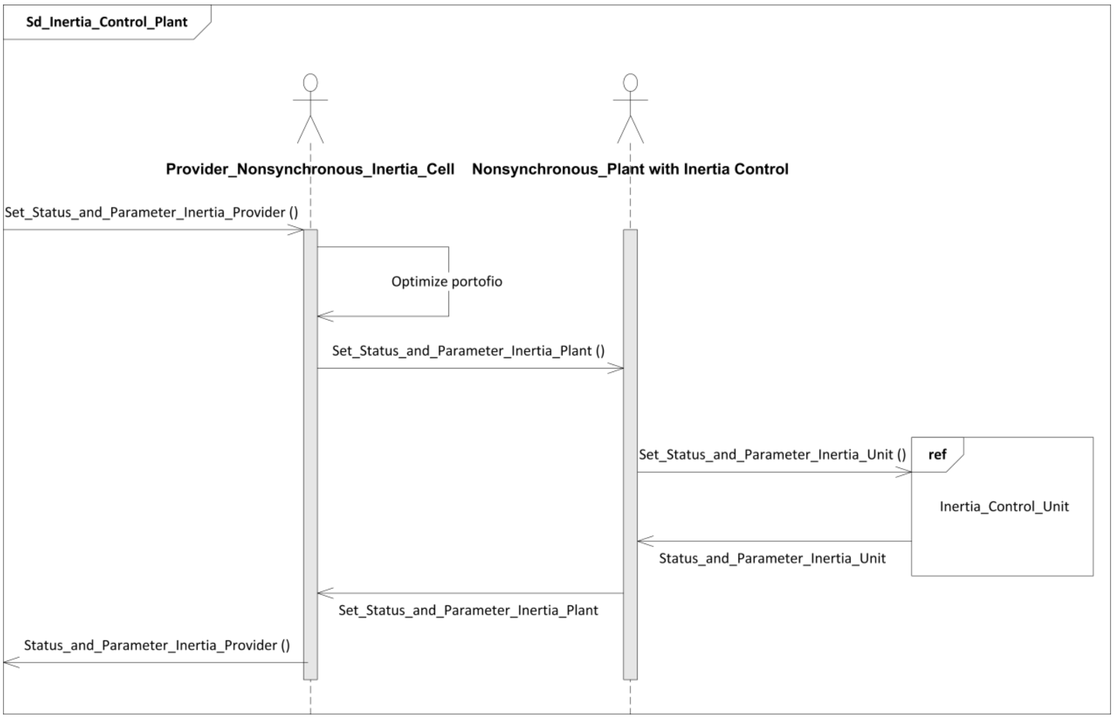

sd Inertia_Control_Cell
Cell_Responsible
Dimensioning of inertia
Observation of available inertia
get_Min_Required_Inertia_Cell ()
Min_Required_Inertia_Cell ()
get_Actual_Inertia_Cell ()
Actual_Inertia_Cell ()
alt
[Actual_Inertia_Cell < Min_Required_Inertia_Cell]
Actual_Inertia_Cell ()
Min_Required_Inertia_Cell ()
ref
Activate_Inertia
Estimated_Inertia_Cell ()
[Actual_Inertia_Cell ≥ Min_Required_Inertia_Cell]
Actual_Inertia_Cell ()
Min_Required_Inertia_Cell ()
ref
Optimize_Inertia_Control_Cell
Estimated_Inertia_Cell ()
alt
[Estimated_Inertia_Cell ≥ Min_Required_Inertia_Cell]
Normal Operation
[Estimated_Inertia_Cell < Min_Required_Inertia_Cell
Warning

Activate Inertia

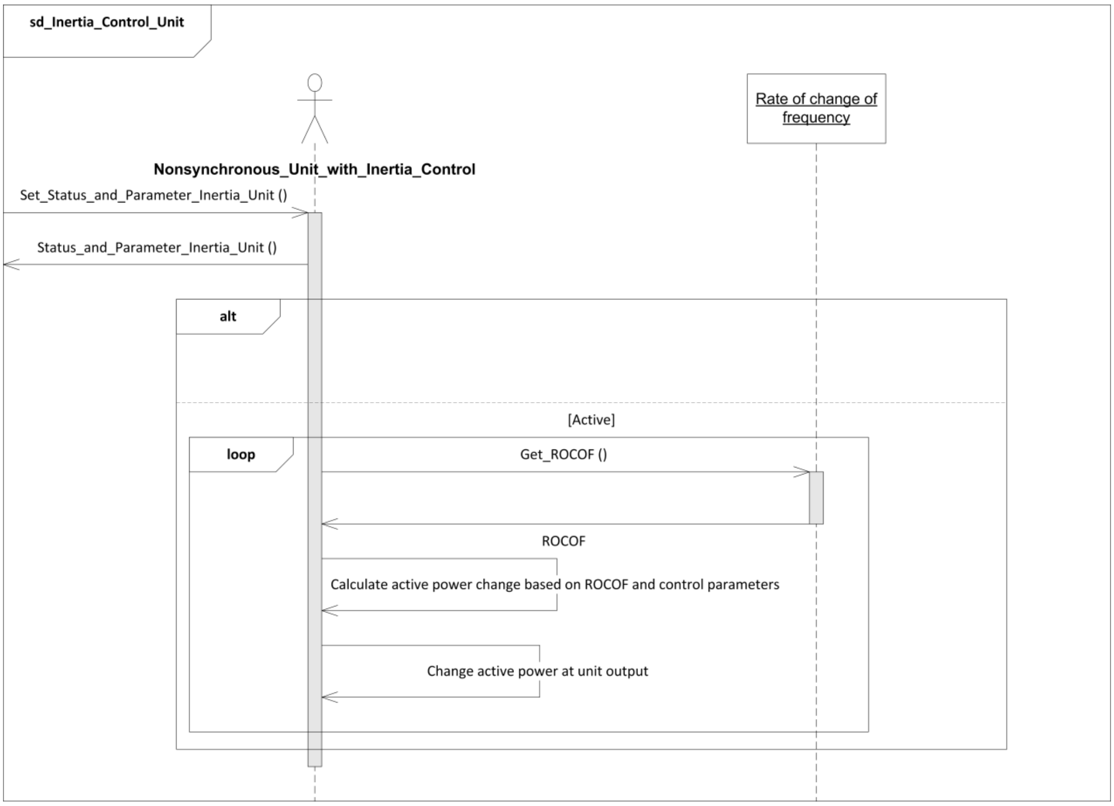
Optimize Inertia response power Cell



Inertia control plant



Inertia response power Control Unit



5.1.3 Technical details

Actors			
Grouping		Group Description	
Actor Name see Actor List	Actor Type see Actor List	Actor Description see Actor List	Further information specific to this Use Case
Cell_Responsible		Cell Operator is a network operator responsible for the operation and the management of inertia response power within its cell	
Responsible_Neighbour_Cell		Cell Operator of a neighbouring cell	

Provider_Nonsynchronous_Inertia_Cell		Provider which offers nonsynchronous inertia response power within the cell. Could be a single plant or an aggregator.	
Nonsynchronous_Plant_with_Inertia_Control		Plant which is based on nonsynchronous generation and is able to provide inertia response power.	Could be also a load
Nonsynchronous_Unit_with_Inertia_Control		Single Unit within the plant which is based on nonsynchronous generation and is able to provide inertia response power.	Could be also a load

Use Case Conditions
Assumption
Synchronism between generators within the power system and rotor angle stability (transient and small signal) is assumed.
Prerequisite

References						
No.	References Type	Reference	Status	Impact on Use Case	Originator / Organisation	Link
1	Guideline	Continental Europe Operation Handbook-CEOH	Release 2004	Function Layer	ENTSO-E	https://www.entsoe.eu/publications/system-operations-reports/operation-handbook/Pages/default.aspx
2	Report	Supporting Document for the Network Code on Load-Frequency Control and Reserves	Version of 28.06.2013	Functional Layer	ENTSOE-E	

3	Network Code	Network Code on Load-Frequency Control and Reserves	Version of 28.06.2013	Functional layer	ENTSO-E	

5.1.4 Step by step analysis of Use Case

Scenario Conditions						
No.	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
1	sd Inertia_Control_Cell	The scenario describes the coordination of the high-level inertia control done by the cell responsible. This scenario assures that the cell is able to provide enough inertia based on the required inertia and the observed actual available inertia in the cell.	Cell_Responsible	Periodically		
2	sd_Activate_inertia	This scenario describes the procedure if identifying available non-synchronous inertia in the cell and their possible activation and parametrisation. In addition it is described how the interaction with neighbouring cells concerning support with inertia is carried out if the inertia requirements in the cell could not be fulfilled by available units.	Cell_Responsible	Activated by Cell_Responsible if additional inertia is required.		
3	sd_Optimize_Inertia_Control_Cell	This scenario describes the procedure for optimization of provided inertia in the cell.	Cell_Responsible	Activated by Cell_Responsible if inertia in cell should be optimized		
4	sd_Inertia_Control_Plant	This scenario describes the procedure how the provider of nonsynchronous inertia can optimize its portfolio. The status and parameter values are sent to the plants	Provider_Nonsynchronous_Inertia_Cell	Activated by Cell_Responsible		
5	sd_Inertial_Control_Unit	The scenario describes the basic principle how inertia	Nonsynchronous_unit_with_Inertia_Contr	Activated by Nonsynchrono		

		control is provided by the single unit based on the received parameters.	ol	us_Plant_with _inertia, then periodically		

Scenario								
Scenario Name :	sd_Inertia_Control_Cell							
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
1	Periodically	get_Min_Required_Inertia_Cell	The responsible for the cell requests the required inertia within the cell for the next time step. The size of the time step is not defined yet. The procedure of the dimensioning for the required inertia is not part of the use case. This could be integrated in a further version.	Request	Cell_Responsible	Dimensioning of Inertia	IE_01	
2	Periodically	Min_Required_Inertia_Cell	The value for the minimum required inertia is sent to the responsible for the cell.	Receive	Dimensioning of Inertia	Cell_Responsible	IE_02	
3	Periodically	Get_Actual_Inertia_Cell	The responsible for the cell requests the actual inertia within the cell. The procedure for observation of the actual available inertia within the cell is not defined yet and not state of the art. Therefore it is assumed that new methods have to be proposed and developed.	Request	Cell_Responsible	Observation of available inertia	IE_03	
4	Periodically	Actual_Inertia_Cell	The real-time value of the available and connected inertia in the cell is provided to the cell responsible	Receive	Observation of available inertia	Cell_Responsible	IE_04	
5	If actual inertia <	Actual_Inertia_Cell	The value of the actual inertia in the cell is provided to sd_Activate_Inertia.	Send	Cell_Responsible	sd_Active_Inertia	IE_05	

	minimum required inertia							
6	If actual inertia < minimum required inertia	Min_Required_Inertia_Cell	The minimal required inertia of the cell is provided to sd_Activate_Inertia.	Send	Cell_Responsible	sd_Active_Inertia	IE_06	
7	If actual inertia < minimum required inertia	Estimated_Inertia_Cell	The estimated inertia in the cell after activation (see sd_Activate_Inertia) is received by the cell responsible.	Receive	Sd_Activate_Inertia	Cell_Responsible	IE_07	
8	If actual inertia >= minimum required inertia	Actual_Inertia_Cell	The value of the actual inertia in the cell is provided to sd_Optimize_Inertia_Control_Cell.	Send	Cell_Responsible	sd_Active_Inertia	IE_08	
9	If actual inertia >= minimum required inertia	Min_Required_Inertia_Cell	The minimal required inertia of the cell is provided to sd_Optimize_Inertia_Control_Cell.	Send	Cell_Responsible	sd_Active_Inertia	IE_09	
10	If actual inertia >= minimum required inertia	Estimated_Inertia_Cell	The estimated inertia in the cell after activation (see sd_Optimize_Inertia_Control_Cell) is received by the cell responsible.	Receive	Sd_Activate_Inertia	Cell_Responsible	IE_10	
11	Estimated Inertia >= Minimal requir		Indication that cell is in normal operation mode		Cell_Responsible		IE_11	

	ed inertia in cell							
12	Estimated Inertia < Minimal required inertia in cell		Indication that cell is in warning operation mode		Cell_Responsible		IE_12	

Scenario								
Scenario Name :	sd_Activate_Inertia							
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
13	Uniquely	Get_Status_and_Parameter_Inertia_Provider	The responsible for the cell requests the status and parameters of nonsynchronous units which could provide inertia.	Request	Cell_Responsible	Provider_Nonsynchronous_Inertia_Cell	ID_13	
14	Uniquely	Status_and_Parameter_Inertia_Provider	The cell responsible receives the information on status and parameter of available nonsynchronous inertia. Note: There could be several provider of inertia.	Receive	Provider_Nonsynchronous_Inertia_Cell	Cell_Responsible	ID_14	
15	Uniquely	Internal	Based on the available information the cell operator calculates the status and parameters for the activation of inertia from nonsynchronous units.		Cell_Responsible		ID_15	
16	Uniquely	Set_Status_and_Parameter_Inertia_Provider	The cell operator sends the new status and parameters for the activation of inertia to the provider of nonsynchronous inertia.	Send	Cell_Responsible	Provider_Nonsynchronous_Inertia_Cell	ID_16	

17	Uniquely	Set_Status_and_Parameter_Inertia_Provider	Information are handled in sd_Inertia_Control_Plant	Send	Provider_Nonsynchronous_Inertia_Cell	sd_Inertia_Control_Plant	ID_17	
18	Uniquely	Status_and_Parameter_Inertia_Provider	Information on actual status and parameters is received.	Receive	sd_Inertia_Control_Plant	Provider_Nonsynchronous_Inertia_Cell	ID_18	
19	Uniquely	Status_and_Parameter_Inertia_Provider	Information on actual status and parameters is received.	Receive	Provider_Nonsynchronous_Inertia_Cell	Cell_Responsible	ID_19	
20	Uniquely	Internal	The cell responsible estimate the inertia of cell after activation of additional units contributing to inertia		Cell_Responsible		ID_20	
21	Uniquely	Minimum_Required_Inertia_Cell	Value received by sd_Inertia_Control_Cell.	Receive	sd_Inertia_Control_Cell	Cell_Responsible	ID_21	
22	If estimated inertia < min required inertia	Get_information_available_Resources_Inertia	The cell responsible requests information on available resources for inertia provision from other cells.	Request	Cell_Responsible	Responsible_Neighbour_Cell	ID_22	
23		Information_available_Resources_Inertia	The cell responsible receives information on available resources from neighbouring cells.	Receive	Responsible_Neighbour_Cell	Cell_Responsible	ID_23	
25		Set_Required_Resources_Inertia_other_cell	The required resources from other cells are sent to the neighbouring cells.	Send	Cell_Responsible	Responsible_Neighbour_Cell	ID_25	
26		Provide_information	The neighbouring cells provide the received information to a risk assessment. This is handled in a separate task and is not described here. This could be integrated in a further version.	Provide	Responsible_Neighbour_Cell		ID_26	
27		Result	The results of the risk assessment are provided to the neighbouring cells.	Receive	Responsible_Neighbour_Cell		ID_27	
28		Decision	Based on the risk assessment a decision is made to which extent inertia could be provided.		Responsible_Neighbour_Cell		ID_28	

29		Status_and_Parameter_Intertia_other_cells	The status and parameter of inertia contribution from other cells are sent to the cell responsible.	Receive	Responsible_Neighbour_Cell	Cell_Responsible	ID_29	
30		Internal	The cell responsible estimate the available inertia (including the contribution from other cells).		Cell_Responsible		ID_30	
31	Uniquely	Estimated_Inertia_Cell	The cell responsible sends the estimated inertia to sd_Inertia_Control_Cell.	Send	Cell_Responsible	sd_Inertia_Control_Cell	ID_31	

Scenario								
Scenario Name :	sd_Optimize_Inertia_Control_Cell							
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
32	Uniquely	Amount_Actual_Inertia	The cell responsible receives the actual amount of inertia in the cell from sd_Inertia_Control_Cell.	Receive	sd_Inertia_Control_Cell	Cell_Responsible	ID_32	
33	Uniquely	Get_Status_and_Parameter_Inertia_Provider	The responsible for the cell requests the status and parameters of nonsynchronous units which could provide inertia.	Request	Cell_Responsible	Provider_Nonsynchronous_Inertia_Cell	ID_33	
34	Uniquely	Status_and_Parameter_Inertia_Provider	The cell responsible receives the information on status and parameter of available nonsynchronous inertia. Note: There could be several provider of inertia.	Receive	Provider_Nonsynchronous_Inertia_Cell	Cell_Responsible	ID_34	
35	Uniquely	Minimum_Required_Inertia_Cell	Value received by sd_Inertia_Control_Cell.	Receive	sd_Inertia_Control_Cell	Cell_Responsible	ID_35	
36	Uniquely	Internal	Optimisation of the distribution of the inertia control is carried out		Cell_Responsible		ID_36	

			based on the available information (technical and economic)					
37	Uniquely	Set_Status_and_Parameter_Inertia_Provider	The cell operator sends the new status and parameters for the activation of inertia to the provider of nonsynchronous inertia.	Send	Cell_Responsible	Provider_Nonsynchronous_Inertia_Cell	ID_37	
38	Uniquely	Set_Status_and_Parameter_Inertia_Provider	Information are handled in sd_Inertia_Control_Plant	Send	Provider_Nonsynchronous_Inertia_Cell	sd_Inertia_Control_Plant	ID_38	
39	Uniquely	Status_and_Parameter_Inertia_Provider	Information on actual status and parameters are received.	Receive	sd_Inertia_Control_Plant	Provider_Nonsynchronous_Inertia_Cell	ID_39	
40	Uniquely	Status_and_Parameter_Inertia_Provider	Information on actual status and parameters are received.	Receive	Provider_Nonsynchronous_Inertia_Cell	Cell_Responsible	ID_40	
41	Uniquely	Internal	The cell responsible estimate the inertia of cell after activation of additional units contributing to inertia		Cell_Responsible		ID_41	
42	Uniquely	Estimated_Inertia_Cell	The cell operator sends the estimated inertia to sd_Inertia_Control_Cell.	Send	Cell_Responsible	sd_Inertia_Control_Cell	ID_42	

Scenario								
Scenario Name :	sd_Inertia_Control_Plant							
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
43	Uniquely	Set_Status_and_Parameter_Inertia_Provider	The provider for nonsynchronous inertia receives the required inertia from the cell responsible.	Receive	sd_Inertia_Control_Cell	Provider_Nonsynchronous_Inertia_Cell	ID_43	
44	Uniquely	Internal	The portfolio is optimized based on the available information of required inertia provided by the cell responsible		Provider_Nonsynchronous_Inertia_Cell		ID_44	

45	Uniquely	Set_Status_and_Parameter_Inertia_Plant	The provider of the nonsynchronous inertia sends the new status and parameters to the plants.	Send	Provider_Nonsynchronous_Inertia_Cell	Nonsynchronous_Plant_with_Inertia_Control	ID_45	
46	Uniquely	Set_Status_and_Parameter_Inertia_Unit	The plants forward the status and parameters to the units (if existing).	Send	Nonsynchronous_Plant_with_Inertia_Control	sd_Inertia:Control_Unit	ID_46	
47	Uniquely	Status_and_Parameter_Inertia_Unit	The units send the new adopted status and parameters to the plant.	Receive	sd_Inertia:Control_Unit	Nonsynchronous_Plant_with_Inertia_Control	ID_47	
48	Uniquely	Status_and_Parameter_Inertia_Plant	The plants send the new adopted status and parameters to the provider of nonsynchronous inertia.	Receive	Nonsynchronous_Plant_with_Inertia_Control	Provider_Nonsynchonous_Inertia_Cell	ID_48	
49	Uniquely	Status_and_Parameter_Inertia_Provider	The provider of nonsynchronous inertia sends the new adopted status and parameters to the cell responsible.	Send	Provider_Nonsynchonous_Inertia_Cell	sd_Inertia_Control_Cell	ID_49	

Scenario								
Scenario Name :	sd_Inertia_Control_Unit							
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
50	Uniquely	Set_Status_and_Parameter_Inertia_Unit	The status and parameters are received from sd_Inertia_Control_Plant	Receive	sd_Inertia_Control_Plant	Nonsynchronous_Unit_with_Inertia_Control	ID_50	
51	Uniquely	Status_and_Parameter_Inertia_Unit	The updated status and parameters are sent to sd_Inertia_Control_Plant	Send	Nonsynchronous_Unit_with_Inertia_Control	sd_Inertia_Control_Plant	ID_51	
52	If inertia control is active, periodically	Get_ROCOF	The actual value of the rate of change of frequency is requested. Appropriate methods concerning accuracy and measurement cycle are not specified yet.	Request	Nonsynchronous_Unit_with_Inertia_Control	Rate of change of frequency	ID_52	

53		ROCOF	The actual value of ROCOF is received.	Receive	Rate of change of frequency	Nonsynchronous_Unit_with_Inertia_Control	ID_53	
54		Internal	The active power change is calculated based on the ROCOF value.		Nonsynchronous_Unit_with_Inertia_Control		ID_54	
55		Internal	The active power output is changed.		Nonsynchronous_Unit_with_Inertia_Control		ID_55	yt

5.1.5 Misc

Information Exchanged			
Information Exchanged ID	Name of Information	Description of Information Exchanged	Requirements IDs
IE_01	Request	Minimal required inertia	
IE_02	Parameter	Minimal required inertia	
IE_03	Request	Actual inertia of cell	
IE_04	Parameter	Actual inertia of cell	
IE_05	Parameter	Actual inertia of cell	
IE_06	Parameter	Minimal required inertia	
IE_07	Parameter	Estimated inertia cell	
IE_08	Parameter	Actual inertia of cell	
IE_09	Parameter	Minimal required inertia	
IE_10	Parameter	Estimated inertia cell	
IE_11	State	Normal Operation	
IE_12	State	Warning	
IE_13	Request	Status and parameter of inertia from provider	
IE_14	Parameter	Status and parameter of inertia from provider	
IE_15	Internal		

IE_16	Send	New status and parameter for activation of inertia	
IE_17	Send	New status and parameter for activation of inertia	
IE_18	Receive	Updated status and parameter for activation of inertia	
IE_19	Receive	Updated status and parameter for activation of inertia	
IE_20	Internal		
IE_21	Receive	Minimal required inertia	
IE_22	Request	Available inertia resources other cells	
IE_23	Receive	Available inertia resources other cells	
IE_24	Internal		
IE_25	Send	Required inertia resources	
IE_26	Provide	Required inertia resources	
IE_27	Receive	Results of risk assessment	
IE_28	Internal		
IE_29	Receive	Status and parameter of inertia contribution from other cells	
IE_30	Internal		
IE_31	Send	Estimated inertia cell	
IE_32	Receive	Actual Inertia	
IE_33	Request	Status and parameter of inertia from provider	
IE_34	Parameter	Status and parameter of inertia from provider	
IE_35	Receive	Minimal required inertia	
IE_36	Internal		
IE_37	Send	New status and parameter for activation of inertia	
IE_38	Send	New status and parameter for activation of inertia	
IE_39	Receive	Updated status and parameter for activation of inertia	

IE_40	Receive	Updated status and parameter for activation of inertia	
IE_41	Internal		
IE_42	Send	Estimated inertia cell	
IE_43	Receive	New status and parameter for activation of inertia	
IE_44	Internal		
IE_45	Send	New status and parameter for activation of inertia for plant	
IE_46	Send	New status and parameter for activation of inertia for unit	
IE_47	Receive	Updated status and parameter for activation of inertia for unit	
IE_48	Receive	Updated status and parameter for activation of inertia for plant	
IE_49	Send	Updated status and parameter for activation of inertia	
IE_50	Receive	New status and parameter for activation of inertia for unit	
IE_51	Send	Updated status and parameter for activation of inertia for unit	
IE_52	Request	ROCOF	
IE_53	Receive	ROCOF	
IE_54	Internal		
IE_55	Internal		

Requirements (optional)		
Category ID	Category Name	Category Description
Requirement ID	Requirement Description	

Common Terms and Definitions	
Term	Definition

Custom Information (optional)		
Key	Value	Refers to Section

5.2 Future Frequency Containment Control

5.2.1 Description of the Use Case

Use Case Identification		
ID	Area/Domain(s)/Zone(s)	Name of Use Case
F-2	Domains: Generation, Transmission, Distribution, DER, Customer Premises Zones: Process, Field, Station, Operation	Frequency Containment Control (FCC)

Version Management				
Version No.	Date	Name of Author(s)	Changes	Approval Status
0.1	12/08/2014	Dominik Geibel	--	Draft
0.2	14/01/2015	Dominik Geibel	Following paragraphs are added: “step-by-step-analysis” and “information exchange”	Proposed

Scope and Objectives of Use Case	
Scope	Maintain frequency
Objective(s)	In case of a power imbalance (positive or negative) within the limits of a reference incident the objectives are: ● To support inertia steering control in order to keep the frequency quality parameter maximum dynamic frequency deviation limit $\Delta f_{dyn,max}$ ● To keep the maximum steady-state frequency deviation $\Delta f_{dyn,static}$ until downstream functionalities take over to restore system frequency by means of Balance Restoration Control and Balance Steering Control.
Related business case(s)	--

Narrative of Use Case

Short description

In future power systems the share of converter-coupled generation/load increases as well as the generation mix changes more frequently. Therefore a flexible Frequency Containment Control (FCC) is required. The FCC has to be designed in a way every unit can bring in its strengths based on its technology.

The basic requirements for FCC are:

- Be sufficiently fast in order to support Inertia response power Control
- Provide sufficient power reserves to cover power imbalance and ensure $\Delta f_{dyn,static}$
- Provide sufficient energy reserves to ensure $\Delta f_{dyn,static}$ until FRR/RR restore frequency

Complete description

In today’s power system Frequency Containment Control is predominantly provided by conventional power plants. This results from existing bidding/market rules. E.g. in Germany primary control has to be provided for a complete week and with a minimum capacity of ±1 MW power reserve. This is not feasible for units with a primary source depending on the weather or with limited storage capacity. Therefore a transition to a more flexible FCC is required. Especially converter-coupled sources can provide due to their high dynamics and fast response times a valuable contribution to FCC. Of course it has to be taken into account that energy reservoir of converter-coupled units as e.g. battery units are limited compared with conventional power plants. Therefore it is advisable to develop a framework where every unit (generation and load) is able to bring in its strengths based on the characteristics of the used technology. This offers also the possibility for an economic optimisation through the distribution of the FCC on different kind of generators or loads.

Figure 23 exemplary shows how FCC could be designed. The FCC for positive and negative frequency deviations should be split up. Based on information of the participating resources with regard to their dynamics, power and energy contribution, the responsible for FCC can compose an aggregated behaviour which fulfils the requirements derived by the coordination with inertia control and Balance Restoration and Balance Steering Control (see Figure 24). The method how to aggregate and to distribute FCC participating units has to be developed within ELECTRA and is therefore not describe in detail in this use case. In addition methods for the coordination with inertia steering control and Balance Restoration and Balance Steering Control have to be considered.

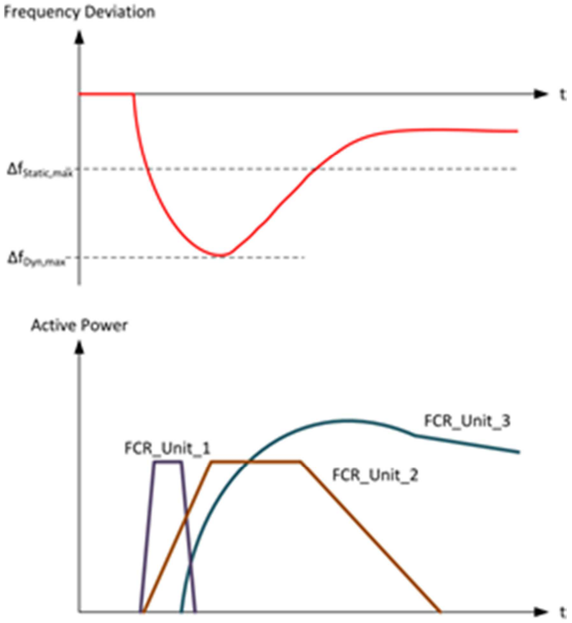


Figure 23: Exemplary composition of proposed Frequency Containment Control. Note: Contribution of Inertia power response Control and Frequency Restoration Reserve is not considered in this graph

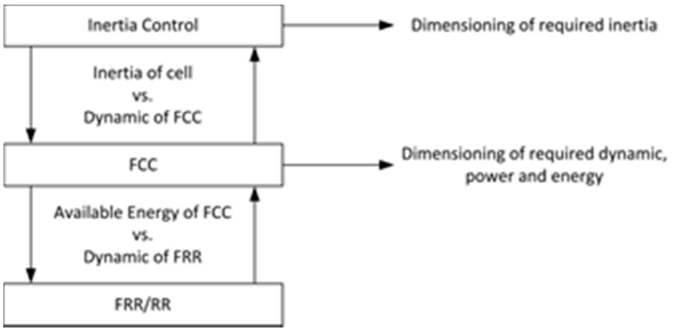


Figure 24: Principal coordination and interrelation between inertia steering control, Frequency Containment Control, Balance Restoration and Balance Steering Control for determination of requirements for the corresponding frequency control use cases

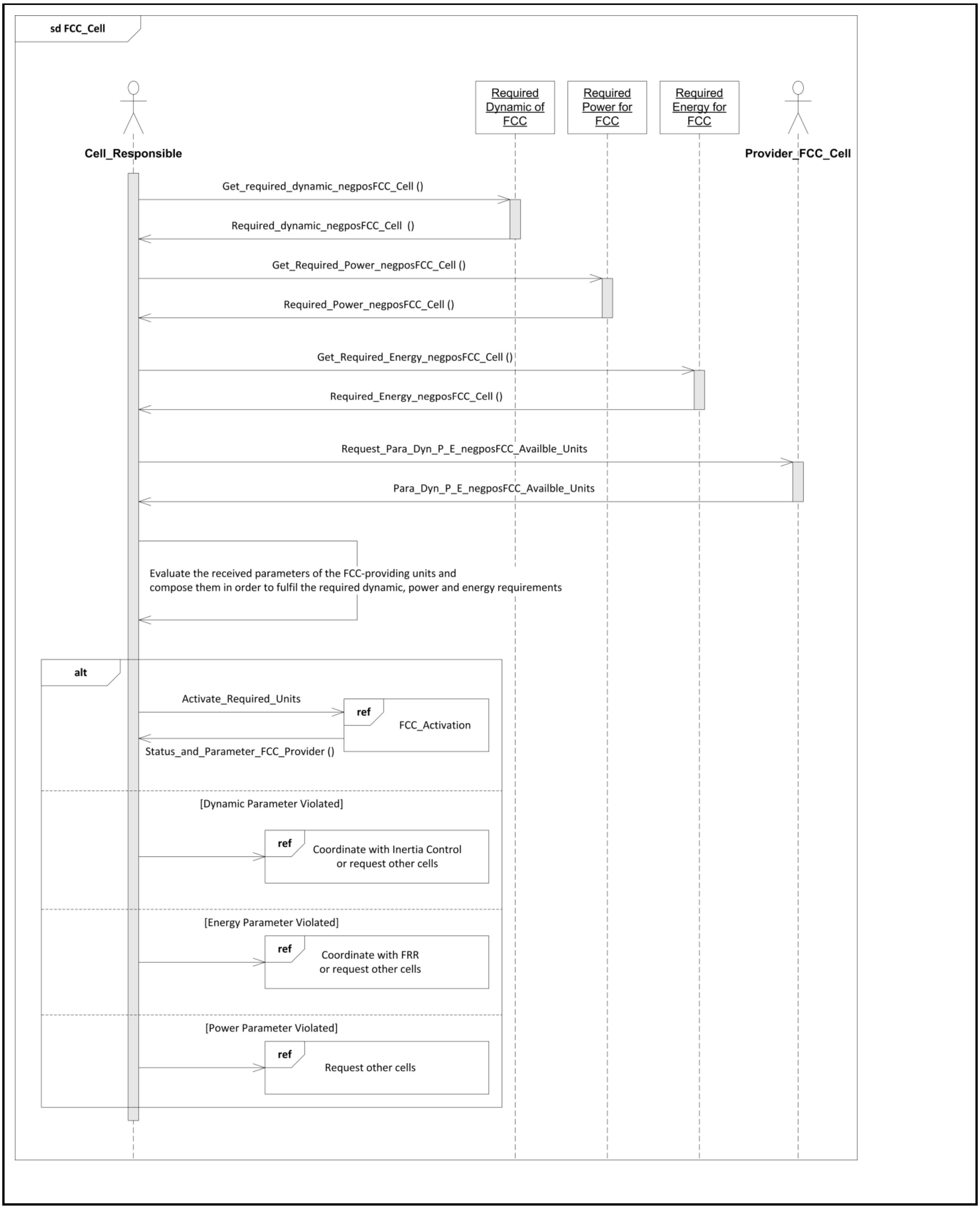
Key Performance Indicators				
ID	Name	Calculation	Scope	Objective
KPI_01	Contribution of cell to grid stability	Time the FCC requirements are fulfilled in relation to total time.		Contribution to frequency stability

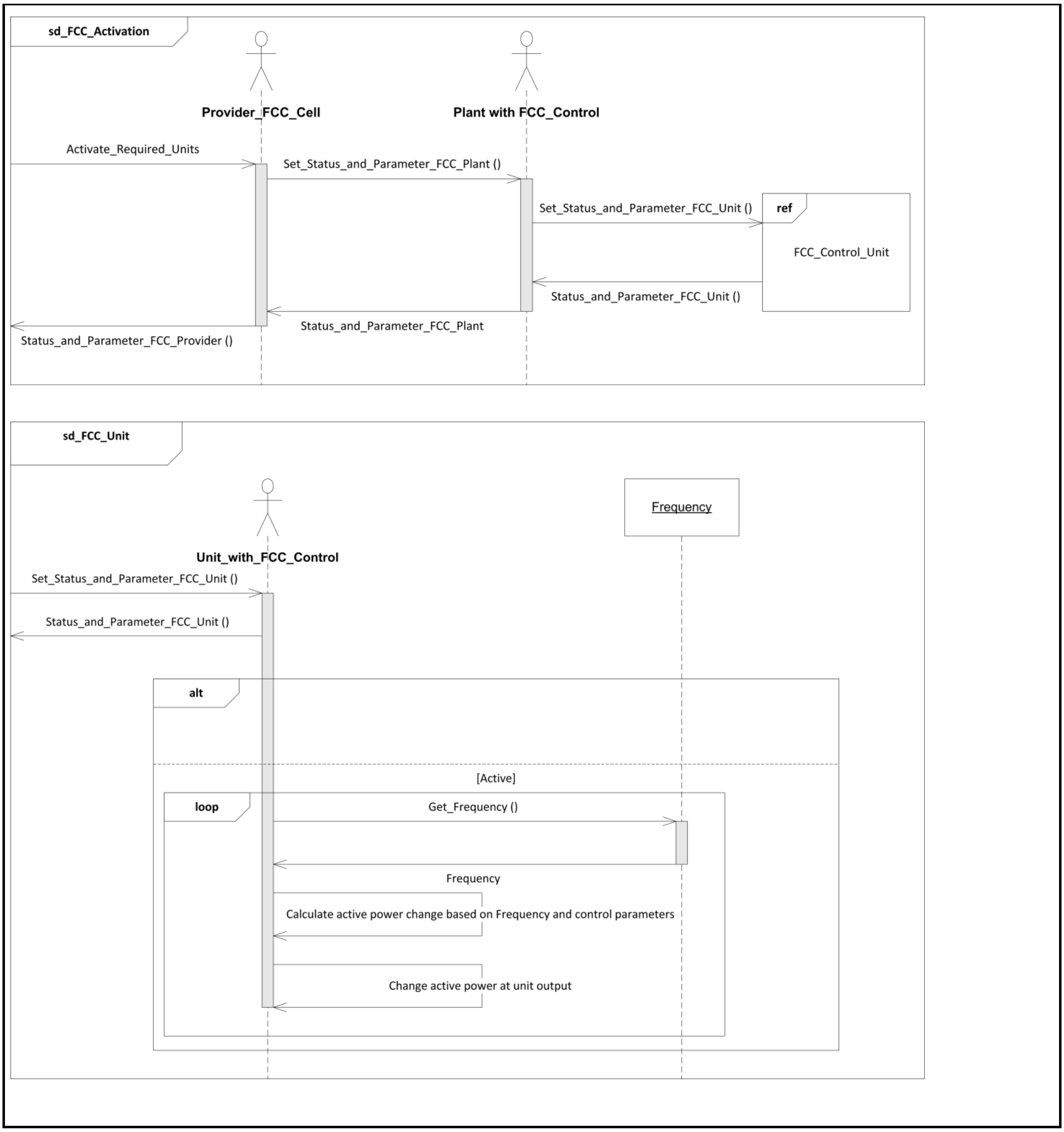
Classification Information
Relation to Other Use Cases
Balance Restoration Control (F-2), Balance Steering Control (F-3) and inertia steering control (F-1).
Level of Depth
High-Level
Prioritisation
Generic, Regional or National Relation
Generic
Viewpoint
System operation
Further Keywords for Classification

General Remarks

5.2.2 Diagrams of Use Case

Diagram(s) of Use Case
Sequence Diagrams: The same sequence diagram is valid for negative FCC.


sd FCC_Cell
Cell_Responsible
Required Dynamic of FCC
Required Power for FCC
Required Energy for FCC
Provider_FCC_Cell
Get_required_dynamic_negposFCC_Cell ()
Required_dynamic_negposFCC_Cell ()
Get_Required_Power_negposFCC_Cell ()
Required_Power_negposFCC_Cell ()
Get_Required_Energy_negposFCC_Cell ()
Required_Energy_negposFCC_Cell ()
Request_Para_Dyn_P_E_negposFCC_Availble_Units
Para_Dyn_P_E_negposFCC_Availble_Units
Evaluate the received parameters of the FCC-providing units and compose them in order to fulfil the required dynamic, power and energy requirements
alt
Activate_Required_Units
ref
FCC_Activation
Status_and_Parameter_FCC_Provider ()
[Dynamic Parameter Violated]
ref
Coordinate with Inertia Control or request other cells
[Energy Parameter Violated]
ref
Coordinate with FRR or request other cells
[Power Parameter Violated]
ref
Request other cells



5.2.3 Technical details

Actors			
Grouping		Group Description	
Actor Name see Actor List	Actor Type	Actor Description see Actor List	Further informati

	see Actor List		on specific to this Use Case
Cell Operator		A party that is responsible for a stable cell operation. The Cell Operator is a network operator responsible for the operation and the management of inertia within its cell as well as frequency containment control.	
Provider_FCC_Cell		Provider which offers FCC	
Plant_with_FCC-Control		Plant which is able to provide FCC	Could be also a load
Unit_with_FCC_Control		Single Unit within the plant which is able to provide FCC	Could be also a load

Use Case Conditions
Assumption
Prerequisite

References						
No.	References Type	Reference	Status	Impact on Use Case	Originator / Organisation	Link
1	Guideline	Continental Europe Operation Handbook-CEOH	Release 2004	Function Layer	ENTSO-E	https://www.entsoe.eu/publications/system-operations-reports/operation-handbook/Pages/default.aspx

2	Report	Supporting Document for the Network Code on Load-Frequency Control and Reserves	Version of 28.06.2013	Functional Layer	ENTSOE-E	
3	Network Code	Network Code on Load-Frequency Control and Reserves	Version of 28.06.2013	Functional layer	ENTSO-E	
4	Paper	A new frequency control reserve framework based on energy-constrained units	18.-22. August 2014	Functional layer	Brosche, T.; Ulbig, A.; Andersson G., 18th Power Systems Computation Conference PSCC	

5.2.4 Step by step analysis of Use Case

Scenario Conditions						
No.	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
1	sd_FCC_Cell	This scenario describes which plants/units have to be activated for negative/positive FCC based on the required parameters for the dynamic, power and energy for the FCC. In addition it is described which measures have to be undertaken if the available plants/units in the cell cannot fulfil the required parameters of dynamic, power and energy for FCC.	Cell Responsible	Periodically		
2	sd_FCC_Activation	This scenario describes the activation and parametrisation of the units for FCC contribution.	Provider_FCC_Cell	Activation by Cell_Responsible		
3	sd_FCC_Unit	This scenario describes the realisation	Unit_with_	Activatio		

		of FCC within the single unit.	FCC_Control	n by Plant_with_FCC_Control		

Scenario								
Scenario Name :	sd_FCC_Cell							
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
1	Periodically	Get_required_dynamic_negposFCC_Cell	The required dynamic for the FCC of the cell is requested. The dimensioning of the parameter is not part of this use case. The time step size is not yet defined for request and update of this parameter.	Request	Cell_Responsible	Required Dynamic of FCC	IE_01	
2	Periodically	Requied_dynamic_negposFCC_Cell	The required dynamic for the negative/positive FCC is send to the Cell_Responsible. The calculation of the required dynamic is not specified yet. Also it is not specified who is responsible for this task.	Receive	Required Dynamic of FCC	Cell_Responsible	IE_02	
3	Periodically	Get_Required_Power_negposFCC-Cell	The required power for the FCC of the cell is requested. The dimensioning of the parameter is not part of this use case. The time step size is not yet defined for request and update of this parameter.	Request	Cell_Responsible	Required Power for FCC	IE_03	
4	Periodically	Required_Power_negposFCC_Cell	The required power for the negative/positive FCC is send to the Cell_Responsible. The calculation of the required power is not specified yet. Also it is not specified who is responsible for this task.	Receive	Required Power for FCC	Cell_Responsible	IE_04	

5	Periodically	Request_Required_Energy_negposFCC_Cell	The required energy for the FCC of the cell is requested. The dimensioning of the parameter is not part of this use case. The time step size is not yet defined for request and update of this parameter.	Request	Cell_Responsible	Required Energy for FCC	IE_05	
6	Periodically	Required_Energy_negposFCC_Cell	The required energy for the negative/positive FCC is send to the Cell_Responsible. The calculation of the required energy is not specified yet. Also it is not specified who is responsible for this task.	Receive	Required Energy for FCC	Cell_Responsible	IE_06	
7	Periodically	Request_Para_Dyn_P_E_negposFCC_Availble_Units	The available parameter for dynamic, power and energy of the negative/positive FCC are requested from the provider of negative/positive FCC within the cell. The time step size is not yet defined.	Request	Cell_Responsible	Provider_FCC_Cell	IE_07	
8	Periodically	Para_Dyn_P_E_negposFCC_Availble_Units	The provider of negative/positive FCC sends the parameters of dynamic, power and energy of the available sources for FCC in the next period to the responsible of the cell.	Receive	Provider_FCC_Cell	Cell_Responsible	IE_08	
9	Periodically	Evaluate received parameters	Based on the parameters of the available source the cell responsible has to compose them in order to fulfil the required dynamic, power and energy requirements for the negative/positive FCC. In a first step only a technical optimisation is foreseen. An economic optimisation could be integrated as well.	Internal operation	Cell_Responsible	Cell_Responsible		
10	All parameters are within limits	Active_Required_Units	If the parameters of dynamic, power and energy are fulfilled the units to be activated are send to the provider of the negative/positive FCC in the cell. In this version of the use case it is not considered that	Send	Cell_Responsible	Provider_FCC_Cell	IE_09	

			parameters for the provision of negative/positive FCC of the units could be adapted by the cell responsible. This could be an option especially if the negative/positive FCC is provided by inverter-coupled units. This could be introduced in a further version of the use case.					
11	All parameters are within limits	Status_and_Parameter_FCC_Provider	The cell responsible receives the status and actual parameters of the sources contributing to negative/positive FCC in the next time step.	Receive	Provider_FCC_Cell	Cell_Responsible		
12	Dynamic Parameter violated		If the available sources in the cell do not fulfil the required dynamic parameter following actions have to be carried out. Either coordinate with the inertia control or request support from other cells. The procedure is not described in this use case. This could be introduced in a further version.	Send	Cell_Responsible	Other cells / Inertia Control Use Case	IE_10	
13	Energy Parameter violated		If the available sources in the cell do not fulfil the required energy parameter following actions have to be carried out. Either coordinate with FRR or request support from other cells. The procedure is not described in this use case. This option could be introduced in a further version.	Send	Cell_Responsible	Other cells / FRR Use Case	IE_11	
14	Power Parameter violated		If the available sources in the cell do not fulfil the required power parameter other cells have to be requested for support The procedure is not described in this use case. This option could be introduced in a further version.	Send	Cell_Responsible	Other Cells	IE_12	

Scenario								
Scenario Name :		sd_FCC_Activation						
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
15	If step no. 11 is true	Activate_Required_Units	The required units are requested / activated by the cell responsible.	Receive	Cell_Responsible	Provider_FCC_Cell	IE_14	
16	If step no. 11 is true	Set_Status_and_Parameter_FCC_Plant	The Provider_FCC_Cell sends status and parameters to the plants with FCC.	Send	Provider_FCC_Cell	Plant_with_FCC_Control	IE_15	
17	If step no. 11 is true	Set_Status_amd_Parameter_FCC_Unit	The plant sends the status and parameters to the single units within the plant (if existing).	Send	Plant_with_FCC_Control	FCC_Control_Unit	IE_15	
18	As soon as sd_FCC_Control_Unit provides information	Status_and_Parameter_FCC_Unit	The plant receives the actual status and parameters of the single units	Receive	FCC_Control_Unit	Plant_with_FCC_Control	IE_16	
19	As soon as sd_FCC_Control_Unit provides information	Status_and_Parameter_FCC_Plant	The provider of the FCC in the cell receives the status and parameters of the plants contributing to FCC	Receive	Plant_with_FCC_Control	Provider_FCC_Cell	IE_16	
20	As soon as sd_FCC_Control_Unit provides information	Status_and_parameter_FCC_provider	The Cell Responsible receives the status and parameters from the provider of FCC in the cell	Send	Provider_FCC_Cell	Cell_Responsible	IE_16	
Scenario								
Scenario Name :		sd_FCC_unit						
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
21	Activation	Set_Status_	The unit receives the status	Receiv	Plant_with_F	FCC_Contro	IE_17	

	by Plant_with_FCC_Control	and_Parameter_FCC_Unit	concerning contribution to FCC (on/off) and the parameters.	e	CC_Control	l_Unit		
22	Activation by Plant_with_FCC_Control	Status_and_Parameter_FCC_Unit	The unit sends the actual status and parameters for the FCC to the plant.	Send	FCC_Control_Unit	Plant_with_FCC_Control	IE_16	
23	If FCC is active periodically	Get_Frequency	If FCC is activated the unit periodically request the actual frequency. The time step size and the accuracy are not specified yet.	Request	FCC_Control_Unit	Frequency	IE_18	
24	If FCC is active periodically	Frequency	The unit receives the actual frequency	Receive	Frequency	FCC_Control_Unit	IE_19	
25	If FCC is active periodically	Calculate active power change based on frequency and control parameters	The unit calculates the required active power change based on the actual frequency and the parameters of FCC.	Internal	FCC_Control_Unit	FCC_Control_Unit		
26	If FCC is active periodically	Change active power at unit output	The active power output is changed.	Internal	FCC_Control_Unit	FCC_Control_Unit		

5.2.5 Misc

Information Exchanged			
Information Exchanged ID	Name of Information	Description of Information Exchanged	Requirements IDs
IE_01	Request	Required dynamic for negative and positive FCC	
IE_02	Parameter	Dynamic parameters for negative and positive FCC	
IE_03	Request	Required power for negative and positive FCC	
IE_04	Parameter	Power parameters for negative and positive FCC	
IE_05	Request	Required energy for negative and positive FCC	
IE_06	Parameter	Energy parameters for negative and positive FCC	
IE_07	Request	Request parameters for available sources for positive and negative FCC contribution in the cell	
IE_08	Parameter	Receive parameters for dynamic, power and energy	

IE_09	Parameter	Parameters for activation of the negative and positive FCC send to the provider.	
IE_10	Parameter	Status and parameters of the FCC are received	
IE_11	Request	Inertia Control and/or other cells are requested for support	
IE_12	Request	FRR and/or other cells are requested for support	
IE_13	Request	Other cells are requested for support	
IE_14	Parameter	Required plants/units for FCC (and parameters)	
IE_15	Parameter	New Status and parameters	
IE_16	Parameter	Actual status and parameter	
IE_17	Parameter	New Status and parameters	
IE_18	Request	Frequency	
IE_19	Measurement	Actual value	

Requirements (optional)		
Category ID	Category Name	Category Description
Requirement ID	Requirement Description	

Common Terms and Definitions	
Term	Definition

Custom Information (optional)		
Key	Value	Refers to Section

5.3 Future Balance Restoration Control

5.3.1 Description of the Use Case

Use Case Identification		
ID	Area/Domain(s)/Zone(s)	Name of Use Case
F-3	Domains: Generation, Transmission, Distribution, DER, Customer Premises Zones: Process, Field, Station, Operation	Balance Restoration Control

Version Management				
Version No.	Date	Name of Author(s)	Changes	Approval Status
0.1	6/11/2014	R. D'hulst (VITO)	initial version	Draft
0.2	17/11/2014	R. D'hulst (VITO)	changed sequence diagram	Draft
0.3	14/12/2014	R. D'hulst (VITO)	Update after further discussions	Proposed

Scope and Objectives of Use Case	
Scope	The objective of Balance Restoration Control is to restore the cell balance, i.e. restore cell consumption/generation to its scheduled value, as well as restore power exchange with other cells to their scheduled values. Restoration Reserves may be offered by loads, production units as well as storage units within the cell. Response of Balance Restoration Reserves activation orders should be between TBD sec and TBD min. *(TBD to be determined and analysed through detailing of the design and modelling/simulation).* The system under discussion in this UC is the Cell.
Objective(s)	Power balance within the cell as well as power exchange with other cells is restored to its scheduled value after activating Balance Restoration Reserves.
Related business case(s)	--

Narrative of Use Case
Short description
In the future ELECTRA scenario, the system operator within each 'cell' will contract Balance Restoration Reserves, offered by a Restoration Reserve Provider. Based on the total of the differences between scheduled power flow and measured/actual power flow across the cell borders (= Balance Restoration control error), Balance Restoration reserves (available within the cell) are activated. Balance Restoration Control process: a. Detection of Balance Restoration error b. Determination of state of cell c. Definition of restoration reserves merit order d. Determination of activation orders e. Sending of activation orders to restoration reserve providers

f. Activation and monitoring of reserves

Complete description

The Balance Restoration process is run by the Cell Operator of each cell within the overall electricity system. Only restoration reserve capacity from within the cell is activated by the restoration process. Restoration reserves should be activated 30 sec. after detection of a Balance Restoration error.

a. Detection of Balance Restoration error
The Balance Restoration Process is activated after the Cell Operator control center detects a difference between the total scheduled power flow and the total of measured/actual power flow across the cell borders (= Balance Restoration control error).

b. Determination of state of cell
To be able to determine the impact on the cell grid of activation of certain restoration reserves, the Cell Operator determines the state of the cell. This is done by taking into account measurements throughout the cell.

c. Definition of restoration reserves merit order
The decision to dispatch which activation order to whom is taken based on a merit order.
The merit order considers bids that were previously sent by restoration reserve providers to the Cell Operator. Bids indicate the volume that is available for restoration reserve, as well as an activation price. In the Balance Restoration process only restoration reserve providing units connected to the cell are taken into account.
The merit order takes into account activation prices and the system state, such that activating a certain restoration reserve unit does not cause congestion issues within the cell.
The merit order could also include other objectives such as maximal reliability and efficiency.

d. Determination of activation orders
Depending on the Balance Restoration error, and the restoration reserves merit order, activation orders are determined.

e. Sending of activation orders to restoration reserve providers
Activation orders are sent to the restoration reserve providers. If a restoration reserve provider is responsible for the management of a cluster of different reserve providing units, the activation order is subsequently dispatched by the reserve provider amongst his portfolio.

f. Activation and monitoring of reserves
After receiving an activation order, the reserve capacity is activated. Activation of the reserve providing units is monitored for ex-post handling.

Key Performance Indicators				
ID	Name	Calculation	Scope	Objective
KPI_01	Balancing	Min(BalanceRestorationError) = Min ($\Sigma P_{scheduled}$ - $\Sigma P_{measured}$) where P expresses power flows across cell interconnections	Calculation of power flows at specific interconnection lines	Maintaining power balance

KPI_02	Cost minimisation	Cost=$\Sigma fc_i(P_i)+\Sigma OM_k(P_k)+\Sigma(SU_l+SD_m)$ where $fc_i(P_i)$ is the fuel cost of unit i running at power yield P_i, $OM_k(P_k)$ is the operation and maintenance cost of unit k, and SU_l and SD_m are the start-up and shut-down costs of the units.	Calculation of cost induced from restoration reserves activation	Minimization of the cost based on optimal scheduling of restoration reserves

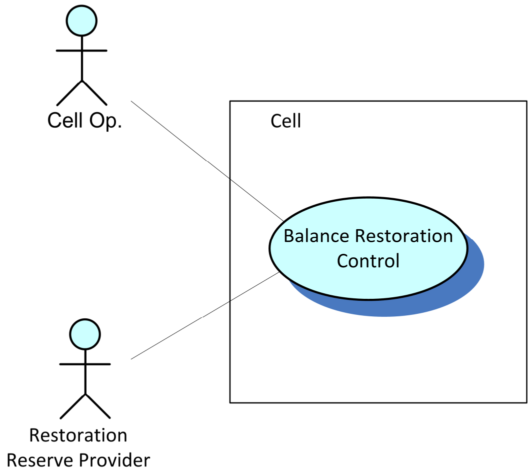
Classification Information
Relation to Other Use Cases
Frequency Containment Control (F-2) and Balance Steering Control (F-4)
Level of Depth
High-Level Use Case
Prioritisation
Generic, Regional or National Relation
Generic
Viewpoint
Technical
Further Keywords for Classification
Balancing Control

General Remarks

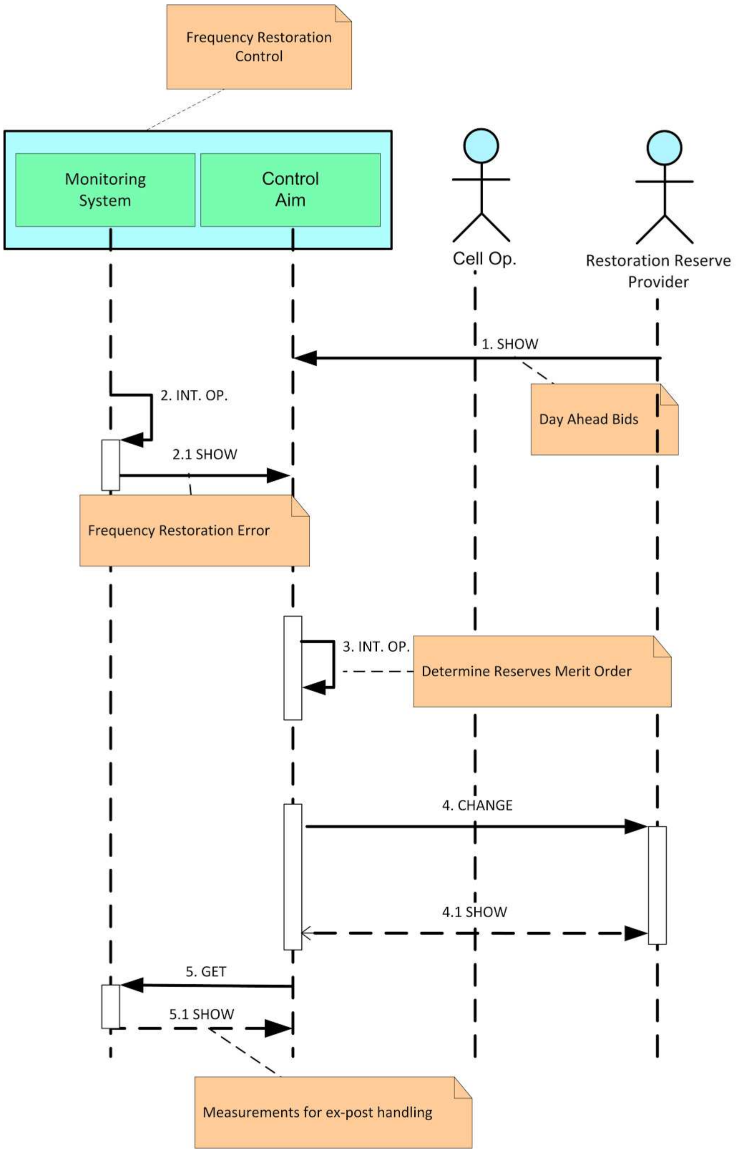
5.3.2 Diagrams of Use Case

Diagram(s) of Use Case

1. Context Diagram



2. Sequence Diagram



5.3.3 Technical details

Actors			
Grouping		Group Description	
Actor Name see Actor List	Actor Type see Actor List	Actor Description see Actor List	Further information specific to this Use Case
Cell Operator	Role	A party that is responsible for a stable cell operation. The Cell Operator is a system operator responsible for the operation and the management of balancing reserves located within the cell. The Cell Operator also determines and is responsible for cross border capacity and exchanges between adjacent cells.	
Restoration Reserve Provider	Role	A party that is responsible of providing restoration reserves. Reserves may be provided by a load, production or storage unit. A Restoration Reserve Provider may group or aggregate a combination of different units to provide reserves.	

Use Case Conditions
Assumption
Each Cell Operator can procure restoration reserves within its own cell. Each Cell Operator has a view on its cell state, to determine the impact on its system state before activating reserves.
Prerequisite

References						
No.	References Type	Reference	Status	Impact on Use Case	Originator / Organisation	Link

5.3.4 Step by step analysis of Use Case

Scenario Overview and Conditions						
No.	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
1	Balance Restoration Control	Balance Restoration Control is activated after a cell Balance Restoration error is detected	Cell Operator	a cell Balance Restoration error is detected		Cell Balance is restored

Scenario Steps								
Scenario Name :	No. 1: Balance Restoration Control							
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
1	Submission of day-ahead bids		Each restoration reserve provider submits bids for restoration reserve capacity	SHOW	Restoration Reserve provider	Cell Operator	IE_01	
2	Determine restoration frequency detection error		Cell Operator detects Balance Restoration error, based on the scheduled power flows across the cell borders and the actual power flows.	GET	Cell Operator	Cell Operator	IE_02	
3	Determine cell system state		Cell Operator determines the state of the cell system	GET	Cell Operator	Cell Operator	IE_03	
4	Determine activation merit order		Cell Operator determines the restoration reserves activation merit order	INT. OP.	Cell Operator	Cell Operator		
5	Send activation		Cell Operator sends activation orders to	CHANGE	Cell Operator	Restoration Reserve	IE_04	

	order		restoration reserve providers			Provider		
6	Activation of reserve providing unit		The activation of reserve providing units is measured	SHOW	Restoration Reserve Provider	Cell Operator	IE_05	

5.3.5 Misc

Information Exchanged			
Information Exchanged ID	Name of Information	Description of Information Exchanged	Requirements IDs
IE_01	restoration reserve bid	Restoration reserve bids indicate the volume (per quarter hour) that is available for restoration reserve, as well as an activation price. The volumes bid must be in agreement with the contract the reserve provider has with the Cell Operator.	
IE_02	Balance Restoration error	difference between scheduled power flow and measured/actual power flow across the cell borders	
IE_03	Cell system State	Measured or estimated cell system state, i.e. power flows through lines, voltages on busses of cell system.	
I_04	Restoration Reserve Activation Order	Control signal to active restoration reserve unit, contains: ● Restoration Reserve Provider ID ● Power [MW] ● activation time [min]	
I_05	Measurements of reserve activation	Measurements of reserve activation enabling ex-post handling and remuneration.	

Requirements (optional)		
Category ID	Category Name	Category Description
Requirement ID	Requirement Description	

Common Terms and Definitions	
Term	Definition

Custom Information (optional)		
Key	Value	Refers to Section

5.4 Future Balance Steering Control

5.4.1 Description of the Use Case

Use Case Identification		
ID	Area/Domain(s)/Zone(s)	Name of Use Case
F-4	Domains: Generation, Transmission, Distribution, DER, Customer Premises Zones: Process, Field, Station, Operation	Balance Steering Control (BSC)

Version Management				
Version No.	Date	Name of Author(s)	Changes	Approval Status
0.1	07/11/2014	Evangelos Rikos	--	Draft
0.2	18/11/2014	Evangelos Rikos	Major revisions regarding scope, objectives, description, scenarios, steps according to comments by VITO	Draft
0.3	26/11/2014	Evangelos Rikos	Revisions and simplification of roles and scenarios according to comments by VITO	Proposed

Scope and Objectives of Use Case	
Scope	• Reactive substitution of Balance Restoration Reserves (BRRs) by Replacement Reserves (RRs), and thereby achieving the most economical dispatch of reserves. • Proactive activation of Balance Steering Resources based on short-term forecasting The system under discussion in this UC is the Cell.
Objective(s)	In any of the two abovementioned modes the ultimate goal of BSC is to restore balance to the set point in the most economical way. This is achieved either pro-actively or reactively by covering imbalances induced by forecast errors and other reasons, happening under normal conditions or contingencies. Particularly, the substitution of BRRs by RRs makes the former available for potential subsequent contingencies, while the proactive use of BSRs covers potential imbalances and reduces the invoking of the other two types of reserves (FCR and BRR). This way, the system becomes more reliable against contingencies and its operating cost is optimized.
Related business case(s)	--

Narrative of Use Case
Short description
The use of BSC can be distinguished into two main modes, all of which ensure a specific system balance and, hence, an indirect frequency containment within predefined boundaries. The future cell-centric Balance Steering Control strategy addresses two major operation issues, such as prevention of potential

contingencies by proactive coverage of residual imbalances and support/substitution of secondary frequency reserves (namely BRRs) by Replacement Reserves (RRs) in order to make the former available to tackle potential future contingencies.
Complete description

The two operation issues mentioned above can be dealt with the use of one high-level control scheme, named Balance Steering Controller. It is worth mentioning that the proposed control scheme has at its core the utilisation of the cell capabilities in terms of BSRs and RRs provision and its ultimate objective is to control/maintain power flows within and among cells so as to achieve specific balancing and, therefore, indirectly restoring and maintaining frequency at required levels. This general objective can be further analysed into balance (frequency) maintenance to a set-point (in contrast Balance Restoration Control, BRC, pursues the restoration of frequency to that value) via fulfilment of specific power flow set points between cells (either restoration or redistribution according to what the optimal result is). It should also be stressed that in the future cell-centric view of the system, the utilisation of bulk generation connected to transmission system is supplementary to the use of cell's resources in order to cover residual imbalances in the BSR and RR schedules, in other words as emergency resources in case DER cannot meet the operator's request .

More analytically, for each of two problems the operation of the BSC is summarized below:

- Proactive prevention of contingencies: In this case, BSC has the responsibility of supervising the system and based on short-term forecasting tools predict potential incidents that may substantially affect frequency. As soon as such a situation is predicted, the actions of BSC should include the activation and commitment of resources that can instantly respond to the forthcoming incident upon dispatching request. This function of the BSC can prove very important in terms of minimising the risks of the system's operation, reducing the invoking of reactive frequency controllers and their associated reserves, increasing so the reliability and profits of the system. The core element of this proactive operation of BSC is the cell in which the potential incident is predicted. Therefore, the most effective use of BSRs to prevent an upcoming incident should be covered as much as possible by local (within the cell's boundaries) resources (e.g. load shift to prevent a fast ramp of the wind solar production).
- Substitution of Balance Restoration Reserves: Last but not least, Balance Steering Control is nominated with the responsibility of making BRRs available after their activation. This is achieved by replacing BRRs by tertiary reserves, traditionally called as Replacement Reserves. In the future cell-centric approach of the system operation, not only will RRs (and BSRs in general) be provided by resources within cells but also with power exchanges between cells. In any case, the ultimate objective of this operation is to make BRRs available for use in next potential incidents that would require their activation, because otherwise the system may become incapable of dealing with successive fast frequency deviations. It is worth mentioning that any tertiary resources used to support BRRs when the latter cannot fully restore frequency, should be considered as part of and managed by Secondary Frequency Control, achieving so a clear distinction between the objectives of the two control schemes and the portfolios of resources to be used. For example, tertiary resources used to aid BRRs should be located within the cell, contrarily to BSC activation which makes use of resources from adjacent cells as well. In any case the activation of RRs is always reactive because it is based on the system's BRRs state and the ultimate objective is the maintenance of the restored frequency within the desired margin.

In all the above cases, the main and highest priority observable is power balancing within cell or between cells within Control Area and therefore BSC should observe power flows at selected lines, so as to identify and validate the control effectiveness and the overall system's state. Furthermore, as mentioned previously, one major difference between BSC and BRC is that the former deploys resources not only within the cell but also from neighbouring cells in contrast with BRC which only deploys reserves locally and strictly within the cell. Therefore, the monitoring of power imports to and exports from cells is an important observable for the BSC effectiveness. In addition, monitoring of frequency is required as a validation means but not for activation of the control actions as these are envisaged to be commenced due to different sort of signals, while additional indicators such as operating costs can be used for validation of cost-optimisation algorithms deployed by the BSC. The timeframe of activation and operation of BSC in any of the above cases ranges from 15 min to 1 hour. It is assumed that flexibility and forecasting algorithms used for BSC have a granularity on the scale of quarters and hours. Next to that, the assumption is made that (other) market processes will be able to take over any remaining balancing issue after one hour.

In terms of its internal structure and hierarchy, BSC can be regarded as something similar to the Load-Frequency Control scheme, currently used in Control Blocks and Control Areas at TSO level. Particularly, the hierarchy can be either central with one single BSC located at CA level and responsible for management of all subordinate cells, hierarchical where one BSC at CA level influences individual cell BSCs, or pluralistic where each cell controller regulates its own cell area while there is one CA controller for the regulation of the whole CA towards its neighbouring CAs. The use of these types of hierarchy ensures that BSC effectively manages tertiary reserves not only within cells but also ensures balance within the Control Area in which these cells are located.

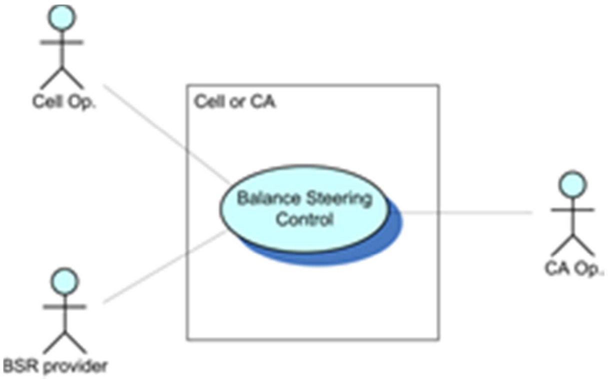
Key Performance Indicators				
ID	Name	Calculation	Scope	Objective
KPI_01	Balancing	$\Sigma P_i=0$ where Pi expresses power flows, including production, consumption and import/exports	Calculation of power flows at specific interconnection lines	Maintenance of power balancing
KPI_02	Substituted BRRs	$\max(\Sigma P_{RRi})>\max(\Sigma P_{BRRi})$, $t_{cont}<t<t_{cont}$ +15min where: -tcont is the contingency time -P_{RRi} is the active power of the i-th RR after its activation. -P_{BRRi} is the active power of the i-th BRR after its activation	Calculation of total Active Power provided by RRs	Thorough substitution of BRRs activated after a contingency by RRs for use of the former in next events
KPI_03	Cost minimisation	$Cost=\Sigma fc_i(P_i)+\Sigma OM_k(P_k)+\Sigma(SU_l+SD_m)$ where $fc_i(P_i)$ is the fuel cost of unit i running at power yield P_i, $OM_k(P_k)$ is the operation and maintenance cost of unit k, and SU_l and SD_m are the start-up and shut-down costs of the units.	Calculation of cost induced from balance steering reserves activation	Minimization of the cost based on optimal scheduling of Balance Steering Reserves.

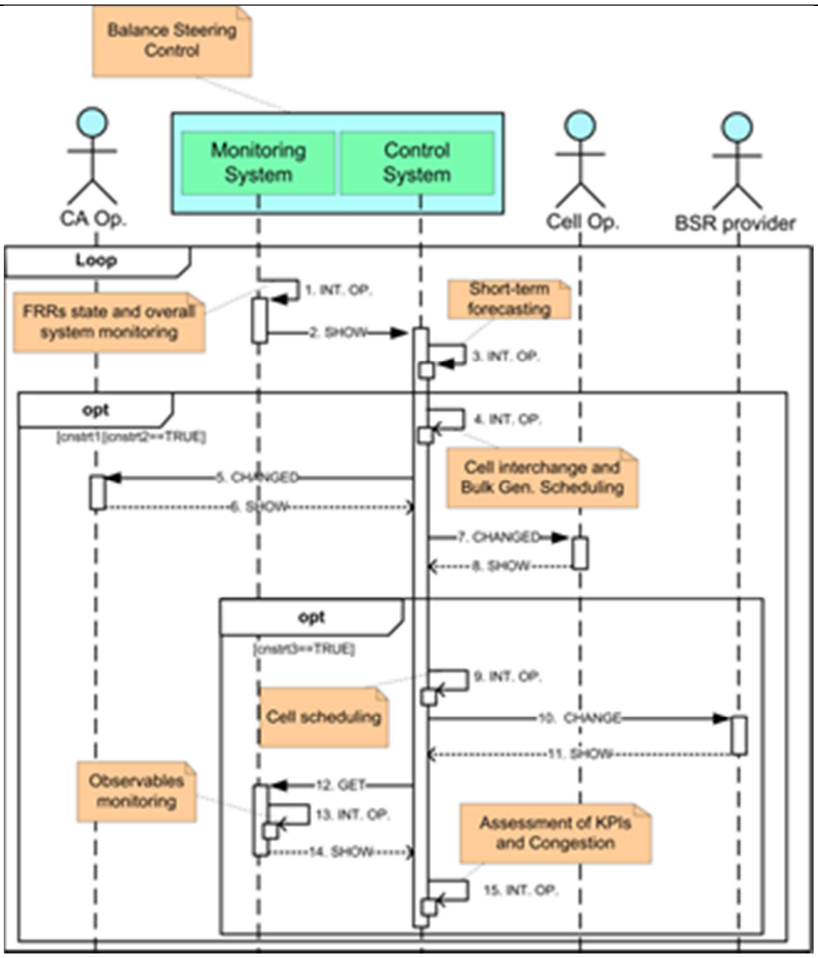
Classification Information
Relation to Other Use Cases
Balance Restoration Control (F-3)
Level of Depth

High-Level
Prioritisation
Generic, Regional or National Relation
Generic
Viewpoint
System operation
Further Keywords for Classification
Balancing Control

General Remarks

5.4.2 Diagrams of Use Case

Diagram(s) of Use Case
Context diagram:  Sequence Diagrams:



5.4.3 Technical details

Actors			
Grouping		Group Description	
Actor Name see Actor List	Actor Type see Actor List	Actor Description see Actor List	Further information specific to this Use Case
Cell Operator	Role	A party that is responsible for a stable cell operation. The Cell Operator is a system operator responsible for the operation and the management of balancing reserves located within the cell. The Cell Operator also determines and is responsible for cross border capacity and exchanges between adjacent cells.	

CA Operator	Role	Control Area Operator: supervisor and coordinator of the area of cells around the cell of the incident, in order to coordinate potential imports/exports between the affected cell and the adjacent ones.	
Balance Steering Resources (BSR) Provider	Role	A party that is responsible of providing Balance Steering Resources including replacement reserves. Resources may be provided by a load, production or storage unit. A BSR Provider may group or aggregate a combination of different units to provide reserves.	

Use Case Conditions
Assumption
Prerequisite

References						
No.	References Type	Reference	Status	Impact on Use Case	Originator / Organisation	Link
1	Guideline	Continental Europe Operation Handbook-CEOH	Release 2004	Function Layer	ENTSO-E	https://www.entsoe.eu/publications/system-operations-reports/operation-handbook/Pages/default.aspx
2	Report	Roles and Responsibilities of Actors involved in the Smart Grids Deployment	Release 2011	Business/Function Layer	EC-TF for SG-EG3	http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/expert_group3.pdf
3	Report	The Harmonised Electricity Market Role Model	Version 2014-01	Business/Function Layer	ENTSO-E	https://www.entsoe.eu/fileadmin/user_upload/edi/library/role/harmonised-role-model-2014-01_approved.pdf

5.4.4 Step by step analysis of Use Case

Scenario Overview and Conditions						
No.	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
1	Proactive BSC	Cell Op. makes a short-term prediction of substantial imbalance or other deviation based on forecasting tools and proactively deploys BSRs so as to support and enhance system immunity against frequency departures	Cell Operator	Forecasting tools output showing imminent contingencies due to production/consumption variations	Signals produced by forecasting tools about imminent disturbance	Activation of BRRs to mitigate disturbance and maintain balancing
2	Activation of RRs/reactive use of BSC	Cell Op. within which contingency happens and has activated BRR initiates a process of replacing BRRs in order to render them available for potential next incidents. The actions are also supported by imports of RRs from adjacent cells and bulk generators within the CA	Cell Operator	Activation of BRRs which requires replacement of them	BRRs are active	RRs take over in order to maintain frequency and make BRRs available

Scenario Steps								
Scenario Name :	No. 1 - Proactive and no. 2 reactive** Balance Steering Control							
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
1	Periodically	System Monitoring	The monitoring system of BSC monitors the power system and the state of BRRs	INTERNAL OPERATION	Monitoring System	Monitoring System	IE_01	
2	Periodically	Show System Status	The monitoring system shows status and provides the control system with data for its calculations and	SHOW	Monitoring System	Control System	IE_01	

			control actions					
3	Periodically	Short-term forecasting	Short-term forecasting tool used by the control system to estimate potential contingency or other type of imminent imbalance incident	INTERNAL OPERATION	Control System	Control System	IE_01, IE_02	
4	CA-level schedule calculation	Schedule and dispatching calculation of BSRs at CA level	The control system calculates internally the schedule of BSR at CA level focusing on cell interchange and bulk generators contributions	INTERNAL OPERATION	Control System	Control System	IE_03	
5	Schedule activation	CA Operator is firstly informed of the immediate BSR activation at CA-level	The control system sends a signal notifying the CA Op. of the imminent BSRs activation	CHANGED	Control System	CA Op.	IE_04	
6	Activation acknowledgement	CA Operator acknowledges new BSRs state	The CA Operator responds by acknowledging and if necessary updating the activation	SHOW	CA Op.	Control System	IE_04	
7	Schedule activation	Cell Operators are informed of the immediate BSRs activation	The control system sends a signal notifying Cell operators of the imminent BSRs activation	CHANGED	Control System	Cell Op.	IE_03	

8	Activation acknowledgement	Cell Operators acknowledge new BSRs state	Cell Operators respond by acknowledging and if necessary updating the activation	SHOW	Cell Op.	Control System	IE_04	
9	Cell-level schedule calculation	Schedule and dispatching calculation of BSRs at Cell level	The control system calculates internally the schedule of BSRs at Cell level focusing optimal DER BSRs portfolio	INTERNAL OPERATION	Control System	Control System	IE_03	
10	BSRs activation	BSRs are activated to balance the system	BSRs are activated to provide the required service of balancing	CHANGE	Control System	BSR provider	IE_03	
11	Show BSR status	BSR units dispatched show their status	The control system becomes aware of the achievement of the required goal of BSRs provision for the specific incident	SHOW	BSR provider	Control System	IE_05	
12	BSR Observables request	Request for BSR Observables monitoring	The control system requests from the monitoring system information regarding BSR observables	GET	Control System	Monitoring System	IE_06	
13	BSR Observables monitoring	Monitoring of BSR observables	The monitoring system performs the monitoring and calculation process required to obtain the requested observables	INTERNAL OPERATION	Monitoring System	Monitoring System	IE_06	
14	BSR	BSR	The control	SHOW	Monitoring	Control	IE_06	

	Observables send	observables acknowledgement by the control system	system is informed on the requested observable values		System	System		
15	Assessment of KPIs and constraints violation	Examination of potential congestion issues and KPIs	The control system examines potential congestion issues caused by the selected dispatching as well as KPIs. If the condition is violated there is a repetition of the steps with small corrections in dispatching to obtain the optimal distribution of power flows	INTERNAL OPERATION	Control System	Control System	IE_07	

*** The same steps also apply to the reactive use of BSC after a contingency which has led to BRRs activation. The only exception in the process is step 3 (forecasting is unnecessary in this scenario)

5.4.5 Misc

Information Exchanged			
Information Exchanged ID	Name of Information	Description of Information Exchanged	Requirements IDs
IE_01	System and BRRs state	Active Power flows and BRRs power/state	
IE_02	Frequency deviation	Frequency deviation	
IE_03	Schedule/activation of BSRs within and/or between cells	Active Power set-point schedule/dispatching, Cost estimation	
IE_04	Acceptance/modification	Acknowledgement Message, Active Power set-point schedule/dispatching	
IE_05	State/Active Power	State signal, Active Power	

IE_06	Observables	Active Power flows, Frequency	
IE_07	KPIs/Constraints	Active Power flows, Operating costs, Frequency	

Requirements (optional)		
Category ID	Category Name	Category Description
Requirement ID	Requirement Description	

Common Terms and Definitions	
Term	Definition
Balance Steering Control (BSC)	A number of proactive/reactive control actions towards restoring balance within and between cells in an optimal way. In case the resources are used to replace already active FRRs they fall into the special category of Replacement Reserves
Balance Steering Resources (BSR)	Resources used by the Balance Steering Control towards restoring balance within and between cells
Replacement Reserves (RR)	Reserves used to restore/support the required level of FRR to be prepared for further system imbalances. This category includes operating reserves with activation time from Time to Restore Frequency up to hours
Balance Restoration Reserves (BRR)	Operational reserves activated to contain System Frequency after the occurrence of an imbalance

Custom Information (optional)		
Key	Value	Refers to Section

6. Use Cases for Future (2030+) voltage control

As explained in Section 3, moving towards a cell-based architecture will result in new mechanisms for voltage control: primary voltage control and post-primary voltage control.

In WP4 of the ELECTRA project was decided to employ a Use Case Methodology to describe functionalities of new developed mechanisms and control concepts [21]. Therefore all developed voltage control mechanisms, as described in section 3, are written down as High-Level Use Cases in the ELECTRA Use Case template, based on IEC 62559-2.

By employing the Use Case methodology, the role of the different actors involved in each functionality are made clear. Also, the interactions, needed observables and control aims are specified in each Use Case document. These high level specifications of observables and control aims will subsequently be considered and used for further development within WP5 and WP6 of the ELECTRA project.

6.1 Future Primary Voltage Control

6.1.1 Description of the Use Case

Use Case Identification		
ID	Area/Domain(s)/Zone(s)	Name of Use Case
V-1	Domains: Generation, Transmission, Distribution, DER, Customer Premises Zones: Process, Field, Station, Operation	Primary Voltage Control

Version Management				
Version No.	Date	Name of Author(s)	Changes	Approval Status
0.1	01.09.2014	Dariusz Kolodziej Jacek Jemielity	Initial stage	Draft
0.2	22.09.2014	Dariusz Kolodziej Jacek Jemielity	Correction/clarification	Draft
0.3	12.11.2014	Dariusz Kołodziej	Update	Draft
0.4	21.11.2014	Dariusz Kolodziej	Correction/clarification	Proposed

Scope and Objectives of Use Case	
Scope	Primary voltage control is a fast process (fractions of seconds to several seconds) executed locally concerning generating units: synchronous generators connected to the grid, that are equipped with Automatic Voltage Controller (AVC), or other energy sources (PV, WF,..) with power electronics and control functionalities. In this Use Case the system under discussion is the controller of a generating unit.
Objective(s)	Primary voltage control maintains locally the required voltage level of the feeder or busbar in generator's interconnection point according to the present voltage set point and voltage-reactive power droop line.
Related business case(s)	--

Narrative of Use Case
Short description
Primary voltage control utilizes reactive power capabilities of grid connected generating units to maintain voltage level in an interconnection point. Active power control can also be required to achieve the desired voltage level in a low voltage grids where the line resistance is greater than the line reactance (R>X). The generating unit voltage set point can be set by Cell Operator or it's system that perform post-primary voltage control.
Complete description
The primary voltage control can be performed by the following devices connected to the grid at different voltage levels: ▪ Synchronous generators in conventional power plants are capable to supply or absorb reactive power depending on the excitation. They are required to operate between 0.85 lagging power factor and 0.95 leading power factor at rated power output. ▪ Synchronous condensers (rotating machines).

- Capacitor or inductor banks, that operate in discrete steps of capacitance or inductance
- Capacitors or inductors that are interfaced by power electronic converters, and operate continuously to provide both inductive and capacitive reactive power (FACTS devices).
- Renewable Energy Sources (wind farms, photovoltaics) are interfaced by power electronics that is capable to operate between 0.95 lagging power factor and 0.95 leading power factor at active power outputs between 50% and 100% of rated power.

Generating unit connected to a cell node, in the interconnection point, is shown below in Figure 25.

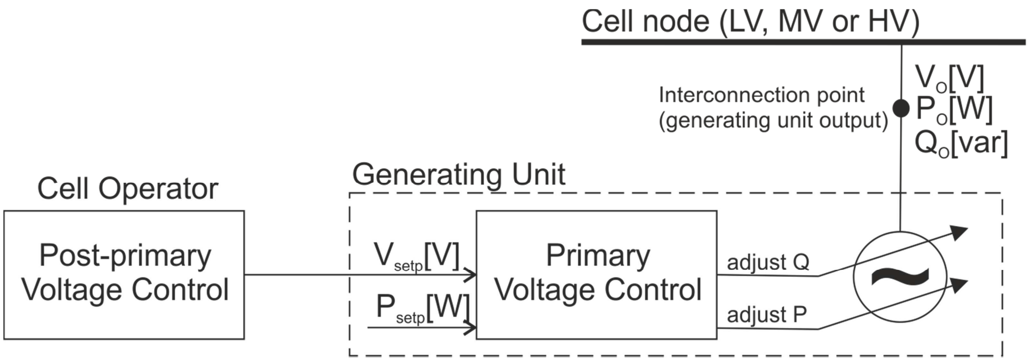


Figure 25: Generating unit connected to a cell node

Primary voltage control is related to a generating unit locally. Adjusting of output active and reactive power is a means to achieve a desired working point of a device that is characterized by output voltage (V_O), active (P_O) and reactive (Q_O) power. Local primary voltage control can be remotely coordinated by a post-primary voltage control that is placed at a cell operator level. Voltage setpoint (V_{setp}) is a crucial information exchanged between both voltage control layers to coordinate operation.

The general schematic diagram of primary voltage control is depicted below in Figure 26.

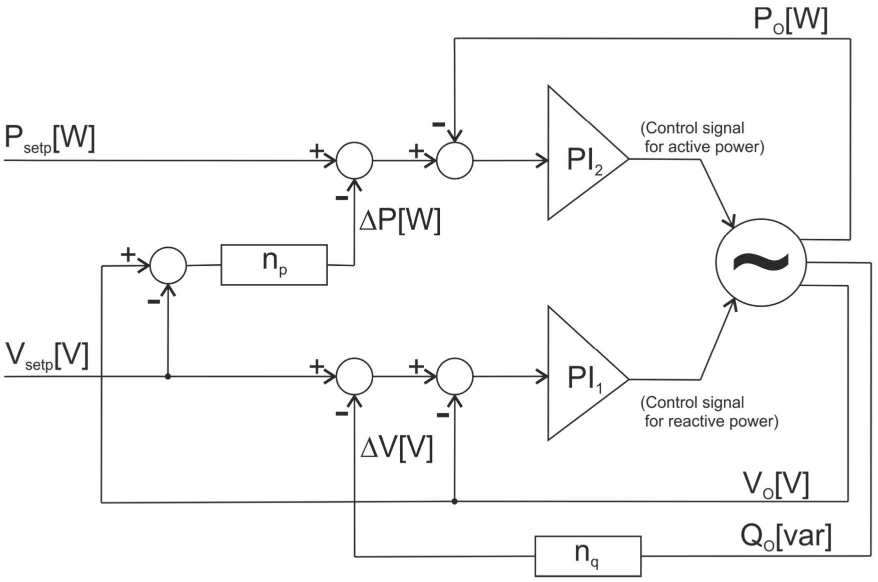


Figure 26: The primary voltage control schematic diagram

The proposed primary voltage control comprises of two control loops where:

1. The first loop (PI1 controller) is destined to control output voltage through adjusting of generator's reactive power.

$$V_O = V_{setp} - n_q Q_O \qquad \Delta V = n_q Q_O$$

$where:$

$V_O - output\ voltage\ measurement$

$Q_O - output\ reactive\ power\ measurement$

$n_q - droop\ coefficient\ for\ reactive\ power$

$V_{setp} - voltage\ setpoint\ (primary\ voltage\ control\ input)$

V$setp$ is a voltage setpoint while the current value, used by the first control loop to adjust generating unit's output reactive power (ΔV) is calculated according to the droop characteristic (Figure 27) shown below.

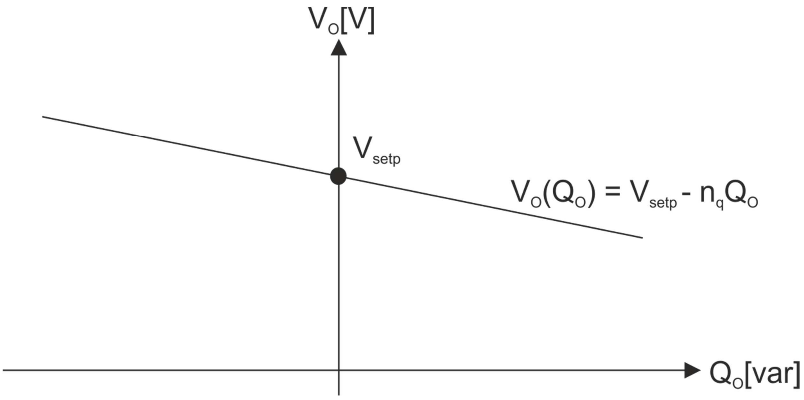


Figure 27: Voltage droop characteristic

2. The second loop (PI2 controller) is destined to control output voltage through adjusting of generator's output active power.

$$P_O = P_{setp} - n_P(V_O - V_{setp}) \qquad \Delta P = n_P(V_O - V_{setp})$$

$where:$

$V_O - output\ voltage\ measurement$

$P_O - output\ active\ power\ measurement$

$n_p - droop\ coefficient\ for\ active\ power$

$V_{setp} - voltage\ setpoint\ (primary\ voltage\ control\ input)$

$P_{setp} - active\ power\ setpoint$

P_{setp} is an active power setpoint while the current value, used by the second control loop to adjust generating unit's active power (ΔP), is calculated according to the droop characteristic (Figure 28) shown below:

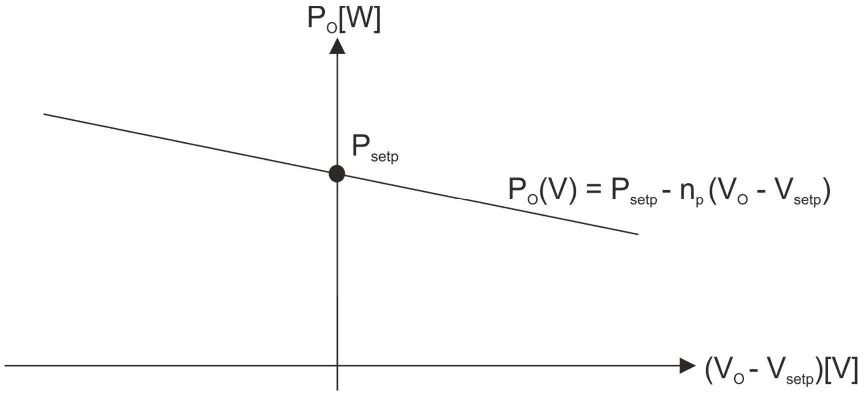


Figure 28: Active power droop characteristic

Finally output voltage V_O reaches the requested value of V_{setp} through the changed output active power P_O likely different from the active power setpoint P_{setp} value. P_{setp} is not an input for the primary voltage control but it's changed value is used to control output voltage.

Typically for MV and HV grids voltage control the second control loop could be inactive (and $n_p = 0$) since reactive power is used to increase or decrease voltage V_O in the interconnection point. For LV grids voltage control the first control loop could be inactive (and $n_q = 0$) as active power is used to increase or decrease voltage $V_O$in the interconnection point. If relevant it is also possible to employ both active and reactive power to control output voltage $V_O$activating two control loops with $n_p > 0$ and $n_q > 0$.

The primary voltage control is a process that is executed periodically in the following steps:

1. Measurement of present values of generating unit output voltage, active and reactive power (V_O, P_O, Q_O).
2. Voltage control step execution if required (typically MV and HV grids). Generating of a signal to control generating unit's output reactive power to level out the voltage deviation ($\Delta V_q \approx 0$).

$$\Delta V_q = V_O - (V_{setp} - n_q Q_O)$$

3. Active power control step execution if required (typically LV grids where feeder R>X). Generating of a signal to control generating unit's output active power to level out the voltage deviation ($\Delta V_p \approx 0$).

$$\Delta V_p = V_O - V_{setp}$$

Control signals type depends on the type of generating unit. Value of control signals depends on transmittance and implementation of controllers PI1 and PI2.

The communication task of a primary voltage control is executed in the following steps:

1. Authorisation of a new established connection to the Cell Operator.
2. Receiving and checking of a new value of voltage set-point (V_{setp}) sent by the Cell Operator.
3. Reporting of the generating unit and controller status when requested by the Cell Operator.

Key Performance Indicators				
ID	Name	Calculation	Scope	Objective
KPI_01	Voltage deviation for control based on reactive power	$\Delta V_q = V_O - (V_{setp} - n_q Q_O)$ $where:$ $V_O -\ output\ voltage$	Calculation of voltage deviation value [V]	Voltage control efficiency assessment

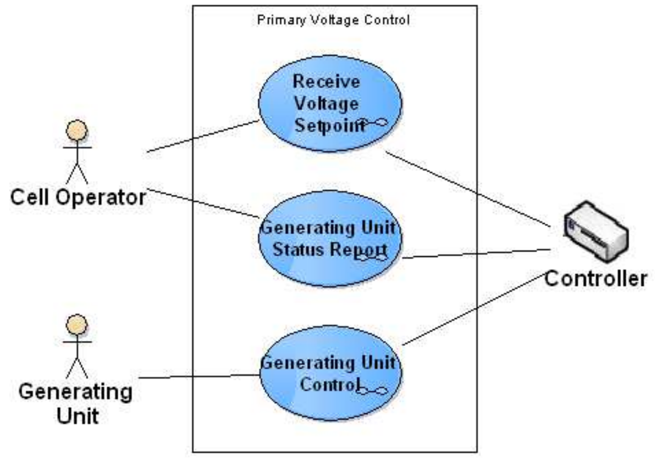
		$Q_O - output\ reactive\ power$ $n_p - droop\ coefficient\ for\ active\ power$ $V_{setp} - voltage\ setpoint$		
KPI_02	Voltage deviation for control based on active power	$\Delta V_p = V_O - V_{setp}$ $where:$ $V_O - output\ voltage$ $V_{setp} - voltage\ setpoint$	Calculation of voltage deviation value [V]	Voltage control efficiency assessment

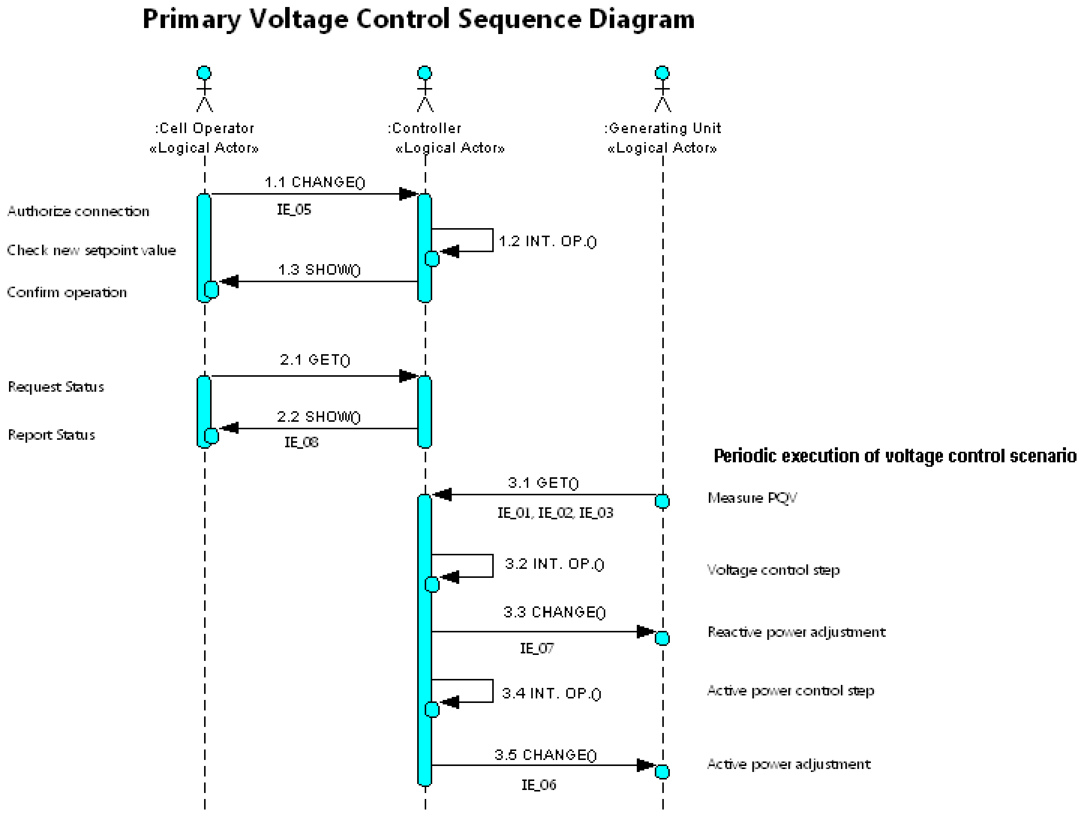
Classification Information
Relation to Other Use Cases
Post-primary voltage control (V-2)
Level of Depth
High Level Use Case
Prioritisation
Generic, Regional or National Relation
Generic
Viewpoint
Technical
Further Keywords for Classification
Voltage Control

General Remarks
None

6.1.2 Diagrams of Use Case

Diagram(s) of Use Case





6.1.3 Technical Details

Actors			
Grouping		Group Description	
Actor Name see Actor List	Actor Type see Actor List	Actor Description see Actor List	Further information specific to this Use Case
Cell Operator	Role	A party that is responsible for	

		a stable cell operation. The Cell Operator is a system operator responsible for the operation and the management of balancing reserves located within the cell. The Cell Operator also determines and is responsible for cross border capacity and exchanges between adjacent cells. The voltage set-points for primary voltage control are determined by the Cell Operator.	
Generating Unit	Role	Unit that is able to generate electric energy and obtain a specific working point: terminal voltage, active power, reactive power (Generator, WF, PV,…)	

Use Case Conditions
Assumption
Prerequisite

References						
No.	References Type	Reference	Status	Impact on Use Case	Originator / Organisation	Link
1	Standard	IEC/PAS 62559 Edition 1.0 2008-01	Approved	Methodology, Use case template	IEC	http://www.iec.ch
2	Report	Smart Grid Reference Architecture v3.0 08/11/2012	Final TR for adoption by M/490	Methodology, Use case template, SGAM	CEN-CENELEC-ETSI Smart Grid Coordination Group	http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/xpert_group1_reference_architecture.pdf

6.1.4 Step by Step Analysis of Use Case

Scenario Conditions and Overview						
No.	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition

1	Receive Voltage Set-point	New value of voltage set-point received from actor: DSO or TSO (depending on the interconnection point), local operator or system executing post-primary voltage control. Authorisation of new value source and value checking.	Operator	New voltage set-point available	Actors must be certified and on-line to send new set-points	New voltage set-point value replaces the previous
2	Generating Unit Status Report	Status consist of present measurements of V, P, Q, currently available range of reactive power Qmin…Qmax and binary status and alarm information.	Operator	Request of present status	Actors must be on-line to get status	
3	Generating Unit Control	Periodical process of voltage control consisting of acquisition of present measurements, droop calculations, voltage deviation detection and generating unit output power adjustment to decrease this deviation with respect to all generating unit limitations.	Controller	Periodically	Generating unit must be connected to the grid and operating	Generating unit output active and/or reactive power adjusted

Scenario Steps								
Scenario Name:		No. 1 – Receive Voltage Set-point						
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
1	New voltage set-point available	Authorize connection	Only authorized Cell Operator is allowed to change value of voltage set-point.	CHANGE	Cell Operator	Controller	IE_05	
2		Check new set-point value	Only values that belong to a particular value range are accepted. When accepted the new value of set-point updates the present set-point.	INTERNAL OPERATION	Controller	Controller		
3		Confirm operation	Positive or negative confirmation. Voltage set-point value accepted or rejected.	SHOW	Controller	Operator		

Scenario								
Scenario Name:	No. 2 – Generating Unit Status Report							
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
1	Request of present status	Request Status	Preparing of aggregated information of voltage control process.	GET	Controller	Operator		
2		Report Status	Preparing and reporting of aggregated information of voltage control process.	SHOW	Controller	Operator	IE_08	

Scenario								
Scenario Name:	No. 3 – Generating Unit Control							
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
1	Periodically	Measure PQV	Sampling, filtering and measurement calculations of output voltage (V_O) and power (P_O, Q_O).	GET	Generating Unit	Controller	IE_01, IE_02, IE_03	
2		Voltage control step	Voltage droop and deviation calculation. (option for LV grids)	INTERNAL OPERATION	Controller	Controller		
3		Reactive power adjustment	Detection of voltage deviation ($\Delta V_q \neq 0$).Checking of present limits of various quantities depending on the type of generator. Adjustment of output reactive power if power reserves still available. (option for LV grids)	CHANGE	Controller	Generating Unit	IE_07	
4		Active power control step	Active power set-point modification calculation. (option for MV and HV grids)	INTERNAL OPERATION	Controller	Controller		
5		Active power adjustment	Checking of present limits of various quantities depending on the type of generator. Adjustment of output active power if	CHANGE	Controller	Generating Unit	IE_06	

			power reserves still available. (option for MV and HV grids)					

6.1.5 Misc

Information Exchanged			
Information Exchanged ID	Name of Information	Description of Information Exchanged	Requirements IDs
IE_01	Output Voltage	Voltage measured at generator terminals or in interconnection point (V_O).	
IE_02	Output Active Power	Active power measured at generator terminals or in interconnection point (P_O).	
IE_03	Output Reactive Power	Reactive power measured at generator terminals or in interconnection point (Q_O).	
IE_04	Voltage Set-point	Present value of voltage set-point that is used in control process (V_{setp}).	
IE_05	New Voltage Set-point	New value of voltage set-point received from Cell Operator. After authorisation and value checking it becomes a present set-point IE_04 (V_{setp}).	
IE_06	Generating Unit Active Power Adjustment	Information representing a signal that change generating unit output active power.	
IE_07	Generating Unit Reactive Power Adjustment	Information representing a signal that change generating unit output reactive power.	
IE_08	Voltage Control Status	Aggregated information containing present measurements, voltage set-point, available active and reactive power range, status signals and alarms.	

Requirements (optional)		
Category ID	Category Name	Category Description
Requirement ID	Requirement Description	

Common Terms and Definitions	
Term	Definition

Custom Information (optional)		
Key	Value	Refers to Section

6.2 Future Post-Primary Voltage Control

6.2.1 Description of the Use Case

Use Case Identification		
ID	Area/Domain(s)/Zone(s)	Name of Use Case
V-2	Domains: Generation, Transmission, Distribution, DER, Customer Premises Zones: Process, Field, Station, Operation	Post-primary voltage control (PPVC)

Version Management				
Version No.	Date	Name of Author(s)	Changes	Approval Status
0.1	04.11.2014	TECNALIA		Initial Version
0.2	12.11.2014	TECNALIA		Draft
0.3	18.11.2014	TECNALIA		Final

Scope and Objectives of Use Case	
Scope	Nowadays, the voltage control is organized in terms of a three-step hierarchy —Primary, Secondary and Tertiary Voltage Control—. Primary Voltage control (PVC) is an automatic control accomplished by fast-acting devices such as the automatic voltage controllers (AVRs) of the generation groups. It operates in the range of milliseconds. The goal of PVC is to act over the reactive power injection in the point of interconnection of the device or in a very close node. Based on this, by regulating the reactive power flow, the voltage in the node sets close to the required set-point. The secondary voltage control (SVC) supervises and coordinates the primary voltage regulators within an area, in a time frame of around one minute. The reactive power has to be supplied locally, since it cannot be transported along large distances. SVC allows a proper coordination of the reactive power contribution of the voltage regulators while the load changes in the system. The tertiary voltage control (TVR) represents an optimisation of the secondary voltage control scheme. It is usually based on a global system optimization which calculates updated voltage set-points for the regional voltage controllers associated to SVR while minimizing reactive power losses. It is completed in a time scale comprising from 10 min to 30 min. The evolution of power grids will imply the development of new architectures based on the coordination and mutual collaboration of modular structures —called cells—. This will also entail a decentralization process with less available big power plants for voltage and reactive power control. As a consequence, part of this responsibility, actually managed by TSOs will be displaced to DER units connected by DSOs at lower voltage levels. From this new perspective, the traditional voltage schemes will also need to be revised to fulfil the system requirements of stability, security of supply and reliability. With this use case it is intended to set the basis for this original scheme (called PPVC) that will substitute the traditional secondary and tertiary voltage controls that will be no longer valid in the ELECTRA scenario.
Objective(s)	The objective of the PPVC is to provide an optimal and local voltage control for future electrical grids. PPVC, as a result of the coordination between the cells at different voltage levels, will restore the voltage in the nodes to nominal values, optimizing the reactive power flows in the system, and operate in present SVC time frames.
Related business	--

case(s)	

Narrative of Use Case
Short description
The post-primary voltage control has the commitment to keep the voltage levels in the nodes of the power system to nominal values while optimizing the reactive power flows in order to reduce the losses in the network. In the future cell-based grid structure, the PPVC is intended to replace the present secondary (local) and tertiary voltage control (global) schemes existing in power grids by a decentralized control, located a cell level. Each cell is responsible for its own voltage control while a close coordination between cells guarantees the provision of PPVC service between neighbouring cells.
Complete description

The power grid is subdivided in three voltage levels: HV, MV and LV. Each level consists of several layers, each of them formed by cells operating in a coordinated way. The resulting structure is made up of a web of cells with multiple interconnections.

Every cell is an independent structure with own capabilities for the voltage control itself. Most will be able to have extra resources to contribute for the restoration of normal voltage levels in close cells. The cell operator (CO) will manage the voltage set-points of the nodes inside and, as a result, also in the border nodes with neighbouring cells. The neighbouring cells will be required to maintain those voltages in the interconnection points, previously agreed with the CO for the establishment of operational security limits in terms of voltage ranges and reactive power exchanges across the borders.

A graphical representation of the cell-based power system is displayed in Figure 29.

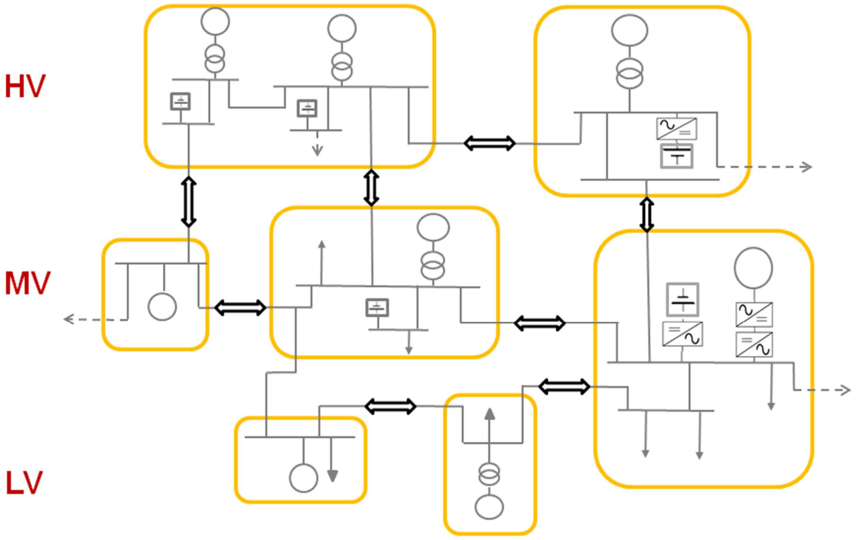


Figure 29: Cell-based structure for future power grid and PPVC reserves flows between cells

The provision of PPVC service can be summarized in the following steps:

- Reserves are contracted by agreement between PPVC resource providers and the CO

  In a PPVC market, the providers offer the bids to the cell operator for the next period (day-ahead market) and their activation price. In order to assure the availability of PPVC in case of unscheduled events, the reserves providers with extra capacity can participate in an intraday market with the purpose of supplying resources in real-time hourly periods. The resource providers bidding in the market will be the parties connected to the cell —producers, consumers or prosumers—, the aggregators and the neighbouring cells, that can act as an independent entity to bid in the market for PPVC reserves provision.

- The CO solves an Optimal Power Flow (OPF) analysis

  The CO receives data about capacity of PPVC resources contracted, location of the reserves and responsible operator of the cell they belong to —if they are located in other cell—. This information has to be updated according to the market time frame (once a year, monthly, daily…). It also receives from the monitoring system the data concerning to the grid topology. This dynamic information has to be periodically updated since the cell is a reconfigurable and flexible structure. The CO estimates the state of the cell by using the information acquired together with the static information stored in the database. The CO also gets information about the generation and consumption patterns in the cell and predicts the consumption and generation for following periods using forecast tools.

  With all the information, de CO solves an OPF with the technical and market constraints and with the objective function of minimizing losses to avoid cost overruns. As a result, the CO determines the voltage set values for the nodes with capacity for voltage control (nodes with AVRs or same function devices). The voltage set points are sent to the post-primary voltage controllers for optimal reactive power flows management in the cell.

- Monitoring system detects a voltage mismatch in any node under the cell operator responsibility.

  The monitoring system of the cell registers in real-time the voltage values in the nodes and the reactive power flows in the cell and in the interconnections, to be sure all the limits are satisfied. If the monitoring system detects a voltage value in one of the nodes out of the tolerance band, sends an error signal to activate the process for PPVC provision.

- The cell operator checks the availability of its self-procured PPVC reserves, that had previously participated in the PPVC market

  The cell operator sends a confirmation signal to its PPVC providers to corroborate the availability of the contracted resources, just in case any failure has left the reserves not ready for being used for the service provision.

- The cell operator checks possible congestion issues

  The cell operator studies if the provision of the PPVC reserves according to market and to OPF analysis results supposes any constraint due to congestion issues that could put into risk the cell stability.

- If there is no congestion, the cell operator restores the required set-point by sending the activation order to the reserves.

  If there is no congestion, the contracted PPVC reserves resulting from the application of the market mechanisms and the OPF analysis are activated, to recover the voltage levels in the node with an optimal allocation of the reserves. These reserves will be provided by aggregators and parties connected to the grid in the cell.

- If there are congestion problems, the cell operator sends a congestion signal to the neighbouring cell operator.

If constraints exists that limit the PPVC provision inside the cell by using its reserves, a congestion signal is sent to the neighbour cells, responsible of the management of additional PPVC resources.

- The cell operator re-dispatches to supply the lack of PPVC reserves and sends the activation order to the service providers

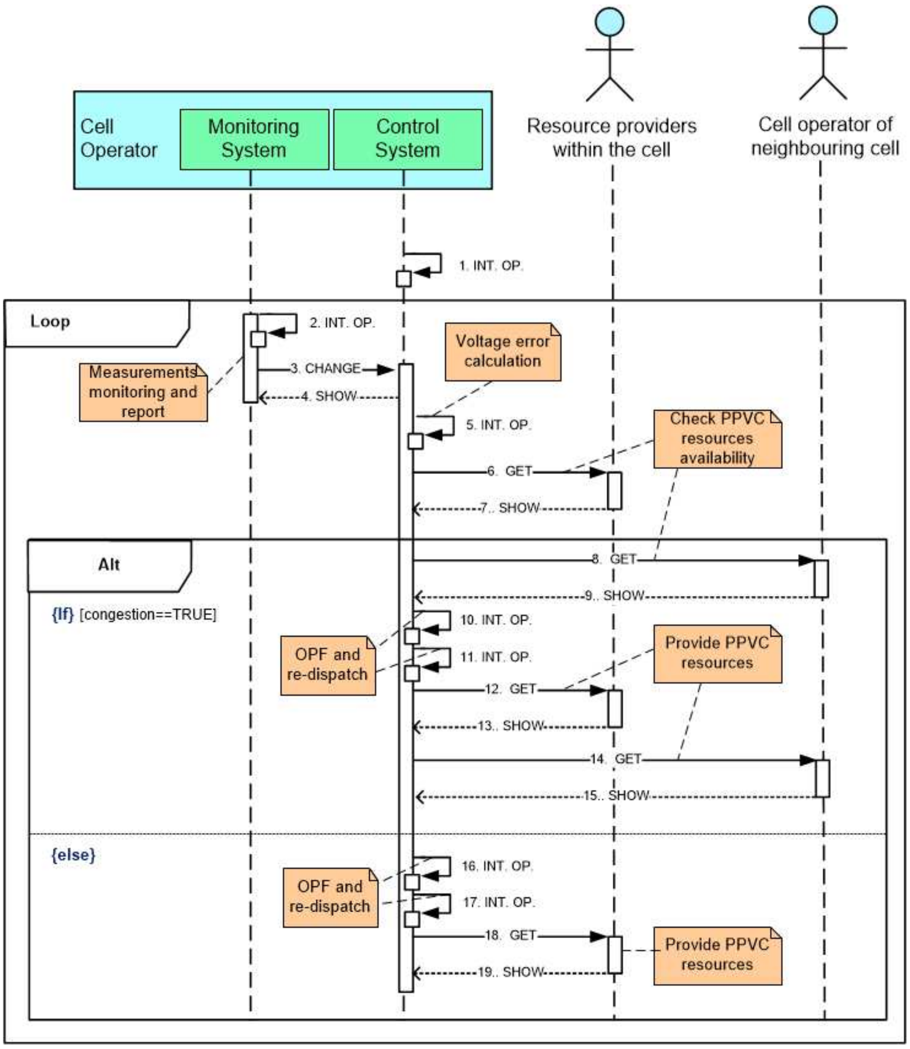
  The cell control system re-dispatches to drive the system back to the normal state in such a way the congestion is gotten rid of. This can entail the purchase of power from areas with higher costs. The extra resources not available at the cells are supplied by the neighbouring cells through interconnections.

Key Performance Indicators				
ID	Name	Calculation	Scope	Objective
KP_01	Voltages ranges within limits	$V_{\min} \le \lvert V_i \rvert \le V_{\max}$	Voltages measured in the nodes inside normal operating limits	Maintenance of power quality
KP_02	Minimum reactive power losses	$\min F_1 = \sum_{i=1}^{n} Q_{gi}$ Where Q_{gi} is the reactive generation/absorption capacity of every unit subject to restrictions $Q_{gi\,min} \le Q_{gi} \le Q_{gi\,max}$	Balance of reactive power in the system	Minimization of reactive power losses inside the cells and in the interconnections
KP_03	Cost minimization of PPVC provision	$\min F_2 = \sum_{i=1}^{n} f_i(Q_{gi})$ Where f_i is the cost of PPVC provision of every party participating in the market (Q_{gi})	Calculation of the cost for PPVC reserves	Minimization of the total generation cost

Classification Information
Relation to Other Use Cases
Primary Voltage Control Use Case (V-1)
Level of Depth
High-Level Use Case
Prioritisation
Obligatory
Generic, Regional or National Relation
Generic
Viewpoint
Further Keywords for Classification
Voltage control, ancillary services

General Remarks

6.2.2 Diagrams of Use Case

Diagram(s) of Use Case
<u>SEQUENCE DIAGRAM</u> 

6.2.3 Technical details

Actors			
Grouping		Group Description	
Actor Name see Actor List	Actor Type see Actor List	Actor Description see Actor List	Further information specific to this Use Case
Cell Operator	Role	A party that is responsible for a stable cell operation. The Cell Operator is a system operator responsible for the operation and the	

		management of balancing reserves located within the cell. The Cell Operator also determines and is responsible for cross border capacity and exchanges between adjacent cells.	
Resource provider	Role	A role that manages a resource object and provides the schedules for it. They can be consumer, producers or prosumers	The resource providers are the aggregators or parties connected to the grid with capacity for PPVC provision

Use Case Conditions
Assumption
● LV cells will have a high degree of observability due to likely improvements in measurement and communication systems in future power grids, as covered by ELECTRA. Due to this, the cells can be regarded as equal to the ones in MV or LV (e.g. it is possible to realize an OPF at some LV layers). ● It is assumed that, provision of PPVC reserves by providers within the cell is economically more advantageous than importing the PPVC provisions from the other cells (e.g., it has been considered a prioritization of aggregators and parties connected to the cell grid over neighbouring cells). It may happen that the neighbouring cells could provide PPVC service under no congestion scenarios and due to market reasons.
Prerequisite

References						
No.	References Type	Reference	Status	Impact on Use Case	Originator / Organisation	Link
1	Report	Continental Europe Operation handbook. P3: Operational security	Final version (2004)		ENTSO-E	
2	Standard	IEC PAS 62559:2008-01	Approved (2008)	Use cases methodology	International Electrotechnical Commission (IEC)	
3	Technical report	CEN-CENELEC-ETSI Smart Grid Coordination Group – Sustainable Processes	Draft (2012)	Use cases methodology, similar work and examples	CEN-CENELEC-ETSI	

		v1.0.				

6.2.4 Step by step analysis of Use Case

Scenario Overview and Conditions						
No.	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
1	PPVC	If a voltage mismatch is detected, PPVC contracted reserves have to be activated in order to recover the voltages in the system with a minimum cost	Cell Operator	Voltage mismatch detected in any node	Monitoring system is periodically receiving measurements of the voltages in the nodes and the reactive power flows	After the PPVC activation, voltage levels are recovered with and optimal distribution of reactive requirements according to units capabilities

Scenario Steps								
Scenario Name :	**PPVC**							
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged IDs	Requirement IDs
1	Initial state of the system in safe but non optimal state	Initial OPF	Calculate OPF	INT. OP	Control system	Control system	I_01	
2	[LOOP]	Voltage and reactive measurements	Real-time updating of the measurements of the voltages and the reactive	INT.OP,	Monitoring system	Monitoring system	I_02	

			power outputs and flows					
3		Send measurements	The monitoring system transmits the measurements to the PPVC	CHANGE	Monitoring system	Control system	I_02	
4		Confirmation receipt measurements	PPVC sends a confirmation signal about received measurements	SHOW	Control system	Monitoring system	I_03	
5		Error calculation	Error = f (ΔV)	INT. OP	Control system	Control system	I_04	
6		Check PPVC reserves availability	CO confirms the availability of the PPVC reserves contracted	GET	Control system	Resource providers within the cell	I_05	
7		Availability reply	The resource providers respond to the PPVC with their updated state	SHOW	Resource providers within the cell	Control system	I_06	
8	[ALT] Cong = true	Check PPVC reserves availability	CO confirms the availability of the PPVC reserves contracted	GET	Control system	Cell operator of neighbouring cell	I_07	
9		Availability reply	The PPVC of the neighbouring cell respond to the PPVC with the updated state of its reserves	SHOW	Cell operator of neighbouring cell	Control system	I_06	
10		Select PPVC providers	Select PPVC providers	INT. OP.	Control system	Control system	I_08	
11		Re-	Calculate	INT. OP	Control	Control	I_09	

		dispatch	OPF and re-dispatch		system	system		
12		Activation of PPVC reserves	The PPVC communicates the resource providers within the cell about PPVC reserves activation	GET	Control system	Resource providers within the cell	I_10	
13		PPVC activation confirmation	The resource providers within the cell confirm the receipt of activation order	SHOW	Resource providers within the cell	Control system	I_11	
14		Activation of PPVC reserves	The PPVC communicates the cell operator of neighbouring cell about PPVC reserves activation	GET	Control system	Cell operator of neighbouring cell	I_10	
15		PPVC activation confirmation	communicates the cell operator of neighbouring cell confirms the receipt of activation order	SHOW	Cell operator of neighbouring cell	Control system	I_11	
16		Select PPVC providers	Select PPVC providers	INT. OP.	Control system	Control system	I_08	
17		Re-dispatch	Calculate OPF and re-dispatch	INT. OP	Control system	Control system	I_09	
18	[ALT] else	Activation of PPVC reserves	CO acknowledges the availability of the PPVC reserves contracted	GET	Control system	Resource providers within the cell	I_10	
19		PPVC activation	The resource providers	SHOW	Resource providers	Control system	I_11	

		confirmation	respond to the PPVC with their updated state		within the cell			

6.2.5 Misc

Information Exchanged			
Information Exchanged ID	Name of Information	Description of Information Exchanged	Requirements IDs
I_01	OPF information	PPVC reserves information (contract, location, responsibility) Cell topology Generation and consumption forecast Measurements of controllable devices (voltages, currents, active and reactive power) Voltage and reactive power limits	
I_02	Real-time measurements	Voltage measurements Reactive power outputs and flows	
I_03	Real-time measurements receipt by Control system	Confirmation message Status signal	
I_04	Calculated Voltage Error	Voltage error	
I_05	Availability signal	Availability check	
I_06	Availability status	Status signal	
I_07	Congestion and availability signal	Congestion signal Availability signal	
I_08	Selected PPVC providers	Available PPVC resources PPVC reserves information (contract, location, responsibility)	
I_09	Re-dispatch	PPVC reserves information (contract, location, responsibility) Cell topology Generation and consumption forecast Measurements of controllable devices (voltages, currents, active and reactive power) Voltage and reactive power limits Congestion constraints	
I_10	Activation of PPVC reserves	Voltage set-points	
I_11	PPVC provision	Confirmation message	

Requirements (optional)		
Category ID	Category Name	Category Description
Requirement ID	Requirement Description	

Common Terms and Definitions	
Term	Definition

Custom Information (optional)		
Key	Value	Refers to Section

7. Conclusions

In this deliverable a high level functional architecture for frequency and voltage control for the future (2030+) power system is proposed. The need for a transition towards a new functional architecture is based on a number of scenario assumptions regarding the 2030+ power system. It is assumed that in the future power system, generation will shift from classical dispatchable units to intermittent renewables and CHP. As a consequence, a great part of the generation will shift from few large units to many smaller units. It is assumed that electricity consumption and therefore system loads will increase significantly. Electrical energy storage is expected to be a cost-effective solution for offering ancillary services that stabilise the system and fill the momentarily gap between system generation and system load. Next to this, it is presumed that the power system's observability will increase due to more ubiquitous sensors. In addition to this, the large amounts of fast reacting distributed resources will be able to offer reserves capacity.

This deliverable proposes a new control architecture for reserves activation that better addresses the fundamental changes of the future power system. The document focuses on reserve activation to correct for real-time imbalances, as well as to regulate voltages.

In the proposal, the EU power grid is decomposed into a ***Web-of-Cells*** structure, where the cells are defined as a group of interconnected loads, distributed generators and storage units within well-defined grid boundaries corresponding to a physical portion of the grid and corresponding to a confined geographical area. Cells have adequate monitoring infrastructure installed, as well as local reserves capacity enabling them to (partially) resolve voltage and cell balancing problems locally. Each cell is managed by a single system operator, who takes responsibility for the real-time reserves activation and dispatching in his cell. Inter-cell reserve exchanges and coordination is included for optimal system-wide management. In each cell, the Cell System Operator 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 principle, no global system state information is required for this. In this way, a 'divide and conquer' way of tackling voltage and balancing issues is implemented, and local problems are resolved locally in the cell in a fast and secure manner, limiting complexity and communication overhead. There is no need to expose local problems at global system level.

In the proposed web-of-cell based architecture, Cell System Operators are responsible to contribute to containing and restoring system frequency, as well as containing local voltage within secure and stable limits. For this purpose, proposals for frequency and voltage control within a web-of-cells system are developed, and given in Table 1 and Table 2 below. It must be noted that by moving to a cell-based architecture, different observables and control aims may be required. The proposed frequency control as well as voltage control mechanisms are written down as High-Level Use Cases in the ELECTRA Use Case template, based on IEC 62559-2.

Table 1: Overview of frequency control use cases

Frequency/Balance Control	
Now	**2030+**
	Inertia Steering Control
Frequency Containment Control	Frequency Containment Control
Frequency Restoration Control	Balance Restoration Control
Frequency Replacement Control	Balance Steering Control

Table 2: Overview of Voltage Control Use Cases

Voltage Control	
Now	**2030+**
Primary Voltage Control	Primary Voltage Control
Secondary Voltage Control	Post-Primary Voltage Control
Tertiary Voltage Control	

This proposed high level functional architecture underlies the development of innovative monitoring systems that will be developed in WP5, and dynamic autonomous distributed control function that will be developed in WP6. Subsets of these will subsequently be implemented for lab integration and testing in WP7.

Throughout the further progress of the ELECTRA project, the proposed cell-based functional architecture will be further evaluated and fine-tuned, given the outcomes of WP5 as well as WP6. Also feedback from industry will be taken into account while evaluating the proposed concept. By the end of the project, an upgrade of the proposed high-level cell-based functional architecture will be made.

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9. Disclaimer

The ELECTRA project is co-funded by the European Commission under the 7th Framework Programme 2013.

Annex A: Summary of scenarios from e-Highway 2050 project

Quoted from [2]

According to the eHighway methodology, possible “futures” are created from “uncertainties”, and possible “strategies” are created from “options” of decision makers. The following tables summarize this:

Table 3: Summary of the five e-Highway2050 Futures

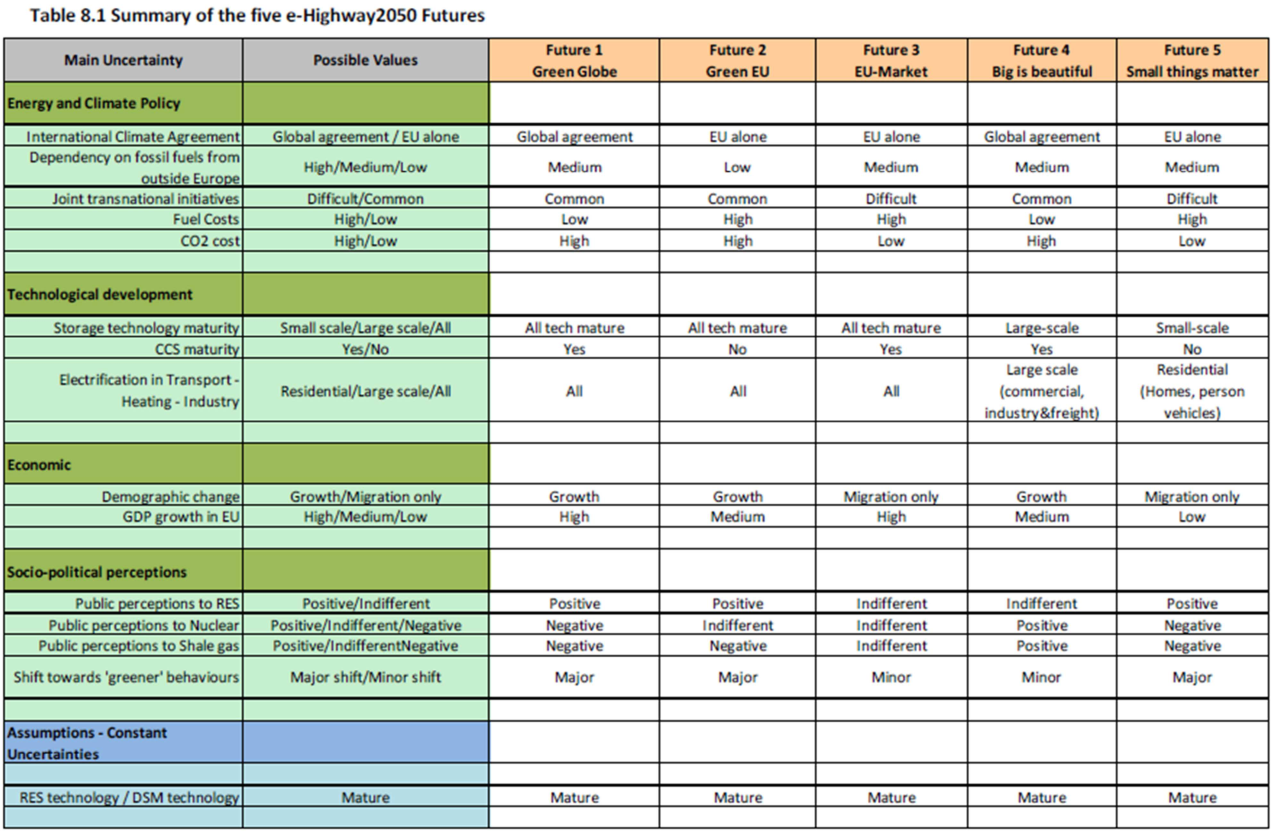

Table 8.1 Summary of the five e-Highway2050 Futures

Main Uncertainty	Possible Values	Future 1 Green Globe	Future 2 Green EU	Future 3 EU-Market	Future 4 Big is beautiful	Future 5 Small things matter
Energy and Climate Policy						
International Climate Agreement	Global agreement / EU alone	Global agreement	EU alone	EU alone	Global agreement	EU alone
Dependency on fossil fuels from outside Europe	High/Medium/Low	Medium	Low	Medium	Medium	Medium
Joint transnational initiatives	Difficult/Common	Common	Common	Difficult	Common	Difficult
Fuel Costs	High/Low	Low	High	High	Low	High
CO2 cost	High/Low	High	High	Low	High	Low
Technological development						
Storage technology maturity	Small scale/Large scale/All	All tech mature	All tech mature	All tech mature	Large-scale	Small-scale
CCS maturity	Yes/No	Yes	No	Yes	Yes	No
Electrification in Transport - Heating - Industry	Residential/Large scale/All	All	All	All	Large scale (commercial, industry&freight)	Residential (Homes, person vehicles)
Economic						
Demographic change	Growth/Migration only	Growth	Growth	Migration only	Growth	Migration only
GDP growth in EU	High/Medium/Low	High	Medium	High	Medium	Low
Socio-political perceptions						
Public perceptions to RES	Positive/Indifferent	Positive	Positive	Indifferent	Indifferent	Positive
Public perceptions to Nuclear	Positive/Indifferent/Negative	Negative	Indifferent	Indifferent	Positive	Negative
Public perceptions to Shale gas	Positive/IndifferentNegative	Negative	Negative	Indifferent	Positive	Negative
Shift towards 'greener' behaviours	Major shift/Minor shift	Major	Major	Minor	Minor	Major
Assumptions - Constant Uncertainties						
RES technology / DSM technology	Mature	Mature	Mature	Mature	Mature	Mature

Table 4: Summary of the six e-Highway2050 Strategies

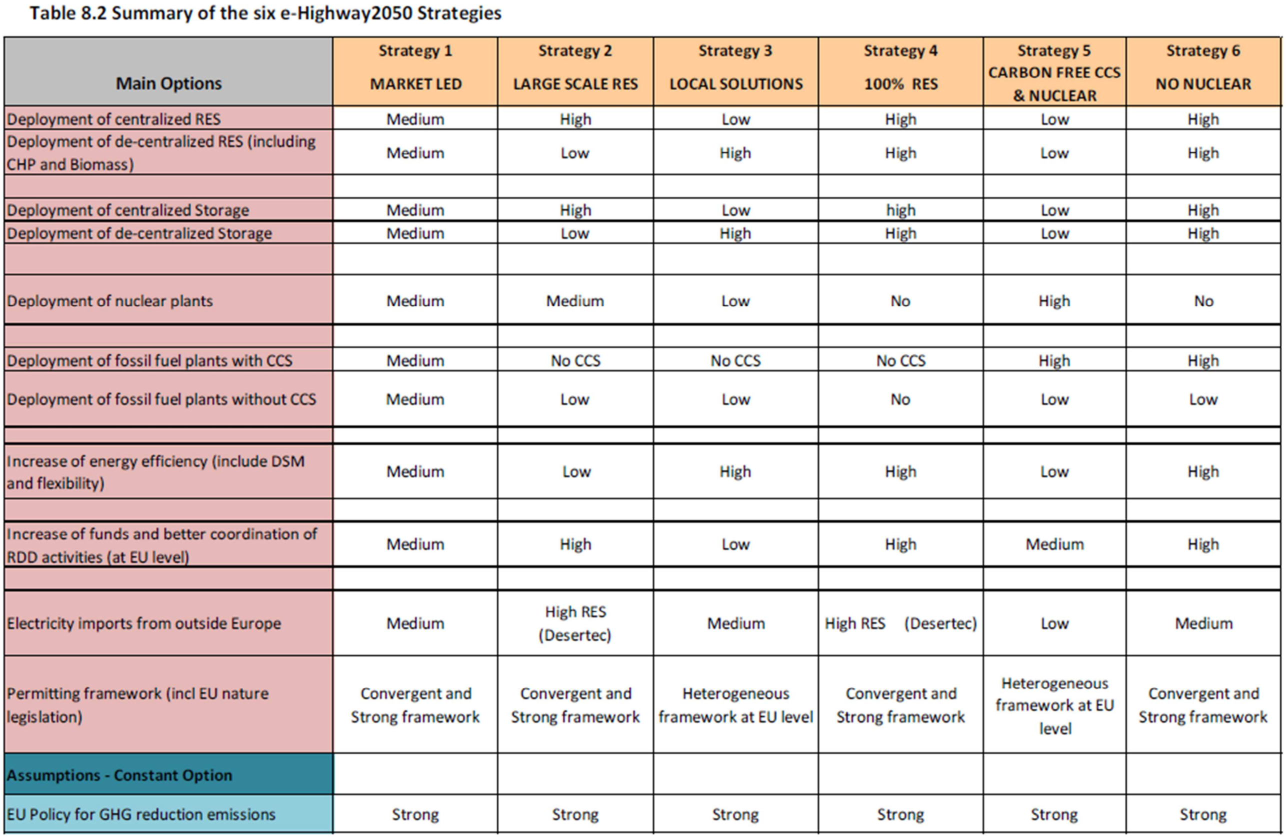

Table 8.2 Summary of the six e-Highway2050 Strategies

Main Options	Strategy 1 MARKET LED	Strategy 2 LARGE SCALE RES	Strategy 3 LOCAL SOLUTIONS	Strategy 4 100% RES	Strategy 5 CARBON FREE CCS & NUCLEAR	Strategy 6 NO NUCLEAR
Deployment of centralized RES	Medium	High	Low	High	Low	High
Deployment of de-centralized RES (including CHP and Biomass)	Medium	Low	High	High	Low	High
Deployment of centralized Storage	Medium	High	Low	high	Low	High
Deployment of de-centralized Storage	Medium	Low	High	High	Low	High
Deployment of nuclear plants	Medium	Medium	Low	No	High	No
Deployment of fossil fuel plants with CCS	Medium	No CCS	No CCS	No CCS	High	High
Deployment of fossil fuel plants without CCS	Medium	Low	Low	No	Low	Low
Increase of energy efficiency (include DSM and flexibility)	Medium	Low	High	High	Low	High
Increase of funds and better coordination of RDD activities (at EU level)	Medium	High	Low	High	Medium	High
Electricity imports from outside Europe	Medium	High RES (Desertec)	Medium	High RES (Desertec)	Low	Medium
Permitting framework (incl EU nature legislation)	Convergent and Strong framework	Convergent and Strong framework	Heterogeneous framework at EU level	Convergent and Strong framework	Heterogeneous framework at EU level	Convergent and Strong framework
Assumptions - Constant Option						
EU Policy for GHG reduction emissions	Strong	Strong	Strong	Strong	Strong	Strong

A summary of the 15 scenarios resulting from the elimination of spurious scenarios (involving contradictions between the defined futures and strategies) from the initial set of 30 is presented in the following table:

Table 5: Summary of the characteristics of the 15 scenarios selected in e-Highway2050

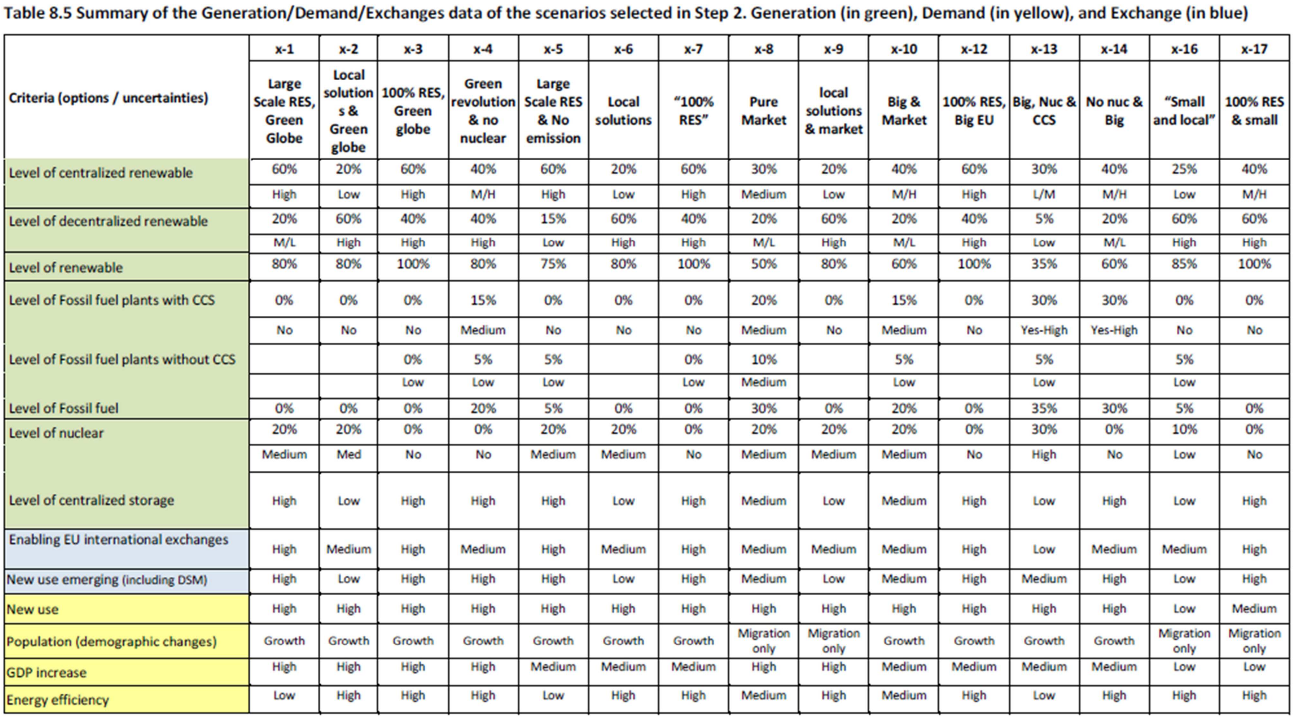

Table 8.5 Summary of the Generation/Demand/Exchanges data of the scenarios selected in Step 2. Generation (in green), Demand (in yellow), and Exchange (in blue)

Criteria (options / uncertainties)	x-1	x-2	x-3	x-4	x-5	x-6	x-7	x-8	x-9	x-10	x-12	x-13	x-14	x-16	x-17
	Large Scale RES, Green Globe	Local solutions & Green globe	100% RES, Green globe	Green revolution & no nuclear	Large Scale RES & No emission	Local solutions	"100% RES"	Pure Market	local solutions & market	Big & Market	100% RES, Big EU	Big, Nuc & CCS	No nuc & Big	"Small and local"	100% RES & small
Level of centralized renewable	60%	20%	60%	40%	60%	20%	60%	30%	20%	40%	60%	30%	40%	25%	40%
	High	Low	High	M/H	High	Low	High	Medium	Low	M/H	High	L/M	M/H	Low	M/H
Level of decentralized renewable	20%	60%	40%	40%	15%	60%	40%	20%	60%	20%	40%	5%	20%	60%	60%
	M/L	High	High	High	Low	High	High	M/L	High	M/L	High	Low	M/L	High	High
Level of renewable	80%	80%	100%	80%	75%	80%	100%	50%	80%	60%	100%	35%	60%	85%	100%
Level of Fossil fuel plants with CCS	0%	0%	0%	15%	0%	0%	0%	20%	0%	15%	0%	30%	30%	0%	0%
	No	No	No	Medium	No	No	No	Medium	No	Medium	No	Yes-High	Yes-High	No	No
Level of Fossil fuel plants without CCS			0%	5%	5%		0%	10%		5%		5%		5%	
			Low	Low	Low		Low	Medium		Low		Low		Low	
Level of Fossil fuel	0%	0%	0%	20%	5%	0%	0%	30%	0%	20%	0%	35%	30%	5%	0%
Level of nuclear	20%	20%	0%	0%	20%	20%	0%	20%	20%	20%	0%	30%	0%	10%	0%
	Medium	Med	No	No	Medium	Medium	No	Medium	Medium	Medium	No	High	No	Low	No
Level of centralized storage	High	Low	High	High	High	Low	High	Medium	Low	Medium	High	Low	High	Low	High
Enabling EU international exchanges	High	Medium	High	Medium	High	Medium	High	Medium	Medium	Medium	High	Low	Medium	Medium	High
New use emerging (including DSM)	High	Low	High	High	High	Low	High	Medium	Low	Medium	High	Medium	High	Low	High
New use	High	High	High	High	High	High	High	High	High	High	High	High	High	Low	Medium
Population (demographic changes)	Growth	Growth	Growth	Growth	Growth	Growth	Growth	Migration only	Migration only	Growth	Growth	Growth	Growth	Migration only	Migration only
GDP increase	High	High	High	High	Medium	Medium	Medium	High	High	Medium	Medium	Medium	Medium	Low	Low
Energy efficiency	Low	High	High	High	Low	High	High	Medium	High	Medium	High	Low	High	High	High

The detailed description of the five scenarios selected by the eHighway2050 project is the following:

A.1 Big and market (x-10)

In this Scenario, a global agreement for climate mitigation is achieved. Thus, CO2 costs are high due to the existence of a global carbon market. Europe is fully committed to meet its 80-95% GHG reduction orientation by 2050 but it relies mainly on a market based strategy.

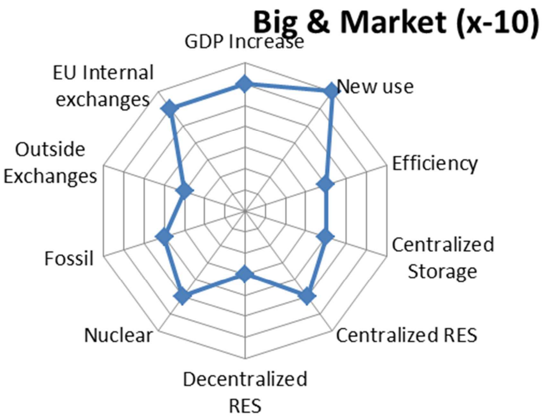

Figure 30: Radar diagram of x-10 scenario ("Big & Market")

Moreover, in this scenario, there is a special interest on large scale centralized solutions, especially for RES deployment and storage. Public attitude towards deployment of RES technologies is indifferent in the EU, while acceptance of nuclear and shale gas, as energy sources, is positive since being preferred to decentralize local solutions. CCS technology is also assumed mature in this scenario.

Electrification of transport, heating and industry is considered to occur mainly at centralized (large scale) level. Only a minor shift towards 'greener' behaviours is experienced in this scenario compared to present practices. Therefore, the efficiency level is low. In general, the public is somehow passive, and the players are active in a market-driven energy system.

A.2 Large fossil fuel with CCS and nuclear (x-13)

In this Scenario, a global agreement for climate mitigation is achieved and Europe is fully committed to its target of 80-95% GHG reduction. Thus, CO2 costs are high due to the existence of a global carbon market.

Europe is mainly following a non-RES strategy to reach this target. Acceptance of nuclear and shale gas as energy sources is positive. Nuclear and fossil fuel plants with CCS play pivotal roles in achieving the 80-95% GHG targets without large scale RES deployment. Public attitude towards deployment of RES technologies is indifferent in the EU. There is a low focus on development of RES and storage solutions.

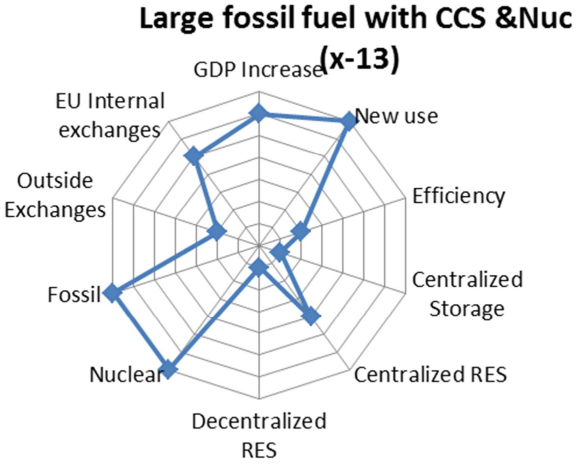

Figure 31: Radar diagram of x-13 scenario ("Large fossil fuel with CCS & Nuc")

Electrification of transport, heating and industry is considered to occur mainly at centralized (large scale) level. Energy efficient options (including DSM and flexibility of EV use) are deployed only at medium level, mainly aiming at reducing energy demand. Indeed a minor shift towards 'greener' behaviours is experienced in this Future compared to present practices. No further flexibility is needed since variable generation from PV and wind is low.

The energy strategy is deployed from a top-down approach at EU level with coordinated trans-national approaches based on a strong framework for policy and incentives, supporting market operation. In general, the public is somehow passive and everything has to be coordinated at high level, following a top-down vision.

In this case, electricity exchanges with outside Europe are low.

A.3 Large scale RES & no emission (x-5)

In this Scenario, a European agreement for climate mitigation is achieved and fossil fuel consumption is generally low worldwide. Therefore, fuel costs are relatively low. On the other hand, the CO2 costs are high due to the existence of a global carbon market. The EU's ambition for GHG emission reductions is achieved: 80-95% GHG reduction.

The strategy focuses on the deployment of large-scale RES technologies, e.g. large scale offshore wind parks in the North Sea and Baltic Seas as well as the DESERTEC project in North Africa. A lower priority is given to the deployment of decentralized RES (including CHP and Biomass) solutions.

Similarly, a high priority is given to the development of centralized storage solutions (pumped hydro storage, compressed air, etc.) which accompanies the large-scale RES deployment. Decentralized storage solutions are considered to be insufficient to support the large-scale RES deployment: they are not given priority.

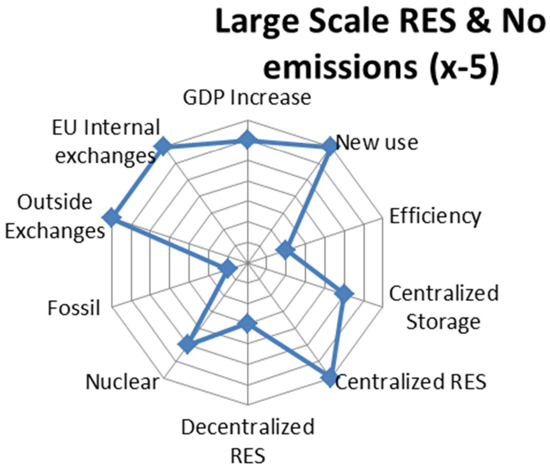

Figure 32: Radar diagram of x-5 scenario ("Large Scale RES & No Emissions")

Nuclear technology as a centralized technology is included in this Scenario. Yet, no development in new nuclear technologies is assumed: the current level of deployment is maintained according to standard decommissioning rates for present nuclear plants up to 2050. Since only Europe has a strong policy for the reduction of GHG emissions, CCS technologies are not mature enough (high cost): they are not among the options to reach GHG reduction targets.

Electrification of Transport, Heating and Industry is considered to occur both at centralized (large scale) and decentralized (domestic) level. However, the political focus is mainly on the supply side: large amount of fossil-free generation will make investments in energy efficiency solutions less attractive. A low increase in energy efficient solutions is foreseen (including DSM and flexibility of EV use). Moreover, a clear shift towards 'greener' behaviours is experienced compared to e.g. present practices (focused and active involvement towards more energy efficiency, focused and active involvement towards more use of sustainable energy by the European citizen).

A convergent and strong policy framework for the whole European Member States is in place: the deployment of the available RES potential is possible everywhere. Common agreements/rules for transnational initiatives regarding the functioning of an internal EU market, EU wide security of supply and coordinated use of interconnectors for transnational energy exchanges exist.

Little attention paid to large-scale solutions which lowers the priority for imports of fossil fuels at EU level. As a consequence, Europe's energy dependence is low. However, a high import of RES from North Africa – DESERTEC project is included.

A.4 100%RES (x-7)

In this Scenario, the global community has not succeeded in reaching a global agreement for climate mitigation. Yet, Europe is fully committed to its target of 80-95% GHG reduction and the CO2 costs in EU are high due to these strict climate mitigation targets. The strategy to achieve this target has a higher ambition than the other scenarios: it bases Europe's energy system entirely (100%) on renewable energy. To reach this target, both large scale and small-scale options are used: offshore wind parks in the North Sea and Baltic Seas and the DESERTEC project in North Africa, combined with EU-wide deployment of de-centralized RES (including CHP and biomass) solutions.

Public attitude towards the deployment of RES technologies is very positive in the whole Europe, while attitude towards nuclear and shale gas is negative.

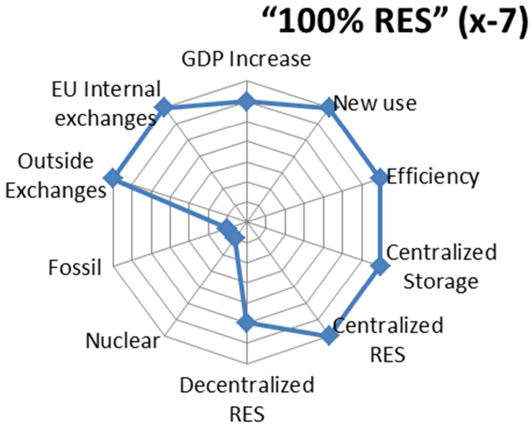

Figure 33: Radar diagram of x-7 scenario ("100% RES")

Neither nuclear nor fossil fuels with CCS are used in this Scenario. Thus, both centralized storage solutions (pumped hydro storage, compressed air, etc.) and de-centralized solutions are needed to balance the variability in terms of renewable energy generation

On the consumer side, a marked increase in energy efficiency (including DSM and flexibility of EV use) is also needed. Electrification of transport, heating and industry is considered to occur both at centralized (large scale) and de-centralized (domestic) level and these solutions will reduce resulting energy demand as well as provide complementary flexibility and storage to account for variability of RES production from PV and wind. There is a strong drive towards 'greener' behaviours in the population with active involvement towards more energy efficiency, more use of sustainable energy and clean transport etc.

As part of the 100% RES strategy, no import of fossil fuels occurs. Only renewable sources (solar energy from Africa, biomass from FSU region etc.) are imported from outside EU.

A.5 Small and local (x-16)

In this Scenario, the global community has not succeeded in reaching an agreement for climate mitigation. Yet, Europe is fully committed to meet its target of 80-95% GHG reduction. Compared to the other scenarios, the European member states have chosen a bottom-up strategy mainly based on small-scale/local solutions to reach this target. Common agreements/rules for transnational initiatives regarding the operation of an internal EU market, EU wide security of supply and coordinated use of interconnectors for transnational energy exchanges do not exist. The focus is rather on local solutions dealing with de-centralized generation and storage and smart grid solutions at transmission and mainly on a distribution level

In this Scenario, there is a high focus on deployment of de-centralized storage and RES solutions (including CHP and biomass), while nuclear and CCS are not considered as options to reach the GHG emission reduction target. The public attitude towards the deployment of local de-centralized RES technologies is positive in the EU.

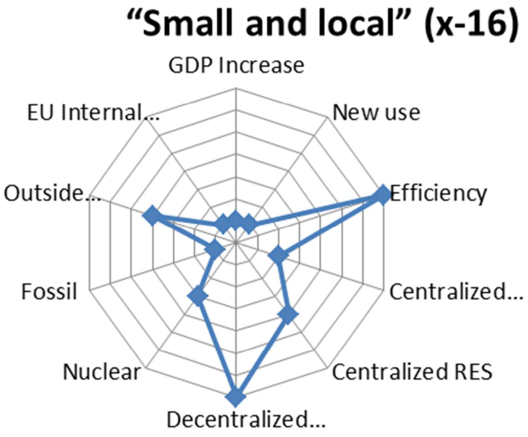

Figure 34: Radar diagram of x-16 scenario ("Small and local")

A high degree of electrification of transport, heating and industry is considered to occur mainly at de-centralized (small scale) level; there is a corresponding high focus on the deployment of energy efficient solutions (including DSM and flexibility of EV use).

GDP growth in EU is assumed low, mainly due an inhomogeneous economic activity landscape among Member States. Demographic change towards 2050 is assumed to be migration only at EU level. A major shift towards 'greener' behaviours is experienced in this scenario compared to present practices. In general, the public is very active and most of the development occurs at a local de-centralized level.

The European permitting framework (including nature legislation) is also inhomogeneous/de-centralized at member state level. Some countries will still require energy imports from outside the EU.

Annex B: Comparison of Microgrids versus Cells as defined in the Web-of-Cell concept

	Microgrid	Cell
Focus and Goal	The stability and security of the microgrid and the welfare of the connected prosumers only, ensuring their security of supply.	The stability and security of the complete power system (synchronous area), ensuring stability and security of the grid in a decentralized but coordinated manner.
Geographical boundaries	Usually located in small areas like buildings or communities (up to islands); boundary based on the connectivity (see below) and associated impact on security of supply.	May occupy areas that from small (e.g. urban areas) up to large (e.g. complete control area); boundary based on trade-off between (1) real-time self-balancing capability, and (2) cell controllability-observability and minimization of transaction costs. Cells with relatively large sizes facilitate the (internal) imbalance mitigation due to a higher number of available resources. However, the smaller cells are easier to be monitored and operated.
Energy balance	Designed and dimensioned to run in islanded mode, meaning that it must be able to guarantee microgrid local demand and supply matching for the full demand for longer times.	Can rely on structural imports and exports from other cells (hence for instance large offshore wind parks) and no need to be self-reliant for matching the local load with local supply. Only needs to be self-reliant for what concerns the correction of real-time deviations from the scheduled set-point at t_0.
Power balance	In connected mode the balance is guaranteed by the TSO of the CA	The TSO of the CA to which the cell belongs is responsible

	to which the microgrid belongs (both the scheduled balance as well as the real-time corrections). In islanded mode, the microgrid central controller (MGCC) is responsible for guaranteeing the power balances (both the scheduled balance as well as the real-time corrections).	for the scheduled balance (set-point at t_0). The Cell System Operator is responsible for the real-time corrections.
Operation mode	Both interconnected and islanded modes are possible. Switching can be quite frequent even under normal operation but it certainly takes place when frequency/voltage stability incidents happen so as to maintain the uninterruptible power supply of the consumers regardless of the upstream system state.	Usually interconnected, as the goal is to contribute to the global system stability in a decentralized but coordinated manner. Of course, if required, a cell could be dimensioned and technically equipped to operate as a microgrid, for instance in response to an incident or emergency situation to either contain or isolate the faulted area from the mains.
Power level	Typically from KW to MW	From MW to GW
Voltage level	Usually LV. MV microgrids can be an exceptional scenario depending on their size.	Any voltage level (LV/MV/HV) or combination of voltage levels (LV/MV).
Grid architecture	Radial only.	Radial or meshed grids. Distribution system level radial grids could be connected to create a mesh[4], enabling, for example, direct exchanges at LV level between neighbouring cells avoiding the multilevel conversions (LV-MV-HV), reducing the losses and the congestion risk.
	Microgrids can be nested within larger microgrids	Cells cannot be nested.

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[4] Due to the insertion of DERs at distribution level, radial grids could be progressively been connected, by forming a meshed structure.

Connectivity	Connected only to upstream network.	Any connection is possible: upstream, downstream or with cells at an equivalent level
	Only one single connection is possible. Otherwise the automatic connection/disconnection becomes difficult.	More than one connection is allowed; actually all cells except those that are most downstream will have at least two connections (e.g. one upstream and one downstream).
Resource portfolio	Exclusively DER units and loads	There is no specific restriction in the portfolio of cell resources. They can integrate either DER or central resources, and the ratios are not specific, (e.g. not necessary to include storage)
Control architecture	Only two levels of control: at the lowest level there exist local controllers (Load and Microsources Controllers or LC and MC). Above them there is one central controller (Microgrid Central Controller or MGCC)	More than two levels can exist in cells. e.g. when aggregators mediate between the Cell System Operator and the resources
	Interactions between MGCC and resources outside the microgrid are not allowed.	Interactions of Cell System operator and resources located in adjoining cells are allowed, especially when it comes to BSC or PPVC.
Market framework	Can participate in market processes only with the mediation of microgrid operator as an aggregator. No nested market processes can exist in microgrids	Any market processes can exist within cells. The different resources can individually or by means of aggregation participate in any market process without the mediation of the Cell System Operator

Annex C: Handling of concentrated RES generation by the Web-of-Cells

The aim of this annex is to illustrate how the web-of-cells handles concentrated generation connected at transmission level, and to show how the concept does not ignore nor is incompatible with this type of generation. The concentrated generation can be RES or not; the case of off-shore wind parks is selected here since it incorporates potential difficulties like connection distances and intermittencies, but the approach can be extended to many other situations.

C.1 Integration of Offshore Wind Parks into Web-of-Cells

Construction of offshore wind parks is one of the key actions, which will reduce the overall CO2 emissions from power generation in Europe and reduce the energy imports. Based on preliminary conclusions from the eHigway 2050 project, which were presented in Internal Report R3.1 [17], big scale offshore wind is a consistent part of at least two scenarios, setting border conditions for development of the European future power system. Already during the last decade the overall capacity of offshore wind has quadrupled a growth that is expected to continue.

In principle integrating offshore wind into the web-of-cell concept is straight forward. However, there are different ways this may be implemented. The reason for this is due to the fact that it is not yet known how the concept of offshore wind will evolve in the future. In today's system offshore wind is connected to the main grid through point to point connections, and can thus be treated as any other intermittent production within a cell. The question becomes more interesting when one looks at how offshore wind might be connected to the mainland in the future. It is envisioned that one in the North Sea will have a meshed offshore grid connecting the North Sea countries and offshore wind farms. There are different ways this future meshed offshore grid can be integrated into the web-of-cell concept mostly dependent on how this system will be operated legally. The most likely possibilities are as follows:

- The offshore grid will be defined as a cell and operated as any other cell. This alternative requires that the North Sea countries appoint one legal entity as the cell operator. From a legal perspective this may be difficult given that the wind farms and end users (oil rigs) in the North Sea are operated under different legislations enforced by the different countries.
- The offshore grid will just be an extension of the mainland cells. In this alternative each of the North Sea countries operate their respective part of the North Sea grid as a part of their mainland cell.

Among one of the strengths of the web-of-cell concepts is the rather general notion of cell, which facilitates the inclusion of new concepts. Due to this, one can easily identify two ways of integrating offshore wind and an offshore grid into the concept. Although, there are obstacles in implementing such an offshore grid, they are mostly regulatory and technological.

C.2 Dealing with the intermittencies

The main and the most obvious challenge is the inherited intermittency of the wind power. However, as it was stated in Section 3.1, a cell does not have to reset to zero exchange of power on its tie-lines with other cells, but merely should be able to follow its power exchange schedule, which was submitted to the day-ahead market. The residual unforeseen imbalances will be traded on the Intraday market, which is highly operational in several European countries already now. It is anticipated that the Intraday will take the main burden of the intermittent generation. The Nordic Intraday market (Elbas) trades imbalances until one hour to the operation. It is complicated to discuss how to address these sudden imbalances because in the real life it is likely to be a trade-off between costs and effectiveness of the solution.

C2.1 Alternative 1: resolving imbalances offshore

The imbalances can be resolved already offshore, for example by using big capacity storages. Considering that procurement of balancing reserves for frequency regulation is quite costly, this solution can be vital. Basically this would mean that the offshore generation will be able to stay balanced after closure of the Intraday market.

C2.2 Alternative 2: resolving imbalances onshore

The alternative way will be addressing these imbalances onshore within the web-of-cells. Referring to Figure 12 the present web-of-cell concept presumes that a HV-part of a TSO control area can be a cell, comprising both offshore wind and consumption connected to HV. Big scale industrial consumption has proved to be an efficient DR resources, for example at the Nordic Regulating Power Market. This provides an opportunity to compensate deviations in offshore generation[5].

C.3 Web-of-Cells in action

The Web-of-Cell concept does not neglect a large increase in offshore wind cells. The Web-of-Cells concept only proposes that cells need to take care of balancing out the residual imbalances that are caused in their cell. Since a cell does not need to be self-reliant, it can import energy from offshore wind parks. To depict this more clearly a simplified example is presented:

- Let us suppose an LV cell is fed top-down from an offshore wind park because it does not have sufficient (or cheaper) own generation: this is clear and decided at t_0 as a result of the BRP (and TSO) day-ahead and intraday demand-supply matching process.
- As a result of this, a scheduled import into the LV cell is determined (the cell does not even care where it comes from, but let us assume it comes (mostly) from the offshore wind park.
- If now in the real-time period the load in the cell is lower than planned (or the local generation is higher than planned) the cell will try to either increase its local load (e.g. by charging a battery or starting an additional load) or decrease its local generation in an attempt to not change/impact the import (that is provided by the offshore wind park for instance).

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[5] www.statnett.no/Drift-og-marked/Markedsinformasjon/RKOM1/Om-regulerkraftmarkedet-RKM/

- Similarly, if now in the real-time period the load in the cell is higher than planned (or the local generation is lower than planned) the cell will try to either reduce its local load or increase its local generation in an attempt to not change/impact the import (that is provided by the offshore wind park for instance).

So basically, the cell concept is ‘protecting’ the offshore wind farm from variances in demand when compared to what was planned.