SCENARIOS AND REQUIREMENTS FOR THE OPERATION OF THE 2030+ ELECTRICITY NETWORK

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ABSTRACT

This paper summarizes the control mechanisms for operation of the future network (2030 and beyond) proposed by the ongoing EU-funded ELECTRA Integrated Research Programme (IRP) on Smart Grids [1]. After describing a future grid scenario in compliance with the European Energy Strategy, the new ELECTRA control scheme is introduced to outline a high-level functional architecture for frequency and voltage control. The future role of resources connected to the distribution network for the provision of ancillary services is formulated and the requirements necessary for the integration of all stakeholders drafted.

INTRODUCTION

According to the European Commission Energy Roadmap 2050 [2] for long-term vision, by the year 2030, around 25% of the primary energy will come from renewable energy sources (RES) and the percentage will increase until up to 60% by 2050. If comparing these forecasts with the results by 2005 —Fig. 1—, it is clear that the commitment of the European Union with a low-carbon energy future is a one-way journey.

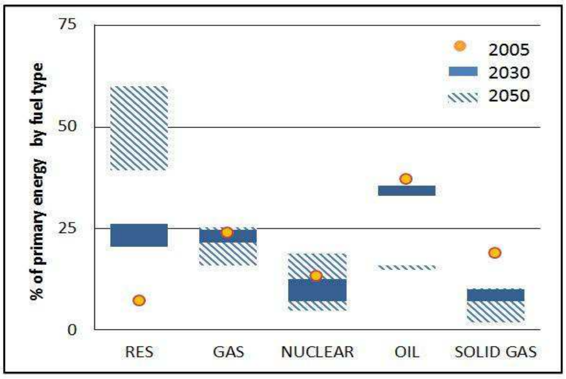

Fig. 1. Percentage of primary energy by fuel in 2030 and 2050 horizons [2]

The availability of energy in the future, compatible with sustainability, is supported by the development of the electrical network, with a high share of RES connected at distribution levels. By 2030 and based on different outlooks, it is expected that between 52% and 89% of electricity production will proceed from RES [3-5]. The scenarios are still more aggressive under the 2050 scope, when the European Commission foresees, in optimistic predictions, around a 90% of the electricity production coming from RES [2].

ELECTRA ASSUMPTIONS FOR 2030+ POWER SYSTEM

Main assumptions concerning to future power grids and considered as foundations for ELECTRA can be rooted on some of the scenarios developed inside the project e-Highway2050 [6]. The project e-Highway2050 raises several scenarios based on the combination of controllable (options) and non-controllable (uncertainties) factors. The scenarios predict feasible problems and challenges for 2030+ power systems but the proposal of solutions is out of the scope of the project.

Some relevant characteristics of the expected 2030+ power system can be mentioned. Generation will be mainly decentralized. Current schemes of few and large power plants connected at transmission level will be replaced by new approaches with a larger number of smaller units connected to distribution levels. Additionally, some RES centralized power plants, mainly with wind or photovoltaics (PV) generation, will be found at medium or high voltage levels. The substitution of classical dispatchable units with intermittent RES will increase the needs of reserves for real-time balancing purposes in order to correct the mismatches created by forecast errors. These extra reserves will be mainly covered by flexible loads or storage. If decentralized RES is installed in distribution networks the current radial structures will be affected. This unexpected changes in the power flows directions can lead to additional power quality issues, such as overvoltages/undervoltages or dips/swells.

By 2050, electricity consumption will noticeably increase —around 43% [7]— as a consequence of the electrification of transport and heating/cooling even when considering the cutback due to energy efficiency improvements. Electric storage will be a cost-effective solution for offering multiple services like peak shaving or damping of power oscillations from intermittent sources. The surplus of energy during high-generation periods may be stored to be used during low-demand cycles. The great amount of flexible loads and storage systems available in the networks, with fast-acting times, will participate providing their flex capabilities as an additional ancillary service.

DESCRIPTION OF THE CONTROL SCHEME PROPOSED WITHIN ELECTRA

The objective of ELECTRA is the development of new control techniques for the operation of the future electricity network, in order to fulfill the guidelines defined by the European Union for development of power systems in the horizon 2030+ [8]. The project focuses on both technical and market aspects. From the technical perspective, the ELECTRA advances must contribute to facilitate the insertion of RES, defining new architectures to favor the provision of ancillary services and their trading in an electricity market. Concerning to markets, ELECTRA strives to facilitate the establishment of a common European electricity real-time balancing competitive market.

The global control scheme proposed within the project draws the integration of the network at a Pan-European level, without the present limitations in exchange power at the borders between countries. It requires the close coordination between the different operators at the diverse voltage levels. This coordination will foster the capacity of energy exchanges and the share of ancillary services between areas supervised by different operators.

These "*Vertical Integration control schemes*" as such rely for the information to be aggregated and control signals to be effectuated on other local control schemes. The individual local control schemes must reduce the power imbalance within one characteristic time-scale, e.g. at TSO level (seconds to minutes), DSO level (minutes to hours), Retail level (hours to days), Prosumer Aggregator level (minutes to hours) or Consumer/Prosumer level (minutes to hours). This type of control may be referred to as "*Horizontally-Integrated control schemes*".

Therefore the integration is considered to be developed in two directions of scale; bi-directional "vertically integrated control schemes" reinforced by "horizontal integration" of distributed control schemes, and divided over the multiple voltage layers inside the system, as displayed in Fig. 2.

This paradigm of horizontal and vertical control does not prescribe a specific architecture yet, except for the presence of vertical integration and horizontal distribution of the control schemes. Therefore it is possible to implement different control architectures, ranging from the present wide area synchronous grid, to part-time islanded areas, and to a subdivision in smaller grid areas that not necessarily need to operate in synchronism while still being interconnected.

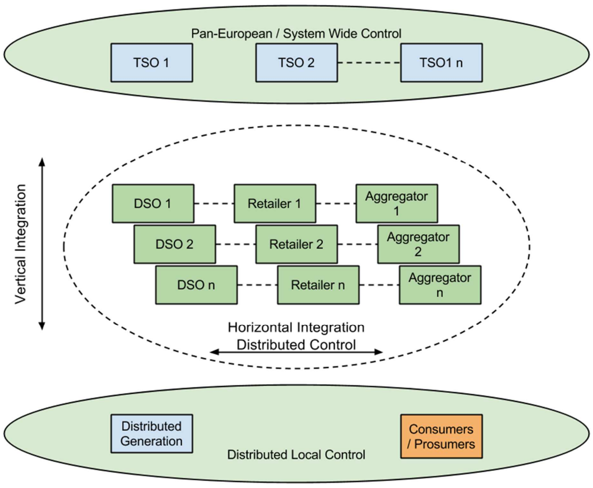

Fig. 2. Network integration levels

This paradigm of horizontal and vertical integration is supported at all voltage levels, based on the available resources for ancillary services provision. The vertically-integrated control schemes reinforced with distributed control are expected to provide a dynamic power balance in a more appropriate way compared to the current central control schemes.

The need of implementing this integration paradigm into future power systems requires the formulation of a compatible functional architecture developed inside ELECTRA project.

FUNCTIONAL ARCHITECTURE FOR FUTURE NETWORKS

According to the new approaches proposed within ELECTRA, the current grid structure, where the TSO is responsible of reserves activation within its own control area is no longer valid. Future grid developments imply a new architecture concept, where the electrical power system is divided into smaller grid units (*Control Cells*). This so-called *Web-of-Cells* arrangement, created from the interconnection of the Control Cells, defines the new functional architecture which is shown in Fig. 3. Some cells belong to the high-voltage level (HV). There is a blurred line between medium-voltage (MV) and low-voltage (LV), and some control cells integrate both levels. Cells can be interconnected through several tie-lines, allowing a dynamic structure with reconfiguration capabilities.

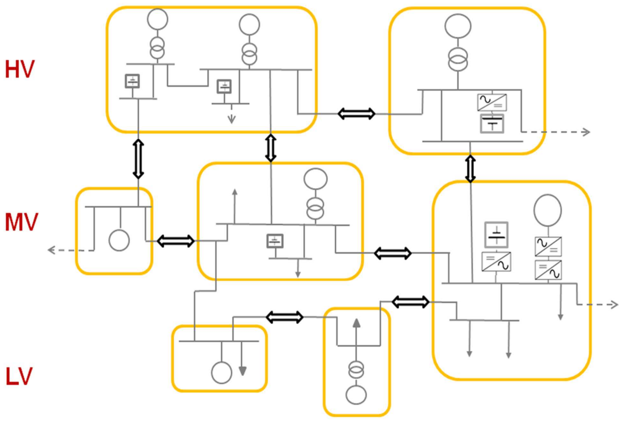

Fig. 3. Control cell-based architecture

A control cell is defined as a group of interconnected loads, distributed generation resources and storage units, with well-defined electrical and geographical boundaries and with sufficient reserves to solve voltage and cell balancing issues locally. There is no expectation for the control cells to operate in island mode, so they can rely in energy imports or exports from their local Balance Responsibility Party (BRP) market-based balancing. In every cell multiple BRPs and aggregators can coexist.

Each Control Cell is assigned to a Control Cell Operator (CCO) who is responsible for local balancing and voltage control. The CCO has the overview of the cell state though real-time system monitoring, in order to guarantee continuous secure and stable operation and appropriate response in case of disturbances. The CCO also dispatches the reserves while considering that the impact of providing ancillary services in its own cell presents no risk over neighbouring cells. This way, a 'divide and conquer' implementation to tackle voltage and balancing issues can be accomplished.

Coordination between neighbouring operators is essential to share responsibilities in the cells boundaries but also beyond them. Due to high amounts of fluctuating RES, collaboration between neighbouring CCOs it is also beneficial because natural forecast errors may be cancelled across cell boundaries in order to reach a globally optimized state. For example: if an individual cell has to restore its balance to the scheduled set-point, a certain amount of reserves must be activated. In case of different sign imbalances in neighbouring cells, an imbalance can be tolerated, by agreement and without compromising system safety. This way each cell has to activate fewer reserves, so an optimal reserves management can be achieved.

Among the benefits of this new architecture there can be cited the solving of local problems locally, in a fast and secure manner, limiting complexity and communication overhead. Inside the ELECTRA project the development of new controls for RES aligned with the new architecture are foreseen too. This proposed control system will add an inter-cell control layer to favour optimized reserves activation in normal state operation.

ANCILLARY SERVICES PROVISION IN 2030+ HORIZON

It is clear that above-mentioned expected changes for future grids will bring new challenges with no previous known experience. The wide rise in the share of RES and distributed generation (DG) also implies the reliance on that kind of sources for the provision of ancillary services for the electricity supply. Based on the Control Cell concept, each cell must be able to use its own reserves for ancillary services provision.

Frequency control

Frequency deviations come up as a result of imbalances between generation and load. When a frequency fluctuation is detected in the system, the restoration must be accomplished by a cascade control system including containment, restoration and replacements reserves [9]. At present, the load-frequency reserves are mainly provided by synchronous generators. Some services, as frequency containment reserves, are mandatory in some countries, as Spain, Portugal or Italy while some others are subject to payments according to regulated price or by means of bidding. Distributed generation (DG) is required to participate in frequency control according to certain grid codes. They are usually obliged to reduce the power output in case of overfrequency, being underfrequency not requested in almost any of them —it is usually linked to the availability of the resources—. In the proposed Web-of-Cells structure main principles of load-frequency control are still applicable. The proposed mechanism for frequency control in a Web-of-Cells based system consists of the following parts: inertia control, frequency containment, balance restoration and balance steering control.

In future scenarios, it is expected an increase on the steady-state frequency deviations as it has already been detected in some parts of the European grid [10]. This is mainly due to the combined effect of increasing the power of generation connected through converters while reducing the direct-coupled inertia of rotating generators. In order to mitigate the short-term imbalances, an adequate inertia must be maintained in the system avoiding the rate-of-change-of-frequency (ROCOF) going beyond limits. This coupled inertia which is disappearing from the power system must be replaced by synthetic inertia provided by the converters used to connect asynchronous generation or storage units. The CCO is the responsible to switch on/off this inertia control functionality with the aim of keeping enough inertia in the system to minimize frequency excursions.

There are no expected changes for frequency containment mechanisms itself. However, new potential resources can be used to provide the service. The demand can be frequency controlled from distributed loads. The underlying idea is to adjust the consumption depending on frequency deviation. There are several types of loads which can be used to fulfil this goal as electric vehicles (EVs) or Building Automation Systems (BAS).

In new scenarios, potential providers can include PV, wind power plants, storage devices and demand side providers. The balance restoration reserves must be activated CCO when it detects an imbalance between the scheduled power flow and the actual power flow across the control cell borders.

The balance steering control (BSC) has the purpose to replace the balance restoration reserves (BRR) by other reserves, probably provided by neighbouring cells. By pro-active action of BSC it is avoided the activation of containment and balance restoration reserves, maintaining the stable operation of the system while the cost for service provision is optimized. BSC has also the responsibility of supervising the system and based on short-term forecasting tools predict potential incidents that may substantially affect the 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. Activation times for the different reserves are not yet defined since further investigation and experimentation inside ELECTRA project must be accomplished.

In future scenarios, DG will also participate in BRC and BSC. DG connected in cells at distribution level can also provide the service in a proper market. It can be required a high level of aggregation of DG sources in order to be able to supply enough reserves to be competitive in the market framework.

Voltage control

Voltage is a local variable. Over this basis, it is especially relevant one of the ELECTRA design principles: “local problems require local solutions”. Since it is expected that more generating units will be connected at distribution level, less 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 CCOs at the different voltage levels. Two control layers are identified in the process: primary and post-primary voltage controls. No fundamental change will be noticed in the primary voltage control compared to the today standards but, it was previously shown also for frequency control, new reserves providers are included within the portfolio.

Post-primary voltage control (PPVC) has the commitment to bring the voltage levels in the nodes of the power system back to nominal values. At the same time, it has to optimize 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 (around 1 minute). It is clear that mainly reactive power will be used to restore any voltage issue at higher voltage levels. 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. If active power proves to be more effective and optimal to be used to control the voltage level in the LV grid, active power may be procured as PPVC resource as well. Each cell is responsible for its own voltage control while a close coordination between neighboring cells guarantees the provision of PPVC service between neighboring cells. Each time a voltage issue is detected, the CCO determines its necessary PPVC resources by taking into account technical as well as economic constraints. Before activating any PPVC resource, the CCO determines whether the activation causes congestion problems that could put the control cell stability into risk.

It has to be remarked that many PPVC resources may be located at MV levels, with possibility of service contributions to LV layers as well as HV layers. For example, the PPVC mechanism assures the possibility of supplying voltage control resources from MV cells to HV cells if there is a lack of self-procured resources within the HV cell.

A summary of present mechanisms as well as future provision of ancillary services according to the foreseen web-of-cells structure is shown in Tables I and II.

Table I. Present and future of ancillary services for frequency control

	Present grid	**Future 2030+ grid**
Frequency control	-	Inertia control
	Frequency containment control (FCC)	Frequency containment control (FCC)
	Frequency restoration control (FRC)	Balance restoration control (BRC)
	Frequency replacement control (FRC)	Balance steering control (BSC)

Table II. Present and future of ancillary services for voltage control

	Present grid	**Future 2030+ grid**
Voltage control	Primary voltage control (PVC)	Primary voltage control (PVC)
	Secondary voltage control (SVC)	Post-primary voltage control (PPVC)
	Tertiary voltage control (TVC)	

Market mechanisms

The present model for the European electricity market is based on a zonal approach (bidding zones) and in every area one wholesale electricity price exists. A bidding zone is the largest geographical area where market participants are able to exchange energy without any constraint. The ongoing markets have a minimum bid size of 10 MW, but with a high penetration of RES, this limit can become smaller in the future.

The horizontal and vertical integration defined for grid coordination can also be applied to markets. This market integration concept can be later extended to the web-of-cells structure. In a liberalized market, the CCO will be able to contract the ancillary services from the resources connected within its own cell as well as from other CCOs, which can bid into the market to procure its reserves as any other service provider. The CCO will be responsible to verify if the best solution from an economical point of view is compliant with network constraints. Further specific market mechanisms adapted to the new functional architecture and concepts within ELECTRA will be developed in next steps of the project.

CONCLUSIONS

According to the expected growth of distributed energy resources (DER) and intermittent RES installed into power systems in the horizon 2030+, drastic changes are foreseen in the electricity grids. These changes will have an effect not only on the architecture but also on the control systems, the provision of ancillary services and the electricity markets. ELECTRA is on the road to identify and provide solutions for all these challenges. In this paper, a new functional architecture concept developed inside the project, the so-called Web-of-Cells concept, has been presented. In addition, the ELECTRA vision related to the provision of ancillary services in the 2030+ grid has been drafted and foundations for future development of market mechanisms has been settled.

MISCELLANEOUS

Acknowledgments

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