ELECTRA IRP APPROACH TO VOLTAGE AND FREQUENCY CONTROL FOR FUTURE POWER SYSTEMS WITH HIGH DER PENETRATION

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ABSTRACT

The high penetration of DER into the European power system requires a radical new approach to the real time grid operation. The ELECTRA Integrated Research Programme on Smart Grids is active in the definition of the new system requirements, deploying flexibility resources to be triggered in response to proper grid observables inputs. This paper presents the ELECTRA vision on the 2030+ power system together with its proposal for frequency and voltage control schemes. The proposed approach on grid control envisages the deployment of flexibility resources, the provision of new ancillary service as well as the use of advanced ICT solutions to improve the network observability.

INTRODUCTION

The whole-sale deployment of Renewable Energy Sources (RES) connected to the network at all voltage levels will require radically new approaches for real time voltage and frequency control that can accommodate the coordinated operation of millions of devices, of various technologies, at many different scales and voltage levels, dispersed across the EU grid.

Uncertainty increases - Renewable sources come in many shapes and sizes and will be connected across every voltage level. The increase and the fluctuating nature of the foreseen electrical demand necessitate a radical change from a deterministic estimation of demand from fixed loads towards demand and storage moving in time and space, offering potential flexibility to system operation in terms of demand response and storage. At the same time, automation and market action will mask inherent physical generation and load changes [1].

Need for flexibility from all available resources - The increase in uncertainty has to be met by flexibility in power system operation. Such flexibility must play on all available resources and across todays traditional boundaries between the power system stakeholders. An important prerequisite for any control strategy is the ability to observe the systems current state. With developments in state estimation, sensors and ICT, one can expect network observability on a level far beyond what todays control strategies are built upon. This opens a new "world" of possibilities with regard to novel control strategies, and in particular the ability to optimally exercise flexible resources across current "network levels" in real time [2].

Complexity in the network itself increases - At present, Europe is on the verge of the development of a power system with increased complexity – with more and more hybrid AC/DC systems, widespread use of converters in LV-grids, stand-alone dynamic ratings and self-healing schemes, etc. The network-wide deployment of such technologies fundamentally challenge the way the future network can be operated, for instance related to the lack of system rotational inertia and hence increases the need for establishing new control strategies using new complex components.

The EU-funded ELECTRA Integrated Research Programme (IRP) on Smart Grids [3] addresses this challenges, and will establish and validate proofs of concept that utilise flexibility from across traditional boundaries in a holistic fashion. In this paper, the exploitation of flexibility in voltage and frequency control schemes is analysed to visualize, simplify and overcome the increasing complexity in the future power system.

THE ELECTRA IRP

The ELECTRA IRP has been set-up by the participants of the Joint Programme (JP) on Smart Grids [4] of the European Energy Research Alliance (EERA) [5]. The ELECTRA IRP overarching goal is to reinforce the EERA JP on Smart Grids in the European coordination of smart grid research roadmaps and joint research activities, coordinated development and use of common research infrastructures, exchange of researchers and international collaboration; thus building effective support for realizing the European SET Plan objectives.

The ELECTRA RTD VISION

Addressing the above mentioned challenges, ELECTRA IRP will research radical new control solutions for voltage and frequency control in the 2030+ power system, utilizing flexibility from across traditional boundaries in a holistic fashion and building on ubiquitous sensing and dynamic/autonomous control functions. In order to ensure reliable control over the power grid, also distributed generators and loads will be controlled in such a way that increases the predictability of the maximum power imbalance as perceived system-wide by the TSO's. Means to achieve that goal may be through the changing of the top-down vertical control into a bi-directional "Vertically Integrated control scheme", including an exchange of information about the global and local power balance and the related grid constraints on a "need-to-know" basis, next to required control signals such as a desired change in total load, generation or system inertia. These "Vertical Integration control schemes" rely on information to be aggregated and control signals to be actuated on other local control schemes. The individual local control schemes must reduce the power imbalance within specific 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". As depicted in Fig. 1, ELECTRA is going to develop a vertically-integrated control schemes reinforced with horizontally-distributed control schemes to provide for a dynamic power balance by activating all the available distributed resources. This will enable grid operators to ensure that the balance and stability in a future power system with a high share of decentralised generation is maintained at the same level as today or even better. The new control concepts, as well as the foreseen experimental laboratory testing to be performed within the project to test the developed solutions, will be presented and deeply discussed in view of their possible implementation by industrial stakeholders in future field testing activities and demonstration projects.

A NOVEL APPROACH TO GRID CONTROL

The current "centralistic" approach where the TSO is responsible for frequency and voltage control in his assigned Control Area (CA)/Control Block (CB), by identifying the need to activate reserves as well as subsequently activating them in a safe and most economic manner, possibly by coordination with neighbouring TSOs, will no longer work.

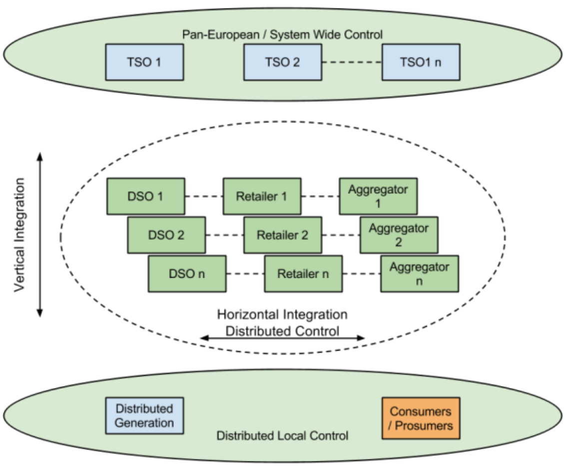

Fig. 1. Vertically and horizontally integrated control schemes

Firstly, the intermittency and limited dispatchability of the PV and wind generation units: short-term and local forecast errors may cause a real-time impact on the local balancing and resulting deviations of scheduled power flows. Yet, local imbalances may counter-balance each other, resulting in a system-wide balance such that no frequency deviation is observed at central system level even though local corrective actions are required. Secondly, a paradigm shift from Supply-Follows-Load to Load-Follows-Supply, resulting in an expected uptake of Demand Response programs at all voltage levels: as a result of this, also more 'intermittency' at the Demand Side (loads) can be expected, aggravating the before-mentioned problem. Thirdly, as both the units (loads and generators) that cause problems as well as the reserves providing units (loads, generators, storage) are increasingly more situated at the distribution grid, a central TSO responsible for real-time control (reserves activation) would require a lot of information provided by the DSO (and Aggregators) to safely active reserves providing resources at the proper location, not causing new or additional (e.g. congestion) problems. Fourthly, the inertia of the power system will be reduced significantly, causing much more and higher fluctuations, i.e. increased Rate Of Change Of Frequency (ROCOF).

The novel approach that is proposed in the ELECTRA IRP, is to solve local problems locally. ELECTRA propose to organize the power grid as a web-of-cells, where a cell is defined as "*a group of interconnected loads, distributed energy resources and storage units within well-defined grid boundaries corresponding to a physical portion of the grid and to a confined geographical area*".
Cells are connected to their neighbours via inter-cell physical tie lines, see Fig. 2; there can be multiple physical tie-lines between any two cells, and at any given time, any connection can be either open or closed. Each of these cells is managed by a Cell Control Operator (role that is most likely mapped on the associated TSO/DSO) that has similar responsibilities with respect to real-time reserves activation at cell level as it is currently assigned to a TSO at Control Area level.

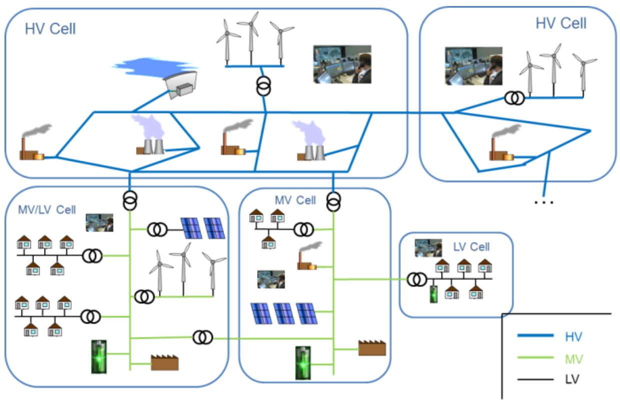

Fig. 2. Schematic example of proposed "Web of Cells" architecture.

One of the fundamental differences, though, is the cell real-time control focus on "Balance control" instead of "Frequency control", resulting from the fact that local balance problems may require a reserves activation action long before a frequency control action is required. This is a direct consequence of the fact that multiple local imbalances may counterbalance each other such that at system level no frequency deviation is observed. Table 1 gives a short summary of the newly proposed real-time control schemes as compared to the present practices. It is important to note that the proposed "Inertia Control" is a slow control that adapts unit's virtual inertia set-points based on forecasted cell/system inertia and generation mixes. It is important to note that in the Balance Control, coordination among cells is envisaged to negotiate a sustained local imbalance if this can be done safely: this way, a system-level global optimization can be achieved by activating less reserves, or by activating reserves in other cells because of economic reasons. All these proposed new controls are described in more detail in [6]. Also, when real-time control (reserves activation) is delegated down from the central TSO to distributed Cell System Operators, there is no longer the need to distinguish between Secondary and Tertiary Voltage control. Each cell can, next to the automatically activated distributed Primary Voltage control, have a centrally and optimally activated Post-Primary Voltage control, see Table 2. This is described in more detail in [6].

OPERATIONAL FLEXIBILITY AND ANCILLARY SERVICES

In its essence, stable and flexible power system operation comes down to keeping a dynamic balance between power supply (by generators) and power consumption (by loads) under the physical limitations of the interconnecting transmission and distribution network. Relevant criticalities to be addressed are related to the power system behaviour under disturbed network conditions, control systems performances and to the stochastic behaviour of RES generation and load demand. With the rise of DER, flexibility services provided by users connected to the distribution grid will grow. As for other energy products, market parties will buy and sell them without consideration for the grids physical state, which could result in raising peak consumption or generation in local networks. The variability of renewable energy can affect the design of ancillary services market

Table 1. ELECTRA proposed real-time frequency control schemes.

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

Table 2. ELECTRA proposed real-time voltage control schemes.

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

increasing the complexity, affecting scheduling and pricing of the required services.

The novel approach to grid control requires a closer look at flexibility and in particular at the **parameters characterising flexibility:**

- Amount of power / energy that can be shifted / reduce
- Duration of power that can be shifted
- Rate of power shifting
- Response time
- Location of available generation and load
- Controllability (frequency, voltage control)
- Starting / ending time
- Market eligibility / flexibility
- Resources potential for aggregation

Sources of flexibility in all parts of the system can be identified, namely in generation, demand, storage and network. The control schemes of the power system 2030+ need especially the development of storages and demand response. Storage systems can contribute to the frequency and voltage control. Charging and discharging of storage systems is within mill-seconds to seconds and is capable of preserving the balance between consumption and generation. Storage can also provide "Balance Restoration" and "Balance Steering" controls as shown in Fig. 3 [7]. Demand Side Management (DSM) is of pivotal importance in the optimisation of resources. A common goal of these control approaches is to shape the load profile (peak shaving). The objective would be to maximise the available possibilities and achieve, among others, peak reduction and network upgrade deferral [8], see Fig. 4.

However, the network operation development is an optimisation process and it will take a different approach from today's practices. The optimal postponement of investments in grid upgrade by exploiting flexibility sources is debatable, however one should consider all sources of uncertainty.

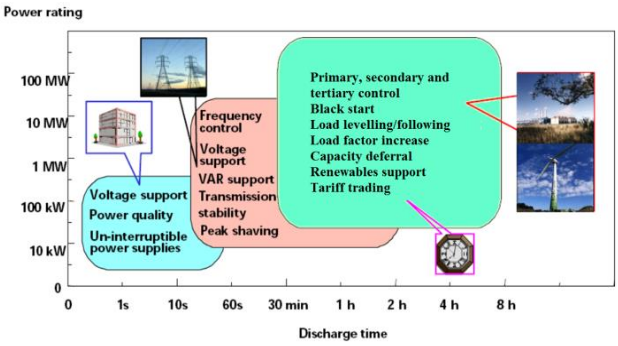

Fig. 3. Use of storage to meet system needs [4].

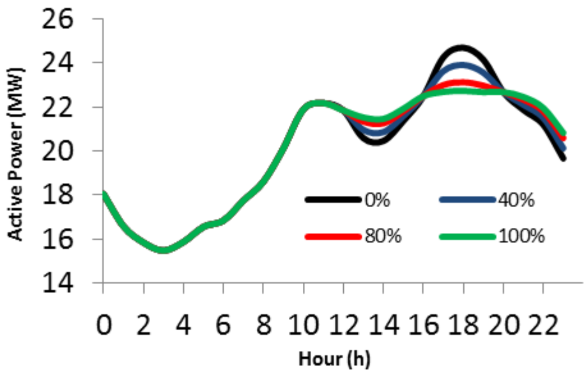

Fig. 4. Demand side management is beneficial national, regional & seasonal [5].

Most economical long-term solutions depend on the combination of costs (energy, DSM, smart charging), available load for DSM actions, Electric Vehicle (EV) load, micro-generation and, of course, on the network reinforcement policy. A long-term cost/benefit analysis should always be completed for the assessment of the most adequate planning solutions. Management of demand can also be assisted e.g. by voltage-led aggregated demand reduction; changing the voltage target of substations and also frequency-based tripping of parallel transformers. Another option is the management of reactive power through substation-based absorption of reactive power by creating circulating currents between parallel transformers through tap staggering.

Market design of the novel approach for grid control needs to be implemented at TSO and DSO levels. Market design at TSO level will need advanced pan-European market tools for ancillary services and balancing, including active demand management. These advanced tools are needed for capacity allocation and congestion management. In addition, tools and market mechanisms for ensuring system adequacy and efficiency in electric systems integrating very large amounts of RES generation are needed. Market design at DSO level needs DG forecasts, schedules and planned maintenances for operating distribution network in real time as well as new approaches for market design analysis.

OBSERVABILITY AND POWER SYSTEM INTEGRATION

As previously mentioned, accommodation of intermittent generation into the network and its reliable operation requires a gradual evolution of the network structure and in particular improvement of its monitoring or observing. In the scope of the present paper, an observable is defined as a uniquely valued function of a number of measurable quantities in a physical system. An observable can either be a scalar or vector ("State Vector") that relates to measured (observed) values in the present or past. Forecasts are not considered to be observables, but merely predictions of the future values of observables.

Forecasts will differ from observable values to be measured in future and, therefore, are not observables, as future system states cannot be measured.

In the past, monitoring of the electricity network was limited both by the lack of capable ICT technologies in combination with the fact that operation of the conventional vertical "downfall" power system did not necessarily require excessive monitoring, especially in the distribution network. Development of ICTs and integration of these as a new layer into the electricity network, also known as smart grids, will diminish the technical limitations and improve the system observability. It is important to mention that the parallel changes on the consumers' side and in particular electrification of transport and growing share of electric space heating, increases the potential volume of Demand Response (DR), thus enhancing flexibility of the power system. However, the experience shows that efficient exploitation of potential DR requires better monitoring of consumption and distribution networks in particular.

Developing the concept of observability ELECTRA project pursues two main principles: instead of following a "what can we observe?" approach, ELECTRA project rather follows "what is necessary to observe" attitude, which will be further combined with communicating the information on "need to know" principle in order to avoid unnecessary flood of data and negative consequences of this. The above mentioned controls schemes were further elaborated in the ELECTRA project and defined as a set of specific Use Cases for the future scenarios for ancillary services (2030 and beyond), build on standard Intelligrid IEC/PAS 62559 specification for development of use cases [9]. The scope of this paper does not allow presenting these use cases, but interested readers are advised to read [10].

Based on these use cases a first set of observability needs for the future control schemes have been identified. The study made a high-level evaluation of these use cases, aligning observability needs with technical challenges in the new control schemes, and defined set of physical requirements applicable for each observability need. The identified observability needs have been described for each type of ancillary services (control levels) and market role as TSO, DSO and Aggregator [11].

Table 3 presents an example of observability needs for DSO involved in the future "Balance Restoration" and "Balance Steering" controls. Similar overviews were done for the rest of the suggested control schemes. The biggest changes with respect to the observability needs appear to be due to the introduction of more RES, new actors and devices and will be further investigated in the subsequent tasks of the ELECTRA project.

Table 3. Example of the emerging observability needs for DSO

Observability needs	Challenges
1. Availability of tertiary reserves	To operate the distribution network aggregators will need to know the availability of reserves provided both by DER and aggregators
2. Geographical distribution of the tertiary reserves	If the loads and DER are to participate as reserves, the geographical distribution of the loads are needed. In particular with respect to potential network congestions
3. Voltages in the distribution grid	Increased bi-directional line flows in the distribution grid due to demand response and DER might lead to voltage issues
4. Line flows	Increased bi-directional line flows in the distribution grid due to demand response and DER might lead to voltage issues
5. Data collection as input for the forecasting algorithms	The forecasting algorithms will have to couple weather and loading data. This increases the need for correctly time stamped data

CONCLUSIONS

The introduction of RES into the power system will require new voltage and frequency control schemes for the real time grid operation to coordinate the dispersed generation across the EU grid. In addition, the level of uncertainties within the system will increase, thus requiring new a closer look at flexibility and in particular at the parameters characterising flexibility**.** Sources of flexibility in all parts of the system can be identified, namely in generation, demand, storage and network.

The ELECTRA IRP will develop appropriate control schemes for the 2030+ power system, investigating new solutions using electrical storage and demand response. Together with the introduction of new technologies and procedures, new market design tools are needed at DSO and TSO level.

The proposed ELECTRA solutions involve a shift from the current approach to power system control towards innovative control schemes embracing the deployment of various flexibility resources. These will also lead to a new market design, allowing the participation of resources located at the DSO level through aggregators.
ELECTRA has established a strong relationship with industry representatives and aims at integrating business needs and vision into the research activity to offer a comprehensive approach towards the future European smart grid.

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