RESERVE

D6.1 V1.0

Regulatory, governance and legal issues of the transition towards 100% RES

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Abstract:

In the scenario of gradually increase the penetration of RES into the power system, up to 100%, a series of technical and regulatory challenges will arise. The research activity input on the technical aspects of frequency and voltage control, aiming at balancing the energy system, will have an important impact, targeting the necessary changes / adjustments in the regulatory area as well.

For this deliverable, a methodology was developed and applied within the RESERVE project, which aimed to analyse and prioritize a set of technical proposals, grouped in the so called "wish list", to establish the top 5 proposals. These top 5 priorities will underpin the upcoming dissemination, promotion and consultation actions with relevant stakeholders, in the context of the process of consolidating and sustaining the changes/ adaptation to be produced from the regulatory perspectives.

Along with the top 5 priorities and based on the exchange of information with the other work packages, it has been developed a set of key regulatory principles (presented in Chapter 7), which can underpin the development of the future regulatory framework on the way to 100% RES integration in the power system.

Keyword list:

Regulatory principles, methodology, technical proposals, prioritization criteria

Executive Summary

This deliverable focuses on the regulatory aspects of possible updates of the existing network codes and/or the elaboration of new ones, with a special focus on requirements for voltage and frequency regulation of network codes.

The objective of this deliverable is to identify a set of key principles and priority actions for redesigning the regulatory framework, in the context of integrating up to 100% RES into the power system, while maintaining the quality of supply and services for the end-user. In this respect, a methodology was developed and applied within the RESERVE project, which pursued this objective.

The applied methodology was a three-step exercise, aiming to exploit the preliminary results of the research carried out in work packages 1, 2, 3, and 6, as following:

- Elaborate an exhaustive list of proposals based on the preliminary research and information provided by work packages 1, 2, 3 and 6
- Defining a set of criteria for analysis and prioritization of the proposals
- Identifying the top 5 priorities based on applying the analysis and prioritization criteria

Following the process described above, we were able to identify a top 5 priority list of technical proposals, that will support/ facilitate the integration of RES into the power systems up to 100%, by meeting in the same time the criteria of functionality and stability. This top 5 priority list will be subject to further promotion, dissemination and consultation actions on behalf of the RESERVE project.

Also, based on rationale and conclusions resulted from the application of the above-mentioned methodology, the authors team was able to identify a list of key regulatory principles that may be considered as landmark options for designing the governance of the future configuration and operation of the High Voltage Electricity Networks. This list of key regulatory principles will be also subject for promotion and dissemination on behalf of the RESERVE project.

Both, the top 5 priority list technical proposals and the key principles for designing the regulatory framework presented in this deliverable will be in more detailed analyzed and developed in the next stage of the RESERVE project.

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1. Introduction

In 2007, the European Commission launched the Third Legislative Package, paving the way for the development of an internal European gas and electricity market to meet these challenges. Regulation (EC) 714/2009 specifically identified the need for common rules to be put in place for these markets to operate effectively. These common rules are known as network codes. When they become regulation, the network codes will l govern all electricity market arrangements with a cross-border impact.

The network codes cover three distinct areas related to, operation of the European power systems, requirements for the users connecting to the electricity networks and the design of a pan-European electricity market. It is possible that, following annual consultations by the European Commission based on the needs identified during the implementation of the current network codes more codes to be required.

Objectives

- To propose major adaptations of existing network codes and/ or new network codes, based on draft inputs from work packages (WP) 1-6, and to promote their adoption internationally
- To propose a set of key regulatory principles, referred to as “options”, to be considered when determining the appropriate governance framework for the future electricity networks (beyond 2040)

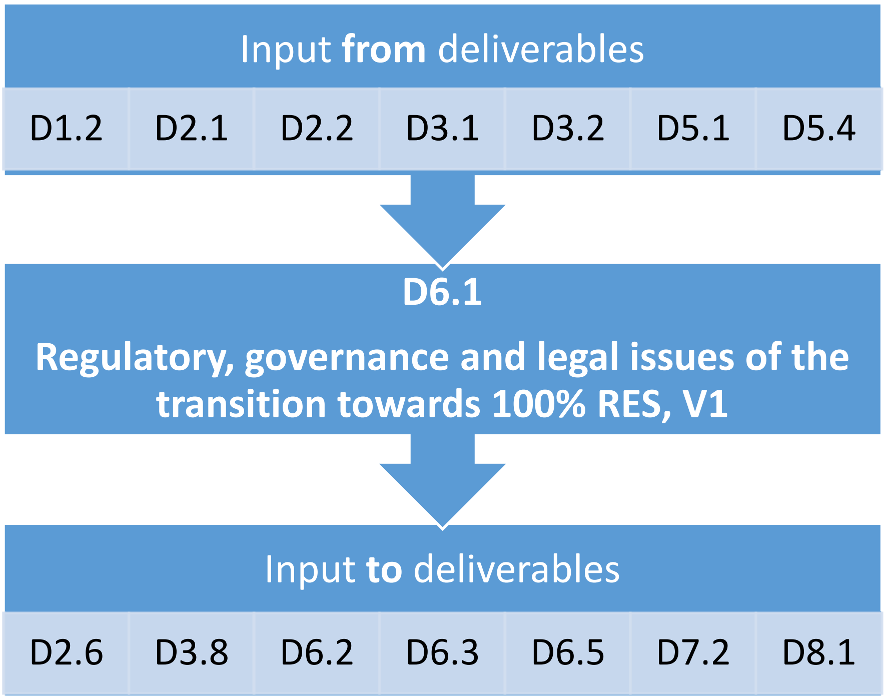
This deliverable takes the inputs from WPs1-6 of the RESERVE project. It has two versions: 1st version is released in March 2018 and the 2nd version will be released in September 2019.

The following deliverables, belonging to the above-mentioned work packages, have been given input for this deliverable:

- D 1.2 – Requirements placed on energy systems on transition to 100% RES
- D 2.1 – Definition of frequency under high dynamic conditions
- D 2.2 – Review of relevance of current techniques to advanced frequency control
- D 3.1 – Power Electronics Stability Criteria for AC Three Phase Systems
- D 3.2 – Demand Response and DG control considering Voltage Control and Stability
- D 5.1 – Report on field trial of voltage control concepts in Ireland and validation of initial network codes and ancillary service definitions, V1
- D 5.4 – Report on trial of frequency control in Laboratory and validation of initial network codes and ancillary service definitions, V1

Furthermore, the information from D6.1 is input data for the following deliverables:

- D 2.6 – WP 2 Drafting of Ancillary Services and Network codes definitions, V1
- D 3.8 – WP 3 Drafting of Ancillary Services and Network codes definitions, V1
- D 6.2 – Regulatory, governance and legal issues of the transition towards 100% RES, V2
- D 6.3 – Definitions of ancillary services and network codes, V1
- D 6.5 – CSR impact of business models and energy systems for the transition towards 100% RES, V1
- D 7.2 – Report on fostering support for RESERVE codes and ancillary services
- D 8.1 – First report on project progress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2. Rationales and Methodology of study

2.1 Rationales

As one of the milestones of the drive towards completion of the internal energy market and achieving the European Union 2020 targets of 20% renewable energy integration, a set of network codes for electricity was defined in the Regulation (EC) No 714/2009. [1]

The EU regulation 714/2009 defines: "*The network codes and guidelines shall (a) ensure that they provide the minimum degree of harmonisation required to achieve the aims of this Regulation; (b) take into account, where appropriate, regional specificities; (c) not go beyond what is necessary for that purpose; and (d) be without prejudice to the Member States' right to establish national network codes which do not affect cross-border trade*."

Network codes are a set of rules to facilitate the harmonisation, integration and efficiency of the European electricity market and renewable energy. Europe's cross-border electricity networks are operated according to the rules governing the actions of the system operators and determine how access is given to users. In the past, these grid operation and trading rules were drawn up nationally, or even sub-nationally. With increased interconnections between countries in the internal energy market, EU-wide rules have become increasingly necessary for effectively manage electricity flows.

In total, eight network codes have been elaborated by ENTSO-E (the European Network for Transmission System Operator in Electricity) and adopted with the approval of the Council of the European Union and the European Parliament.

The existing network codes have been developed taking into account a target of 20% renewable energy sources (RES). On the way toward 100% RES goal, amendments to the existing codes and a set of new network codes are necessary. [2]

2.2 Methodology

Define a set of amended and new network codes and identifying the needs for new ones:

In order to define a set of harmonized network codes, in the first stage, WP 6 team identified the so called "wish list" using a combined top-down and bottom-up approaches:

- Top-down:
    - Starting from the existing list of current network codes, an analysis will be made, in order to see which codes are strongly influenced by the results of the RESERVE project scenarios
    - Extract relevant information from the existing and proposed legislations at the EU level (as it is Clean Energy Package 2017 and other sources) to see which new network codes are requested to be harmonized
    - Key drivers and trends from technology development perspective, e.g. storage, electric vehicle, block chain, fifth generation (5G) of the communication technology development, etc
- Bottom-up:
    - Outcomes in terms of new findings or requirements in WPs 1- 5 related to the voltage and frequency issue on the way toward 100% RES will require additional network codes Further will be identified which current network codes should be adapted and which new network codes should be considered to be harmonized.

The bottom-up approach will represent the main input of this deliverable, and the results of the top-down approach will be considered as the basic premises to connect with the new findings or requirements of WPs 1, 2, 3 and 6.

Prioritisation

In order to prioritize the wish list of possible harmonized network codes, the WP 6 team developed a set of criteria. Using this set of criteria, there was analysed the wish list and determined a priority list. All the details of this prioritization are presented in the section 5 of this document.

Set of key regulatory principles

In order to propose a set of key regulatory principles, referred to as "options", to be considered when determining the appropriate governance framework for the future electricity networks (beyond 2040), different options have been considered:

- Options of governance for transmission network: national, regional and at EU levels
- Design frameworks with customer centric and enable RES integration
- Principles must be EU wide, i.e. must have high impacts at the EU level
- Extract outcomes and recommendations of other relevant R&D projects, e.g. eHighway2050, evolvDSO for regulatory framework setting for the network operation up to 2050.

3. Trends and Current State of the Art of Network Codes and Legislation

3.1 Trends in Technology Advancement

Storage

Storage is one of the key points in the management of the 100% RES power systems addressed by RESERVE. Greater measures to ensure the grid and system integration of variable renewables (i.e. better planning for transmission projects to the development of smart grids, the creation of demand response mechanisms and the promotion of storage technologies). Transmission, distribution and storage of electricity need to be more efficient and flexible, so intermittent and decentralized production can be handled easily and economically. In 2015, IRENA published a market study on the market of storage of renewable energy. The annual revenue for all applications is expected to increase from USD 220 Million in 2014 to USD 18 Billion in 2023. Annual battery storage capacity will rise from 360 MW to 14 GW over the same period.

Electric vehicle

The electrical vehicle technology is about to become more and more popular for personal transportation due to climate change concerns and NOx emissions. The EV penetration degree in distribution networks will increase as their price will decrease or their autonomy will increase. The EV manufacturing has exponentially increased in the last 5 years, reaching 2 million cars around the world, and it is expected to increase by at least 5 times until 2020 [3]. With batteries sized for tens of kWh and the capability of fast charging, the EVs could have a big impact on the power consumption, especially in the distribution network. Under these conditions, the need for controlling the EVs charging becomes critical.

Currently, the EV technology is available as a pure load, for all modes of charging from a power sources, which are governed by the most recent standard IEC 61851-1 [4]. No standard or commercial technology exists today for vehicle to grid (V2G – can operate in discharging mode). As the need for frequency control participation become also critical, appropriate standards and network operator responsibilities must be developed.

VPP

The virtual power plant (VPP) [5] concept has been a discussed topic in many scientific papers, while solutions have been proposed or pilot projects have been implemented in many countries. A VPP is an aggregation of generation units, storage systems and loads, no matter where they are located into the grid. The VPP's primary goal is to maintain a controlled generation or load level in relation to the electricity market, thus aiming mainly at cancelling out the forecast error. Until now, most of the VPPs has focused on using gas-fired of hydro- power plants. With the advent of storage systems, the focus is on storing the renewable energy for later use. So far, no network code was released to combine the economic aspects with the technical aspects because of the problems that may arise at local level. While the aggregate power can be easily controlled, the monitored of each unit in the VPP should be stipulated in grid codes.

Microgrid

There are two types of microgrids: a) one that is naturally restricted by the island configuration of the land area, and b) an well delimited area synchronized to the public network [6]. The naturally isolated microgrids can provide ancillary service to the bulk grid only if they are interconnected by means of a cable, either AC or DC. Microgrid is a concept that has been implemented also in distribution grids, mainly in industrial or university campuses, with the purpose of reducing the interruption of energy supply to the customers. For this latter case, the microgrid is delimited by the bulk network through a single connection point, called point of common connection/coupling. One example is the microgrid created at Illinois Institute of Technology (http:/iitmicrogrid.net/) While various techniques and strategies have been proposed through scientific papers, for both frequency and voltage control, no grid code has been released for microgrids.

Blockchain

Blockchain is newly invented technology. One of its well-known applications is bitcoin. Blockchain is a special technology for peer-to-peer transaction platforms that uses decentralized storage to record all transaction data. In an outlook, PwC [7] sees that blockchain would provide a transparent way of managing certificates for renewable power and emission allowances. There is believe that there are alternative solutions capable of ensuring the functioning of a decentralized supply system. The trend to revert to more decentralized forms of supply, e.g. customer self-generation or RES, is already being promoted in Germany as it is, with the country managing its transition towards a sustainable energy system.

5G

Communications technologies have developed very rapidly in recent years offering greatly increased data throughput rates, latency over 4G wireless networks of under 100ms and increased reliability with quality of service features. Today's ICT systems can support a wide range of industrial and commercial applications, allowing to work from any location at any time, real-time financial services and numerous ICT functions in modern cars and transport systems. However, to support the demanding requirements of the energy sector as it moves towards ever higher levels of RES integration, some of the features being developed for the coming generation of 5G networks will be essential.

Energy systems with high levels of RES integration will require new distributed energy and ICT system architectures and will need to integrate the use of 5G ICT into the design of ancillary services to ensure system stability. 5G systems offer the prospect of seamless and secure connectivity, data processing with the reliability, availability and resilience required by energy providers and their customers in systems to be on the global market from 2020 onwards. One example of a 5G capability which will allow increasing the stability and reliability is the creation of dedicated network slices for such critical infrastructure communication services.

One of the implementation concepts of the RESERVE project is 5G ICT for 100% RES energy systems.

3.2 Current State of the Art of different Networks Codes

The current status on existing network codes alongside with the estimation of the impact level of RESERVE project on each of the codes (strongly or weakly influence) are indicated in the table 1.

Table 1: Current status of the existing network codes and estimated RESERVE project impact level

Network Code family	Network Codes	Status	Impact level of RESERVE project on each code
Connection codes	Requirements for Generators	Adopted	very strong
	Demand Connection	Adopted	significant
	High Voltage Direct Current	Adopted	significant
Market codes	Capacity Allocation and Congestion Management	Adopted	significant
	Forward Capacity Allocation	Adopted	weak
	Electricity Balancing	Pending	strong
Operation codes	Emergency and Restoration	Pending	strong
	System Operations Guidelines	Adopted	very strong

3.3 New proposals of EU legislations

The European Commission issued the Clean Energy package, which was introduced by the EU in November 2016. It includes a package of measures to keep the European Union competitive as the clean energy transition is changing global energy markets. The Commission wants the EU to lead the clean energy transition, not only adapt to it, and has committed to cut CO_2 emissions by at least 40% by 2030.

Along with this package, an adaptation of regulation for electricity is also proposed. The EU COM (2016) 861 stipulates what is proposed to change with the EU Regulation 714/2009. The document is still under discussion and receiving positions from Member States.

Together with the existing areas[1] for network codes development, new areas are proposed at EU level to follow new technologies, market and regulation development. In particular, these new areas of network codes are under consideration:

- rules for non-discriminatory, transparent provision of non-frequency ancillary services, including steady state voltage control, inertia, fast reactive current injection, black-start capability
- demand response, including aggregation, energy storage, and demand curtailment rules
- cyber security rules
- rules concerning regional operational centers

[1] Existing areas to define network codes:

(a) network security and reliability rules including rules for technical transmission reserve capacity for operational network security; (b) network connection rules; (c) third-party access rules; (d) data exchange and settlement rules; (e) interoperability rules; (f) operational procedures in an emergency; (g) capacity-allocation and congestion-management rules including curtailment of generation and redispatch of generation and demand; (h) rules for trading related to technical and operational provision of network access services and system balancing; (i) transparency rules; (j) balancing rules including network-related reserve power rules; (k) rules regarding harmonised transmission and distribution tariff structures and connection charges including locational signals and inter-transmission system operator compensation rules; and (l) energy efficiency regarding electricity networks;

4. Gaps and Barriers to Reach 100% RES

The present set of rules and regulation included in the existing set of network codes comes from the historical development and the present technical characteristics of the generators, and we may say that it fits very well to the existing conditions. It is therefore important to acknowledge and understand these characteristics to identify the necessary changes that will be brought by increasing the share of RES in the energy system.

Into the “classic” power systems, the generation was performed with machines using rotating masses for any kind of primary resources for electricity generation: water, coal, gas and/or nuclear. All of these machines were synchronous ones.

These constructive characteristics of the generators imposed several significant characteristics of the power systems as follows:

- In normal operation, on short term (minutes) only the consumption might fluctuate but in reduced margins, not more than 5%
- In normal operation the consumption changes on a daily basis pattern also known as daily load curve.
- In normal operation generation is not fluctuating and is 100% controllable by a regional authority called dispatcher.
- The only significant changes on short term (minutes) or even midterm (hours – no more than 6) in load or generation are caused by outages.

Taking into account the above-mentioned aspects the system operation rules were designed to help the system recover as smooth as possible after large outages and nothing more. For example, all the reserves levels (primary, secondary and tertiary) have ultimately this purpose: recovery of the frequency level after a significant outage.

The generation based on the renewable energies has a major impact on the power systems because of 2 significant aspects:

- The generators are connected to the grid using invertors.
- The primary source of energy is not 100 % controllable, even in normal conditions of operation. It can only be reduced but cannot be increased or even maintained if the weather conditions are not suitable.

To understand correctly how the power systems of the future will look like, we must understand the forces that drive the changes, and these are both the reduction of CO2 and environment friendly energy sources. In this context we might consider that on a midterm the generation on gas and coal will be stopped because of the CO2 emissions, and the nuclear generation will be stopped because it is not environment friendly (the residues management is a very difficult problem for the environment). Among the “classical” energy sources only the large hydro has a good perspective to be maintained, as it doesn’t have CO2 emissions and it is environmental friendly.

Based on the information we have, we can conclude that in the power systems of the future there will be a mix between invertor type generation with renewable primary energy source and hydro “classic” synchronous rotating generators. Considering that hydro energy is a mature technology and therefore its future development are not significant and considering that all other energy sources will be replaced by renewables energy at a medium time horizon, results a mixture of 10 ÷ 20 % “classic” generators and the rest invertor type generators.

Of course, the development of the society will require more consumption and the new generation installed will be also invertor type but nevertheless there will be always a percentage of “classic” generators still in operation.

The main objective of our project is to identify some of the characteristics and problems of this kind of operation to design an appropriate regulatory framework.

Main outcomes related to the network codes from WP1, 2, 3 and 6 are picked up for further analysis. Hereunder is a preliminary list (table 2). It will be updated during the further implementation of the RESERVE project.

Table 2: Wish list of network codes

No	Wish list	Short description	Why change/add
1	Adoption of reference Scenarios - WP 1	WP1 defines four different scenarios. Network codes could "adopt" them as reference scenarios, i.e. ending points of the evolution of the European system by specifying the year at which 100% RES-electricity is expected.	
2	Distribution system - frequency control - WP 1	Frequency scenarios focus more on HV and MV networks. Different architectures of communications have been suggested in D1.3, for inertial, primary and secondary control. One of the aspects to be clarified is if distribution system will help the frequency control or not. If not, (as in case of decentralised control managed by TSO),there is no necessity to define VPP (Virtual Power Plant) or microgrids as potential actors (as specified in D1.3) ii. From the point 3.a.i, the different actors participating in the control should be deeply described, in terms of technical and market requirements iii. Importance of data integrity, for avoiding lack of information iv. Indication where and how to install the metering units, control units and so on (also highlighting problems due to intentional attacks to the system)	MV and LV networks are part of the distribution system, and this portion with their specific requirements should be considered in the future network codes. Even if detailed technical specification could be left for other documents like distribution codes or other, in the future Network Codes there should be at least a general description of what actions MV and LV grid operators and distributed resources should or should not be guaranteed to perform.
3	Distribution system - voltage control - WP 1	Voltage scenarios focus essentially on LV networks. In D1.3 (within the Appendix on page 78) there is the mention of the EC Article 29.1 Network codes and the ranges note for HV: the ranges mentioned are 0.90 pu to 1.118 pu for connection points between 110 kV and 300 kV stations and for connections between 300 kV and 400 kV the range is 0.90 pu to 1.05 pu. These ranges should either be re-used, or some other similar type of range should be added to the EC Article network codes for LV networks. ii. Concept of dynamic stability of the voltage: future network codes should point out standard stability margins in terms of gain and phase margins and not only static requirements	

	Requirements for power converter-based Energy Storage Systems (ESSs) connected to the transmission grid (new NC) - WP 2	WP2 will study the provision of recommendations on such requirements considering the variety of ESS technologies, capacities, locations, control, etc. Moreover, in systems with 100% RES, i.e. no fossil fuel power plant is in operation, the actual procedures for primary and secondary frequency control may not be valid. Consideration of the storage (other than pumped storage) when providing frequency regulation services should be carefully treated.	Currently, ENTSO-E's requirements on the installation and operation of power converter-based ESSs have not been provided.
5	Requirements of minimum system inertia - WP 2	In the 100% RES, special circumstances from EU must be assigned to the hydro power plants in order to allow maintaining a higher inertia in operation. For the power system operator, recommended practice for maintaining mechanical inertia into the system is advisable.	
6	System swing dynamics - WP 2	WP2 is studying the concept of Linear Swing Dynamics (LSD) that will result in a linear dynamical system with new requirements and roles in RES-tied converters' control and frequency regulation. Correspondingly, new recommendations will be provided based on the research work conducted in WP2.	The nonlinear swing equation is an intrinsic form that represents the mechanical dynamics of synchronous generators. This form interprets the nonlinear swing dynamics caused by the electromechanical oscillations in a synchronous generator. Also, it is used in the control design, frequency regulation and stability analysis. However, in systems with 100% non-synchronous generation, new style of system swing dynamics will appear. This is not discussed in the ENTSO-E network codes.
7	Expanding the frequency control strategy to allow using small-sized and/or intermittent energy resources - WP 2	Two types of control procedures are currently defined: the centralized control specific to the primary frequency control, and the decentralized control specific to the secondary frequency control. In the future, a diversity of control procedures may be required. For example, the distributed control is introduced. The distributed control refers to the coordinated control within a regional network, including both generation sources and loads, as a low level control in the centralized scheme. This control strategy refers to the Virtual Power Plant and Microgrid concepts. These will require standardization of their operation in relation to the network operator in the grid codes, such as: communication type; reserve monitoring; and coordination.	

8	Frequency control categories and time frame - WP 2	WP2 will provide new recommendations from their ongoing and future work.	the full displacement of synchronous generation (with slow dynamics) with power electronic-interfaced non-synchronous generation (with very fast dynamics) will result in a new theme of frequency control categories with a reduced time window.
9	Requirements for the HVDC systems - WP 2	WP2 will provide new requirements for HVDC systems that respect the technical constraints and specifications of each AC network. Furthermore, HVDC systems should provide synthetic inertia to the disturbed AC network without compromising the frequency stability of other HVDC-connected AC networks. These activities will definitely consider the coordination between HVDC system owners and the respective TSO.	considering the different trends and transitions towards 100% RES in Europe, each HVDC-connected AC network will have different technical constraints and specifications. Hence, there will be different roles and participation factors of each HVDC-connected AC network for synthetic inertia provision. This is not defined in the current HVDC network codes.
10	Recommended settings for the controlled units - WP 2	Recommendation regarding the coordination between inverters characteristics for frequency control and droop values is advisable. This is important to achieve coherency into the interconnected power system. Finally, standardized operation characteristics should be provided for those units that respond to both inertial and primary control. This is important because the two actions are linked in time, and the power provided as frequency control service is set by the same controller.	
11	Requirements for the DSOs - WP 2		Increasing penetration of power converter-based devices in the distribution system levels is leading to the need to carefully define the role of the DSOs in the future frequency control procedures, since they are the entities that have access to all converter meters (for both generation units and loads). DSOs may be responsible for monitoring the operation of small sized units located in the distribution networks as related to the available reserve. As there will be new roles for DSOs in frequency regulation, new recommendations are required to build a coordinative framework between DSOs and TSOs from one hand, and to harmonize among different DSOs from the other hand.

12	Requirement on the information and data exchanges between ENTSO-E and TSOs - WP 2	A common complete database of the ENTSO-E system should be available for all system operators.	Currently, [OPERATIONAL RESERVE AD HOC TEAM REPORT, 2012] recommends calculation of the FCR based on statistical data only. Under 100% RES, it should be based on dynamic simulations under various scenarios. These scenarios should be standardized into specific procedures.
13	Requirements on the harmonization of the remuneration rules for Frequency Containment Reserves (FCRs) across all ENTSO-E countries in the Continental Europe - WP 2		This is because it is hard to identify the origin of the service provided from abroad. The principle of the interconnected power systems is the inter-TSO support in case of emergency situations. A survey has been conducted by ENTSO-E to identify all market aspects of the FCR and Frequency Restoration Reserves (FRRs), [ENTSO-E WGAS - SURVEY ON ANCILLARY SERVICES PROCUREMENT, BALANCING MARKET DESIGN 2016, March 2017].
14	Decentralised voltage control - WP 3	We recommend the practice of decentralised voltage control for the DSO. The underlying ideology is that the large number inverter based RES units in the LV grid is seen as degrees of freedom for control.	The state of the art voltage regulation concept in LVAC grids is based upon centralised control. The SSAU regulates the LVAC feeder voltage through changing the tap positions in the OnLoad Tap Changing (OLTC) Transformers or by switching ON and OFF capacitor banks in order to regulate reactive power flow thereby controlling the voltage. With the rise in inverter based RES units, the dynamic interactions among large number of power electronic converters might lead to unstable modes or oscillatory modes in the feeder voltage profile.

15	Requirements for new behaviour of RES inverters - WP 3	In the context of decentralised control, the control command received from a tertiary level or from a Microgrid operator might be setpoints for real and reactive power in a conventional sense. However, the methods developed in WP3, envisions a case where the higher level might modify the behavioural of inverter. By behavioural we mean the control parameters themselves. The examples pertaining to WP3 are presented as follows: • The Dynamic Voltage Stability Monitoring (DVSM) (SV_A) functionality which resides in the SSAU would send control commands back to the VOI controller, which will in turn modify the control parameters of the inverter to achieve the set-point impedance. Hence, the behavioural of inverters are modified here and since the SSAU sends these commands, the DSO grid codes must allow it. • The Active Voltage Management (AVM) (SV_B) technique modifies the volt-var curves of the RES inverter. Hence the concept of volt-var curve definition for house RES inverters must be included into the grid codes.	
16	New requirements for the perturbations injected from RES inverters - WP 3	Grid codes should be formed related to the injection of white noise signal into the grid voltage for a short duration. The white noise signals, otherwise known as Pseudo Random Binary Sequence (PRBS) is generated in the control loop of the inverter, where the duty cycle or current/voltage reference are perturbed. This induces perturbations on the output voltage and current of the inverter for impedance measurement. In WP3, we will determine magnitude of perturbation required for accurate determination of impedance and injection time period that is required for the noise injection and propose them for new grid codes.	
17	Dynamic Stability margins - WP 3	Hence for the futuristic grids, we propose the inclusion of dynamic stability margin definitions. Additionally, we envision through our work to determine minimum dynamic stability margin limits or thresholds that the system must possess.	With large number RES inverters in the LVAC grids, we envision a virtual impedance based decentralised control. For accessing the grid voltage stability, a stability monitoring algorithm is developed which is placed in the SSAU. The stability of such a dynamic system is assessed through dynamic stability margins such as gain and phase

			margins. In the current grid codes, there is no such definitions found.
18	Leading power factor - WP 3	The work done with the scenarios SV_A and SV_B would demand the RES inverters to operate with a leading power factor at times for providing grid voltage support. In the current scenario, the power factor is operated with only a lagging power factor in certain DSOs. Hence this WP will provide recommendations to modify the grid code to include leading power factor.	
19	New power system parameter: flexibility - WP 6	Similar to the system inertia a high percentage of RES will require a new system parameter: flexibility.	In case the parameter margin is not fulfilled it is possible a new market to be required.

5. Evaluation and Priorities

5.1. Criteria of evaluation

In order to prioritize the wish list defined in chapter 4, a set of criteria and an evaluation process was defined by the WP 6 team, in the framework of RESERVE project.

Prioritisation criteria

To answer the goal of the RESERVE project toward 100% RES, in line with a new communication of the Energy Union - COM (2016) 860 [7] of achieving global leadership in renewable energies and providing a fair deal for consumers, in the frame of the RESERVE project we defined the following set of criteria for prioritisation.

- ***Support 100% RES:*** to measure if significant RES can be integrated into the network when the adaptation of an existing network code is applied, or new network code is introduced
- ***Impact:*** to measure if significant impact at EU wide is created when the adaptation of an existing network code is applied, or new network code is introduced. The estimated impact is expected on the technical aspects and considering several countries or regions.
- ***Cost effectiveness:*** to measure the effectiveness from the cost perspective, when the adaptation of an existing network code is applied, or new network code is introduced
- ***Availability:*** to measure if technology and tools are available when the adaptation of an existing network code is applied, or new network code is introduced
- ***Criticality:*** to measure how much critical is the context that requires an intervention, which may result in adapting an existing network code or creating a new code
- ***Timeframe:*** three timeframes of 10 years, 10-20 years and beyond 20 years are considered, if the adaptation of an existing network code is applied or new network code is critically needed, and by when

Evaluation process

A score from 1-5 was applied having an expert view for each of the criteria:

- 1: not relevant or low impact
- 5: highly relevant or high impact

The evaluation process was performed in a sequential filtering manner (on layers), each layer including one or two criteria. In order to pass to the next layer, an average score (higher than 3) was supposed to be achieved. The final layer (Timeframe) is considering the time constraints and show when it should happen.

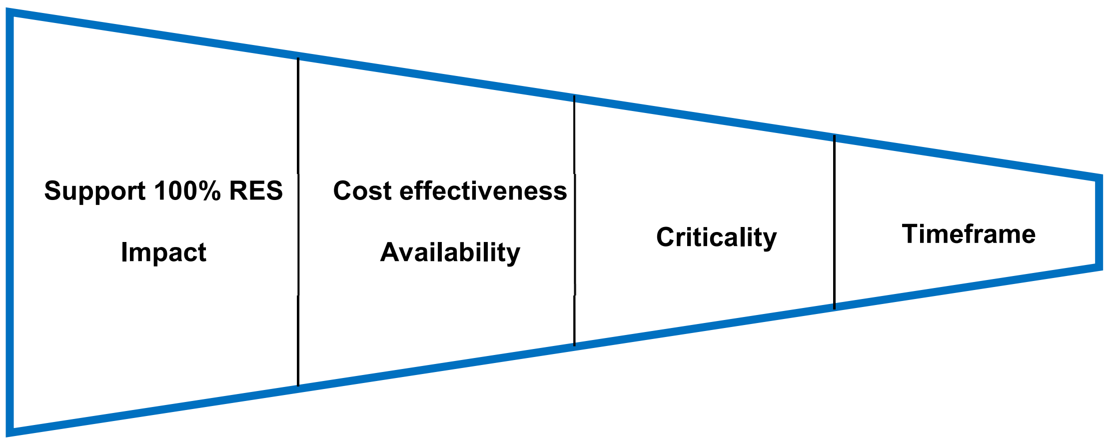

Figure 1: Evaluation process of Priority List

5.2. Prioritisation

The prioritization was made by a group of experts representing each of the RESERVE WPs, from 1 to 6. According to their view and justification, the experts rated and awarded scores for each of the proposals. The results are based on the average scores provided by each of the experts.

Table 3 shows the average rates given by the experts within the prioritisation process, that was made on the wish list of network codes.

Table 3 Average scores based on the RESERVE expert's evaluation

No	Wish list	Supports 100% RES	Impact	Cost effectiveness	Availability	Criticality	Timeframe	AVERAGE
1	Adoption of reference Scenarios - WP 1	4.00	3.50	3.33	3.50	3.17	3.33	3.47
2	Distribution system - frequency control - WP 1	4.33	4.33	2.67	2.83	3.50	3.50	3.53
3	Distribution system - voltage control - WP 1	4.33	4.17	3.00	2.83	3.83	3.50	3.61
4	Requirements for power converter-based Energy Storage Systems (ESSs) connected to the transmission grid (new NC) - WP 2	4.00	4.17	2.50	3.17	2.83	3.00	3.28
5	Requirements of minimum system inertia - WP 2	4.67	4.33	3.33	2.83	3.33	3.33	3.64
6	System swing dynamics - WP 2	4.33	4.17	3.00	2.83	3.83	2.17	3.39
7	Expanding the frequency control strategy to allow using small-sized	4.17	4.00	3.17	2.33	3.00	2.17	3.14
8	Frequency control categories and time frame - WP 2	3.50	3.50	2.83	3.00	3.67	2.50	3.17
9	Requirements for the HVDC systems - WP 2	4.00	3.67	2.50	2.83	3.17	2.67	3.14
10	Recommended settings for the controlled units - WP 2	3.50	3.67	3.17	3.00	3.17	2.67	3.19
11	Requirements for the DSOs - WP 2	4.00	4.00	2.83	3.00	3.50	3.00	3.39
12	Requirement on the information and data exchanges between ENTSO-E and TSOs - WP 2	3.67	4.00	3.50	3.17	3.00	3.17	3.42
13	Requirements on the harmonization of the remuneration rules for Frequency Containment Reserves (FCRs) across all ENTSO-E countries in the Continental Europe - WP 2	3.50	3.17	3.50	2.83	3.00	3.00	3.17
14	Decentralised voltage control - WP 3	4.50	4.33	3.00	3.33	3.17	3.00	3.56
15	Requirements for new behaviour of RES inverters - WP 3	4.50	4.67	2.83	3.17	3.50	2.83	3.58
16	New requirements for the perturbations injected from RES inverters - WP 3	3.17	3.00	2.83	2.33	2.67	2.50	2.75
17	Dynamic Stability margins - WP 3	4.50	4.50	3.17	3.17	3.17	3.00	3.58
18	Leading power factor - WP 3	3.17	3.17	3.67	2.67	2.50	2.33	2.92
19	New power system parameter: flexibility - WP 6	4.67	4.33	3.17	2.83	3.50	2.67	3.53

6. Adapted/ New Network Codes for Voltage and Frequency Control considering up to 100% RES Scenario

Based on the result of the prioritisation exercise described in the section 5.2, the WP 6 team selected the list of top five proposals, that are presented in more detail into this section.

Requirements for new behaviour of RES inverters

- Power converters will be ubiquitous in future power systems, as they will be the base of the connection of RESs, ESSs, HVDC, flexible loads, etc. Therefore, the definition of a set of requirements for their installation is foreseen as a mandatory process.
- For robust and stable operation of 100% RES LV grid.
- Inverters need to take over functionalities from synchronous generators
- Codes are currently silent on the role and parameters of inverter; standard requirements are needed in order to allow for the delivery of Inverters as a tool for network support.

Distribution system - frequency control

- A large number of DERs will be located at the distribution side. These devices will be able to provide local frequency regulation at the point of connection with the transmission grid. Therefore, this is important to be defined.
- Mostly required if the bulk generation in HV system is decreasing.

System swing dynamics

- Supports 100% RES (inertia-less systems)
- Required for systems without significant inertia

Dynamic Stability margins

- Suits power electronic based grids and Microgrids, having a high impact

Requirements of minimum system inertia

- Necessary for future grid with inverter based and low inertia

Table 4. Top five of the wish list of network codes evaluated by the RESERVE experts

Priority No	Origin No	Wish list	Supports 100% RES	Impact	Cost effectiveness	Availability	Criticality	Timeframe	AVERAGE
		Evaluation order	*2*	*1*	*3*	*4*	*5*	*6*	
1	15	Requirements for new behaviour of RES inverters - WP 3	4.50	4.67	2.83	3.17	3.50	2.83	3.58
2	2	Distribution system - frequency control - WP 1	4.33	4.33	2.67	2.83	3.50	3.50	3.53
3	6	System swing dynamics - WP 2	4.33	4.17	3.00	2.83	3.83	2.17	3.39
4	17	Dynamic Stability margins - WP 3	4.50	4.50	3.17	3.17	3.17	3.00	3.58
5	5	Requirements of minimum system inertia - WP 2	4.67	4.33	3.33	2.83	3.33	3.33	3.64

7. Key regulatory principles of governance framework for the future electricity networks

In order to continue the development of the power sector on the way to better answering to the end-user needs in the first place and to all members in the end, we have identified several key principles that have to be considered in designing the governance of the future configuration and operation of the power networks, as follows:

- ***Efficiency of the investments and costs:*** in the power sector all the costs are in the end included in the energy price and therefore covered by the end-user. In this context, it is very important to increase the efficiency of the investments and to reduce or even to avoid when possible the operational costs without reducing in any way the quality of power supply and/ or service.
- ***Harmonization among the power sector members:*** the existence of significant different approaches in technical, market rules and/ or other aspects may generate problems in case of the interconnected power systems like it is the case of Continental Europe part of the ENTSO-E.
- ***Transparency and predictability:*** one of the results of the unbundling in the power sector was the apparition of many companies and firms, private or state owned, linked together in a very intricate activity. In these conditions it is very important to support all of them in the process of developing their business plans by creating and maintaining a transparent and therefore predictable process of regulation.
- ***Priority:*** one of the most important principle for a good rule is to be issued at the right time. It is well known that a good rule may have bad results if it issued to early or may have no results if it is issued to late (or something in between), therefore the timing of the regulations is of outmost importance.
- ***Continuity:*** the rules and regulation must be coherent for all the power sector at a time being, not only for the existing conditions but also for the future ones. More precisely, if a certain development is foreseen in the future, the present regulations must pave the way in that direction and not generate obstacles.

8. Conclusions

A paradigm shift from current target with 20% RES by 2020 toward 100% RES goal, needs amendments to most of the existing network codes and most probably new network codes will be necessary as well. The analysis and prioritization achieved within this deliverable is the starting point in a series of consultations with relevant stakeholders and for a series of more detailed analyses (backed by research and testing from all WPs). These will lead to a more accurate substantiation and anticipation of the changes that need to be made in regulatory aspects, to have sustainability within the RES integration scenario of up to 100% in the energy system.

In addition, this deliverable report provides a set of key principles developed in the framework of RESERVE project that may be considered as potential options for designing the governance of the future configuration and operation of the High Voltage Electricity Networks.

It shows possible paths and options to continue and consolidate further development of RES generation in the power sector with a focus on better answering the end-user and all relevant stakeholders' needs.

9. References

[1] Regulation (EC) No 714/2009: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R0714&from=EN

[2] https://ec.europa.eu/energy/en/topics/wholesale-market/electricity-network-codes

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[5] C.-C. Liu, S. McArthur, S.-J. Lee, *Smart Grid Handbook*, Wiley & Sons, 2016.

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10. Abbreviations

5G	Fifth generation of communication
AC	Alternative current
DC	Direct current
DSO	Distribution System Operator
EC	European Commission
ENTSO-E	European Network on Transmission System Operator in Electricity
EU	European Union
EV	Electric vehicle
FCR	Frequency Containment Reserves
GW	Gigawatt
HV	High voltage
HVDC	High voltage direct current
ICT	Information communication technology
MV	Medium voltage
MW	Megawatt
RES	Renewable energy systems
R&D	Research and Development
TSO	Transmission System Operator
VPP	Virtual power plant
WP	Work package