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D6.4 V1.0

Definitions of ancillary services and network codes

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Abstract:

This is the second deliverable regarding the definition of ancillary services and network codes. It includes the definition of additional proposals for both upgrades to existing network codes and ancillary services, as well as new ancillary services. The proposals described represent the result of the analysis and consultations conducted in the RESERVE project, having as a starting point the same generation structure regarding the RES penetration, developed in WP1 and the computation and analysis performed in the second part of the project implementation within the WPs 2 and 3, in relation to frequency and voltage control. The results of the WP6 regulatory review and prioritization, as well as the stakeholder consultations run within WP7, have been important milestones in the delivery process of this version of the report.

This deliverable also analyses the environmental, economic and corporate social responsibility (CSR) aspects for each of the additional proposals, and the estimated impact from this perspective.

Keyword list:

Network Codes, Ancillary Services, CSR

Executive Summary

Integration of renewable generation represents a key pillar of the European Commission's broader energy and climate objectives in reducing greenhouse gas emissions, improving the security of the energy supply, diversifying energy supplies and improving Europe's industrial competitiveness.

In recent years, there has been a stronger focus of both the European Commission and the EU electricity industry, as well as the national and international regulatory authorities, on the context of increasing penetration of the supply of electricity from renewable energy sources (RES).

Most of the research work has been focused on a time perspective up to 2020, and on the implication of RES at transmission network level. However, it is widely accepted that much of the growth of renewables beyond 2020, and up to 100%, may be based on decentralized generation. So far, no thorough analysis was gone beyond transmission level, which means that the distributions networks are at the current state insufficiently analyzed and tested, which may result in additional future challenges through unidentified behavior.

The proposed scenario "up to 100% RES in the energy system" implies a series of critical changes and adaptations, from a technical point of view (as frequency and voltage control) to support the stability, safety and optimal operation of the energy system. Also, in this context, it is very important to consider energy storage capacities and regulatory implications.

Therefore, it is mandatory to understand how the impacts from alternative future developments in generation, transmission, distribution and storage interact with each other, and what are the resulting implications in respect to the regulatory framework, as well as the Corporate Social Responsibility (CSR) impact.

Based on the work performed in the WP 1, WP 2 and WP 3 in RESERVE, an extensive set of technical proposals for new regulations or updates of the existing regulations have been developed. These proposals have undergone a process of analysis, prioritization and completion in the framework of D6.1, MS15, and finally D6.2. The process included the filtering of consultations with stakeholders, such as TSOs, DSOs, national and international regulatory organisations, and the European Commission, leading to the final definition of the technical solutions proposed.

The detailed definition of the first set of proposals, following the above described workflow, was subject to the first version of deliverable D6.3 - "Definition of ancillary services and network codes", and in this second version of the deliverable (D6.4) a number of additional technical proposals have been added:

- the definition of two new ancillary services,
- three updates of the existing ancillary services,
- three updates within the existing network codes.

A complete list of the proposals (presented in detail in D6.3 and D6.4) developed in RESERVE project, concerning new network codes, new ancillary services definitions, updates of the existing ancillary services and new and updated definitions in existing network codes, is presented in Annex 1 of this deliverable.

For each of the proposals, a compact description of the existing situation, the foreseen changes generated by the operation of the power systems with up to 100% RES, and the potential positive impact of the proposals in facilitating the transition from present situation to future one are provided.

Moreover, these changes will substantially concern the environment and society. For each of the proposals the CSR perspective and impact assessment are important elements that have been considered, analysed and included in this deliverable.

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1. Introduction

The European Commission (EC) regulation defines a set of network codes [1]. These codes have two goals: the first one is to drive the completion of the internal energy marked, and the second one is to support an initial target of 20% renewable integration. Therefore, this initial target of 20% renewable energy sources (RES) was the basis for the definitions of the current set of network codes, and the existing design components of the ancillary services are meeting the same criteria.

Currently large generators, the majority of which are powered by fossil fuels, maintain the stability and quality of energy supplies through the inertia of their synchronous machines. The inertia of these generator-turbine groups gives providers a significant time window in which to react to network events.

On the way toward 100% RES goal, as the amount of inertia present in the grid gradually reduces, several technical and regulatory challenges need to be considered, and amendments to the existing network codes and ancillary services are necessary. Moreover, the European Commission's initiative to set a new target of up to 32% of RES for 2050 justifies and at the same time supports the effort made by the RESERVE consortium.

Starting from the analysis of the regulatory framework and the prioritization of the RESERVE proposals from D6.2, and the CSR analysis framework and evaluation methodology developed in the deliverables D6.5 and D6.6, this deliverable comes with a more detailed definition of the necessary changes in the context of ancillary services and network codes, complementing with new entries the proposals described in the first version of D6.3. At the same time, it provides an overview of environmental, economic and societal aspects in relation to the potential changes.

1.1 Objectives

- To provide additional amendments and definitions of ancillary services and network codes by complementing the original version of the deliverable, that are relevant for supporting the transition up to 100% RES, while meeting the requirements and responding to the challenges of the new context;
- To analyse environmental, economic and societal aspects of different potential energy systems design, with specific reference to the proposed amendments and definitions of ancillary services and network codes.

1.2 Outline of the deliverable

The first chapter of the deliverable includes the necessary information for understanding the statements and rationale presented in this work, and the relationship between the content of this deliverable and the results of the activities performed in other WP’s of RESERVE.

Within the second chapter, we identified and defined five additional proposals for new or updated ancillary services, which then went through a process of analysing the impact from a CSR perspective, within Chapter 3.

Chapter 4 provides the description of three additional proposals on power network codes updates

They rely on the information on regulatory and CSR aspects from the deliverables D6.2 and D6.6, based on the assumptions and analysis from WPs 1, 2, 3 as a starting point, and at the same time passing through the filter of the consultations run under WP7.

Annex 1 is presenting briefly all the proposals developed in RESERVE project concerning new network codes, new ancillary services definitions, updates of the existing ancillary services and new and updated definitions in existing network codes.

1.3 How to read this document

The content of this deliverable leans on the results and findings of the activity performed in several work packages of the RESERVE project. Thus, for fully understanding the statements, the proposals and the rationale supporting them, it is recommendable to acknowledge the information included in several other deliverables, as mentioned in the following. However, in order to support the reader and make the document fully accessible without the necessity of external references, the authors have provided the Annex 1.

The first step of the project was to develop significant scenarios for power system operation with up to 100% RES. Different scenarios, from both studies of EC and other projects in which the RESERVE consortium organizations or experts are involved, have been compared and discussed to find the adequate characteristics. To understand in more details the issues mentioned in this deliverable, related to the scenarios, it is necessary to read all the WP1 deliverables.

The current definition of frequency is accurate for current power systems where synchronous machines are still representing a high share of the total system generation. The rationale is that power plants based on synchronous machines intrinsically respond to local frequency deviations through their inertia. However, this scenario is rapidly changing with the increasing penetration of converter-based generators since they have very low or no inertia. Therefore, as the share of RES increases, the overall system inertia decreases, resulting in larger frequency deviations after a power imbalance. Therefore, the assumption that only minor differences exist between different frequency measurement locations can be incorrect.

The contents of D2.7 are the basis for the proposals concerning the frequency control, developed in RESERVE the project.

Regarding the voltage control, two concepts were developed within WP 3, that make best use of inverter-based RES units. The concepts operate on different time scales and fulfil different objectives. To enable further demonstration on physical hardware and the deployment of the techniques in a field-trial environment both voltage control scenarios warrant extensive experimentation for verification, development and as proof-of-concept.

One of the major challenges in active distribution grids is the harmonic stability issue. Impedances at the power electronic interface were mapped in determining harmonic voltage stability. On this basis, there is a requirement for DSOs to have the impedance information to perform stability analysis of the network. The fundamentals for the proposals concerning the voltage control are part of the deliverables D3.4, D3.5, D3.7, and D3.9.

The next step for identification and definition of the necessary new ancillary services and network codes was to establish the key regulatory principles for facilitating the transition between the present RES penetration percentage in the power systems up to 100 %. Deliverable 6.2 presents the set of key regulatory principles, a methodology for putting these principles in practice and the resulted priority list of proposals (so called Top 5) based on the entire list of proposals (presented in detail in Annex 1 of this deliverable). Reading D6.2 it is necessary for understanding the dissemination and exploitation strategy developed in the project, also addressing for the period after the project finalisation.

This deliverable contains a one-by-one-analysis from a CSR perspective of each proposed ancillary service and network code. A general description of the concept of CSR and its relevance in the RESERVE project can be found in D6.6. Furthermore, D6.6 presents a summary of the most relevant aspects of the detailed analyses from D6.3 and D6.4.

Finally, the dissemination and consultation activities carried out in WP7 and included in the D7.2 and D7.3, have helped to refine these proposals. (Fig. 1.1)

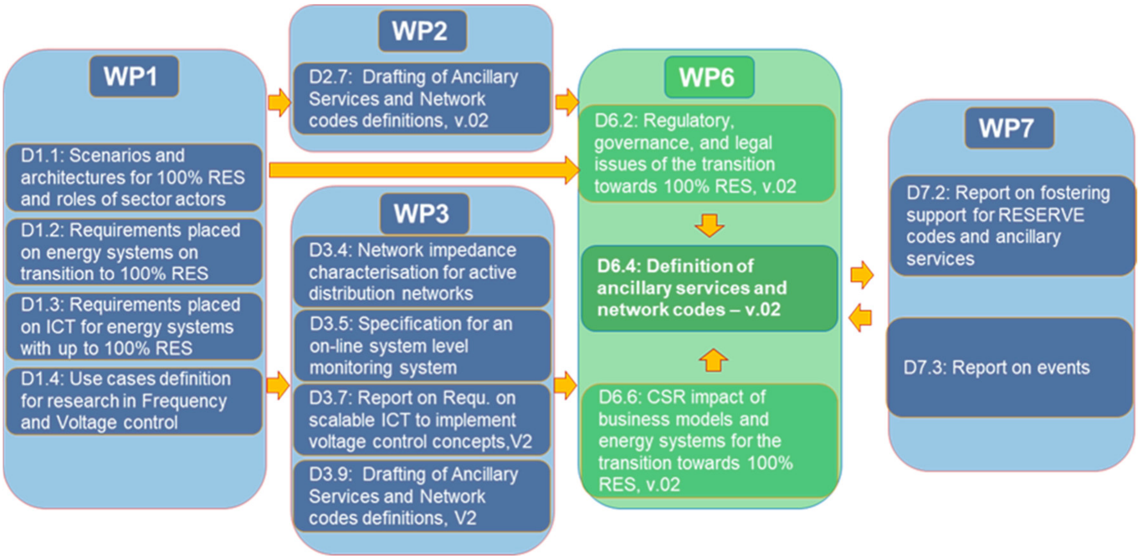


Figure 1.1 Flows of information between work packages and deliverables

2. New definitions and updates of ancillary services towards 100% RES

The calculations and analyses performed in WP 2 and 3 of the RESERVE project have proved the necessity for upgrades of some existing network codes and the development of new ones in order to properly deal with the increasing complexity in the power systems operation while the share of RES generation will reach up to 100%.

As presented in D 6.2 – Regulatory, governance and legal issues of the transition towards 100% RES and in the documentation of MS 15 – Initial definition of ancillary services and network codes, an extensive list of technical proposals for updating the existing network codes has been developed, followed by a prioritization of these proposals. Not all the RESERVE technical proposals require new ancillary services or changes in the existing ancillary services.

Currently, in the power systems there are three categories of ancillary services [10]:

- Related to frequency control;
- Related to voltage control;
- Related to emergency and restoration plans.

Frequency and restoration are exclusively in the transmission area of interest and therefore they are included only in the transmission codes. The voltage related issues are included in both TSO's and DSO's codes.

The estimated impact of analysis and research in the last part of the project implementation generated 5 new proposals on the necessary changes to the ancillary services structure that will be presented in this chapter.

2.1 New approach for "Defense Service"

According to the Electricity Emergency and Restoration Network Code [12], currently in force, the Defense Service Provider it is defined as: a legal entity with a legal or contractual obligation to provide a service contributing to one or several measures of the system defense plan. This definition it will continue to be valid in the future, also for the power systems with up to 100% RES but the measures mentioned and, more important, the triggering criteria for those measures are all fully based on the frequency measurements and values and this particular aspect it is foreseen to change. According to RESEVE simulations and findings the frequency will no longer be the reliability indicator as it is nowadays when the percentage of RES incidence in the power systems will rise to 100%. The frequency it is a very important parameter only for the synchronous rotating generators, for the converter-based generators the frequency has no physical significance. Moreover, in case of the power systems with 100% RES the frequency has no technical significance at all.

In these conditions, new technical indices must be identified in order to be added to the frequency or even to replace it in the relation with the control services, in order to develop a proper defense plan and therefore the service itself should be updated accordingly.

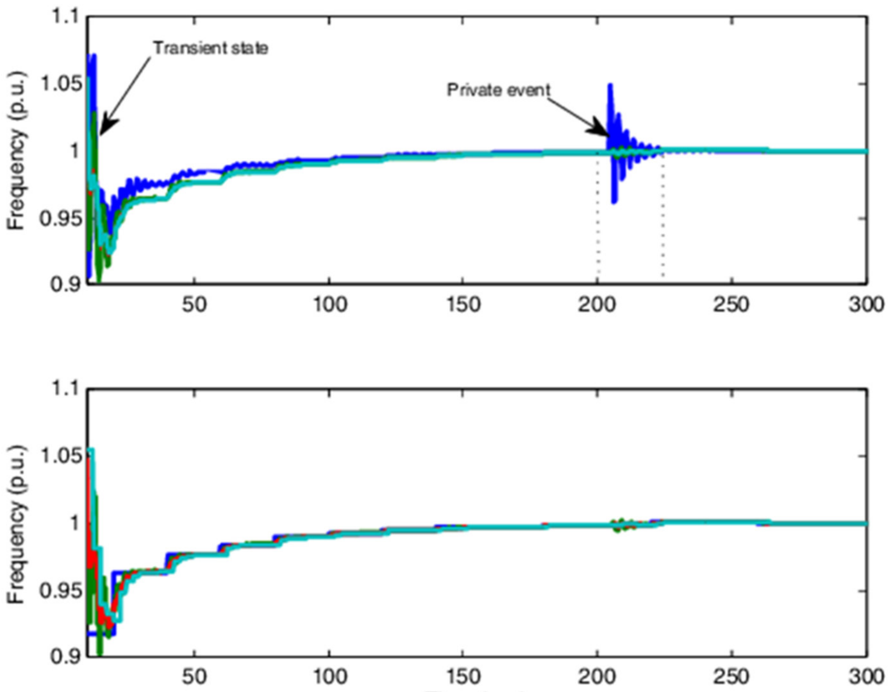


Figure 2.1 Impact of the "Defense service" providing

In the Fig. 2.1 it may be seen the impact of the proper activation of the defence service. In the first part one may notice the frequency oscillations following a significant outage, without defence service activation and in the second part in case of proper defence service activation.

2.2 New approach for "Restoration Service"

The situation with this ancillary service is very similar with the one of the "Defense Service". The existing definition according to Electricity Emergency and Restoration Network Code [12] is the following: a legal entity with a legal or contractual obligation to provide a service contributing to one or several measures of the restoration plan. This definition will continue to be valid in the future, also for the power systems with up to 100% RES but the measures mentioned and, more important, the triggering criteria for those measures are all fully based on the frequency measurements and values. Again, this particular aspect is foreseen to change. As mentioned in the previous paragraph, according to RESEVE simulations and findings the frequency will no longer be the reliability indicator as it is nowadays when the percentage of RES incidence in the power systems will rise to 100%.

In these conditions, new technical indices must be identified in order to be added to the frequency or even to replace it in the relation with the control services, in order to develop a proper restoration plan and therefore the service itself should be updated accordingly.

2.3 Providing reactive power for voltage control

The voltage level in the electricity grids it is strongly connected with the volume and direction of the reactive power flows. Nowadays the main sources of reactive power are the overhead lines of high and ultra-high voltage and to some extent the generator units, and almost all quantity of reactive power is consumed by the end-users connected to the grid in 110 kV and below.

In these conditions, voltage control is performed mainly by using tap changer transformers because the flow of the power is almost all the time from high and ultra high voltage to medium and low voltage.

The above-mentioned situation is foreseen to change significantly when there is massive development of prosumers at the low voltage and medium voltage levels. One of the consequences of this development will be the change of the reactive power flow directions and therefore the tap changer transformers alone will no longer be able to maintain a proper control of the voltage level, not to mention the optimization issues (for example losses).

In this new environment, the only solution for the power network operators will be to purchase generation or consumption of reactive power in medium and/or low voltage and therefore a new approach is needed for this ancillary service. The present approach is more like a penalty system for the power systems actors and electricity market participants, other than network operators.

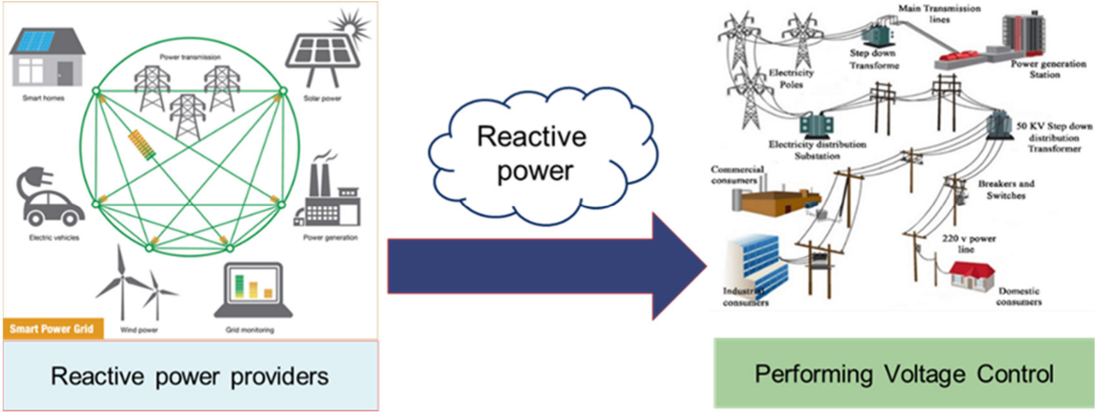


Figure 2.2 Utilisation of reactive power from prosumers for voltage control

2.4 Providing active power for voltage control

This new ancillary service is foreseen to become necessary as a consequence of the massive development of the distributed generation in low voltage networks. It has to be mentioned that this service will be effective only in low voltage electricity grids because in MV and HV the grid parameters (basically the reports between resistance – R and reactance - X) make the usage of the active power for voltage control ineffective. Obviously, considering that the involved type of generation is RES powered, the reduction of the active power generation it will be the action normally available for the grid operator and also, a payment system must be developed accordingly.

From the technical point of view there might be other available options for voltage control, maybe even more effective from economic point of view, but this option cannot be neglected because, especially in rural areas, it may be the only measure available without significant investments.

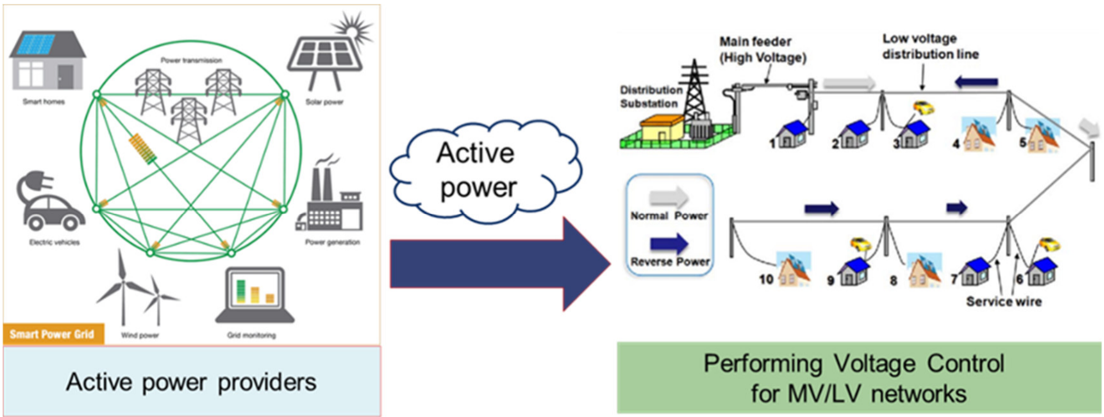


Figure 2.3 Utilisation of active power from prosumers for voltage control

2.5 Providing Input Signal for Frequency Controllers

In the current power systems, the frequency it is a very important parameter describing very accurately the status of the balance between electricity generation and consumption, for all the interconnected power systems. In normal conditions, at a moment in time, it is the same value (with some regional variations but significant) for all the interconnected power systems.

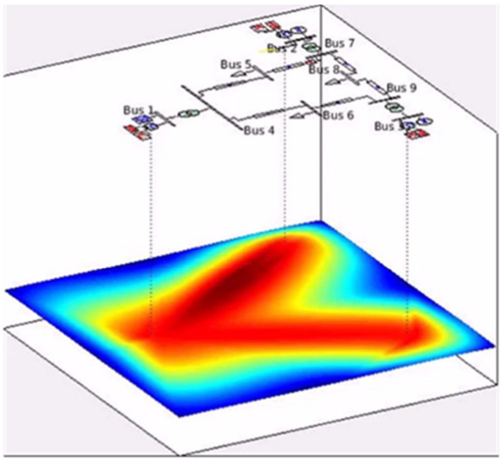
The development of the converter-based generators has started to interfere with the accuracy of using frequency as a parameter for balancing between generation and consumption, because for type of generators does not have an internal reference for frequency (as the synchronous generators) and k they need the input from the power system in order to determine what is the frequency value requested for their output. The solution used nowadays is to consider as reference the frequency value in the connection to the gird point.

The calculations and simulations performed in the framework of RESERVE project have showed that in power systems with up to 100% incidence of RES powered generation (usually converter based type) the frequency oscillations at regional level are faster and larger, therefore the above mentioned approach for frequency input may no longer be suitable or even, may become dangerous for the power system stability. A wrong reference value for the frequency, for a large amount of converter-based generation, in a certain area of the interconnected power systems, may trigger a cascade event ending up with a regional black-out.

It has to be mentioned again that frequency it is an important technical parameter only for the synchronous rotating generators and if in a future power system there will be 100% converter based generators the frequency will lose any technical significance. However, as long as the structure of the electricity generation will be a hybrid between synchronous rotating and converter based generators the necessity for frequency measurements will be present.

In these conditions, the grid operators will have to define areas of the power systems and to provide an input value for the frequency to all the converter-based generation connected to the electricity grid, in those areas. In providing these input values the grid operators must take into consideration the existing frequency oscillations at the time being and the necessity for dumping those oscillations as much as possible.

- **Frequency:** indicator of power unbalance → **Fundamental quantity for estimation and control**.
- Steady-state conditions: **the frequency is unique in the whole system**, regardless its physical dimensions.
- First seconds of a transient following a contingency: each synchronous machine and, hence, **each bus of the system, show a different frequency.**



9-bus test system: three-phase fault and subsequent clearance

Figure 2.4 Frequency variations in power systems with high RES penetration

2.6 Promoting Microgrids and Microgrids by design to reduce the need of ancillary services by locally delegated duties

The interconnected power systems face huge challenges in a 100% RES-based system. Microgrids (MG) and "microgrids by design" (MGbD) can also contribute in reducing the need for ancillary services or by providing them as a grid entity by itself.

A comparison between MGs and MGbD is given in table below.

Table 2.1 Microgrid (MG) versus microgrid by design (MGbD) architecture (MGbDA) comparison

No	Feature	Microgrid (MG)	Microgrid by design -MGbD	Obs.
1	Production means	Yes, distributed	Yes, distributed	(*1)
2	Consumers, prosumers	Yes, distributed by their nature	Yes, distributed by their nature	(*1)

3	Storage	Yes, distributed	Yes, distributed	(*1)
4	Connection to main grid	Usually in one point, namely PCC	Usually in one point, namely PCC	(*1)
5	Control of the entity	Yes, there is a unique, partial or full time control of **some features** in the MG	Yes, there is a unique and full time control of **all features** in the MDA (*3)	(*1)
6	Connected to main grid	This is the usual way of operation (CON)	Simultaneously connected (asynchronously) and in island mode (as basic operation (*3)	
7	Islanded	MG should be able to operate also in an islanded way (ISL)	Simultaneously connected (asynchronously) and in island mode (as basic operation (*3)	
8	Switching from CON to ISL and back	MG goes through zero (anti-island) and then restart as island (*2)	Continuous operation when main grid fails (outage) (*3)	
9	Disturbance from main grid	It affects the MG, as they are sync connected	Does not affect at all MbD, as it is not sync connected (*3)	
10	Disturbance towards main grid	It affects main grid, as they are sync connected	Does not affect main grid, as they are not sync connected (*3)	
11	Prone to mech.inertia reduction	Yes, it depends on main grid mech. inertia	No, it works with zero mechanical inertia, 100% inverter based connection	
12	Dependent on frequency	Yes	No, frequency value has no stability role in MbDA	
13	Principle of dynamic stability	Energy in the rotating machines connected to mai grid	Energy in the capacitors on the DC bus-bar behind the inverters (*5)	
14	Connection to main grid	Synchronous	Asynchronous, through DC busbar, through SST (*4) or B2B connection (*4)	
15	Contributes to mechanical inertia reduction	Yes, as it has inverter-connected generation, unless some mechanical inertia is simulated through VSM technologies	No, MGbD is acting as a unique consumption at PCC, with entire RES invisible from main grid side (*4)	

(*1) this is a MG feature requested by its definition

(*2) MG cannot pass an outage without full disconnection, as it has anti-islanding protections. After disconnection in their PCC, they can start working as an island, presumably that they have full capability to ensure all the time the equality between production and consumption

(*3) Feature which is specific only to microgrid by design (MGbD); there are technical solutions to make functional the main condition (*3): full time control of all grid functions, like the main (public) grid does also full time/full grid functions.

(*4) SST – Solid state transformer, B2B – back to back connection, see also figures below

(*5) A new type of dynamic stability applies in inverter based-only generation grids, which is named "electrostatic energy-based energy inertia" or more simpler "electrostatic inertia" (as a simplified coined phenomenon, used as a metaphor). See paper "On the Electrostatic Inertia in Microgrids with Inverter-Based Generation Only—An Analysis on Dynamic Stability", Energies 2019, 12(17), 3274

Figure 2.5 and 2.6 below shows two possible ways of connecting MGbDs to the main grid, as an additional explanation for item 14 from the table above.

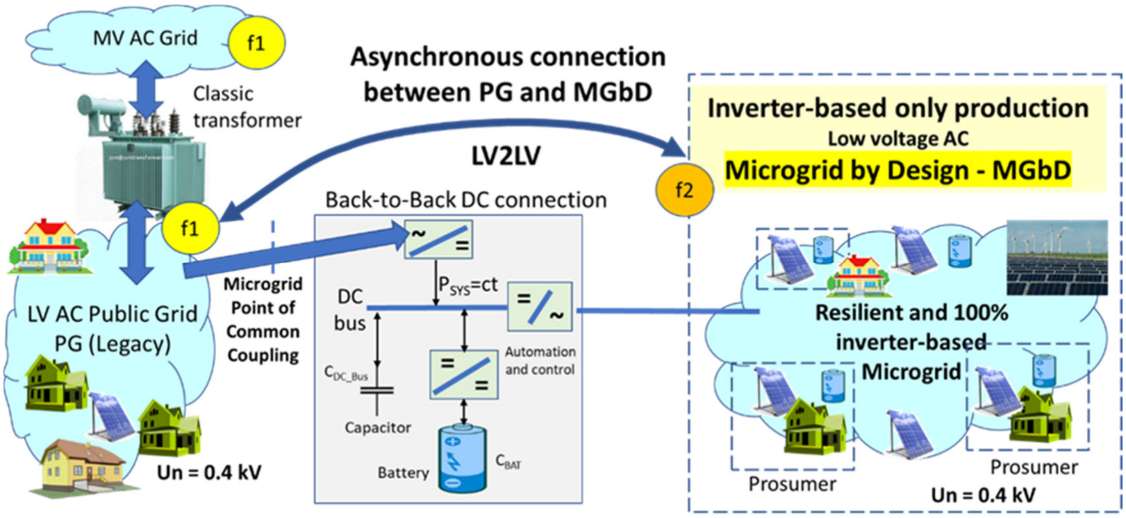


Figure 2.5 B2B connection of a microgrid by design to the main grid

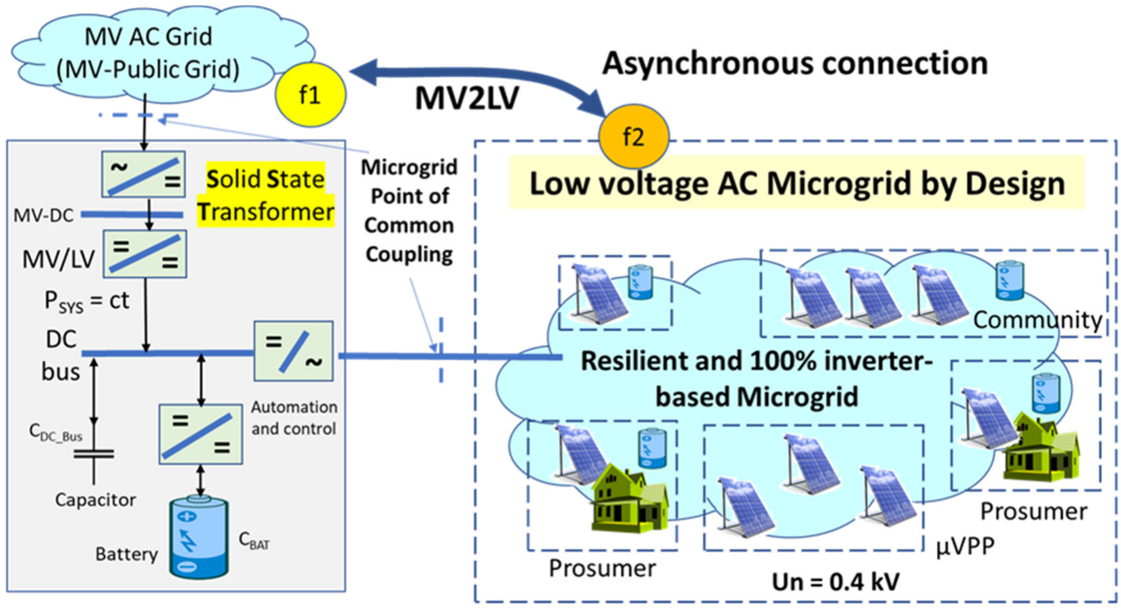


Figure 2.6 SST connection of a microgrid by design to the main grid

The main features of MGbD compared with MGs are the fact that they have fully functionality of an islanded grid, while they are also all time connected in an asynchronous way to the main grid, thus having the technical advantages of both situations. If they have only inverter-based energy resources, the micogrid by design can be operated without any dependency to frequency, the classic dynamic stability based on mechanical inertia being replaced by "electrostatic energy-based inertia" available in the capacitors of the DC-busbars behind the inverters. This has been proven through simulations and with theoretical means in peer-review papers [13] and the concepts will continue to be developed in future works.

3. Proposals for new updates to existing Network Codes

3.1 Updated definition of RoCoP

In Chapter 3 of D2.7, a new Rate of Change of Power (RoCoP) index has been proposed. The RoCoP index can be applied to evaluate the nature of any device, whether it is synchronous or not. These include converter-interfaced generation (wind, solar, etc), energy storage systems, flexible loads, etc. The RoCoP has also been proved to be an accurate and reliable tool to quantify the "amount" of frequency regulation of ancillary service provides. This can be used by regulators to properly remunerate such providers.

The results of the case study discussed in D2.7 indicate that the current approach consisting in measuring the active power injection is, in general, not a sufficient criterion to remunerate the owners of ancillary service providers for the provision of fast frequency control.

The effectiveness of the fast frequency control provided by a device or subsystem does not only depend on its power capacity. The RoCoP can thus be a valuable tool for system operators as it allows to take into account topological, geographical and technical aspects as discussed in the case study mentioned above (see D2.7).

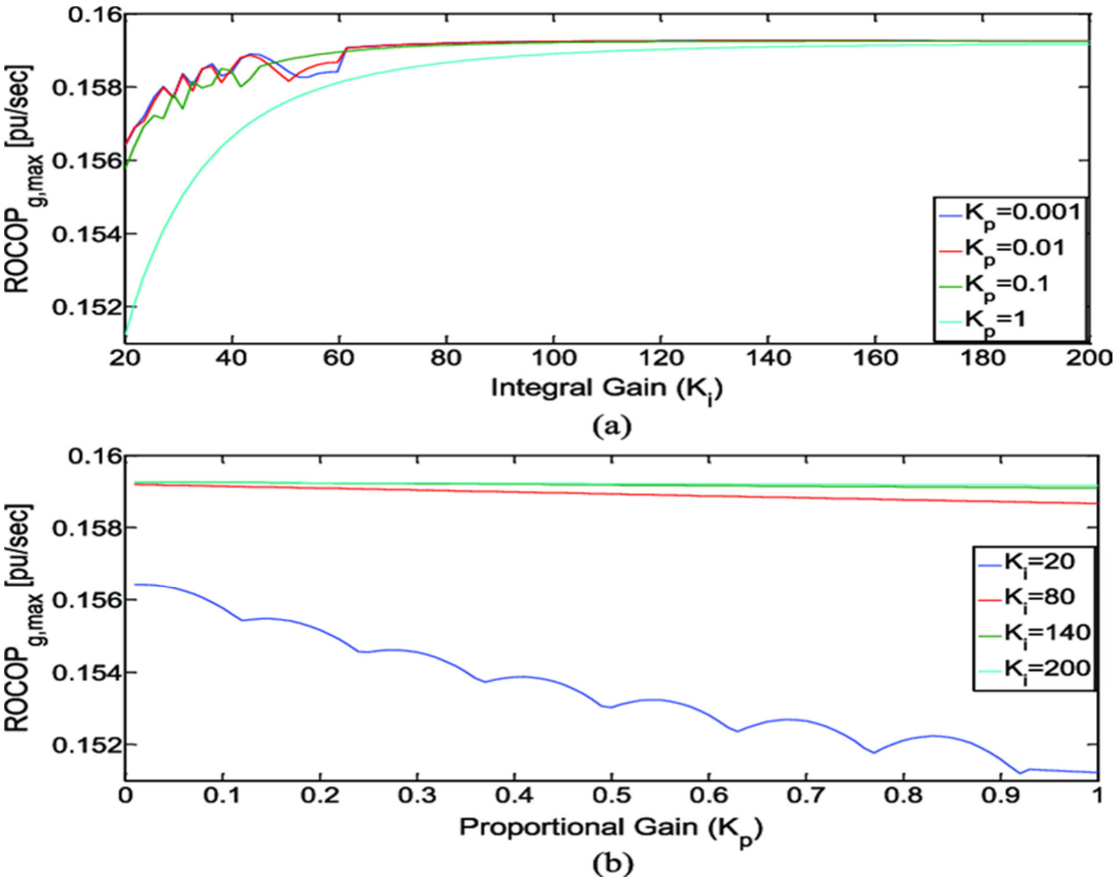


Figure 3.1 Typical rate of change of power for a wind generator, according to wind variations

3.2 New requirements for frequency measurement

Calculations, simulations and analysis performed in the RESERVE project have proved that in power systems with up to 100% converter-based generators powered by RES the speed of the physical phenomenon's it is much higher and therefore the time rate of the frequency measurements must be updated accordingly.

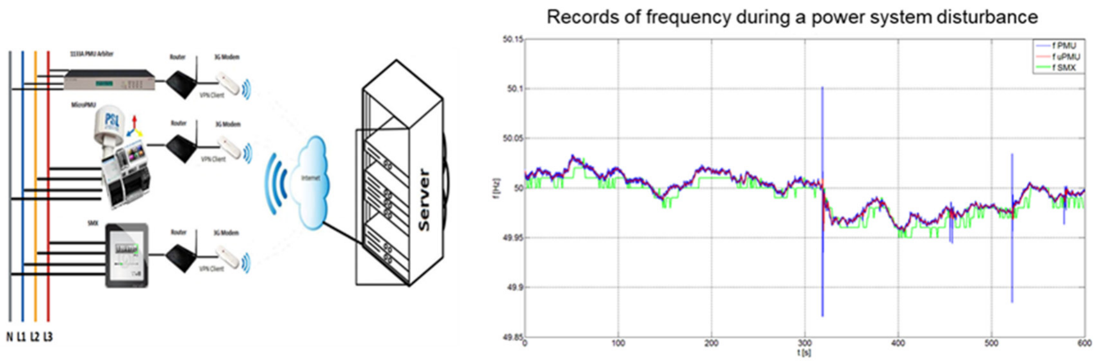


Figure 3.2 High RES penetration require more frequent frequency measurement sequences

In the previous figure one can easily notice that in the case of the power systems with significant RES penetration (around 50%) the speed of the frequency variations are very high and it is possible that an usual meter or other measuring system will not be able to register this kind of fast variations. Usually these frequency spikes become the trigger for cascade events in the power systems, and thus very important financial losses and other unwanted consequences may occur.

In the case were the frequency spike is not noticed the power system operators will not be able to identify properly the real causes of potential major events and therefore will not be able to identify the most adequate solutions.

The implementation of this proposal may be a difficult issue because of the enormous number of meters and other measurement systems already in place in the power systems. Given these conditions it is necessary to define several stages and a long term schedule in order to reduce the financial impact received at end users level.

3.3 New requirements for avoiding mechanical inertia depreciation

Mechanical inertia is the main dynamic stability mechanism in classic grids, based on generators with rotational machines. It is opposing the rapid frequency change by releasing part of their rotational kinetic energy in the period between T0, when the active power unbalance occurs and a period of up to some seconds, when frequency containment reserve FCR (known also as (frequency) primary reserve) starts to stabilize (inject or absorb/reduce power) based on the frequency deviation Δf,

However, the energy covered between T0+ and the moment of FCR activation depends practically on Δf/Δt, as this is the way to extract missing energy from the rotating machines – by reducing their rotational speed, before any automation (such as FCR) occurs.

The speed reduction of rotating machines in the system has therefore the consequence of reducing the frequency, which occur more drastically if there is less rotating mass.

As ROCOF is much more difficult to be measured, as it requires more time to get stable values during measurements, there are several ways of mitigating this problem “similar” with relatvelly similar measures, not perfect but much better than no measure to reduce rocof. The following services are proposed to be considered to reduce the rocof and consequently the reduction of lowest frequency (nadir):

- A special service for enhanced frequency control, based on Δf, but with much quicker reaction time: 200 ms time of reaction (maximum admissible initial delay, according to EU631/2016 terminology, page 25) and 2 seconds full activation time (according to the same EU631/2016 terminology, page 25), with a capability of “providing full active power frequency response for a period” (according to the same EU631/2016 terminology, page 24) of 30 to 60 seconds, to allow classic FCR to enter while preserving a smaller nadir deviation; this can be named as FFR-0.2/2/30 service or “Fast Frequency Response 0.2/2/30 seconds”;
- A similar service to act with a faster reaction time, meaning a maximum admissible initial delay of e.g. 40 milliseconds (2 periods), with a full activation time of maximum 1000 msec. and with a capability of providing full active power frequency response for a

period of 10 seconds. This service can be named “Ultra Fast Frequency Response” and labeled as UFFR-0.04/1.0/10;

- A special service to reduce rocof based on Δf/Δt measurement as input for the active power injection. Such solution has been investigated in RESERVE project by using linear swing dynamics equation. Such a service should be named “Ultra Fast derivaete pf frequency (ROCOF) Response” and should be labeled as UFdfR with appropriate dynamics, such 40 milliseconds maximum delay, full time activation based on ROCOF, but no more than 100 msec and with a full activation time of maximum 500 msec and being bale to perform for one second. The service can be labeled UFdfR-0.04/0.1/0.5

One may see the three new services (FFR-0.2/2/30, UFFR-0.04/1.0/10 and UFdfR-0.04/0.1/0.5) as covering the dynamic part of the period when FCR is not active.

Moreover, the last two services can act as two ways with different principles for simulating mechanical inertia, UFFR-0.04/1.0/10 proportional with Δf and very fast and UFdfR-0.04/0.1/0.5 proportional with Δf/Δt and also very or even faster. This method of providing a protection against loss of system stability with two different methods is also used in protection relays, where two different protection relays, from two different vendors are mounted oin important lines, in order to have different methods in protecting the line, which has to be well protected no matter the type of fault.

3.4 New requirements for microgrids

Future 100% based RES will see high portion of the overall deployment in the low voltage networks.

The LV network supplied by an MV/LV transformer is practically a microgrid, as it will have (or already has) local and distributed RES with inverter-based connection, storage and consumers/prosumers, being also able to provide flexibility such as demand response. In addition, it has a geographical as well as an electric boundary, while it is connected usually in only one point of common coupling, namely the MV/LV transformer.

As through smart grids technologies the LV microgrid supplied by the MV/LV transformer can be also controlled in an intelligent way such that it complies with some conditions at PCC (either on MV or on LV part of the transformer), the LV grid is fully compatible with the definition of a microgrid.

Existing code for connecting generators (EU631/2016) does not address at all a cluster of generators – acting as a VPP, or a microgrid, acting as a “system in system”, thus it is concentrating on conditions for individual generators, rather than aggregated generators or microgrids, which is a more general combination of generators, storage, consumption and microgrid control. Also it is fully missing the prosumer situation, which as also a sort of smaller microgrid, meaning the internal AC network of the end customer. It is thus missing an essential type of condition: the approach of connection conditions at PCC level of a prosumer and/or of a microgrid.

While the full coverage of this big miss of 631/2016 is not possible to be made in this project, and as the project was the co-initiator (together with H2020 Storage4Grid project) of the “microgrid by design” (MGbD) architecture (MGbDA), several requirements for this type of approach will be proposed below.

In order to mitigate impact on main grid of both MGs and MGbDs, the following requirements needed in Network codes are considering conditions in PCC instead of conditions for each equipment connected in the MG or MGbD.

This is a complex task which is approached only as a basic principle, to facilitate that the microgrid makes investments to comply with technical requirements in PCC, and not for each connected equipment, as this can bring much lower costs for solving the grid problem.

The following main characteristics are proposed in PCC instead of for each generator connected to the grid behind the PCC (internal network of the microgrid):

- MG should be considered as a generator or a consumer, based solely on the excgange power sign at PCC
- In case of generation in PCC, curtailment orders should be judged only in PCC
- Power quality features should be approved in PCC only

- Mandatory services, such as FCR should be fulfilled only at PCC level
- Reactive power and power factor should be judged only in PCC

4. Corporate Social Responsibility Aspects of Potential Changes in Energy Systems Design

Due to the central importance of regulations in the electricity market, both the network codes and the defined ancillary services will have a significant influence on all actors on the electricity market in the future. For this reason, the regulatory changes proposed by RESERVE from an environmental, social and economic perspective following the idea of corporate social responsibility (CSR) are evaluated. A general description of the concept of CSR and its relevance in the RESERVE project is given in D6.6 In the following the previously presented ancillary services and network codes are analysed one by one. Additionally, an overall evaluation is given.

4.1 CSR Evaluation of Updated and New Ancillary services

The following is a CSR evaluation of the revised and new ancillary services.

4.1.1 New approach for “Defense Service”

Economic	Environmental	Social	Technical
Reducing the financial losses resulted from regional blackouts			Change of indicator, as solely frequency is not reliable anymore

The change to the ancillary service proposed by RESERVE is first of all a purely technical change. With an increasing share of RES, the frequency is no longer a reliable indicator. RESERVE proposes to replace or supplement the index for the "Defense Service". The "Defense Service" itself will be retained according to the proposal.

The proposed change of the existing approach is foreseen to increase the accuracy of this service and therefore to reduce the number and, of course, the potential affected areas for the regional blackout in the future. As a consequence, this proposal can reduce potential financial losses caused by regional blackouts. This applies to system operators and end consumers as well. System operators can save possible penalty and reparation costs and end consumers downtime costs.

4.1.2 New approach for “Restoration Service”

Economic	Environmental	Social	Technical
Reducing the financial losses resulted from regional blackouts			Change of indicator, as solely frequency is not reliable anymore

As with the previous proposal, the proposed change is a purely technical one. The frequency is no longer a reliable indicator for this ancillary service with an increasing share of RES and needs to be supplemented or replaced.

The proposed change of the existing approach is foreseen to increase the accuracy of this service and therefore to reduce significantly the duration of the power systems recovery following a regional black out. Consequently, this proposal is foreseen to reduce the potential financial losses caused by regional black outs significantly reducing the duration of the power systems, total or partial operational recovery. This applies to system operators and end consumers as well. System operators can save possible penalty and reparation costs and end consumers downtime costs.

4.1.3 Providing Reactive Power for Voltage Control

Economic	Environmental	Social	Technical
Additional costs for the DSO but also the opportunity to reduce losses New (sub) market for ancillary services Market potential for generation and storage device owners and ancillary service providers	No resource consumption since no additional assets are needed	Participation of private entities Increasing electricity prices could burden consumers without own generation and storage devices	New ancillary service is needed due to the increasing number of generation entities at low voltage level

The respective DSO is responsible for running the Voltage Control. In the conventional grid structure, the DSO can do this by using the tap changer transformer. With an increasing share of RES generation in the low voltage range, this is no longer possible. The DSO must purchase the generation or consumption of Reactive Power as proposed above. According to the proposal, the existing penalty system must be replaced by a market for externally procured ancillary services for Reactive Control.

From an economic perspective, the following factors are relevant: The DSO must procure this new ancillary service externally, creating a financial burden for it. On the other hand, there are possible savings through the reduction of transmission losses. In any case, the new (necessary) ancillary service will lead to a change in the cost structure of the DSO. The creation of a new (sub)market creates new value creation potentials for all operators of generation and storage units at the low-voltage level. Since operators of small installations, in particular private individuals, cannot and do not want to actively deal with their functions as Reactive Power Providers, the business potential for an ancillary service Provider arises (described in detail in D6.6). This provider bundles the individual generation and storage units and offers the DSO the respective ancillary service as a whole.

From an environmental perspective, the proposed ancillary service has the following effects: Since no additional assets are required for this ancillary service, there is no additional burden due to additional resource consumption. As transmission losses are reduced, this can accelerate the reduction of CO2 emitting power generation to 100% RES.

From a social perspective, there can arise the following impacts: As described above, the financial burden for each DSO may increase. Since its cost structure is the assessment basis for the corresponding levies on the electricity price, there may be an additional financial burden on all consumers. Only the owners of generation and storage units could counteract this development by offering ancillary services. This is a crucial point, particularly with regard to the social acceptance of the increasing share of RES and the corresponding measures.

4.1.4 Providing Active Power for Voltage Control

Economic	Environmental	Social	Technical
Additional costs for the DSO but also the opportunity to reduce losses New (sub) market for ancillary services Market potential for generation and storage device	No resource consumption since no additional assets are needed	Participation of private entities Increasing electricity prices could burden consumers without own generation and storage devices	New ancillary service is needed due to the increasing number of generation entities at low voltage level

owners and ancillary service providers			

From the perspective of CSR, this new ancillary service "Providing Active Power for Voltage Control" concerns the same aspects as the previous ancillary service "Providing Reactive Power for Voltage Control".

4.1.5 Providing Input Signal for Frequency Controllers

Economic	Environmental	Social	Technical
Reducing economical losses caused by assets disconnection from the grid		Reducing number of disconnections of private-owned assets from the grid	Input signal for frequency is needed due to the decreasing share of synchronous rotating generators

The importance of frequency as an important technical parameter will decrease with an increasing share of converter-based generation. Due to the low share of synchronous machines in the future, there may be larger regional differences in frequency. Therefore, the network operator must introduce a reference signal for the converter-based generators.

The main technical consequence foreseen for this proposal is to reduce the potential frequency variations, amplified by the wrong frequency input signal, ending up with assets (generators and/or consumers) disconnection from the electricity grid. The potential impacts are foreseen in the economic sector: by reducing the financial losses caused by not scheduled disconnections from the electricity grid. Concerning private end consumers this point can be seen as a social impact as well.

4.1.6 Overall Evaluation

In addition to their specific evaluation, the new and modified ancillary services proposed by RESERVE can also be evaluated from a higher perspective with regard to their CSR influence. This is not about their concrete direct influences but about indirect effects and the context in which they were developed.

All proposals for ancillary services presented were developed according to the technical requirements of a network with a RES penetration of up to 100%. In the long term, they thus make a necessary contribution to a functioning and reliable power supply in the future. This is essential for a successful economy in Europe, which depends on an affordable and reliable supply of electrical energy, even if this is provided entirely by RES.

Enabling a network that can handle a penetration of 100% RES enables the indirect a completely CO2-free power supply. Currently, electricity generation in Europe generates approximately 2,400 million tonnes of CO2 per year [11]. If the concept of sector coupling is taken into account, there is even greater potential for savings, which RESERVE ancillary services also contributes to achieving.

From a social perspective, the ancillary services enable extended participation of customers in energy transition. Private entities can exchange power and demand with the grid, depending on the needs of the system operators. Local storage can be interlinked and capacities can be used to manage the balancing power so that consumers can profit financially from technical progress.

4.2 CSR Evaluation of Updated and New Network Codes

The following is a CSR evaluation of the revised and new network codes.

4.2.1 Updated Definition of RoCoP

Economic	Environmental	Social	Technical
Reasonable indicator for determining remuneration payments			Additional index for evaluation of generation and storage devices

Research in RESERVE has shown that with an increasing share of RES and the associated decrease in mechanical inertia in the system, determining the Rate of Change of Power (RoCoP) is an adequate index to evaluate the properties of any generation and storage unit.

From an economic perspective, it is relevant that the proposal to use RoCoP as an indicator for the remuneration of the ancillary service "Provision of Fast Frequency" is relevant. Due to its better suitability for this purpose compared to the measurement of active power injection, the RoCoP improves a performance-oriented remuneration.

4.2.2 New Requirements for Frequency Measurement

Economic	Environmental	Social	Technical
Necessary to avoid significant financial losses Large financial expenditure necessary for the needed infrastructure			Necessary to meet the characteristics of an increasingly volatile grid.

The increasing share of RES in electricity generation increases the volatility of the frequency in the grid. With the existing time rates for frequency measurement, changes in frequency can no longer be adequately recorded in the future. In order to avoid cascade events due to spikes not being detected, the measuring systems must be adapted to a narrower sampling rate.

From an economic perspective, this network code update brings significant added value, as this measure, as already mentioned above, can avoid large financial losses due to power failures and other consequences of undetected spikes. This applies above all to the system operators, but also to all consumers of the power. On the other hand, there are the costs of renewing the affected metering systems. As already mentioned in the proposal itself, in this respect, a long-term conversion is to be aimed at.

4.2.3 New Requirements for microgrids and microgrids by design

Economic	Environmental	Social	Technical
Necessary to integrate large number of RES	Can help at 100% RES target	Empower local communities	Necessary to meet the characteristics of an increasingly volatile grid where microgrid duties are solved locally.

The increasing share of RES in electricity generation ask for strong conditions for connecting to the main public grid. With microgrids and microgrids by design architectures there is a possibility to have extensive control inside the microgrids, while the grid-related conditions need to be settled at PCC level only. Even if these solutions make self-consumption a possible threat for some utilities, there is a window of opportunity for utilities to help the new trends and contribute to be made the transition easier, while still keeping the system needs for preserving grid stability. This can be seen also a CRS subject, as utilities have still geographical monopoly and need to contribute for a smooth transition to resilient solutions such as local energy communities and prosumers.

4.2.4 Overall Evaluation

As was already the case with ancillary services, a general classification from the perspective of sustainability can also be given in addition to the individual consideration.

The overriding goal of RESERVE research and specifically the development of the new and revised network codes is to enable a European power grid that allows feeding-in 100% RES-based electricity and the way to achieve this. The network codes developed in RESERVE contribute to the fact that the power supply in Europe will remain secure and reliable despite the increasing requirements due to the volatility and missing mechanical inertia. This is an indispensable value for the entire European economy. In addition, increased technical requirements introduced at an early stage force actors and manufacturers to deal with future issues and implement solutions. For example, the network code "New Requirements for Frequency Measurement": its introduction could promote the manufacturers of measuring instruments and give them an advantage over the international competition, which is not yet required in this direction.

From an environmental perspective, the same aspects arise as for the ancillary services described above. As a contribution to a grid that can handle up to 100% RES, the RESERVE network codes can contribute to a significant reduction of European CO_2 emissions.

5. Conclusions

It is already known that the process of increasing the RES penetration in the power systems up to 100% raises a lot of technical challenges for operation while keeping the same level, or even better, quality of services.

The RESERVE project focuses on the challenges related to the frequency and voltage control in this context, pointing out not only the technical aspects but also regulatory, environmental and corporate social responsibility.

The modelling and simulations performed so far in the project have supported the general conclusion that increasing the share of the converter-based generators and while reducing the share of the synchronous generators (as a counterpart) will cause stronger dynamics occurring in the power system with more complex control actions.

To properly handle the above-mentioned challenges and facilitate the transition between the existing situations to the targeted one, the most important mean to be considered is the necessary new regulations and ancillary services or the updates required by the existing ones.

Based on the work performed in the second half of the project implementation, 8 new proposals have been added to those already presented in the first version of this deliverable:

- Two new ancillary services: a new approach for “Defense service” and a new approach for “Restoration service”
- Three updates of existing ancillary services: providing reactive power for voltage control, providing active power for voltage control, and providing input signal for frequency controllers
- Two updates within the existing network codes: updated definition or RoCoP and new requirements for frequency measurement

Initial definition, the most significant substation aspects and brief description of each proposal are presented in the chapters 2 and 4 of this document and Chapter 3 presents CSR assessment and impact aspects.

Based on the aspects presented in the first version of the deliverable and in this document as well, we can draw two important conclusions:

- A new generation of converters will be needed in the near future: smarter, faster and more flexible in operation.
- The relationship between TSO’s and DSO’s will have to adapt to the effects of the distributed generation generalisation.

From CSR perspective, RESERVE is helping to make the grid more efficient and reliable. The network codes cover the most important aspects of the changes in the energy transition, after evaluation of the consortium. Thereby, it is important to check all network codes and ancillary services if they do not affect any counterproductive consequence of the energy transition. As it can be seen above, the network codes and ancillary services, which have been developed on the basis of technical needs, can be assessed positively from a sustainable point of view as well. Furthermore, no standout negative consequence could be identified. Of course, energy transition will bring up a lot of changes and some of them are disruptive. Nevertheless, the clustered needs written down in the network codes and ancillary services assure a sustainable system change respecting the needs of the society first.

6. List of Figures

7. References

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8. List of Abbreviations

AC	Alternative current
CSR	Corporate Social Responsibility
D	Deliverable
DC	Direct current
DSO	Distribution System Operator
EC	European Commission
ENTSO-E	European Network on Transmission System Operator in Electricity
ESSs	Energy Storage Systems
EU	European Union
FCR	Frequency Containment Reserves
FRR	Frequency Restauration Reserves
GW	Gigawatt
HV	High voltage
KPI	Key Performance Indices
LDS-VSG	Linear Swing Dynamic-based Improved Synchronous Generator
LSD	Linear Swing Dynamic
MG	Microgrid
MGbD	Microgrid by Design
MGbDA	Microgrid by Design Architecture
MS	Milestone
MV	Medium voltage
NC	Network Code
RR	Replacement Reserves
RES	Renewable Energy Systems
SG	Synchronous Generator
SV	Synchronverter
T&D	Transmission and Distribution Losses
TSO	Transmission System Operator
VSG	Virtual Synchronous Generator
WP	Work package