No 727481 RESERVE

D1.5 Adaptation of Research Concepts based on Simulation, Live ICT Tests and Field Trial Results, V1

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Abstract

This deliverable discusses the procedures for validating the frequency and voltage control concepts in RESERVE. The procedures extend from software simulations of simplified networks to simulations of real networks and field trials. The procedures are a way to build confidence in the performance and applicability of the control concepts, which are being developed in RESERVE. The procedures also lead to updates in the control sequences of the approaches and their system-level requirements. These updates are also reported in this deliverable. To capture future updates, this deliverable is planned to be updated every 6 months. This is the first version.

Keyword list

Electricity System Requirements, 100% RES Electricity Networks

Executive Summary

New control concepts are being developed in RESERVE for electrical systems with up to 100% RES. Each concept provides either frequency control or voltage control in the electricity network. This deliverable gives the reader an overview of the intended procedure for investigating these new control concepts. The investigations extend from simulation environments to field environments. These investigations aim to 1) validate the concepts and 2) give industry confidence that the concepts will work in real systems.

The new control concepts require power system components and functions. These components and functions are collectively referred to as system-level requirements in this deliverable. The system-level requirements to implement the control concepts are defined in D1.2. Some of these definitions were revised since the submission of D1.2. In this regard, this deliverable also provides the updates.

In RESERVE, the system-level requirements of the new control concepts are studied using four scenarios. There are two scenarios for frequency control:

- Sf_A: Mixed Mechanical-Synthetic Inertia
- Sf_B: Full Synthetic Inertia

There are also two scenarios for voltage control:

- Sv_A: Dynamic Voltage Stability
- Sv_B: Active Voltage Management

These scenarios are defined in D1.2. However, refinements on the scenario definitions were made since the submission of D1.2. These refinements are found in the Annex of this deliverable.

The planned investigations for the control concepts across the scenarios are summarized as follows:

Sf_A:

For Sf_A, the investigations will focus on the following concepts:

- RoCoF (a.k.a. Inertial) and primary frequency control (IPFC) provided by the Distribution System (DS)
- RoCoF and primary frequency control provided by Energy Storage Systems (ESSs)
- Definition of Frequency Makers and Frequency Takers
- Requirements of minimum system inertia.
- Inclusion of Virtual Power Plants in the Secondary Frequency Control

These concepts will be investigated using real-time simulations. Initially, the simulations will use a simple approximation of the Western System Coordinating Council (WSCC) 9-bus test system.

In the latter parts of the project, the simulations will use the Romanian Grid modeled inside the software tools (DOME, EUROSTAG, and OPAL-RT).

Sf_B:

For Sf_B, the investigations will focus on the following concepts:

- RoCoF and primary frequency control, based on the Linear Swing Dynamics (LSD) concept, in transmission systems.

- Inclusion of LSD-based HVDC system for the participation in system frequency support.

- RoCoF and primary frequency control, based on the Linear Swing Dynamics (LSD) concept in distribution systems.

- Research on system dynamics and frequency-related matrices

Similar to Sf_A, these concepts will be tested using real-time simulations. It will use the WSCC 9-bus test system initially, and then part of the Romanian grid implemented inside SIMULINK and OPAL-RT.

The effects of the frequency control concepts are widespread and cannot be isolated. Therefore, it should be noted that the new frequency control concepts cannot be investigated in the field (i.e. on actual transmission systems). Therefore, a model of the actual grid inside a software, and then the concepts are tested on this model. In contrast, the voltage control concepts can be tested in smaller systems. Therefore, field trials are planned for the two scenarios for voltage control.

Sv_A:

The investigations for Sv_A focus on the use of Wideband System Identification (WSI) and Virtual Output Impedance Control (VOI) in distribution systems. These concepts prevent dynamic instability in systems with many power converters.

The investigation for Sv_A will proceed from software simulations, into hardware-in-the-loop simulations inside the laboratory, into the field trials in the Irish low-voltage distribution network.

Sv_B:

The investigations for Sv_B focus on the use of Active Voltage Management (AVM). This concept aims to maintain the effective (a.k.a. RMS) values (e.g. 220 Volts, 110 Volts) of system voltages within allowed values. It also minimizes the power losses or voltage unbalance in the system.

The investigation for Sv_B will proceed from software simulations into field trials in the actual Irish low-voltage network. Four separate field trials are planned for each of the following technologies: vehicle-to-grid chargers, photovoltaics, battery storage, and air-sourced heat pumps.

The future investigations of the different control concepts may further modify their system-level requirements. The updates on the requirements will be collected under WP1 of RESERVE, and the final definitions will be reported in D1.6, due on the 36th month of the project.

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Table of Contents

1. Introduction

The project RESERVE aims to demonstrate the applicability of the new control concepts developed during the project. The demonstrations aim to increase the confidence of the network operators that the introduced concepts will be effective in future electricity systems.

In summary, there are four scenarios defined in the project from the system-level perspective. Different concepts for frequency and voltage control are being developed and investigated across these scenarios. The scenarios and the control concepts are summarized below:

1. Sf_A (Mixed Mechanical-Synthetic Inertia): Sf_A is the scenario where there is 100% penetration of RES, including Hydro, in the power system. Due to the high penetration of RES, there is a reduced-mechanical inertia in the system. With less inertia in the system, the frequency is less stable. Thus, the investigations in Sf_A focus on new concepts to stabilize frequency using distribution systems (DS), energy storage systems (ESSs), and virtual power plants (VPPs). The investigations also cover the requirements for minimum system inertia and the definitions of frequency makers and frequency takers. Furthermore, since the concepts in Sf_A are developed for systems with reduced mechanical inertia, the concepts will be applicable to systems with high penetration of RES, even if the penetration is not 100%.

2. Sf_B (Full Synthetic Inertia): Sf_B is a futuristic power system scenario with 100% penetration of RES. The power system in Sf_B have HVDC grids, hybrid AC/DC grids, and very low (from hydro) or no mechanical inertia. The investigations in Sf_B focus on the use of Linear Swing Dynamics (LSD) to stabilize the frequency.

3. Sv_A (Dynamic Voltage Stability): Sv_A is the scenario in the low-voltage part of the grid where numerous loads, distributed energy resources (DERs), and ESSs are connected to the system via power converters. These converters may cause dynamic instability. Thus, the investigations in Sv_A focus on the application of the Wideband System Identification (WSI) in distribution systems to determine the system stability margins. Based on the stability margins, the research work in Sv_A also looks at Virtual Output Impedance (VOI) Control to maintain stability.

4. Sv_B (Active Voltage Management): Sv_B is the scenario where the loads, DERs and ESSs are used for Active Voltage Management (AVM). AVM minimizes voltage unbalance and power losses by optimizing the generation from RES and other sources of electricity.

The expected system-level requirements to implement these concepts have been defined initially in D1.2.

1.1 Task 1.5

In Task 1.5, we regularly update and refine the system level requirements of the control concepts, as well as the scenario descriptions. The updates and refinements may come from updates in the conceptual framework, or from the results of simulations and tests of the control concepts. This deliverable reports these updates.

1.2 Objectives of the Work Report in this Deliverable

In summary, the objectives of this deliverable are:

- To describe the procedure for validating the frequency and voltage control concepts for electricity sector with up to 100% RES.

- To provide the updates regarding the preliminary system-level requirements in D1.2 for implementing the control concepts.

1.3 Outline of the Deliverable

Chapter 2 describes the procedure of validating the frequency control concepts for Sf_A and Sf_B. It also reports 1) the timeline for the simulations and laboratory tests and 2) the resulting updates in the system-level requirements.

Chapter 3 is the counterpart of Chapter 2 for voltage control. Chapter 3 describes the procedure of validating the voltage control concepts in Sv_A and Sv_B. Similar to Chapter 2, it reports the timeline for simulations and field trials, and the resulting updates in the system-level requirements.

Chapter 4 concludes the report, highlighting the main findings and providing an outlook on the future versions of this document.

Furthermore, this deliverable includes two annexes. Annex A.1 summarizes of the changes in the different scenarios studied in RESERVE. It also gives the reader the information on where to find the different details of the scenarios. Meanwhile, Annex A.2 summarizes the updates in the ICT requirements of the different scenarios.

1.4 How to Read this Document

The reader is expected to have read D1.2 before reading this document. D1.2 provides the descriptions of the scenarios, overview of the control concepts, and the respective system-level requirements. The reader can refer to Table 8-3 and Table 8-5 in the Annex for the location of the scenario descriptions and requirements in D1.2 and D1.3. In addition, for further reading about the test setups and trial sites, the reader can refer to the following list:

- D2.2 and D2.3 – in-depth discussions on the frequency control techniques being developed in RESERVE
- D2.4 – ICT requirements for implementing the frequency control concepts
- D3.1 and D3.2 – theoretical background of voltage control and management concepts developing in RESERVE
- D4.1 and D4.2 – laboratory connection infrastructure and real-time solver needed to test the frequency and voltage control concepts in RESERVE.
- D5.1 – overview of the test set-ups and field trial sites
- D5.2 – field trials of voltage control concepts in Ireland and validation of initial network codes and ancillary service definitions.
- D5.4 – trials of frequency in the laboratory and validation of initial network codes and ancillary service definitions.

Figure 1-1 shows how D1.5 relates to the other deliverables in WP1 and the other work packages. D1.5 is the first installment of a series of reports. The reports in this series incrementally describe the procedure for validating and updating the control concepts using the simulations, setups, and trials coming from work packages WP2, WP3, WP4, and WP5. Updates in this series will be provided every 6 months. The last installment of the series is D1.6, which is due on Month 36 of the project.

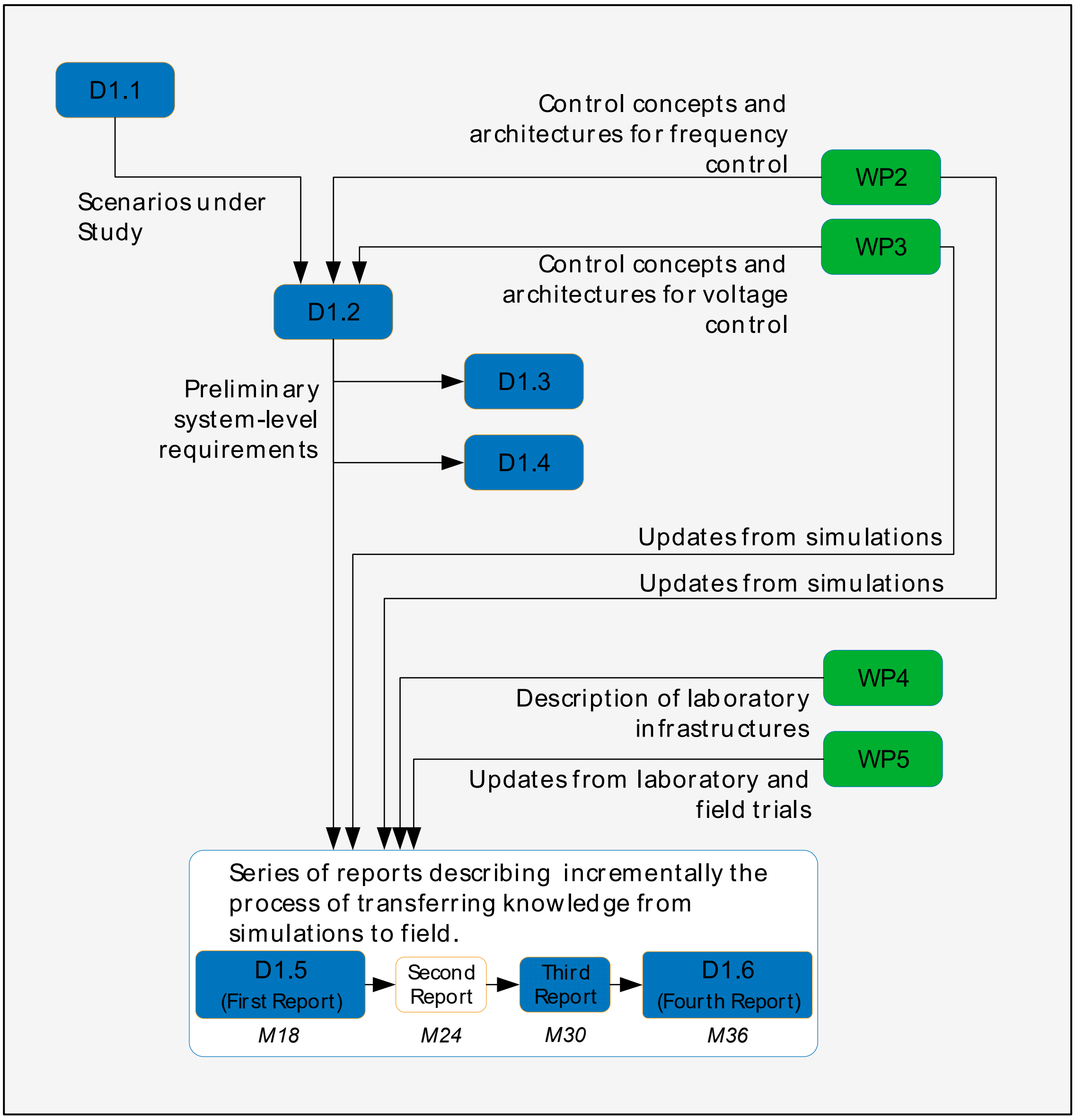

Figure 1-1. Relations between deliverable in WP1 and other work packages

1.5 Approach used to Undertake the Work

Project partners in WP2 and WP3 were consulted for the changes in the system-level requirements since the submission of D1.2. The partners in WP1, WP2, and WP3 also discussed the details and status of the investigations for the different control concepts. These steps will be repeated in the future to capture updates in the system-level requirements, as well as the status of the investigations. All these steps fall under Task 1.5 of RESERVE.

2. Frequency control concepts

2.1 The Sf_A scenario

The Sf_A scenario assumes a power system with 100% of the generation provided by RES, among which wind, solar, and hydraulic power plants. Additionally, for the purpose of power balancing and frequency stabilization, energy storage systems (ESSs) are considered.

The control concepts in Sf_A are developed for power systems with reduced mechanical inertia. This means that the control concepts are applicable to systems with high (up to 100%) penetration of RES.

2.1.1 Control Concepts in Summary

Following the strategy of switching the power generation from large fossil-fueled power plants to small RES-based units, the mechanical inertial is drastically decreasing to dangerous values so that the frequency is no longer stabilized by the natural reaction of the mechanical systems of both the generation and load entities, as shown in deliverables D2.1 and D2.2.

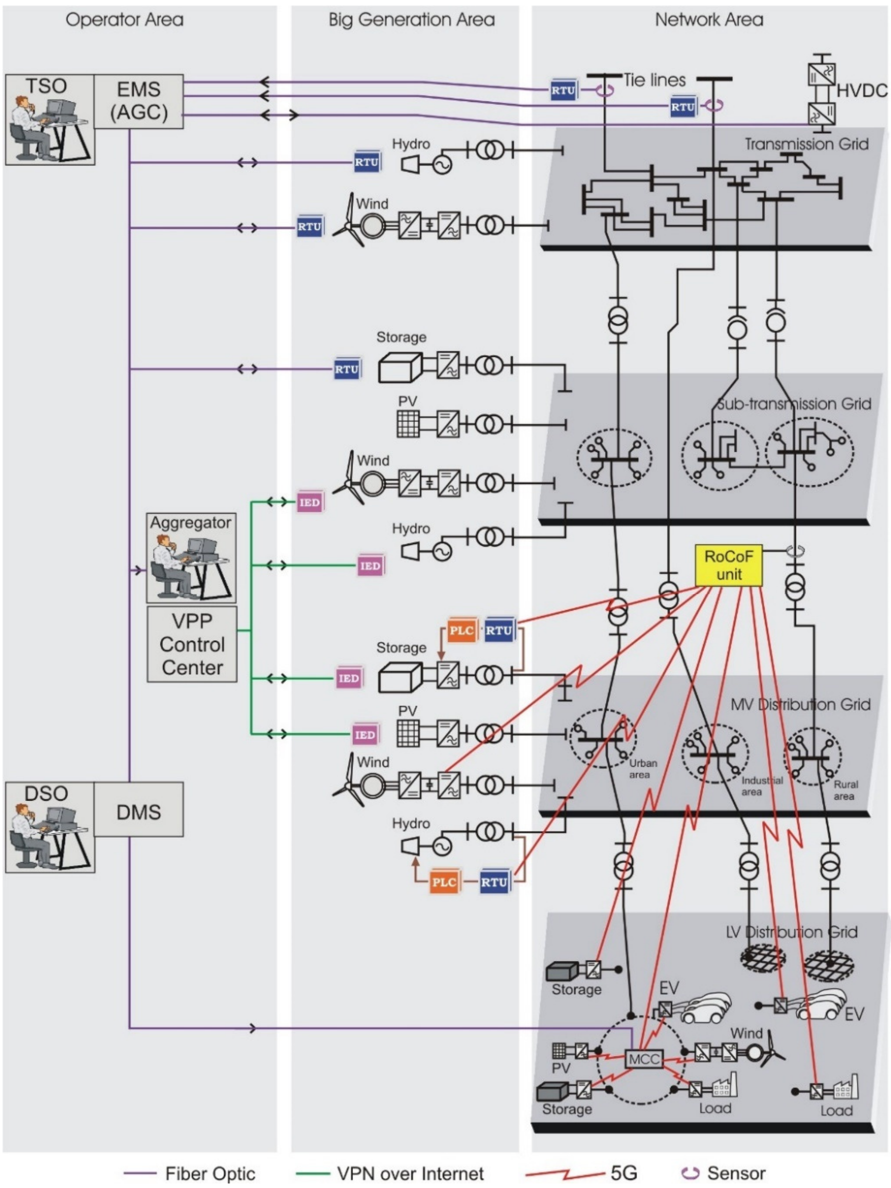

Figure 2-1. Overview of the system components and communication in the hierarchical frequency control

In the Sf_A scenario, it is assumed that a certain mechanical inertia is available due to the presence of hydraulic power plants. However, simulations conducted and shown in D2.1 and D2.2 have revealed that the hydraulic units cannot totally replace the steam and gas turbines because of their lower inertia constant. For this reason, ESSs are extensively employed at all control levels.

As explained in D2.2, the frequency regulation is performed using a hierarchical architecture, including automatic and manual actions. In RESERVE, our focus is on the automatic actions. The following control strategies are explored:

- RoCoF control (decentralized or distributed)
- Primary Control (decentralized or distributed)
- Secondary Control (centralized)

The entities involved at all the automatic control levels are illustrated in Figure 2-1.

2.1.2 Updated System-Level Requirements

Since the submission of D1.2, there were no changes in definitions of the system-level requirements for Sf_A. This fact is reflected in Table 2-1. The requirements specific to both frequency control scenarios, are described in the section 3.2 of D1.2.

Table 2-1. Changes in the definitions of component and functional requirements for frequency control in Sf_A

System-Level Requirement	Changes with respect to the definitions in D1.2
Component	
Hydro, storage-connected solar plants, and wind plants	No Changes
Power Converters	No Changes
Energy Storage Systems (ESSs)	No Changes
Tie Lines	No Changes
Local Meters	No Changes
Local Controllers	No Changes
Remote Terminal Units (RTUs)	No Changes
RoCoF units	No Changes
Supervisory controller	No Changes
VPP Controller (of DSO or Aggregator)	No Changes
Function	
RoCoF control (independent or coordinated)	No Changes; It may also be referred to as “Inertial Control”

Primary Control (independent or coordinated)	No Changes
Secondary Control (centralized)	No Changes

2.1.3 Validation Procedure

To validate the control concepts in Sf_A, the control concepts will be simulated first using the simple Western System Coordinating Council (WSCC) 9-bus test system [1]. Then, the control concepts will be simulated on a software model of the Romanian Grid. Offline and real-time simulations are planned for both test-systems (i.e. WSCC 9-bus system and the Romanian grid model). The offline simulations will be done under WP2. The real-time simulations will be done under WP5. In addition, the real-time simulations will use a 5G-flight rack to investigate the communication requirements of Sf_A.

During the second year of the project, the main concepts to be studied regarding Sf_A are the following:

- **RoCoF/inertial and primary frequency control (IPFC) provided by the Distribution System (DS)**

  The increasing penetration of converter-based Distributed Energy Resources (DERs) in distribution systems will require the redefinition of the role of the Distribution System Operators (DSOs) in future frequency control procedures. To this aim, it is necessary first to study and quantify the capability of such DERs to provide RoCoF and primary frequency control. A distribution system with a variety of DERs capable of providing IPFC will be first connected to the 9-bus system in the real-time simulator (RTS). The main aspects to be studied are:

  i. the signals used as input to the frequency controllers;
  ii. the level of coordination for the best performance (i.e., centralized, decentralized, distributed);
  iii. impact of associated delays and noises in the signals;

  The initial study of the IPFC provided by the distribution system is expected to last from March 2018 until May 2018. After the initial study, this scenario will be further studied considering also the Romanian Power System database.

- **RoCoF/inertial and primary frequency control provided by ESSs**

  ESSs have the potential to provide a large variety of ancillary services to the power system thanks to their capability to supply/absorb active and reactive powers very fast. While the capability of ESSs to provide primary control has been extensively studied in the literature (this is partially shown in D2.1), the concept of ESSs and RoCoF control at both transmission and distribution system levels needs a more-in-depth study. This will help defining the set of requirements for the connection of ESSs in future transmission and distribution systems. To this aim, a variety of ESS technologies, capacities, locations, and so on, will be considered. Such studies will be based on the Romanian Grid implemented in the software tools DOME and EUROSTAG, upon completion of the implementation and testing of such grid. This task is expected to be completed between January-June 2018.

- **Definition of Frequency Makers and Frequency Takers**

  Currently, it is indirectly assumed that “frequency makers” are the synchronous machines installed in the system, whereas any other power system device is “frequency taker”. This classification is correct in the context of current power systems. However, the distinction of frequency “makers” and “takers” is not straightforward in systems with very large or full penetration of non-synchronous generation. This is crucial to properly define the set of required measurements and signals needed for a proper estimation of the system state and operation. This is because in power systems with 100% renewables, the generation units are no longer naturally synchronized, and thus adequate coordination is required. This concept will be initially studied and tested on the 9-bus system in DOME between

January-June 2018, followed by a further study and validation considering the Romanian Grid in later stages of the project.

- **Requirements of minimum system inertia**.

  In systems with up to 100% RES penetration that includes inertial hydro power plants, it is required to know, for any operating condition, the minimum inertia that must be present in the system in order to ensure not only frequency stability, but also an appropriate frequency response. To this aim, the Romanian power system database will be considered. This task will be developed January-September 2018.

- **Including Virtual Power Plants in the Secondary Frequency Control**

  The Secondary Frequency Control (SFC) is traditionally provided by large power plants, which meet certain flexibility criteria. The RES generation consists mainly in small entities distributed on wide geographical areas. While the large power plants are decommissioned, new solutions must be found to control the RES entities. In RESERVE, we will use the virtual power plant concept as a way of ensuring the required power reserve and providing frequency control in the SFC level. Simulations will be performed on the Romanian power system database. This task will be developed between January and September 2018.

The Romanian Power System database, available in CIM and EUROSTAG format, considered in the simulation consists of:

- load flow data, including the network topology and parameters
- dynamic models of the hydro power plants, wind power plant, and PV power plant
- information specific to the AGC system

2.1.4 Status

So far, the WSCC 9-bus system has been used to test and validate all frequency concepts developed for the Sf_A scenario – RoCoF and primary frequency controls. Such simulations and the discussions drawn from them are duly collected in Deliverables D2.1 and D2.2. It is important to note that, since both Sf_A and Sf_B scenarios consider studies of Transmission Systems, the concept of "Field Trial" is different in this case; as the frequency is a global parameter, field tests in-situ must be performed on real power systems only, which requires the access to the controllers of a very large number of physical generators or other entities. In this regard, we have to rely on the results of the tests carried out in the Real-Time Simulators (RTSs) and other software tools (DOME and EUROSTAG) to validate the concepts to be studied in the next stages of the project. To this aim, the 9-bus system will be firstly considered for simulations in the RTSs.

Meanwhile, the Romanian Transmission System database will be implemented also in the RTS for final tests and validations in the final stages of the project. The process of building the setups on the RTS for Sf_A has already started at the beginning of March 2018. Additionally, it is important to note that the majority of the tests to be performed in the frequency scenarios are not linked/related one to each other, apart from the fact that they will share the same test systems (9-bus and Romanian systems). This means that separate set-ups are expected for the different concepts studied in Sf_A. Finally, most of the frequency control requirements are common to all scenarios as they involve similar data and similar equipment. The difference among them are the time reactions and the simulation timeframe.

2.1.5 Findings

Below are the findings so far from the completed simulations:

- Various simulations have been conducted on the 9-bus test system in DOME and RTS for RoCoF and primary frequency control;
- The Romanian power system database has been implemented in DOME and is almost ready for final verification;

- The two-level secondary frequency architecture is under development; It will be tested in EUROSTAG and RTS;
- ESSs are essential for frequency stability, at all levels; the importance of the time reaction as a replacement for the mechanical inertia will be evaluated for power systems of different size, i.e., the 9-bus test system and the Romanian power system.

2.2 The Sf_B scenario

The Sf_B scenario assumes a power system with 100% of the generation provided by RES, limited to only wind and solar plants. Hydro power plants are not present in Sf_B, resulting in very little to no inertia in the grid. Instead, virtual inertia is provided from the storage-connected wind and power plants. Note that in Sf_B, a little mechanical inertia might be considered. This inertia is injected from the HVAC-connected neighbor network (country), which has the mechanical inertia, i.e. Sf_A. Like the case in Sf_A, ESSs are also considered in Sf_B. Unlike the case in Sf_A, the DC systems will be embedded in the AC systems.

2.2.1 Control Concept in Summary

In Sf_B, the Linear Swing Dynamics (LSD) will be embedded in the control of DC (HVDC) and RES-tied converters. The objectives in doing so are as follows:

- provide linear dynamical system, with the capability of providing RoCoF/inertial and primary frequency control;
- maintain system synchronization and coherency; and
- enhance system dynamic performance.

In Sf_B, the Synchronous Generator (SG) emulation control is considered, e.g. Virtual Synchronous Generator (VSG) and Synchronverter (SV). In this regard, the LSD concept will be integrated in both VSG and SV. VSGs and SVs are not yet listed as requirements for Sf_B. However, their applicability will be studied under Sf_B.

The LSD control will be embedded into the VSG aiming to achieve the following features:

- System synchronization and coherency;
- Provisions for virtual inertia;
- Consistent performance in frequency control and regulation;
- A simple method to capture the stability information of the whole system.

Hence, the aim of proposed LSD-VSG is to preserve the advantages of SG, e.g. system synchronization and inertia provision, and tackle its disadvantages represented by nonlinear characteristics. In this work, both decentralized (independent) and coordinated control are considered.

More details about the LSD concept are under development. The latest descriptions of the LSD concept can be found in deliverable D2.3.

2.2.2 Updated System-Level Requirements

Since the submission of D1.2, there were no changes in the definitions of the system-level requirements in Sf_B. This fact is reflected in Table 2-2. The definitions can be found in section 3.2 of D1.2.

Table 2-2. Changes in the definitions of component and functional requirements for frequency control in Sf_B

Requirement	Changes with respect to the definitions in D1.2
Component Requirement	

storage-connected solar and wind power plants	No Changes
Power Converters	No Changes
Energy Storage Systems (ESSs)	No Changes
Tie Lines	No Changes
Local Meters	No Changes
Local Controllers	No Changes
Remote Terminal Units (RTUs)	No Changes
RoCoF units	No Changes
Supervisory controller	No Changes
VPP Controller (of DSO or Aggregator)	No Changes
Functional Requirement	
RoCoF control (independent or coordinated) *	No Changes It may also be referred to as “Inertial Control”
Primary Control (independent or coordinated) *	No Changes
Secondary Control (centralized)	No Changes

* The requirement to implement RoCoF and Primary Control using LSD-VSG or LSD-SV is being investigated in WP2.

In order to perform the functional requirements, communications will be embedded in the control structure. Some remarks regarding the use of communications in Sf_B are as follows:

- **Primary control**: communication is necessary in the coordinated primary control (LSD-VSG), and the communication metrics will be determined based on the preliminary simulation scenarios.

- **Secondary control**: the base station will be used in the secondary control, and the communication among all the controllers will be provided by (Virtually Interconnected Laboratories for Large Scale Simulation/emulation) VILLAS node. The details about the VILLAS platform can be found in deliverable D4.1 of RESERVE.

The schematic for the control scheme in Sf_B is shown in Figure 2-2.

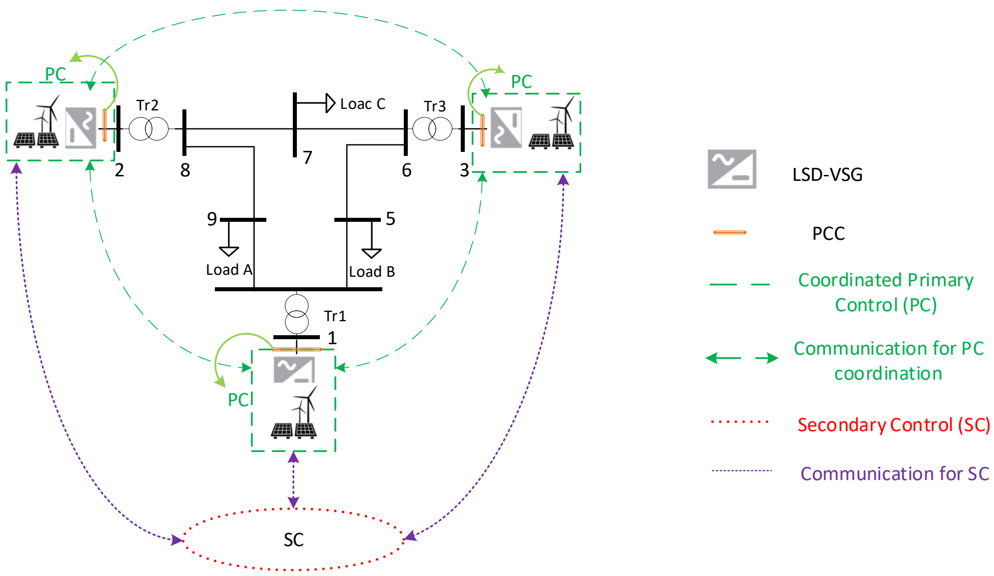

Figure 2-2. Control and communication for Sf_B in the 9-bus test system

2.2.3 Validation Procedure

The LSD-VSG concept is currently being tested and validated on a Single-Machine Infinite-Bus (SMIB) system. Then it will be tested based on simulations on two power systems. First, it will be tested on the WSCC 9-bus system (see Figure 2-2). After that, it will be tested on a part of the Romanian power system containing only non-hydro RES.

Similar to Sf_A, offline and real-time simulations are planned for Sf_B. The offline simulations will be done under WP2, and the real-time simulations will be done under WP5. Furthermore, the real-time simulations will involve the use of 5G flight rack to test the communication requirements of Sf_B.

Later in the validation procedure, a sample of distribution system will be considered and connected to the studied transmission system. The LSD-SV will also be studied later in the project. The procedure of validating the concepts using LSD are planned from January to June 2018.

The control concepts using LSD will be validated via the following steps in sequence:

a) Theoretical validation from the mathematical formulations and physical/technical interpretations

b) Offline simulations using SIMULINK

c) Real-time simulations using OPAL-RT

2.2.4 Status

So far, the LSD concept has been evaluated using generic simulations on the Single-Machine Infinite-Bus (SMIB) system, and stability analysis has been performed. In addition, the LSD-VSG has been developed to include both active power (including inertia emulation) and voltage control loops. The proposed LSD-VSG is developed for transmission system and will be improved in future work to be applicable for distribution systems as well. The LSD-VSG is implemented in the HVDC and RES-tied converters, as the future power systems will be a combination of AC and DC systems. Stability analysis has been performed for the proposed LSD-VSG based-system.

2.2.5 Findings

Below are the findings so far from the completed simulations:

- From the theoretical point of view, the currently developed LSD-VSG can achieve LSD characteristics up to infinity, i.e. beyond the maximum power point. However, as observed in the simulation results, the LSD characteristics has been achieved up to a margin very close to the maximum power point. This is due to the standard voltage threshold, which cannot be exceeded in practice. This means that the control needs to ensure LSD characteristics without deteriorating the system voltage profile.
- In WP2, the LSD concept is being developed further, in theory and/or control structure, to be compatible for more sophisticated (e.g. transmission or distribution, with coordinated or with decentralized control) power systems.

3. Voltage control concepts

3.1 Sv_A

3.1.1 Control Concept in Summary

3.1.1.1 Objective of the control concept

Dynamic voltage instability may arise due to the high number of power converters in future distributions systems. The objective of the control concept in Sv_A is to maintain dynamic voltage stability. It uses the concept of Wideband System Identification (WSI) to determine the present voltage stability margins of the system. If the margins are lower than the prescribed value for maintaining stability, then the control concept in Sv_A will use the Virtual Output Impedance (VOI) control to improve the stability margins.

3.1.1.2 Updated Control Sequence

In D1.2, the steps for implementing the control sequence in Sv_A were discussed. However, this control sequence has been updated since the submission of D1.2. The updates are caused by some changes in the theory behind the concept and some minor corrections.

Presented below is the updated control sequence:

1. The *SSAU* commands a WSI Tool (*WTx*) to perform WSI.
2. *WTx* performs WSI by making its power converter (*PCx*) inject noise into the network. The injected noise is a pseudo-random binary signal (PRBS). This noise should not violate future requirements in power quality.
3. *PCx* senses the changes in the voltage and the current at its connection point to the network. It sends these sensed voltage and current back to *WTx*.
4. Based on the sensed voltage and current, *WTx* determines the impedance of the grid as seen by *PCx*. We call this impedance Z_G.
5. Based on the parameters of PCx, WTx calculates the output impedance of the converter. We call this impedance Z_O.
6. *WTx* sends Z_G and Z_O the *Secondary Substation Automation Unit* (*SSAU)*. This concludes the WSI process.
7. Based on Z_G and Z_O, the *SSAU* calculates the stability margins of the power system.
8. Based on the margins, the *SSAU* responds with one of three ways:
    i. Case 1: The margins are acceptable. The *SSAU* does no control action.
    ii. Case 2: The margins are critically low. The *SSAU* alarms the *DSO* via the Distribution Management System (*DMS*). To maintain stability, the DSO makes a manual corrective action.
    iii. Case 3: The margins are low but not within critical levels. Here, the next steps are as follows:
        1. The *SSAU* performs the Stabilizing Control Routine. It produces the desired output impedance of the converter to maintain stability.
        2. The *SSAU* sends the desired output impedance to *VOIx*, the VOI controller of *PCx*.
        3. *VOIx* adjusts the output impedance of *PC1* accordingly.

9. Steps 1 to 8 is repeated until stability margins are calculated and/or adjusted for all power converters in its coverage.

3.1.2 Updated System-Level Requirements

Since the submission of D1.2 in M12, there were no changes in definitions of the system-level requirements for Sv_A, as shown in Table 3-1. Section 4.2.1 of D1.2 contains the definitions for these requirements.

Table 3-1. Changes in the definitions of component and functional requirements for voltage control in Sv_A

Requirement	Changes with respect to the definitions in D1.2
Component Requirements	
Power Converters	No changes
Local controllers with WSI Tool and VOI Controller	No changes
SSAU	No changes
Distribution Management System	No changes
Functional Requirements	
WSI	No changes
Compliance with Power Quality Standards	No changes
VOI Control	No changes
Stability Margin Calculation	No changes
Provision for Stability Margins	No changes
Stabilizing Control Routine	No changes
DSO's Manual Corrective Action	No changes

3.1.3 Validation Procedure

3.1.3.1 Objectives of Simulation and Field Trials

For Sv_A, the major objectives of simulation and field trials together are as follows:

- Validating the control concept,
- Investigating the implications to the network codes of these concepts that are listed in D5.2.

The validation of the control concept in Sv_A involves the following steps:

- Verification of WSI concept, i.e. to see if the grid impedances are identified correctly
- Implementing the VOI algorithm and observing simulation in real time
- Implementing the dynamic stability monitoring algorithm

These steps involve offline simulations under WP3, as well as real-time simulations and field trials under WP5. Furthermore, similar to cases of Sf_A and Sf_B, the real-time simulations for Sv_A will use a 5G flight rack to test the Sv_A's communication requirements.

Three (3) laboratory real-time simulation related experiments are planned leading to the field trial. These procedures are briefly summarized as follows:

1. The first setup tests the performance of the WSI concept in real-time environment. This setup uses a Hardware-in-the-Loop (HiL) Simulation with LabVIEW and OPAL-RT.

2. The second setup tests the performance of the control concept using a Flexible Power Simulator (FlePS) converter. The FlePS converter is a stand-in converter. It is used at the laboratory while waiting for the acquisition of the actual converter that will be used to implement the control concept. FlePs is a power amplifier built at RWTH that allows performance of PHiL test. It interfaces the hardware device under test and the rest of the system (ROS) which is a software component in the RTDS.

3. The third setup tests the performance of the control concept using an actual converter. This converter will be the same converter that will be used in the field trials.

The details about the objectives, components, schematic diagrams, and planned timelines for each of these setups are given in the following sections.

3.1.3.2 Lab-Setup 1: Hardware-in-the-Loop (HiL) Simulation with LabVIEW and OPAL-RT

Timeline:
September 2017 – October 2017

Objectives:

- Test the performance of the WSI concept on a real-time simulation

Components:
LabVIEW and OPAL-RT

Description:
This setup uses the schematic diagram in Figure 3-1. The PRBS generator, voltage/current data acquisition and impedance calculation routines are implemented in LabVIEW. The RT-Lab environment of OPAL-RT system provides the link to MATLAB Simulink. This allows detailed switched models of power converters[1] and grid-connected converters built in MATLAB Simulink to be transferred to the RT-LAB environment, where the complex system can be simulated in a real-time manner with feasibility of real time multiple inputs and outputs. This allows the distribution grid model with converters and active rectifiers from MATLAB Simulink to be loaded into RT-LAB for real time simulations. The input to this simulation from the external world is the PRBS signal and the output is the voltage and current values.

[1] In other deliverables of RESERVE, the term "inverter" may be used in place of "power converter". Please note that inverter is one type of power converter. In D1.2 and this deliverable, the term power converter is used to cover the different types of power converters that may be present in future power systems (e.g. rectifiers, inverters, DC-DC converters)

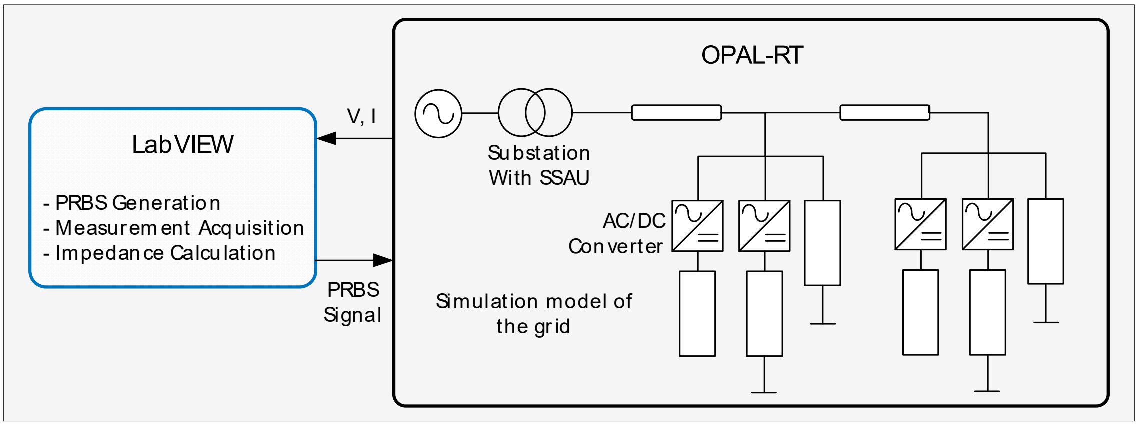

Figure 3-1. Schematic Diagram of HiL Simulation with LabVIEW and OPAL-RT for Sv_A

3.1.3.3 Lab-Setup 2: RWTH LAB Trial with FlePS converter and LabVIEW

Timeline:
October 2017 – December 2017

Objectives:

- Verify WSI concept on a stand-in laboratory converter
- Implement and test VOI control
- Determine the amount of PRBS required to determine the grid impedance

Components:
FlePs converter (3-phase converter) and LabVIEW

Description:
This setup uses the schematic diagram in Figure 3-2. The Pseudo random binary sequence (PRBS) signal is injected on command using a virtual PC. In parallel, the data acquisition into LabVIEW environment takes place. A dedicated measurement port is used to meet the bandwidth criteria for enabling impedance measurements up to high frequency range. By performing the impedance calculation routine in LabVIEW, the grid impedance or output impedance of the converter is determined. Since in this case, a simple passive load gives the grid impedance, the analytical expression is known. Hence, verification of impedance identification will be conclusive when repeated for many different passive load values.

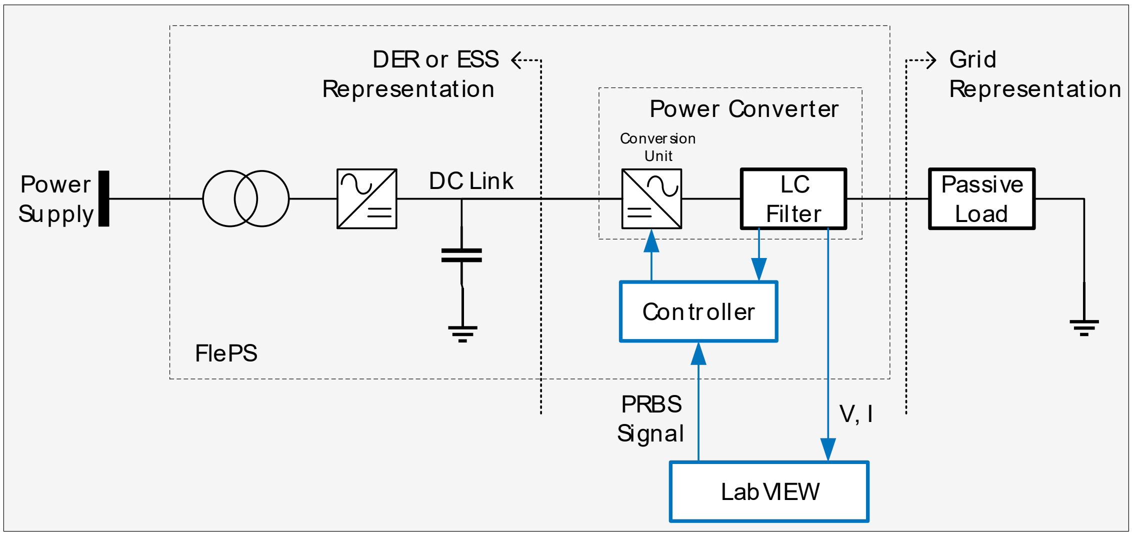

Figure 3-2. Schematic Diagram of the RWTH LAB Trial with FlePS converter and LabVIEW for Sv_A

3.1.3.4 Lab-Setup 3: HiL and PHiL trial with new converter

Timeline:
January 2018 – March 2018

Objectives:

- Implement and test the complete voltage control concept using an actual converter.
- Determine the stability margin limits to be used for dynamic voltage control

Components:

Real time digital simulator (RTDS), LabVIEW, Low-Power Converter

Description:

This setup used the schematic diagram in Figure 3-3.The WSI algorithm will be implemented in the RTDS. LabVIEW, which is external to the converter, acts as the WSI tool and controller of the converter. However, in the future, it is envisioned that the WSI function will be incorporated into the converter hardware. The RTDS will send PRBS inject command to the LabVIEW, and the LabVIEW sends impedance data to the RTDS. RTDS executes the Stabilizing Control Routine and returns the VOI command back to LabVIEW and LabVIEW implements that impedance value.

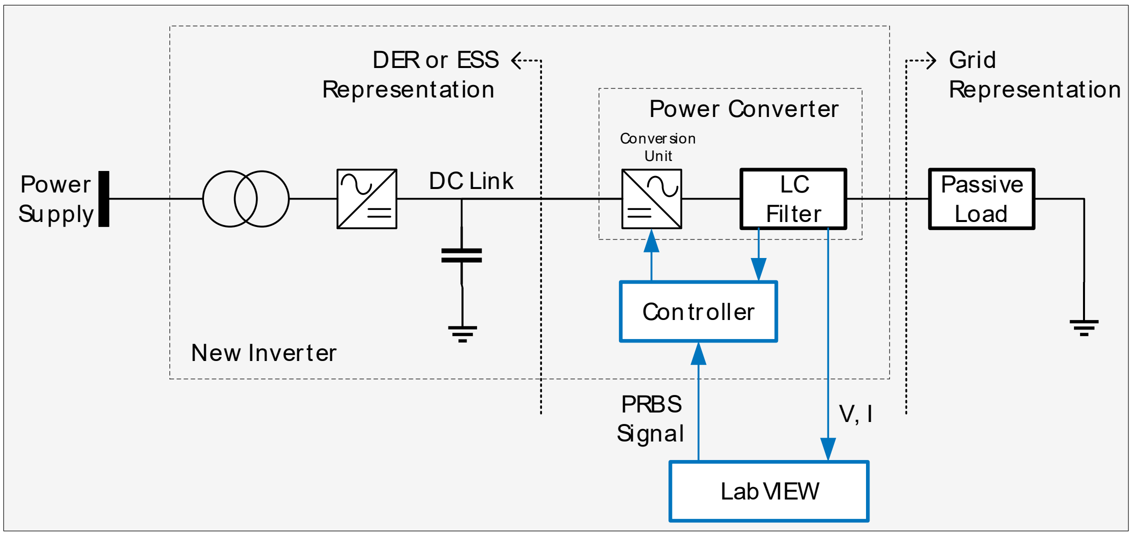

Figure 3-3. Schematic Diagram of the HiL and PHiL trial for Sv_A

3.1.3.5 Irish Trials

After the laboratory trials, the power converter capable of performing WSI and VOI Control functions are brought to the field. They will be installed in the ESB trial grid, where its performance in the field will be validated and assessed. The trial grid is a part of the Irish low-voltage distribution network manage by ESB.

Timeline:
April 2018 onwards

Objectives:
To show that the impedance can be determined with a real grid and to determine the magnitude of PRBS required to accurately determine the grid impedance. However, the VOI control cannot be demonstrated in the field using only a single converter. This is because VOI control is effective when there are about at least 80% RES converters in the radial feeder – hence it is applicable for the future grids.

Components:
LabVIEW, Low-Power Converter, SERVOLive, ESB Trial grid

Description:
The field trials will use the schematic diagram in Figure 3-4. Here, only the WSI function is performed to see if we can really measure the grid impedance effectively. Additionally, communications to and from the converter will be implemented and tested. The calculations for the Stabilizing Control Routine are to be implemented in SERVOLive. However, the VOI commands will not be used for field trials.

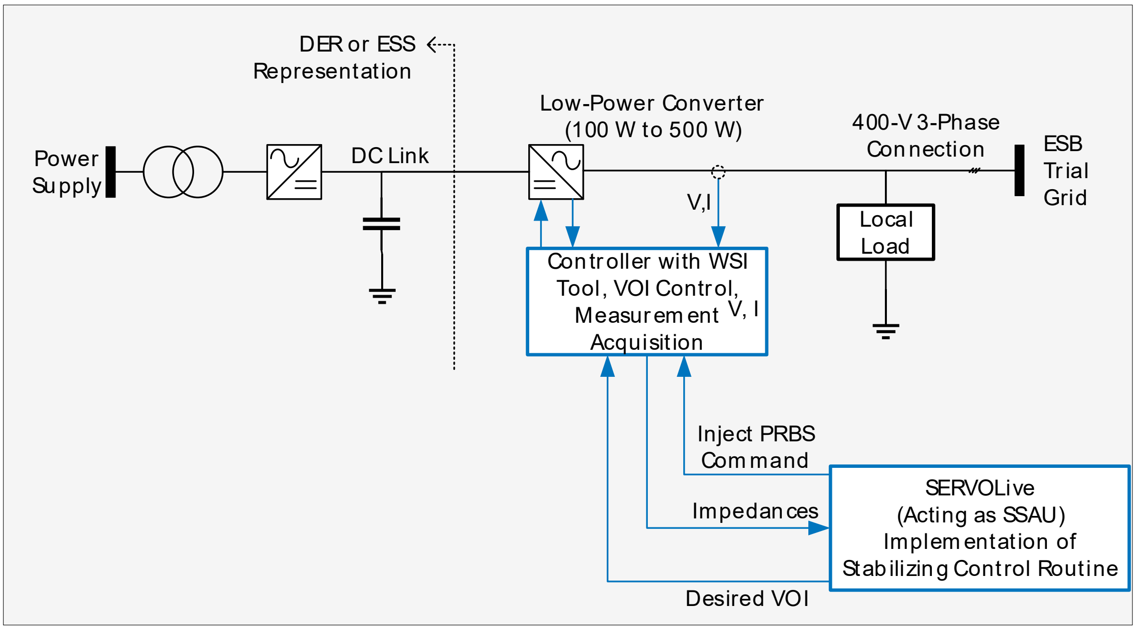

Figure 3-4. Overview of the test grid used in the field trials for Sv_A

3.1.4 Status

The first two laboratory setups have been completed and the experiments have been done. However, at the moment, the preparation for the field trial preparation is currently taking time. To implement the voltage control concept in Sv_A, low-cost, low-power, and high-switching frequency converters are required. Moreover, these converters are being searched for purchase. Thus, the dates for the field trials are not yet finalized.

3.1.5 Findings

Below are the findings so far from the completed tests:

- The impedance identification works, i.e., WSI tool is verified and developed
- Currently the VOI controller is under development.
- WSI and VOI algorithms are developed but will be tested in the coming months (Before March)

3.2 Sv_B

3.2.1 Control Concept in Summary

3.2.1.1 Objective of the control concept

The concept used in Sv_B is called Active Voltage Management (AVM). The objectives of AVM are as follows:

- Maintain the RMS values of distribution voltages within their allowable limits despite the penetration of DERs and ESSs in future distribution systems.
- Minimize the power losses and voltage unbalance in the system.

In order to achieve these objectives, AVM will use the numerous power converters expected in future grids. With AVM, the system will be able to accommodate an RES connection on the most electrically distant point on LV feeders while also facilitating connections on MV that exhibit altogether closer electrical proximity.

3.2.1.2 Updated Control Sequence

In Section 4.1.3 of D1.2, the steps for implementing the control sequence in Sv_A were discussed. Since the submission of D1.2, there are no updates in these steps. However, we provide below the summary of these steps in numbered list. This list is not present in D1.2.

Steps for implementing AVM:

1. The *SSAU* selects a power converter in the system.
2. The *SSAU* performs *Optimized Curve Selection* for the power converter.
3. The *SSAU* performs *Curve Implementation* for the power converter.
4. Steps 1 to 3 are repeated for all power converter in the system.

Optimized Curve Selection and Curve Implementation are both functional requirements in Sv_B. Both requirements are defined in Section 4.2.2 of D1.2. Moreover, the next section contains the updates for both requirements, along with the updates for the other requirements in Sv_B.

3.2.2 Updated System-Level Requirements

Table 3-2 shows the updates in the component and functional requirements in Sv_B since the submission of D1.2.

Table 3-2. Changes in the definitions of component and functional requirements for voltage control in Sv_B

Requirement	Changes with respect to the definitions in D1.2
Component Requirements	
Power Converters	No changes
Local Meters	No changes
Local controllers	No changes
SSAU	No changes
Functional Requirements	
Optimized Curve Selection	The optimization objective was updated from *minimizing losses or cost* to *minimizing losses or voltage unbalance*. New definition: *"For each converter, the SSAU will select an appropriate Volt-VAr curve to use. The selection will be based on the objective set by the DSO, which can be to minimize losses or voltage unbalance."*
Coordination with the present voltage control devices	It is clarified that the present control devices will be incorporated in the offline-modeling phase of Sv_B.

	New definition: "*During the transition from the present scenario to converter-based feeder in Sv_B, the control actions of converters, OLTC, shunt devices are incorporated into the offline modelling phase of Sv_B, for more information refer to D 3.2. This coordination ensure they will not reduce the effectiveness of each other and voltage hunting problems are mitigated.*"
Reactive power injection or consumption of RES or ESSs	Some modifications in the wording. New definition*: "Future network codes must contain provisions on the required reactive power generation or consumption of converter-based RES or ESSs. This means that the power factor of RES should be allowed to be leading or lagging. In the section DCC6.9.1 of ESB Networks Distribution code, customers can operate from 0.9 to 1 when drawing power, and between 0.95 to 1 when injecting power. The same section specifies that wind generators must have a power factor between 0.92 and 0.95 lagging. These present requirements assume that the loads and their RES or ESSs only consume reactive power. However, RES or ESSs should be able to provide reactive power in the future to provide voltage control. This means that present limitations must be relaxed to allow RES, ESSs, and converter interfaced loads to operate at a leading power factor."*
Optimized Volt-Var curves	Some modifications in the wording. New definition*: "The derivation of volt-var curves for each participating power converter is undertaken in an offline three-phase optimal power flow study of the network native to the controller. The optimization ensures no violation of thermal constraints of lines and transformers in the surrounding power system. Different volt-VAr curves will be required for different optimization objectives. The DSO will decide which volt-var curve to engage. These curves only ensure that voltages in the power system are within acceptable values, they improve the power system efficiency by optimizing power losses, improve the load balancing among the different phases of the AC system, and minimize operation cost."*
Curve Implementation	No changes

3.2.3 Validation Procedure

The concept of AVM will be validated through the offline simulations in WP3, and real-time simulations and field trials in WP5. The validation procedure follows the following steps:

1. Perform *Optimized Curve Selection* on a simulated network.
2. Perform the whole concept of AVM on a simulated network.
3. Simulate in a real-time environment (OPAL-RT) the performance of AVM for each planned field trial.
4. Perform the field trials.

Four separate field trials are planned on the Irish LV distribution system using converter-based RES:

1. Battery storage
2. Vehicle-to-grid charger
3. Photovoltaics and
4. Air-sourced heat pumps.

In WP3, the simulations for each field trial are to be undertaken in the second half of the project. The objective is to determine, from the offline studies, the selection of volt-var curves native to each RES field-trial network. Further simulations will be reported and in WP3 to inform the efficacy of the volt-var technique.

Validation of these simulations by way of the field trial results will be reported in WP5. In addition, the actual distribution networks for each field trial are discussed in detail in Section 2.2 of Deliverable D5.1.

In addition to the simulations and field trials, the concept of AVM will also be demonstrated live during the project review meeting. This demonstration will use the VILLAS Node connection at TSSG Waterford Ireland and the real-time simulator in RWTH Aachen Germany. In this demonstration, live measurements from a vehicle-to-grid charger will be communicated to a network simulated in real-time to showcase the volt-var control of AVM in Sv_B. More details about the VILLAS platform can be found in deliverable D4.1.

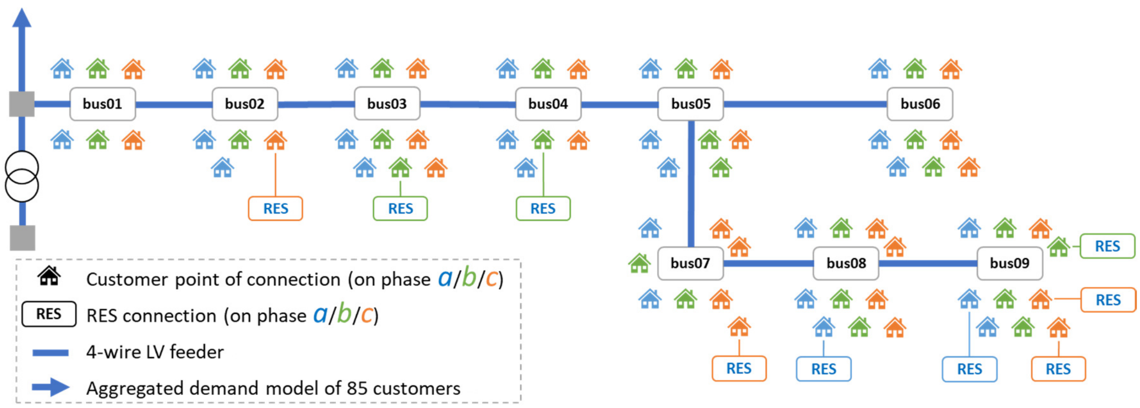

Figure 3-5. The chosen network to showcase the AVM technique, and determine the volt-var curves for a series of RES, is a radial LV feeder with 85 nodes

3.2.4 Status and Findings

So far, the “Optimized Curve Selection” is complete on a simulated network (see Figure 3-5) with notional RES connection, as reported in D3.2. Expanding this technique to a real network with actual RES characteristics is the subject of the simulations in WP3 and the real-time simulations and field trials in WP5.

4. Conclusions

The collection of updates and validations procedures in this deliverable is the result of consultations with a number of partners within RESERVE. So far, the collection of updates includes 1) the updated control sequence for the concept of WSI and VOI control, and 2) revised definitions of the system-level requirements for AVM.

Furthermore, the range of validation procedures discussed in this deliverable show that all control concepts being developed in RESERVE will be tested for their applicability in real electrical networks. It also show that there are definite plans to demonstrate the application of the control concepts.

For the frequency control concepts, the final demonstrations will be the real-time simulations of the concepts using the software model of the Romanian grid or parts of the Romanian grid. For the voltage control concepts, the final demonstrations will be the field trials in the low-voltage parts of the Irish Network. The tests and demonstrations will not only prove or disprove that the concepts work, but it will also refine the control concepts, refine the system-level and communication requirements for each concept, and help establish the future network codes for systems with up to 100% RES.

The future revisions in control concepts and system-level requirements will be collected. The final version of these requirements will be reported in D1.6. In D1.6, the revisions on the validation procedures will also be reported to reflect the process followed in the project.

5. References

[1] Texam A&M University, "Electric Grid Test Cases Repository - Engineering, Texam A&M University," [Online]. Available: https://electricgrids.engr.tamu.edu/electric-grid-test-cases/wscc-9-bus-system/. [Accessed 24 February 2018].

6. List of Abbreviations

AGC	Automatic Generation Control
AVM	Active Voltage Management
DER	Distributed Energy Resources
DMS	Distribution Management System
DSO	Distribution System Operator
ESS	Energy Storage Systems
HiL	Hardware-in-the-Loop
IPFC	Inertial and Primary Frequency Control
LSD	Linear Swing Dynamics
PV	Photovoltaic
RES	Renewable Energy System
RoCoF	Rate-of-Change-of-Frequency
RTDS	Real-Time Digital Simulator
RTS	Real-Time Simulator
RTU	Remote Terminal Units
SFC	Secondary Frequency Control
SSAU	Secondary Substation Automation Unit
SV	Synchronverter
VOI	Virtual Output Impedance
VPP	Virtual Power Plant
VSC	voltage-sourced power controllers
VSG	Virtual Synchronous Generator
WSCC	Western System Coordinating Council
WSI	Wideband System Identification

7. List of Figures

8. List of Tables

Annex

A.1 Summary of the updates occurring in the scenarios

This Annex reports the summary the scenarios of RESERVE project. This summary aims to be useful to the reader, who can find all key features of the scenarios in one document.

The material reported here is mainly extracted from D1.2 and D1.3, and part of it is update according to the above chapters of the current version of D1.5.

It is worth to note that for the detailed description of every element of the scenarios the reader should refer to the proper deliverable.

Based on the descriptions of the update in the chapters above, the modifications of the scenarios can be summarized as reported in Table 8-1. The cross means no modification with respect to the previous versions, whereas the symbol **v** means that modifications occurred.

Table 8-1 Summary of the Modifications

Requirements	Sf_A	Sf_B	Sv_A	Sv_B
Components	X	X	X	X
Functional	X	X	X	**v**
ICT	**v**	**v**	X	X
Control sequence	Not applicable	Not applicable	**v**	**X**

The updated ICT Requirements for Frequency Control are described in Deliverable D2.4.

A.1.1 Sf_A and Sf_B

The characteristics of the two frequency scenarios are reported in Table 8-2: the main difference of the two scenarios are the presence or not of hydro generation, which means that same functions (such as the RoCoF control) needs different strategies to be pursued.

Table 8-2 Summary of the characteristics of the two frequency scenarios

Scenario	Energy Perspective	Research questions
Sf_A: Mixed Mechanical-Synthetic Inertia	frequency studies up to 100% RES power system hydro generation considered Fully AC network Update of ICT requirements	provide synthetic inertia implement primary and secondary frequency
Sf_B: Full Synthetic Inertia	hybrid AC/DC (with use of HVDC) no inertia Updates of ICT requirements	frequency control by linear swing dynamics (**LSD**) **zero mechanical inertia** intermittent generation intermittent operating reserves

The characteristics described in D1.2 and D1.3 are still valid. For convenience of the reader, Table 8-3 shows the different parts where the characteristics of the two scenarios can be found.

Table 8-3 Indication of the position of different features of Sf_A and Sf_B

Feature	Position
Components	D1.2 – Section 3.2 – p.18
Functions	D1.2 – Section 3.2 – p.18
ICT requirements:	D2.4 – Chapter 3
Sf_A	
Sf_A, inertial control, decentralised control, TSO	D1.3 – Section 3.1.1.1 – p.18
Sf_A, inertial control, distributed control, TSO	D1.3 – Section 3.1.1.3 – p.20
Sf_A, inertial control, decentralised control, DSO	D1.3 – Section 3.1.1.5 – p.23
Sf_A, inertial control, distributed control, DSO	D1.3 – Section 3.1.1.7 – p.25
Sf_A, primary control, decentralized control, TSO	D1.3 – Section 3.1.2.1 – p.29
Sf_A, primary control, distributed control, TSO	D1.3 – Section 3.1.2.3 – p.32[2]
Sf_A, primary control, decentralized control, DSO	D1.3 – Section 3.1.2.5 – p.33
Sf_A, primary control, distributed control, DSO	D1.3 – Section 3.1.2.7 – p.35
Sf_A, secondary control, centralised control, TSO	D1.3 – Section 3.1.3.1 – p.39
Sf_A, secondary control, centralised control, DSO	D1.3 – Section 3.1.3.3 – p.44[3]
Sf_B	
Sf_B, inertial control, decentralized control, TSO	D1.3 – Section 3.1.1.2 – p.19
Sf_B, inertial control, distributed control, TSO	D1.3 – Section 3.1.1.4 – p.22
Sf_B, inertial control, decentralised control, TSO	D1.3 – Section 3.1.1.6 – p.25
Sf_B, inertial control, distributed control, DSO	D1.3 – Section 3.1.1.8 – p.27
Sf_B, primary control, decentralized control, TSO	D1.3 – Section 3.1.2.2 – p.31
Sf_B, primary control, distributed control, TSO	D1.3 – Section 3.1.2.4 – p.32
Sf_B, primary control, decentralized control, DSO	D1.3 – Section 3.1.2.6 – p.34
Sf_B, primary control, distributed control, DSO	D1.3 – Section 3.1.2.8 – p.37

[2] In scenario Sf_A, large power plants are directly connected to the transmission grid. Therefore, the frequency will be controlled by the TSO and not by each generator individually.

[3] In scenario Sf_A, the DSO will not have an active role in the secondary control level. This is due to economic reasons. From the security point of view, one coordinator of this control level is enough.

Sf_A, secondary control, centralised control, TSO	D1.3 – Section 3.1.3.2 – p.42
Sf_B, secondary control, centralised control, DSO	D1.3 – Section 3.1.3.4 – p.45

A.1.2 Sv_A and Sv_B

The characteristics of the two voltage scenarios are reported in Table 8-4: the main difference of the two scenarios is how the voltage should be controlled. In fact, Sv_A focuses on the dynamic control of the voltage, whereas the Sv_B focuses on the active management of the voltage in steady state.

Table 8-4 Summary of the characteristics of the two voltage scenarios

Scenario	Energy Perspective	Research questions
Sv_A: Dynamic Voltage Stability	**voltage transients** **voltage harmonics and stability**	**virtual Output Impedance** (VOI) control high number of controllable power converters
Sv_B: Active Voltage Management	**steady-state** voltage management	**steady-state** voltage control

Some characteristics described in D1.2 and D1.3 are still valid. For convenience of the reader, Table 8-5 will show the different parts where the characteristics of the two scenarios can be found.

Table 8-5 Indication of the position of different features of Sv_A and Sv_B

Feature	Sv_A	Sv_B
Components	D1.2 – Section 4.2 – p.32	D1.5 – Section 3.2.2
Functions	D1.2 – Section 4.2 – p.32	D1.5 – Section 3.2.2
ICT requirements:		
Sv_A	D1.3 – Section 3.2.1 – p.47	
Sv_B	D1.3 – Section 3.2.2 – p.51	

The two algorithms have been modified for Sv_A, whereas the functional and components have been modified for Sv_B, as reported in Section 3.1.1.2 and 3.2.2 of the current version of this deliverable.

A.2 ICT Concepts

This Annex summarizes the updates in the ICT requirements of the control concepts in RESERVE. The details about these updates can be found in D2.4 and D3.6.

For Transmission systems, the project proposes to use powerline and fiber optics communications. The large distances and the relatively small number of end points in the transmission network make the use of 5G mobile communications possible, but not necessarily beneficial.

For frequency and voltage control in Distribution systems, however, this project recommends the use of 5G mobile networks as they offer the following benefits:

- Cost-effective connectivity for very **large number of devices** even in remote, rural areas or densely populated areas, where putting up additional cables would be too expensive. In a large DSO system, there can be 100,000 devices, which need to be connected to the distribution control centers.

- The end points include all types of voltage-sourced power controllers (**VSC**) or converters that connect distributed energy resources (DER), mostly from *renewable energy sources* such as wind and solar energy. The VSCs are also used to connect energy storage systems (ESS), virtual power plants (VPP), or loads, which require frequency control.
- 5G networks include built-in support for low-cost and low-energy **devices**, using concepts such as Internet of Things, massive machine-to-machine communications, and Narrowband-IoT.
- **Latency** in the end-to-end communication must be kept at a minimum, well below 1.0 second, to ensure that the control units can react swiftly on any trends of deteriorating frequency or voltage values.
- **Jitter**, i.e. the variation of transmission times in the communications network, must be kept at a minimum, so that control centers receive incoming frequency or voltage measurements at the same time, avoiding the need for lengthy buffering procedures. The control centers need to analyses the data from the same point in time, in order to compare the frequency and voltage status in various parts of the distribution grid.
- **Bandwidth**, all exchanged information consists of a few Kbytes of data per signal sent. In other words, the needed data volume between two points such as VSC and control center is not higher than 0.5 Mbytes per second.
- **Authentication**, EU and national regulations require that no unauthorized access to the communications system of the electric grid may occur. This is essential to prevent any type of illegal reading, writing or deleting of data being transmitted. The built-in security mechanisms of 5G communications ensure that only authorized users including devices can participate in the communications.
- Secure **end-to-end data encryption** is required on all links, if the communication does not use a closed loop, or private network. 5G mobile connections support the complete encryption of measurements and commands throughout the communications network of the distribution grid.
- **Data integrity** is important and needs to ensure that any measurements and control information sent from one point to another in the power network is not changed by malicious parties. This is an essential requirement imposed on communication infrastructure. Standards such as IEC 61907 can be investigated for different control scenarios.

The following image visualizes the overall layout of the Communications Network for Transmission and Distribution systems.

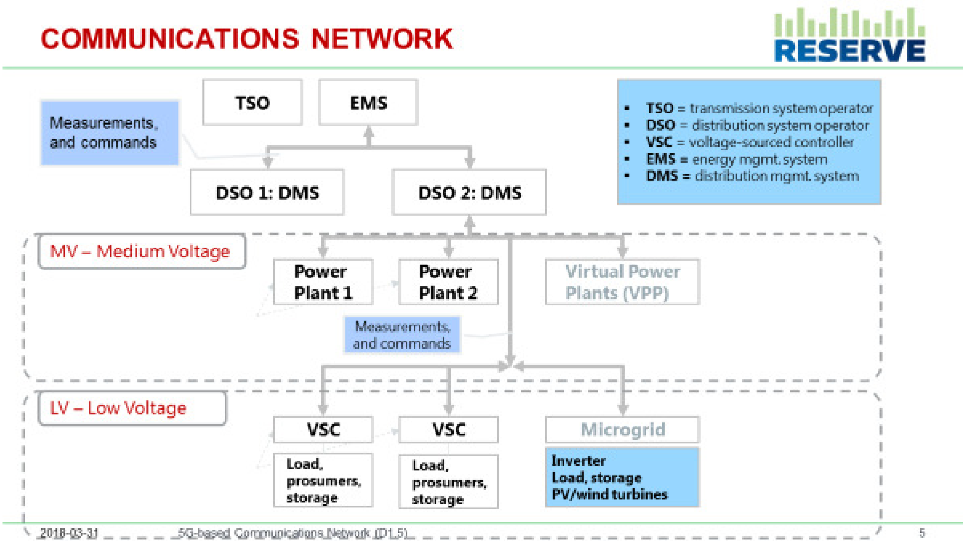

Figure 8-1: Communications Network for Voltage and Frequency Control