RESERVE
D5.6 V1.0
Report on the 100% Renewable Grid Scenario, V1

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Abstract:

The original title of this report was "Report on the 100% Renewable Irish Scenario, V1". The title has been changed because the Romanian transmission system data is more representative for most European countries. More details on the change of title can be found in the introduction. This report describes the simulations to be performed extrapolating a futuristic scenario of 100% renewable in a large grid based on real data from the Romanian transmission system and the Irish distribution system. After giving of an overview of the major results of WP2/3 and the considered network topology, it is explained how these can be used for a large grid study which is implemented on the real-time simulation platform developed in WP4.

Keyword list:

Laboratory, Infrastructure, pan-European, Co-simulation, Romania, 100% Renewable

Executive Summary

The research topics of RESERVE include frequency and voltage control concepts for future grids as well as simulation techniques to enable large-scale distributed real-time co-simulation. The objective of this deliverable and its second iteration is to describe how the co-simulation platform developed in WP4 is used to evaluate the control concepts proposed by WP2/3.

The presented simulation scenarios are going to be conducted with grid data of the Irish distribution system and Romanian transmission system because the Romanian transmission system data is more representative for most European countries. Therefore, the deliverable title was changed from “Report on the 100% Renewable Irish Grid Scenario” to “Report on the 100% Renewable Grid Scenario”.

Before presenting the implementation of the control concepts on the co-simulation platform, it is summarized which components of the power system are involved in the control. In general, the presented control algorithm would be executed either on control center level, primary/secondary substation level or completely decentralized within the controlled components. Every control technique considered for the real-time co-simulation is discussed with regard to this topic.

Finally, it is explained how the control concepts are distributed to the components of the real-time simulation platform: communication network equipment, power system simulators and power system field devices.

Since the mapping of control concepts to co-simulation platform is defined at this stage of the project, the focus lies now on the implementation. The simulation results will be presented in the second version of this report.

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1. Introduction

Renewables in a Stable Electric Grid (RESERVE) is a three-year European Commission funded project within the Work Program H2020-LCE-2016-2017. The project officially started in October 2016.

1.1 Change of Title

The original description of the task stated that the Irish grid would be used for a 100% renewables scenario. It was decided to deviate from this objective and include Romanian transmission system data. In contrast to the Irish transmission system, the Romanian system has more tie-line connections to other European countries. Therefore, the transition from the Irish data to the Romanian data does have advantages in that it makes the simulation case more representable for the situation of the majority of European countries.

1.2 Task 5.4

This deliverable is the first major output of task 5.4 in WP5. Task 5.4 is about a large grid real-time simulation where the concepts developed in WP2/3 are implemented on the simulation platform from WP4. The considered grids are derived from real grid data of the Romanian TSO and Irish DSO. Therefore, the simulation scenario is larger and more realistic than previous simulations conducted in the frame of RESERVE. Compared to the simulation studies in WP2/3, task 5.4 aims at testing in a setup closer to reality which means that the simulation is run in real-time to be able to integrate real communication network equipment and power system field devices.

1.3 Objectives of the Work Report in this Deliverable

The main objectives of this report are the presentation of the considered network topology and components reused from previous work packages. Furthermore, it is explained how we intend to implement the described simulation case on the real-time co-simulation platform developed in WP4. Simulation results will be presented and discussed in the second version of this deliverable which is D5.6.

1.4 Outline of the Deliverable

The first section describes the grid data which is used to compose the considered simulation cases. The next section, gives a brief overview of the results from WP2/3 which are considered in task 5.4. It is also pointed out which components of the power system would be involved for each of the control schemes. This is important for the deployment of the simulation parts onto the real-time co-simulation infrastructure. Finally, it is shown how the different hard- and software components of the real-time co-simulation platform are interconnected and how the tests of the control scenarios are mapped on this platform.

1.5 How to Read this Document

This document can be read on its own, but should the reader want to learn about the concepts implemented on the co-simulation platform or the architecture of the co-simulation platform itself, it is recommended to read deliverables from WP2/3/4 before. Overall, this deliverable (D5.6) is related to other documents in the RESERVE project as depicted in Figure 1.1.

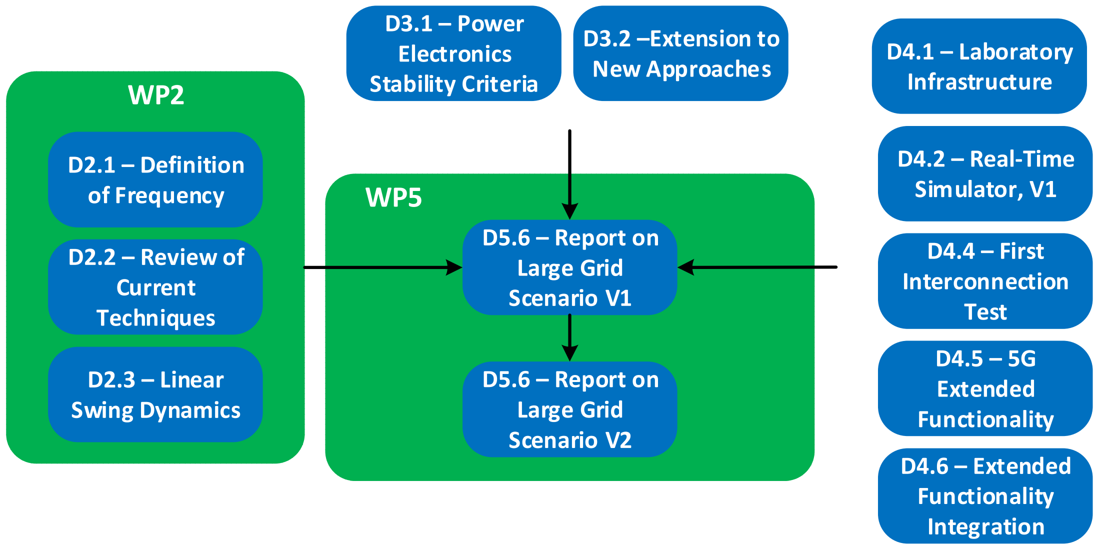

Figure 1.1: Relations between this deliverable and other work

2. The Simulated Power System

The realistic grid scenarios investigated in task 5.4 include three different grid sections:

- A high voltage (HV) grid derived from the Romanian transmission system of TransE
- A synthetic medium voltage (MV) network that extends the high voltage grid and includes distributed energy resources which are used for frequency control
- A low voltage (LV) feeder derived from the Irish distribution grid of ESB and which is considered for the voltage control

Since the frequency control techniques developed in WP2 consider only devices in the HV and MV grid and the voltage control techniques developed in WP3 control devices in the LV grid, the simulation studies are divided into two cases which are depicted in Figure 2.1.

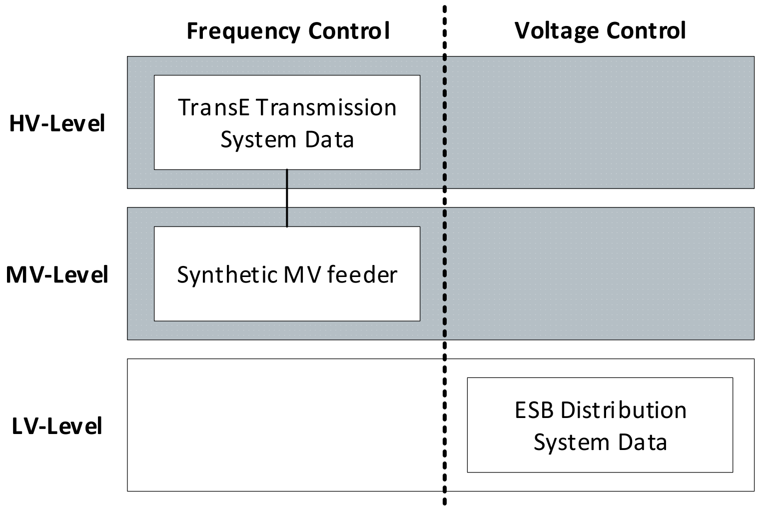

Figure 2.1: Overview of the grid sections considered for frequency and voltage control studies

2.1 High and Medium Voltage Level

The HV system investigated in task 5.4 is derived from the Romanian transmission system. The Romanian power system consists of:

- 81 substations, including one 750 kV substation, 38 substations at 400 kV, and 42 substations at 220 kV, as well as 216 transformers with a total installed power of 38,058 MVA
- 8,834.4 km of transmission lines encompassing 3 km of 750 kV lines, 4912 km of 400 kV lines, 3875.6 km of 220 kV lines, and 40.4 km of 110 kV lines, of which 486.2 km are interconnection lines.

The HV system used in the RESERVE project considers only the HV buses and lines of the Romanian transmission system. The full model of the Romanian power system database contains about 1500 nodes. Therefore, all the 220 kV and 110 kV elements are aggregated to the 400 kV nodes.

Figure 2.2 shows the geographic location of the main (groups of) power plants in Romania, where the different types of generation are represented in different colors. Additional spots illustrating the presence of small generation units can be added, but they are not of interest for our simulations because load and generation are balanced locally. As can be seen, the largest share of generation is concentrated in the South and so are the transmission lines.

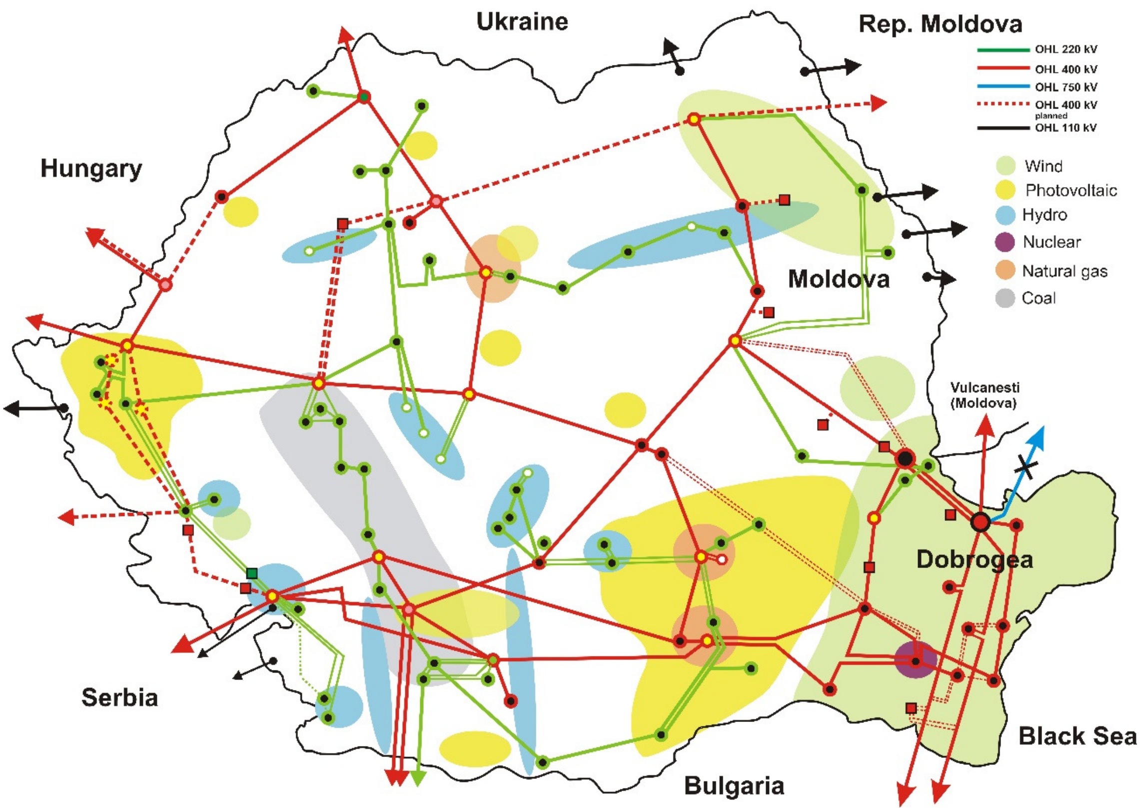

Figure 2.2: Single-line diagram of the Romanian transmission grid and geographic location of the generation sources [2]

Some observations can be made about the geographic location of the power plants:

- The **coal**-fired power plants are located in the same area, as indicated by the gray color.
- Few large **gas**-fired power plants, running all year, are located in two positions. During winter, city power plants are used to produce combined heat and power.
- The **hydraulic** power plants are spread in a large area, and the generation is shared between run-of-river and storage-dam power plants in balanced proportion.
- Out of the 3025 MW [1] installed **wind** capacities in Romania, about 86% (about 2600 MW) are in the Dobrogea region, near the Black Sea. The rest of 14% is mostly located in the North-East of the country.
- A 2x700 MW **nuclear** power plant is also located in Dobrogea, thus more than 4000 MW of installed power are concentrated in this region.
- **Photovoltaic** power plants are spread all over the country; however, the largest power share is located in the south of the country.

Figure 2.3 depicts the development of energy generation since 2008. It can be seen that the power generation from coal and natural gas has decreased from ~55% to ~39%. Meanwhile, the generation from renewable energy sources has increased from ~28% in hydro generation to ~44% since wind and solar are contributing with ~15%.

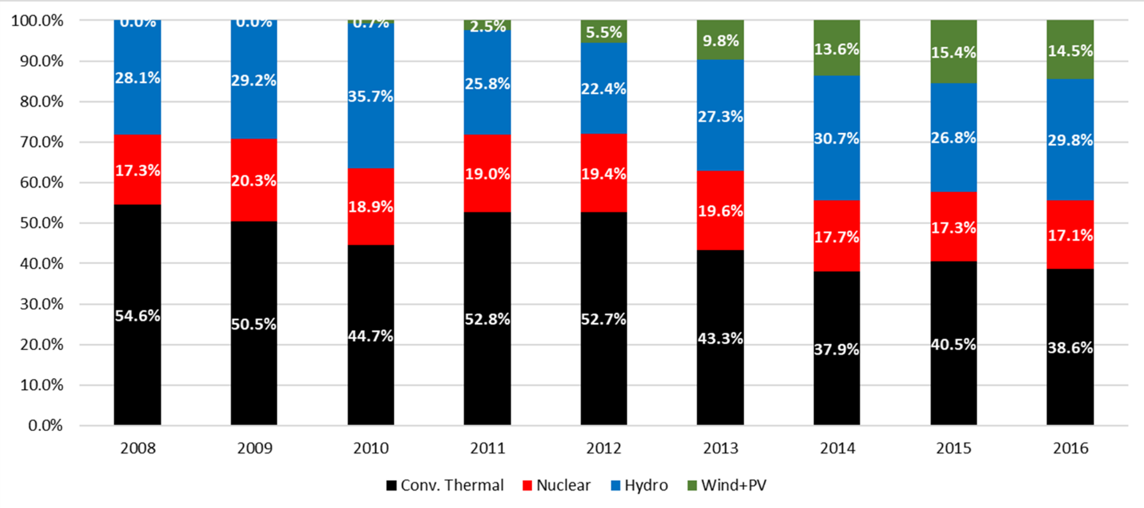

Figure 2.3: Share of electrical energy generation in Romania [3]

According to Transelectrica [4], in 2015, the demand for approval of new wind power plants was about 4550 MW in Dobrogea only. Furthermore, there are requests for approval of new wind power plants in the Moldova region of Romania. All these projects are in stand-by, while no wind power plant was commissioned in 2017 because of the change in the legislation for supporting renewable energy sources by green certificates.

The coal- and gas-fired power plants, most of them located in South, will be replaced with RES based power plants, also located in the south. The transmission network may not require dramatic changes in the configuration, however, new transmission lines may be required to relay the power produced in Dobrogea region. It is foreseen that construction of new AC transmission lines is more and more difficult because of the cost of the land, and therefore, HVDC technology will be adopted.

Based on the above-mentioned assumptions, three network configurations of the Romanian power system have been considered for the 2030 time horizon:

- RO-195 bus system, that includes the whole 400kV transmission network, and the block transformers of the power plants;
- RO-119 bus system, reduced to the southern part of the transmission network;
- RO-29 bus system, reduced to the Dobrogea region; the reason for keeping this region is that in the future, the largest part of the generation capacity will be installed here.

Since some of the frequency control techniques developed in WP2 employ MV-level devices, the described HV grid is extended by MV grid feeders according to Figure 2.4.

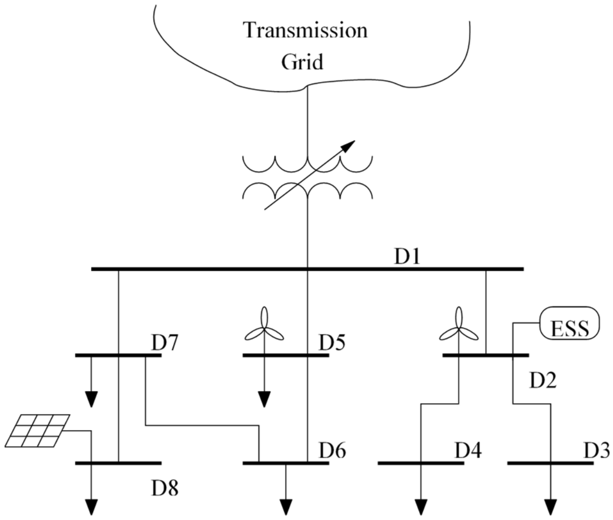

Figure 2.4: MV grid section including DER devices

The MV distribution network section, depicted in Figure 2.4 is composed of eight buses, eight lines, six loads, two wind power plants, one solar PV plant, and one Energy Storage System (ESS). The operating nominal voltage of busses D1-D8 is 38 kV and the distribution system is connected through an Under-load Tap Changer (ULTC) type step down transformer with the transmission grid. The network parameters are adjusted according to the grid connection point. The original parameters can be found in [5].

The DER devices in this grid section are used for the frequency control techniques developed in WP2. Since the DER devices do not include synchronous generators directly interfaced to the grid, the frequency measurements are relayed to the DERs from a substation or locally measured at the DERs' converter site.

2.2 Low Voltage System

The LV feeder for voltage control studies is derived from Irish grid data provided by ESB. Busses 1 to 11 are connected via three phase lines whereas the remaining 9 busses only have single phase connections. This section is connected to the MV grid through a 10kV-400V transformer operating on a fixed tap. Different load profiles are considered for each bus and phase. The single phase representation of the grid is depicted in Figure 2.5.

For the voltage control studies, it is assumed that the 9 buses with single phase connections host a 3kW Vehicle-to-Grid device. The converter of this device has a wireless connection to an edge computing unit running the voltage control algorithm.

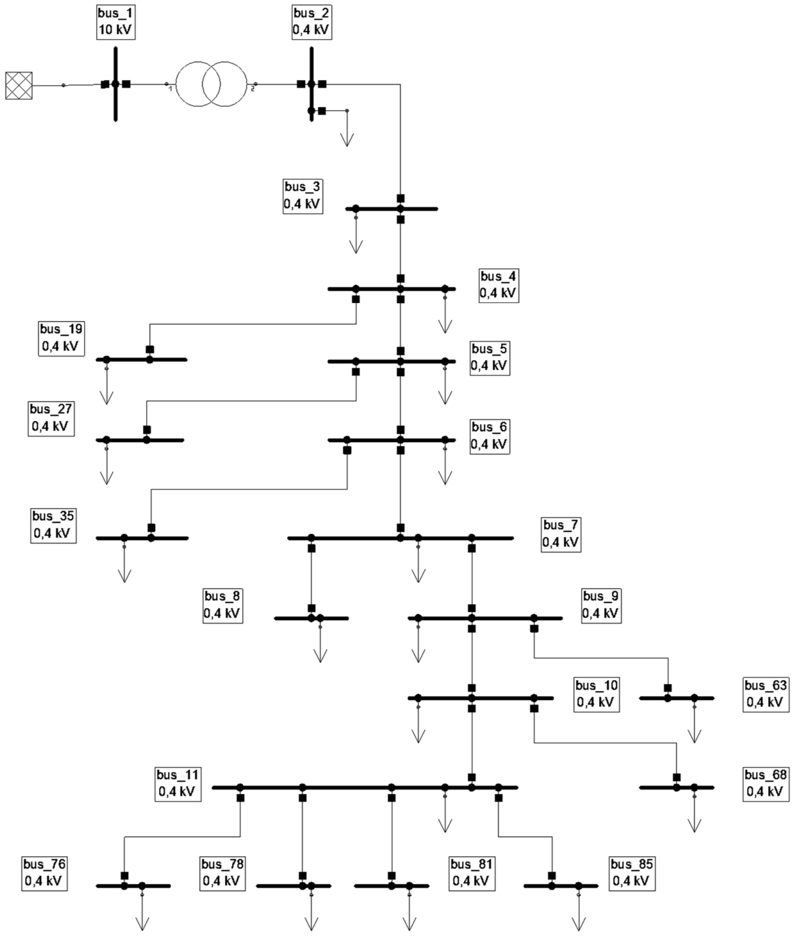

Figure 2.5: LV network feeder

3. Overview of New Control Techniques Developed in RESERVE

This chapter gives a broad overview of the developed control techniques which can be implemented for the large grid scenario described in this deliverable. Whenever possible, there are indications on where to find more details in other deliverables. Here, the focus is on the power system components involved in the control scheme and the communication required for control.

3.1 Control Techniques and Distributed Cloud System

The distributed cloud system which consists of an edge computing solution and a base station is considered to be located in or close to a secondary substation. Therefore, the parts of the described control concepts which run in secondary substations can be deployed to the distributed cloud system. The base station provides wireless communication channels to LV / MV facilities. Besides, the base station is connected to the core network which allows communication with other parts of the grid that might be out of reach for wireless communication.

3.2 Frequency Control Techniques

3.2.1 Primary Frequency Control (SF_A / SF_B)

The primary frequency control algorithms developed in WP2 can be divided into decentralized and centralized approaches. The centralized approaches always rely on communication, whereas the decentralized controllers might work independently from the communication network or in a Peer-to-Peer communication scheme. For the real-time simulation tests, it is envisioned that communication with or between MV-level components could be provided by a distributed cloud system including a base station located at the secondary substation.

A.1.1 Decentralized

In the decentralized case each generation unit acts only on its local measurements or communicates to peers, which are on the same level in the control hierarchy, as depicted in Figure 3.1. In the latter case, the control is denominated decentralized-coordinated control.

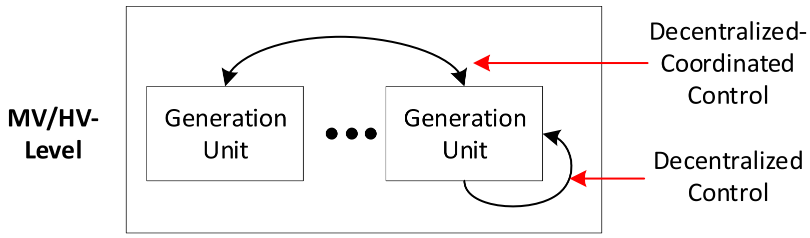

Figure 3.1: Scheme of the decentralized and decentralized-coordinated primary frequency control provided by the distribution system

The concepts related to local frequency measurements only are further described in deliverable D2.1 and D2.2. In this case, there is no communication between generation units or with the control centre related to primary frequency control. At the moment, the focus is on MV-level components such as wind turbine and solar generation plants.

The Linear Swing Dynamics approach, detailed in D2.3, can be designed as decentralized control with and without coordination between peers. If communication is required, it could be either provided by wireless or wired communication networks depending on the distance between generation units. Currently, this approach is being evaluated for components connected to the HV-level.

A.1.2 Centralized

In the centralized primary frequency case, the frequency is either measured at the point of common coupling between MV and HV grid, where the secondary substation is located, or the frequency measurements of several devices with Phase-Locked-Loop (PLL) are averaged and sent to the secondary substation. Then, this frequency measurement signal is distributed to all generation units in the MV grid. The data exchange between the different devices is depicted in Figure 3.2. More details on this control technique and its variants are given in D2.1 and D2.2.

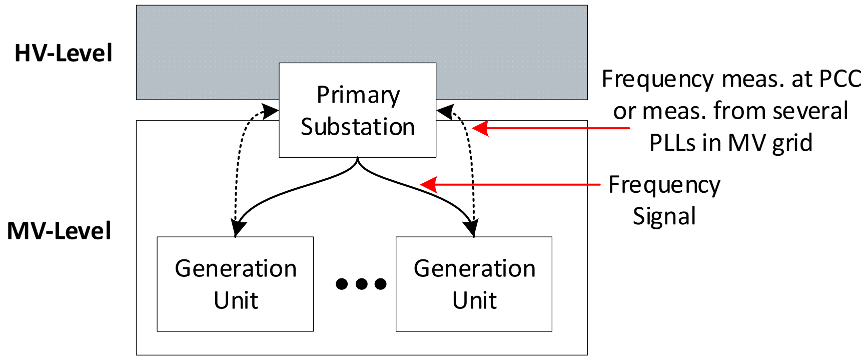

Figure 3.2: Scheme of the centralized primary frequency control provided by the distribution system

3.2.2 Secondary Frequency Control (SF_A / SF_B)

The secondary frequency control algorithm developed in WP2 is a centralized approach, which relies on communication between the control center, the secondary substations at the MV/HV interconnection nodes and the participating generation units. In contrast to the traditional secondary frequency control, the developed concept includes distribution level devices in the frequency control. For this reason, the power control signals sent by the TSO control centre are broken down into smaller contributions on distribution level as depicted in Figure 3.3. Since distribution level generation units are typically smaller, each unit can contribute a part of the total demand that is requested from the network connected to the secondary substation. A more detailed description of this concept will be found in deliverable D5.5.

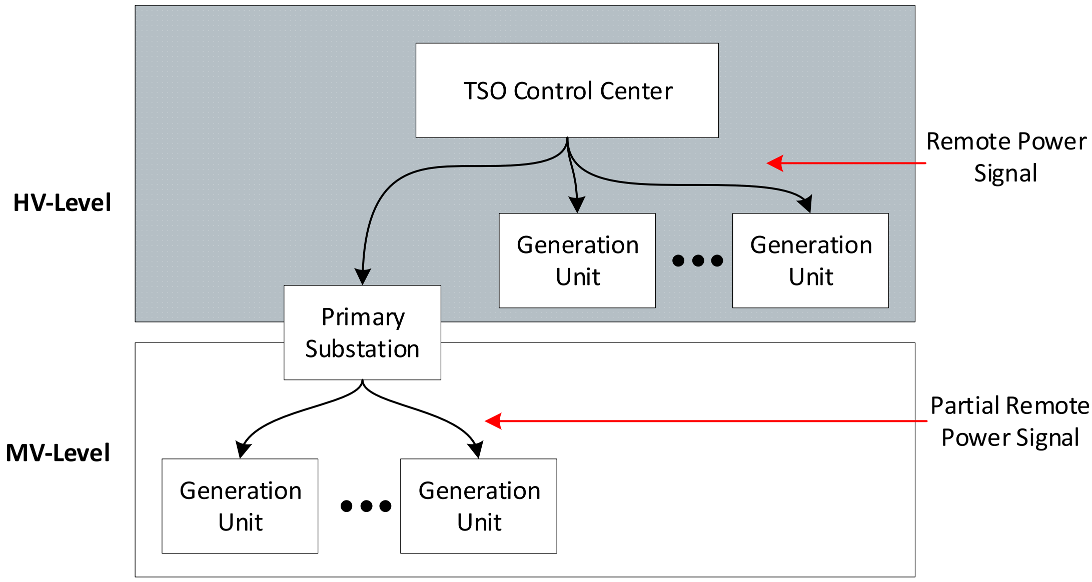

Figure 3.3: Scheme of the centralized secondary frequency control supported by the distribution system

3.3 Voltage Control Techniques

The two voltage control techniques developed in this project rely on communication between the secondary substation and the converters connected to the LV grid. Both techniques require measurements from the converters to generate new set-points which are sent back as indicated in Figure 3.4.

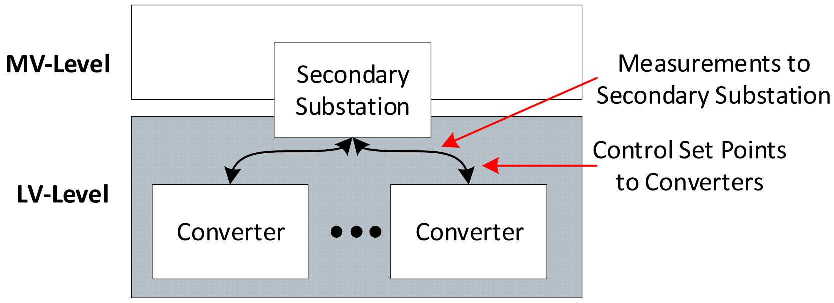

Figure 3.4: Scheme of the centralized voltage control in the LV system

3.3.1 Dynamic Voltage Stabilization (SV_A)

The dynamic voltage stabilization is described in more detail in deliverable D3.2. To summarize, the converters send the grid impedance measured from the converter site to the secondary substation and receive a control set point for their own output impedance. The output impedance of the converters is calculated to ensure stability according to Middlebrook's theory.

3.3.2 Active Voltage Management (SV_B)

The active voltage control requires the converters to send local voltage measurements to the secondary substation. The measurements are input to the volt-VAr curves which are calculated according to D3.2. The resulting reactive power output set points are sent to the converters. This way the voltage should be stabilized by reactive power compensation.

4. Implementation in Pan-European Co-Simulation Platform

The implementation of this simulation scenario, requires

- the interconnection of the simulation sites and devices using the software developed in WP4
- the implementation of the described grids on real-time simulators and
- the implementation of the control techniques developed in WP2/3 on the real-time simulators and 5G equipment.

Therefore, this section gives a brief overview of the components involved in the co-simulation before describing where the algorithms are implemented.

4.1 Hardware Setup and Interconnection of Simulation Sites

In the following, the simulators depicted in Figure 4.1 are aggregated and referred to as “simulation infrastructure”. Therefore, it is imported to note that the simulation infrastructure in the following diagrams may include simulators from several simulation sites, as shown in Figure 4.1, depending on the size of the simulated grid.

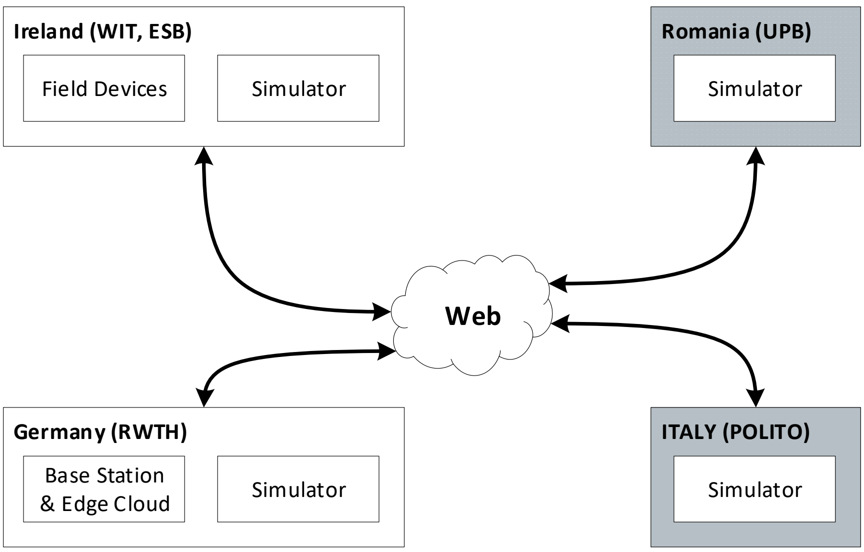

Figure 4.1: Real-time simulation sites and field devices / 5G equipment

Apart from splitting up networks and distributing the computational load by distributing the simulation model parts to several simulation sites, the simulation of larger grids should be enabled by simulating parts of the grid in dynamic phasors. EMT simulations are only conducted for the parts which require high accuracy also in dynamic situations.

Dynamic phasors do not lead to a degradation of accuracy per se as shown in D4.2 but the increased time step that would be employed in this scenario introduces inaccuracies. The time step is increased because this way there is more computation time available for each local simulation step and also the exchange of data between simulation sites. More information about dynamic phasors and why they are used in RESERVE is given in D4.2.

Since there is no commercial dynamic phasor solver available today, DPsim, a reference simulator developed within task 4.3 is used for this purpose. EMT simulations are conducted in commercial EMT solvers as shown in Figure 4.2.

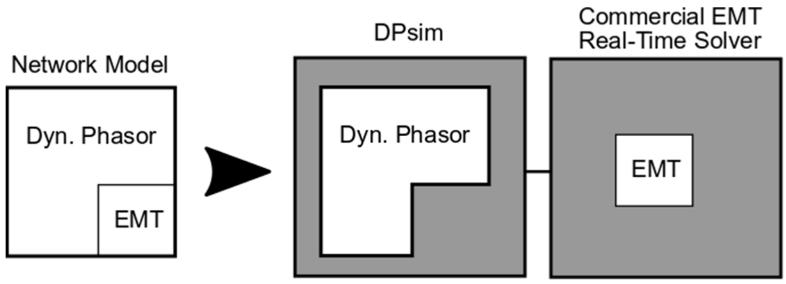

Figure 4.2: Co-simulation using dynamic phasor and EMT

The advantage of this combination of solvers is that Hardware-In-the-Loop experiments, which require a very accurate, small time step simulation, can be conducted with the EMT simulator while the surrounding network is simulated on a broad scale instead of being represented by an aggregated equivalent model or a very detailed EMT model which would be much more demanding in terms of computational power.

In the following, the spatial distinction of simulation sites as in Figure 4.1 is omitted and instead the focus lies on the different types of devices as depicted in Figure 4.3. The real-time experiments feature real-time simulators, communication network hardware and power system field devices.

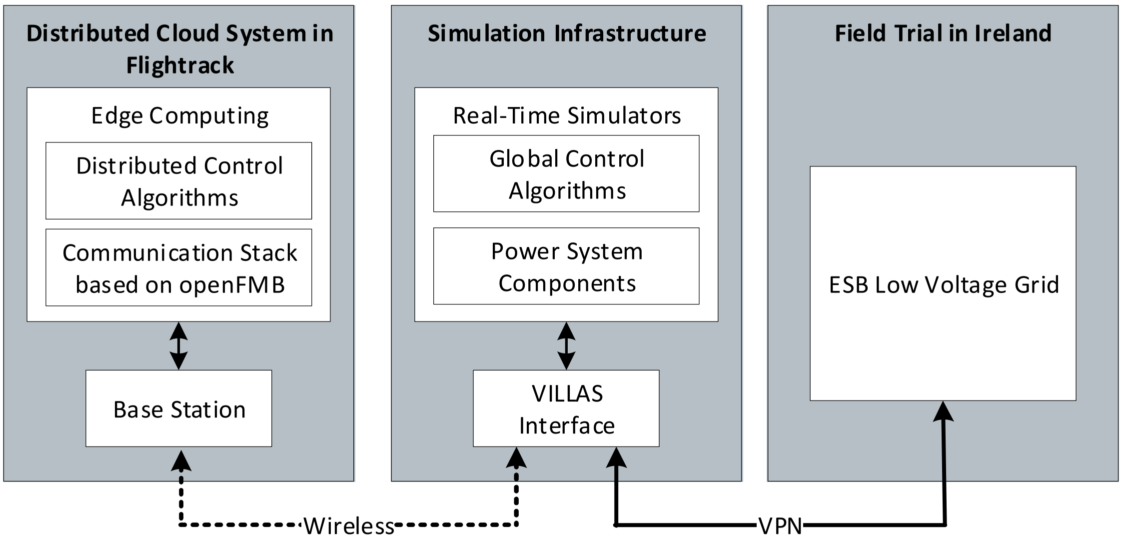

Figure 4.3: Hard- and software setup for the real-time co-simulation studies in RESERVE

The distributed cloud system in a flight rack is located in the RWTH laboratory and includes edge computing capabilities as well as a base station which is connected to the core network and to the simulators in the same laboratory. While openFMB is handling the exchange of communication between the base station and distributed control algorithms inside the flight rack, VILLAS is the interface between the wireless connection and the real-time simulators. VILLAS is not only used to interconnect the simulation sites but also the field trial sites in Ireland and the simulation sites.

Since the power system is simulated in real-time, the wireless connection between the base station and the simulators allows to test new monitoring and control concepts in a setting much closer to reality than offline simulation.

4.2 Frequency Control Techniques

Mostly, the primary frequency control techniques developed in WP2 do not require communication on transmission system level. In case transmission level components need to communicate it is assumed that a wired connection would be used due to the large distances in transmission systems.

The distribution system control techniques that require communication are going to be deployed to the distributed cloud system which is supposed to be located close to or in the substation. This is indicated by the blue box in Figure 4.4. It is assumed that in distribution grids the spatial distribution of controlled DERs would be small enough to use 5G communication for control purposes

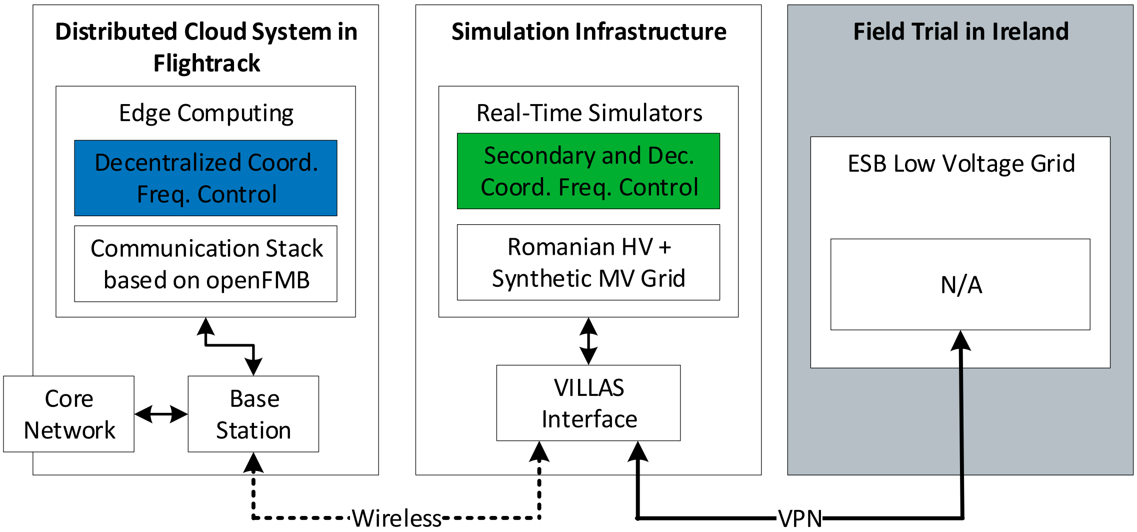

Figure 4.4: Hardware and software components for real-time frequency control experiments

Transmission system level techniques such as the HV level secondary control and decentralized coordinated control between HV peers are implement inside the real-time simulators, indicated in green, since the spread of communication participants is assumed to be very large for wireless communication as mentioned previously.

In the frequency control case, it is not planned to integrate power system field devices because the available devices are located in the LV level which is not considered for frequency control purposes in WP2.

4.3 Voltage Control Techniques

The proposed voltage control techniques are both designed to be deployed to secondary substations which makes them suitable for execution on distributed cloud systems as represented in blue in Figure 4.5.

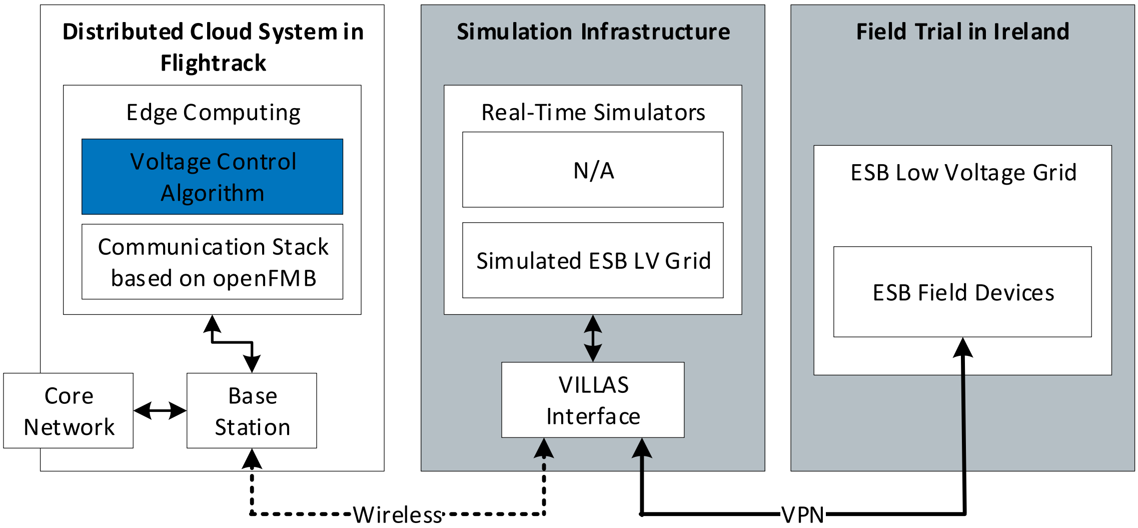

Figure 4.5: Hardware and software components for real-time voltage control experiments

In addition to the experimental setup for frequency control, the field devices in Ireland are used to test the voltage control concepts. The connection between the field sites and the simulation infrastructure as well as the distributed cloud system is established through VILLAS.

5. Conclusion

From this deliverable, it can be seen how the concepts prepared in WP2/3 are going to be implemented in the real-time infrastructure provided by WP4. This allows much more realistic experiments than sole offline simulation because real communication equipment as well as power system field devices can be connected to the simulation environment.

What we have achieved so far is

- the development and implementation of a dynamic phasor based simulator and a co-simulation interface to interconnect simulation sites
- the integration of the communication network hardware with the simulation infrastructure
- the implementation of the MV and LV networks, some of the primary frequency control techniques from WP2 and the active voltage control technique from WP2 in the real-time simulators

The next steps are

- extensions to the real-time dynamic phasor simulator to allow for larger and more complex simulations
- the implementation of the Romanian system in the real-time simulation infrastructure
- the implementation of the remaining frequency and voltage control techniques
- the integration of the Irish field sites with the simulation infrastructure and communication network hardware

6. References

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[3] Transelectrica, Network operation. Online: http://transelectrica.ro/web/tel/functionare-retea

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[5] C. Murphy, A. Keane, “Local and Remote Estimations Using Fitted Polynomials in Distribution Systems,” IEEE Transactions on Power Systems, vol. 32, no. 4, pp. 3185-3194, July 2017.

7. List of Abbreviations

HV	High Voltage
MV	Medium Voltage
LV	Low Voltage
ESS	Energy Storage System
ULTC	Under-load Tap Changer

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