Smart TSO-DSO interaction schemes, market architectures and ICT Solutions for the integration of ancillary services from demand side management and distributed generation

Evaluation report for SmartNet pilots

D5.4

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About SmartNet

The project SmartNet (http://smartnet-project.eu) aims at providing architectures for optimized interaction between TSOs and DSOs in managing the exchange of information for monitoring, acquiring and operating ancillary services (frequency control, frequency restoration, congestion management and voltage regulation) both at local and national level, taking into account the European context. Local needs for ancillary services in distribution systems should be able to co-exist with system needs for balancing and congestion management. Resources located in distribution systems, like demand side management and distributed generation, are supposed to participate to the provision of ancillary services both locally and for the entire power system in the context of competitive ancillary services markets.

Within SmartNet, answers are sought for to the following questions:

- Which ancillary services could be provided from distribution grid level to the whole power system?
- How should the coordination between TSOs and DSOs be organized to optimize the processes of procurement and activation of flexibility by system operators?
- How should the architectures of the real time markets (in particular the markets for frequency restoration and congestion management) be consequently revised?
- What information has to be exchanged between system operators and how should the communication (ICT) be organized to guarantee observability and control of distributed generation, flexible demand and storage systems?

The objective is to develop an ad hoc simulation platform able to model physical network, market and ICT in order to analyse three national cases (Italy, Denmark, Spain). Different TSO-DSO coordination schemes are compared with reference to three selected national cases (Italian, Danish, Spanish).

The simulation platform is then scaled up to a full replica lab, where the performance of real controller devices is tested.

In addition, three physical pilots are developed for the same national cases testing specific technological solutions regarding:

- monitoring of generators in distribution networks while enabling them to participate to frequency and voltage regulation,
- capability of flexible demand to provide ancillary services for the system (thermal inertia of indoor swimming pools, distributed storage of base stations for telecommunication).

Partners

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List of Abbreviations and Acronyms

Acronym	Meaning
aFRR	automatic Frequency Restoration Reserves
AS	Ancillary Services
BCM	Balancing and Congestion Management
CMP	Commercial Market Party
DC	Direct Current
DER	Distributed Energy Resources
DG	Distributed Generation
DSO	Distribution System Operator
EDM	Energy Data Management
GSM	Global System for Mobile communications
HV	High Voltage
HVRS	High Voltage Regulation System
ICT	Information and Communication Technologies
LA	Load Area
LMO	Local Market Operator
LV	Low Voltage
mFRR	manual Frequency Restoration Reserves
MO	Market Operator
MPC	Model Predictive Control
MV	Medium Voltage
MVRS	Medium Voltage Regulation System
OPF	Optimal Power Flow
PCR	Plant Central Regulator
POD	Point of Delivery
PV	Photovoltaic
RES	Renewable Energy Resources
SCADA	Supervisory Control And Data Acquisition
TSO	Transmission System Operator
VPP	Virtual Power Plant

Executive Summary

The objective of the technological pilots developed in SmartNet was to demonstrate the real-life applicability of the TSO-DSO coordination schemes defined in the project and to identify potential implementation barriers, which could not be anticipated in the simulations performed in WP4. In fact, despite the gaining importance of the TSO-DSO coordination topic, there are few real-life experiences, so these three technological pilots are very important to bridge the gap between present conditions and the theoretical developments in the rest of the project.

As the future pan-European market for ancillary services (AS) will be composed of different products, including voltage regulation and frequency regulation, it was important that the pilots demonstrated the feasibility of small-scale units to provide these services. Moreover, since there is a minimum bid size to be eligible to participate in the provision of ancillary services and, hence, small-scale flexibility providers need to be aggregated to participate in these markets, the pilots also had to test aggregation of small-scale distributed energy resources (DER).

The three technological pilots defined and implemented in SmartNet took into account present regulatory and market conditions and, as far as possible, implemented the coordination schemes and the market setups defined within the project. This way, the pilots demonstrated the applicability of those concepts and uncovered several implementation issues (regulatory, technical and practical) which could not have been anticipated before the start of the project.

The three pilots were deployed with a holistic view, so that they complemented each other:

- Each of them focused on different parts of the TSO-DSO coordination value chain, so that one of them looked at the communication requirements between the TSO and the DSO, another one investigated the issues arising from the broadcasting of unidirectional price signals from the aggregator to the DER and the third one studied the capability of the DSO to run a local flexibility market.
- Different potential TSO-DSO coordination schemes were demonstrated, so that issues arising from each of them can be identified.
- Different types of DER were considered, so that their flexibilities could be better assessed and the advantages and disadvantages for real-life implementation were properly identified and addressed.
- Each physical pilot was defined for one of the same national cases (Italy, Denmark, and Spain) used in the SmartNet simulator, in order to analyse issues regarding the monitoring of distribution parameters from transmission and analyse modalities for the acquisition of ancillary services from specific resources located in distribution systems (indoor swimming pools and radio base stations of a telecommunication company).

Based on the results of the pilots, there are no apparent implementation barriers which should prevent the implementation of the different coordination schemes. Therefore, it can be concluded that the three pilots were successfully completed and resulted in several very important lessons learnt for the next step to be taken to deploy the concepts developed in SmartNet, which is the replication of these pilots in other regulatory environments, with different flexibility providers and at a larger scale.

The Italian pilot demonstrated that the information of the units located in the distribution grid can be aggregated and communicated to the TSO with a very high frequency (aggregated every 4 seconds and communicated every 20 seconds). Moreover, it was also demonstrated that DER can provide voltage regulation for the TSO, even if the capability of DER to regulate voltage at transmission level is significantly lower than the potential of big power plants. Likewise, RES can contribute to frequency regulation (probably, to mFRR), but their response time is not in line with the present requirements of the aFRR process.

The Danish pilot confirmed the technological feasibility of using unidirectional penalty signals to modify the consumption profile of summer houses and, hence, to provide AS which are useful for the TSO or the DSO. Indirect control through penalty signals proved to be a lightweight approach which, however, needs a strong communication network to have the system working and requires a deep knowledge by the aggregator to calculate the flexibility functions for the DER.

The Spanish pilot proved that the DSO can sustain a scheduled exchange program at the TSO-DSO interconnection, while avoiding congestions in the distribution grid, by running a local flexibility market. Furthermore, the pilot evidenced the capability of radio base stations to provide flexibility to be used for AS provision to the DSO, without any impact on their core business of providing communication service. For this purpose, the use of standard protocols and an appropriate vendor management showed to be of key importance.

1 Introduction

The increasing amount of generation produced by Renewable Energy Sources (RES) is crucially challenging the pan-European electricity market. These resources have peculiar characteristics (in particular, the variability of their generation pattern) which push towards a reshaping of the traditional transmission system at all levels: local, national and even transnational. In particular, RES generation is leading to increasingly important challenges in terms of frequency stability, congestion management, voltage regulation and power quality, due to its variable behaviour.

At the same time, big transformations are also affecting the distribution activity and its interactions with the transmission system, as a result of the deployment of distributed energy resources (DER), i.e. distributed generation (DG), local storage and flexible loads. In the future, distribution networks will inject a growing amount of energy into the transmission system, and these electricity volumes could be linked to local storage and provide both local compensation and services for the entire system. Beyond local services for distribution grids (voltage regulation, congestion management), resources located in distribution could be helpful for providing reserve provision for the entire system through the connection points to the transmission grids. This would bring a technological advancement of distribution system and the necessity to manage scattered bids coming from DG and active loads. Information and Communication Technologies (ICT) should ensure a seamless integration of these bids within the transnational ancillary services (AS) market and the control carried out by the distribution system operators (DSOs) of the dispatching in their relevant areas.

A delicate issue in this concern is the interface between transmission system operators (TSOs) and DSOs which is a crucial factor to ensure an overall efficiency target. On one side, the DSO network would have to retrieve resources for local services (e.g. voltage support, congestion management) and on the other, it should function as a collector of services for the whole system, in coordination with the adjoining TSO. Therefore, an appropriate coordination between TSOs, DSOs and aggregators will be needed. For this reason, it is interesting to analyse to which extent DER can replace traditional generation in the services provision to network operators. The participation of these distributed resources in the AS markets will require a change in the roles of the distribution companies, as well as greater cooperation and coordination between them and the TSOs. This was recognized by the European Union itself in its Proposal for a Directive on common rules for the internal market in electricity (Article 32, [1]), where it gives the distributor the responsibility to manage the congestion that may appear in its network and enables it to establish market mechanisms to acquire the necessary flexibility to do so, but not to balance the system frequency, whose management remains in the TSO's hand.

Although the coordination between TSOs and DSOs is a topic which is gaining importance, there are few real-life experiences. The project SmartNet provided an important contribution to the ongoing discussions by implementing three technological pilots to bridge the gap between present conditions and

the theoretical developments in the rest of the project. For that purpose, the pilots took into account present regulatory and market conditions and, as far as possible, implemented the coordination schemes and the market setups defined within the project. This way, the pilots demonstrated the applicability of those concepts and uncovered several implementation issues which could not have been anticipated before the start of the project.

The three technological pilots were deployed with a holistic view, so that they complemented each other. First of all, each of them focused on different parts of the TSO-DSO coordination value chain, so that one of them looked at the communication requirements between the TSO and the DSO, another one investigated the issues arising from the broadcasting of unidirectional price signals from the aggregator to the DER and the third one studied the capability of the DSO to run a local flexibility market. Furthermore, different potential TSO-DSO coordination schemes were demonstrated, so that issues arising from each of them can be identified. Moreover, different types of DER were considered, so that their flexibilities could be better assessed and the advantages and disadvantages for real-life implementation were properly identified and addressed. Besides, each physical pilot was defined for one of the same national cases (Italy, Denmark, and Spain) used in the SmartNet simulator, in order to analyse issues regarding the monitoring of distribution parameters from transmission and analyse modalities for the acquisition of ancillary services from specific resources located in distribution systems (indoor swimming pools and radio base stations of a telecommunication company).

The first pilot was implemented in Italy, in an area with high penetration of RES, especially run-of-river hydro, and low demand. Therefore, the TSO was facing the challenge of reverse power flow, i.e. the situation in which power was going from distribution up to transmission. Without observability over the distribution grid, the TSO could not anticipate the amount of power coming up from distribution, with the consequent uncertainty in terms of voltage and frequency control. Hence, the pilot focused on information aggregation by the DSO. In particular, the DSO aggregated real-time information for load and for generation per type of source, which was also used to better forecast grid conditions in upcoming periods. This way, the TSO could anticipate (and avoid) problems in the transmission network and estimate the flexibility that DER could provide for controlling the voltage or to helping balance the system.

The second pilot was deployed in Denmark, with the aim of demonstrating the potential of using price signals to flexibility in summer houses. The summer houses involved in the pilot were equipped with indoor swimming pools, with large thermal inertia. Accordingly, the moment to activate the pumps to circulate hot water into the swimming pools could be shifted to obtain an economic incentive, while keeping water temperature within comfort limits. A characteristic feature of this pilot was the use of price signals to provide the incentives to house owners to provide the required flexibility. For that purpose, the aggregator had to build up the flexibility curve, i.e. the amount of flexibility that summer houses would

provide for different price levels, which was used to bid into a common market, where both the TSO and the DSO posted their balancing and congestion management needs.

The third pilot was installed in Spain, with the objective of demonstrating the technical feasibility of creating a new, local market for congestion management and managed by the DSO. The pilot considered the coordination scheme in which the balancing responsibility is shared between the TSO and the DSO, so that both must ensure the fulfilment of a scheduled program (agree among the two parties) in each TSO-DSO interconnection point. As a result, the DSO organized a local flexibility market, where aggregators bid the flexibility of different types of DER to solve congestions in distribution networks and to meet the requirements of the scheduled program. In this case, flexibility was obtained from radio base stations, leveraging on the availability of back-up batteries, which were installed for maintaining the mobile communication service in case of a blackout, but which were almost never used.

	Pilot A	**Pilot B**	**Pilot C**
Country	Italy	Denmark	Spain
Coordination scheme	Centralised AS market	Common TSO-DSO AS market	Shared balancing responsibility
Services to be gathered by the TSO/DSO	Aggregation of information for the TSO Voltage control for the TSO Frequency control for the TSO	-- Congestion management for the DSO Frequency control for the TSO	-- Congestion management for the DSO Frequency control for the DSO
DER providing flexibility	Run-of-river hydro power plants	Hot water impulsion pumps for indoor swimming pools in rental houses	Back-up batteries for radio base stations used in mobile phone communications
Main focus of the pilot	TSO-DSO communication Aggregation of information Assessment of DER capability to participate in markets	Price-signals from aggregators to obtain DER flexibility Communication chain from market to DER through aggregators	Creation and operation of local flexibility markets Assessment of base station capability to provide services for grid support Monitoring of distribution network

Table 1.1 Complementarity of pilots

2 Focus on information exchange between TSOs and DSOs: the Italian pilot

The first pilot [2] was realised in Italy, in an area with low demand and high production from RES, resulting in reverse power flow from distribution to transmission level. The purpose of the pilot was to develop, implement and test in field innovative devices to demonstrate the technical feasibility of increasing the monitoring of the distribution grid and the controllability of RES connected at lower voltage levels.

2.1 Pilot setup

In Italy, the adoption of a policy that aims to encourage the development of new and renewable forms of energy and the fossil fuel replacement has resulted in a strong growth of the RES penetration. As shown in Figure 2.1, about 6.6 GW of wind power capacity and about 19.6 GW of photovoltaic (PV) capacity have been installed since 2008.

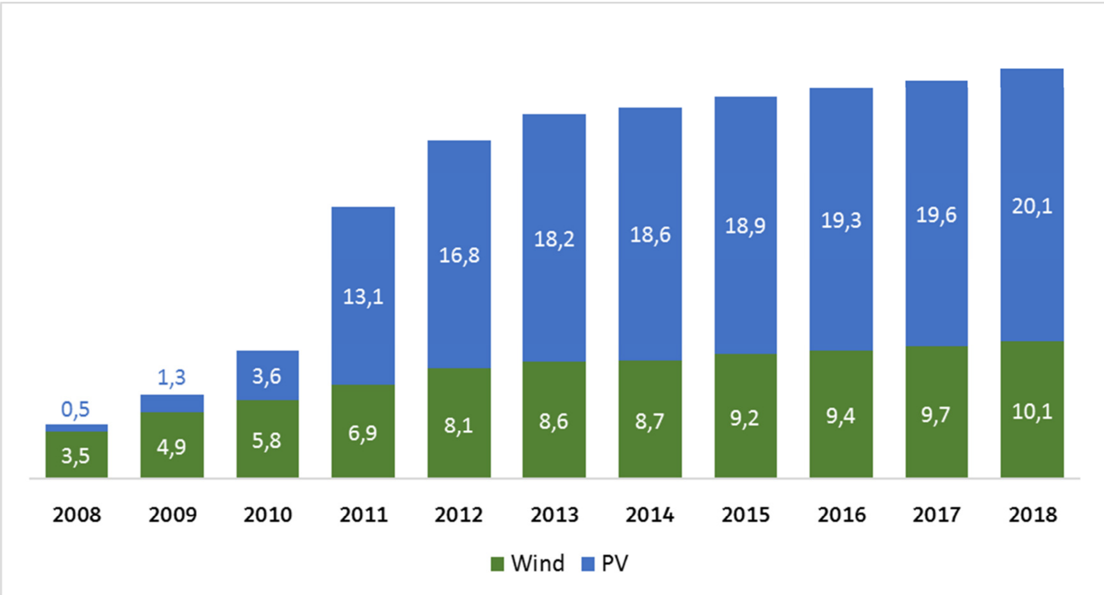

Figure 2.1 Wind and PV capacity installed in Italy (GW), 2008-2018 [3]

This increase in RES production led to two main challenges for the operation of the power system. On one hand, renewable energy sources have a variable behaviour which depends on aleatory primary energy sources (wind, sun or water). On the other hand, the growth of RES penetration is closely linked to the spread of DG, because RES plants are usually small-sized and, hence, often connected to the distribution network, especially PV panels and small hydro power plants.

The consequence is that the power generation structure is moving from a system which was mainly characterised by few, big traditional plants connected to high voltage (HV) transmission grid and directly controlled by the TSO to a park composed by numerous unpredictable power plants connected to medium voltage (MV) and low voltage (LV) grids. In the past, distribution grids were traditionally planned and operated as passive networks, where power flows were unidirectional, from the HV grid, where generation plants were connected, to the distribution grid, mainly composed by loads. However, the growing penetration of DG often leads to reverse power flows, that is, the situation in which there is local oversupply at the distribution level (when DG exceeds local consumption connected to the same substation) and the power rises-up from lower to upper voltage levels of the grid. The bidirectional nature of these power flows may have a big influence in the power system management and in the operation of the transmission grid, especially in three aspects:

- Increased voltage in the HV grid, with the subsequent need of resources to control and regulate the grid voltage.
- Inadequate automation and monitoring capabilities of existing devices at the HV side of the primary substation.
- Reduced selectivity and efficiency of load curtailment processes in case of emergency.

Figure 2.2 shows the growth of the impact of reverse flow in the transformers of the main Italian DSO. This scenario is particularly evident in areas where DG has high penetration, such as low-demand mountain areas where many small-sized hydro power plants are installed.

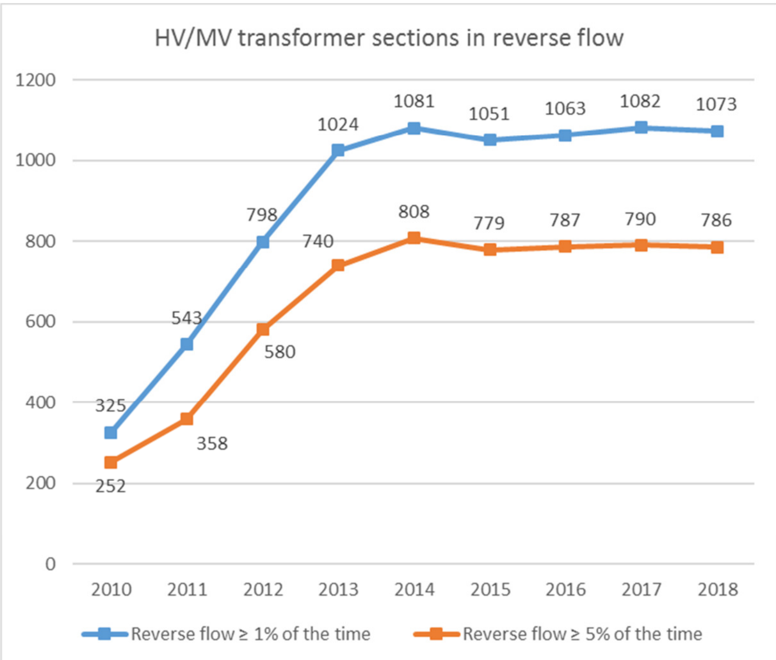

Figure 2.2 HV/MV transformer sections of e-distribuzione in reverse flow [3]

Furthermore, the high penetration of non-programmable DG implies issues related to the capability to regulate system frequency and voltage profiles. Today, only (traditional) programmable, big power plants provide ancillary services for frequency and voltage regulation, as well as reactive power control. RES generators, due to the intermittent nature of the resource they use, cannot foresee and ensure a fixed power exchange with the system, so they cannot provide the ancillary services required by the TSO and, hence, thermoelectric plants will need to be kept in operation, even at off-peak times, to provide the required ancillary services. Moreover, the spread of RES also leads to the reduction of both downward reserve (particularly during daylight hours when the non-controllable PV generation is high) and upward reserve (particularly during periods of drought that reduce the hydroelectric generation).

Figure 2.3 Location of the Italian pilot

Within this context, the Italian pilot represented a technological application within SmartNet project, which aimed to implement new tools to promote the integration of RES generation in smart grid systems. The pilot was located in South-Tyrol (Figure 2.3), an area characterised by a wide exploitation of hydro power plants of different sizes and connected to different voltage levels. The installation of many small-sized power plant at MV and LV levels results in power reverse flow at the interconnection point between the TSO and the DSO, with a peak higher than 30 MW in summer (Figure 2.4).

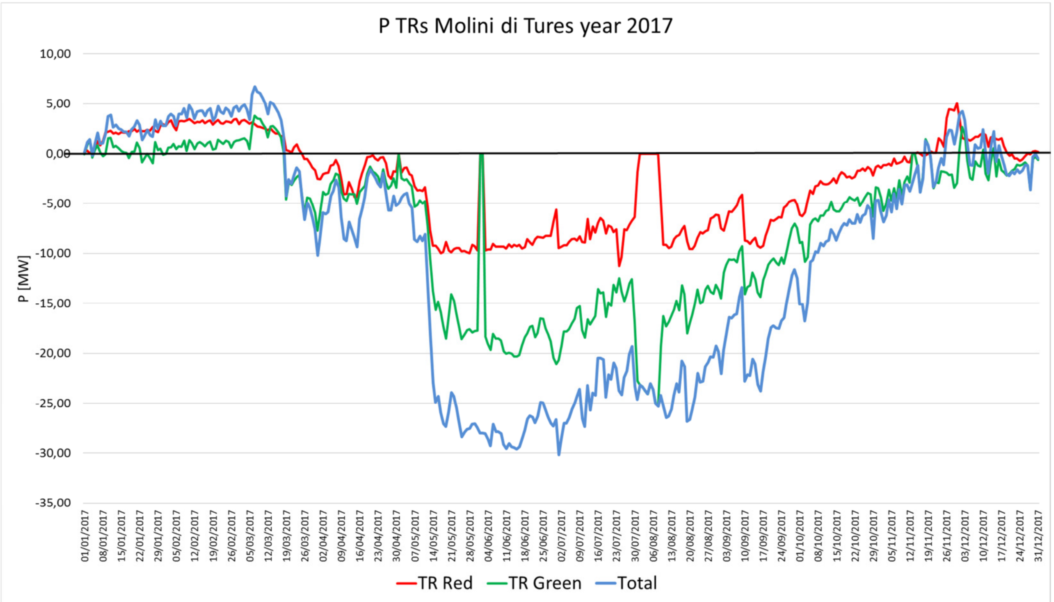

Figure 2.4 Evolution of the active power at the HV/MV primary substation during 2017

The pilot aimed to develop and implement in field two devices (HVRS and MVRS) to monitor the sources connected to the distribution grid in real-time and to use these plants to provide both voltage and power/frequency regulation, controlled by the TSO in a centralised scheme. Figure 2.5 shows the system architecture implemented in field and the data flow among the different devices.

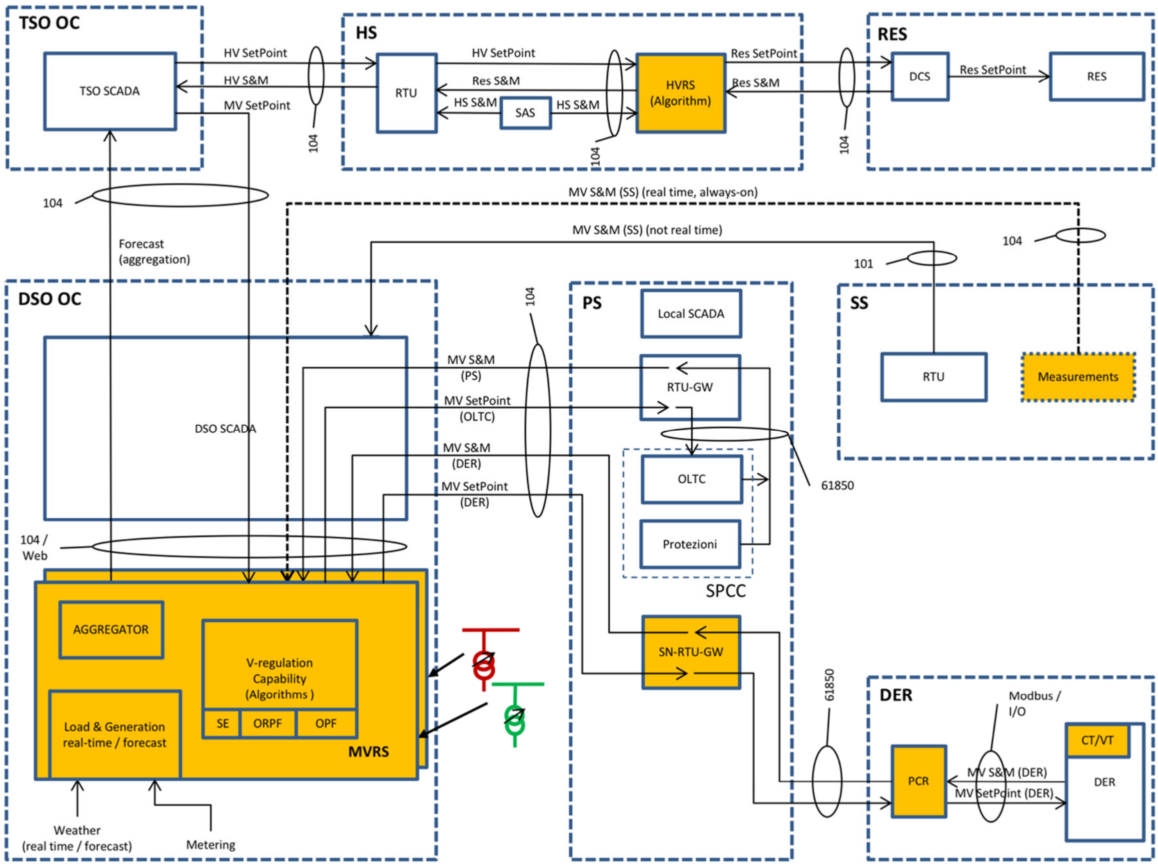

Figure 2.5 Architecture of the system implemented in the Italian Pilot of SmartNet: at the top is represented the HVRS system and at the bottom is represented the MVRS system

The **High Voltage Regulation System (HVRS)**, was installed in the HV substation Molini di Tures (shown as HS in Figure 2.5) to control the reactive power of the two hydro power plants directly connected at the sub-transmission grid (132 kV). These two power plants (represented as RES in Figure 2.5) do not currently participate in the hierarchical voltage regulation.

The **Medium Voltage Regulation Systems (MVRS)**, was installed in the DSO's Operation Centre (DSO OC in Figure 2.5) to allow the TSO to monitor and control the DG connected to the HV/MV transformers of the primary substation (PS in Figure 2.5). This application allows for monitoring a MV grid, composed by 23 plants and 5 interconnection points with subtended DSOs, through Plant Central Regulators (PCRs). PCRs are devices which interface the power generation module control system to the MVRS and, hence, allowed the TSO and DSO to control 7 of the biggest hydroelectric plants, which added about 22 MW total.

2.2 Main activities performed in the pilot: observability and voltage control

2.2.1 HVRS

The HVRS was installed in the pilot to allow RES plants connected to HV to be dispatched by the TSO and, thus, to provide AS, in particular, voltage control.

The HVRS was installed in the HV side (132 kV) of the HV/MV substation to smooth the voltage fluctuations, by controlling the reactive power exchanged by the four synchronous generators (absorption or injection) installed in RES power plants in a coordinated way, so that they satisfy the TSO commands sent from the TSO's operation centre.

The TSO can control the reactive power sending a reactive power (Q) setpoint or a voltage (V) setpoint, as shown in Figure 2.6. If the TSO sends a reactive power setpoint, the setpoint is a percentage value of the capability calculated in current operating conditions, to be interpreted as:

- A value between (0, + 100%] indicates the condition of over-excitation, i.e. represents the reactive power that has to be provided by the plants in order to increase the voltage.
- A value between [-100%, 0) indicates the condition of under-excitation, i.e. represents the reactive power that has to be absorbed by the plants in order to reduce the voltage.

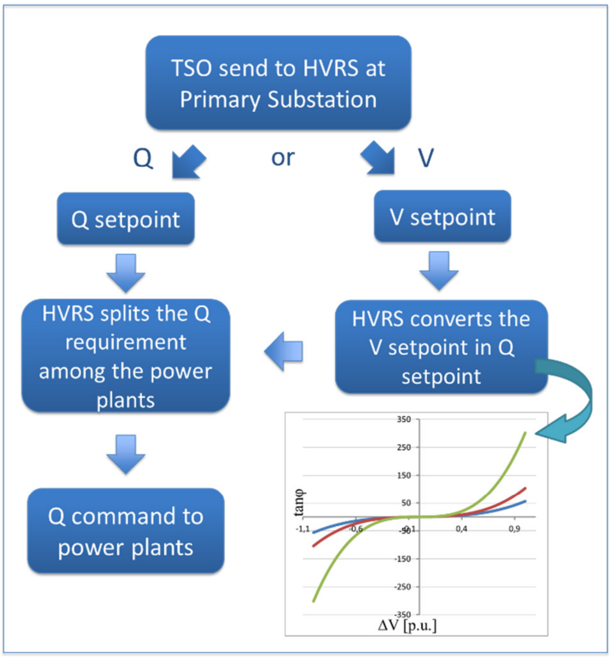

Figure 2.6 Diagram of operation of the HVRS

On the contrary, if the setpoint sent by the TSO is a voltage setpoint, the setpoint is a voltage value expressed in kV. The TSO requests the optimal voltage value at the HV busbar and the HVRS converts the setpoint in a reactive power command on the basis of the voltage error, defined as the difference between the voltage setpoint and voltage measurement.

Regardless of the type of setpoint, the HVRS splits the command amongst the controlled generators in order to obtain a homogenous distribution of the efforts and avoid undue reactive power flows between

providers in the same electrical area. In order to determine the reactive power availability of the whole controlled system, the algorithm developed in the HVRS calculates the reactive capability of each generator corresponding to the operational point, computes the virtual capability of the system on the basis of the grid configuration and sends it to the TSO.

2.2.2 MVRS

The MVRS is intended to manage, monitor and control de DG connected to the distribution grid. Having two technological partners in the pilot, each of them developed its own solution for the MVRS, which were then implemented in field.

The MVRS has three main functionalities: observability, voltage control and frequency regulation. The first two are described in this section, while the frequency regulation is described in section 2.3.

The observability functionality provides different types of information to the TSO:

- **Nominal data**, in order to represents properly the grid. The nominal data regarding the active power installed at the primary substation are collected for the different type of energy sources (PV, wind, storage and other sources) and for the load. These data are updated e.g. every 3-6 months.
- **Aggregated, real-time data**, which allows for exchanging real-time data of the active and reactive power at the distribution level with the TSO's SCADA. The MV level is represented as equivalent aggregations, differentiated by type of source (solar resources, hydro resources and load), connected at the HV/MV substation (Figure 2.7). The aggregation is updated every 20 seconds.

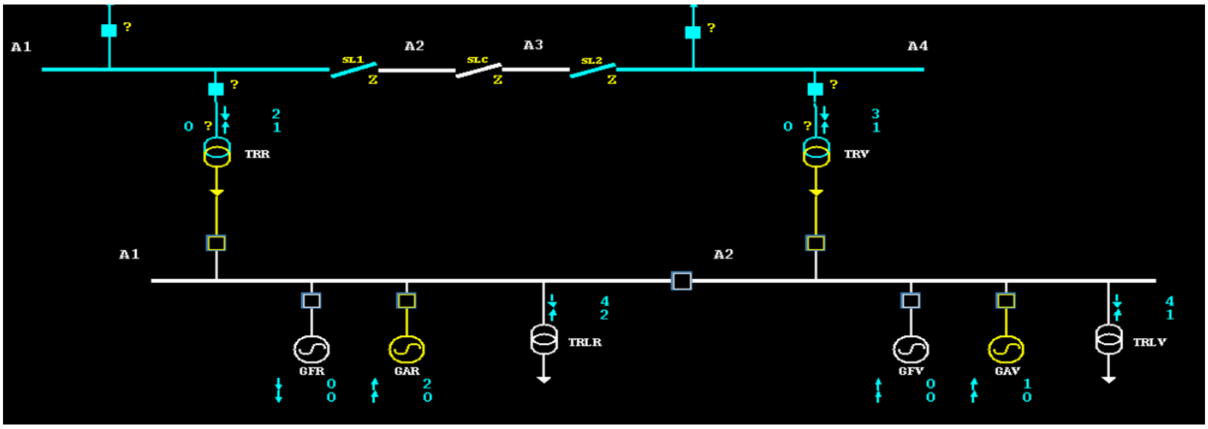

Figure 2.7 Representation of MV grid aggregations in the TSO's SCADA

- **Estimated, real-time data**, to estimate the active power of unmonitored plants through algorithms that elaborate and combine available data (the so-called "sentinel measurements", e.g. weather data, neighbouring plants' measurements, near-real-time data registered by smart energy meters, historical profiles, etc.). In order to be able to test the capability of DG to

provide AS, the network was closely monitored and the production of almost all the power plants and the net power exchange at the interconnection points with subtended DSOs were measured. Therefore, the accuracy of this functionality could be tested offline, by comparing the estimation by the MVRS and the measurement. The results highlighted the dependence on the type of source: the estimation of solar production based on weather data can achieve quite accurate results, but a good accuracy in the estimation of hydro power production can only be achieved by measuring 60 % of the installed hydro power, by choosing the right power plants to monitor and by having access to historical data.

- The **capability of the virtual power plant** (VPP) composed by the DG in order to allow the TSO to know the available active and reactive power margin on DSO network considering the capability of each power plant and the operational limits of the distribution grid. Through the virtual capability, the TSO can send voltage or active power setpoint to the DG, considering it as a unique virtual plant comparable to a traditional plant, so allowing a centralized activation that always respects the DSO network constraints.
- **Forecast data**, in order to predict the future operational conditions: the DSO also has to send the active power profile forecast through the MVRS, taking into account also predicted changes in the grid configuration. The forecast must be sent to the TSO every 3 hours, with 1-hour resolution and covering the next 72 hours.

The process is represented in Figure 2.8.

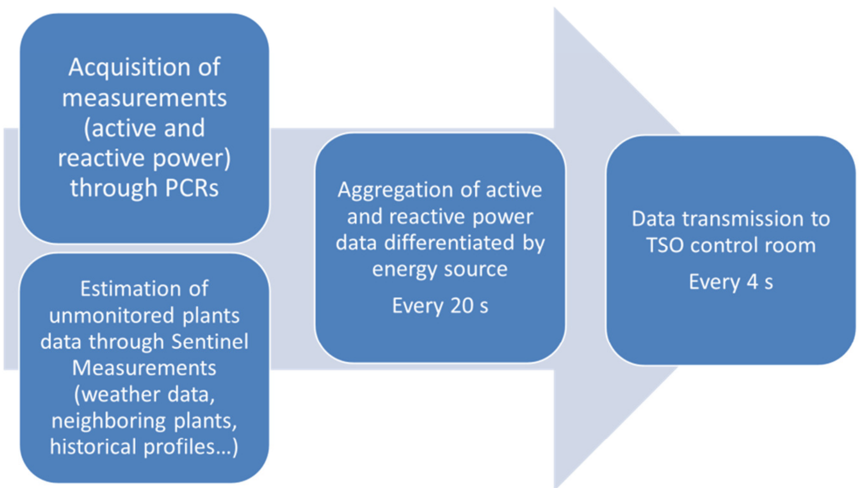

Figure 2.8 Diagram of operation of the observability functionality of MVRS

As shown in Figure 2.9, through the computation of the virtual capability, the MVRS provides to the TSO an instrument to command the reactive power of the plants connected to MV level of the grid considering them as a unique plant in order to regulate the HV voltage. It also considers under- and

over-excitation limits, dictated by the DSO's grid constraints, and then it allows the TSO to send setpoints, while avoiding violations on the MV network. In case of constraints violation in the distribution grid, the priority of the device is to solve the violation, making the generators unavailable for the voltage regulation. Once received the command, the algorithm provides a smart splitting of reactive power command among the controlled plants according to single DERs capability.

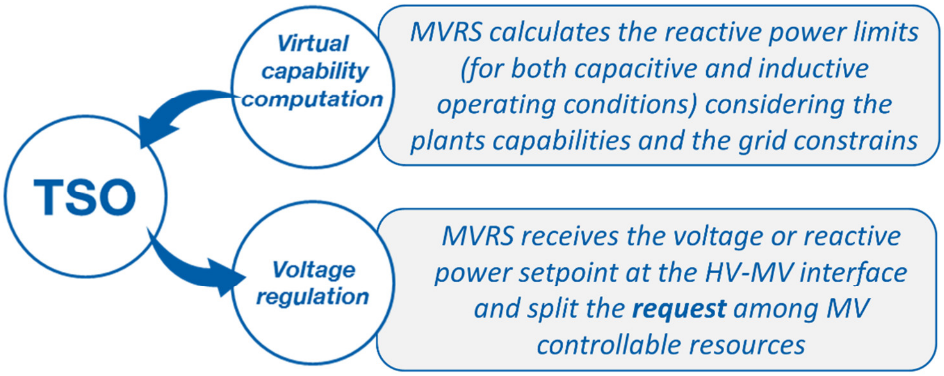

Figure 2.9 Diagram of operation of voltage regulation functionality of MVRS

2.3 Other important activities: frequency control

The last functionality implemented in the MVRS is the frequency/power regulation through DG. The main task of the MVRS is to receive a level command by the TSO and to perform an active power variation of the VPP in order to modulate active power fed into the grid complying with the TSO requirement.

In particular, the pilot tested whether of hydro power plants connected to MV can provide an automatic Frequency Restoration Reserve (aFRR) service. This service consists of providing a modulation of the active power according to a signal level sent by the TSO every 4 seconds to the control system. As shown in Figure 2.10, the setpoint is a value between 0 and 100, which represents the variation within the active power regulation band: 0 is the lower end of the band, 100 is the upper end of band and 50 represents the generation program.

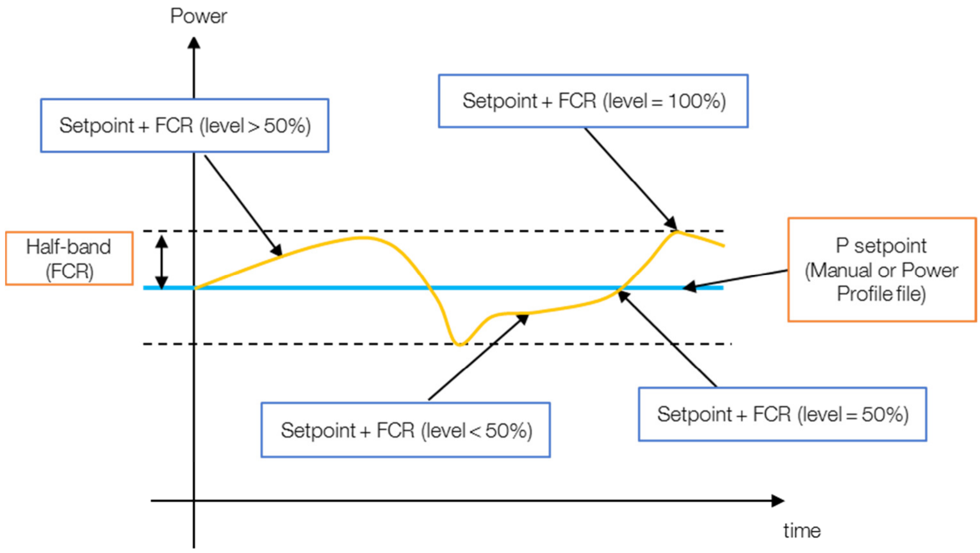

Figure 2.10 Representation of the aFRR regulation in Italy

In SmartNet application, the MVRS, considering all the available data (topology, measurements, etc.), calculates an aggregated dynamic active power capability (i.e. the active power range available for the TSO to provide the power/frequency regulation). The information sent to the TSO are the planned production (mid-value band) and the available modulation (half-band). In this case, due to the non-programmable nature of the power plants involved, each manufacturer has decided which could have been the more suitable value to be considered as mid-value of the band. Furthermore, the half-band available for the regulation is normally defined by the bids and the market outcomes but, in this application, it has been necessary to define an achievable band.

Once the command is received, the algorithm provides a smart splitting of active power command among the controlled plants according to single DERs capability in order to deliver the total necessary active power at the primary substation. The communication with DG is carried out via the PCRs installed at controllable power plants.

2.4 Main results and conclusions

The tests carried out to evaluate the coordinated voltage regulation on the HV-side (HVRS) showed the technical feasibility of controlling the reactive power exchange of power plants, despite the effect on the voltage of the transmission grid and the performance of the power plants controller are not the same of the service provided by big-sized, programmable power plants connected at transmission grid. In any case, the system allows the TSO to coordinate the reactive exchange of these power plants with the area needs, in order to avoid the reactive loop that can be established between the groups and, thus, wasting reactive resources. The potential of the HVRS is the opportunity to control different power plants and parks of different technology in a coordinated way, by sending a unique setpoint. The figures below show

an example of a voltage setpoint, which the HVRS converted into a reactive power command in order to obtain the voltage variation required (Figure 2.11).

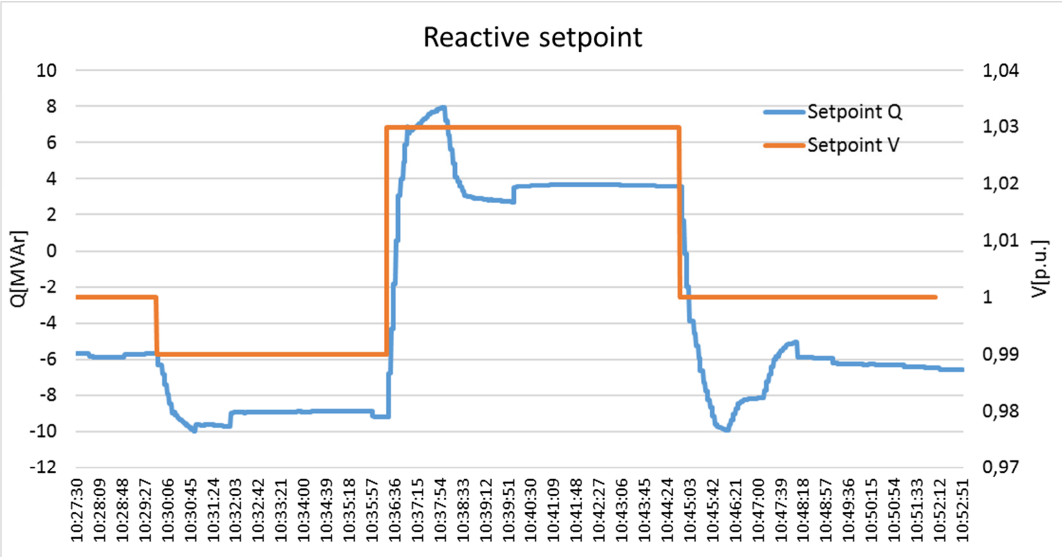

Figure 2.11 Trend of reactive power requirement calculated by HVRS

Then, the HVRS split the provision among the controller generators to avoid overloading a single unit and to coordinate the reactive power flow to prevent wasting reactive power within loop (Figure 2.12).

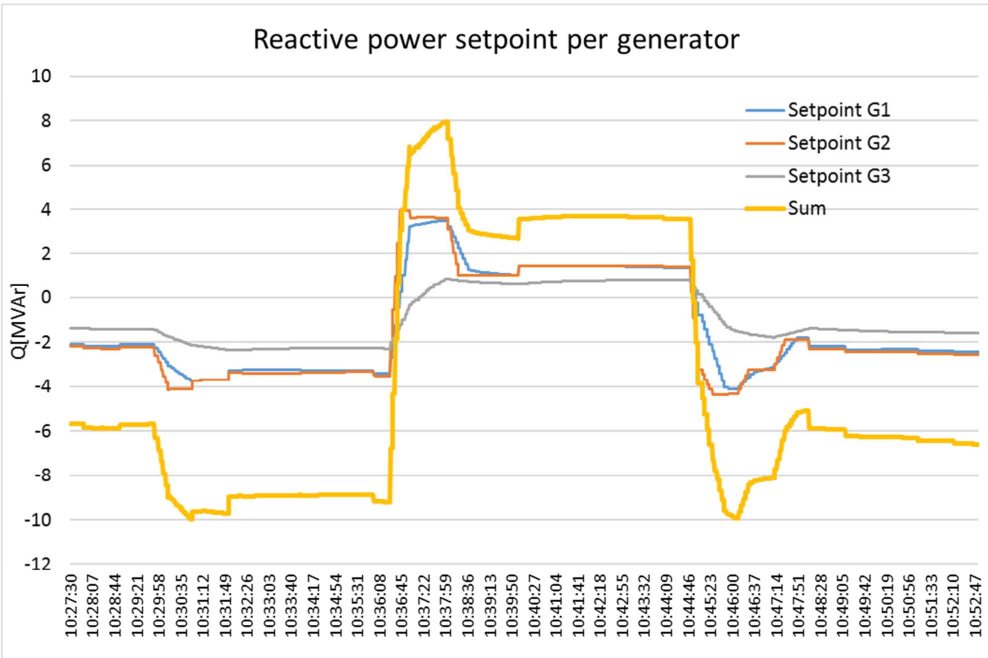

Figure 2.12 Distribution of the reactive power setpoint among the generators

Figure 2.13 shows the actual voltages measures at each generator's terminals and the sum of the setpoints and of the measurements of the three generators constitutes the overall response of the coordinated regulation, which is shown in Figure 2.14.

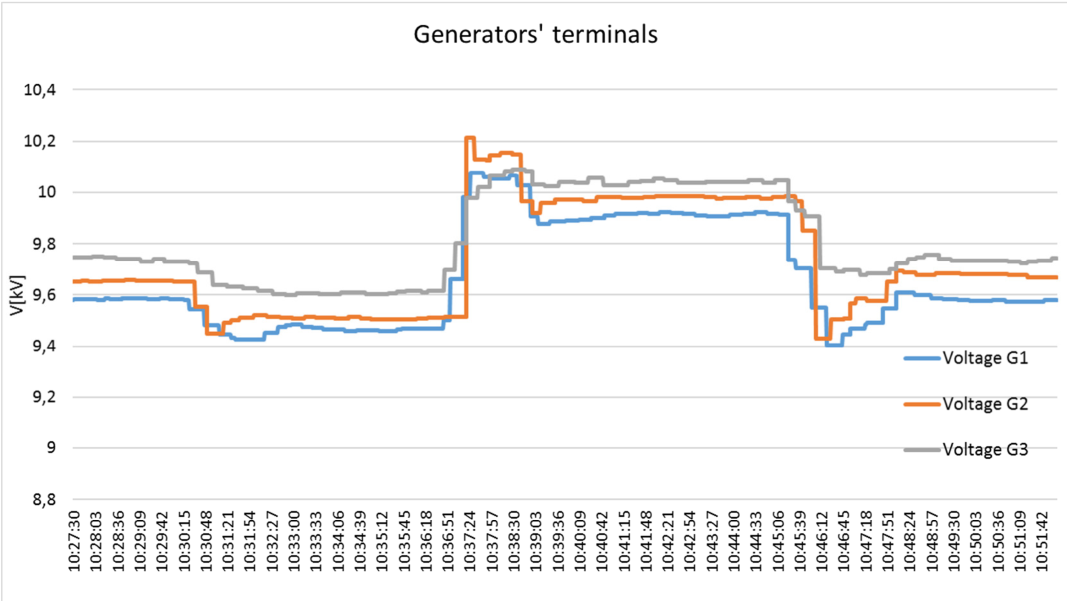

Figure 2.13 Voltages at generators terminals

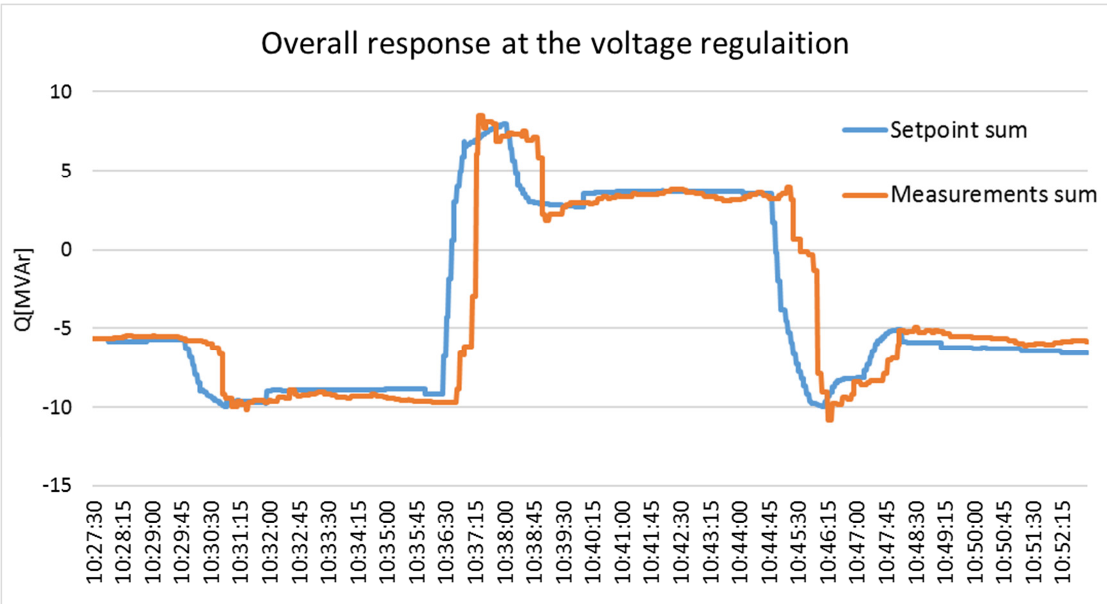

Figure 2.14 Reactive power response of the coordinated regulation

As illustrated in Figure 2.15 Effect of the regulation at the HV busbar

, it has to be pointed out that the controlled voltage depends on several grid parameters (load, short circuit power, etc.) and even the modulation of reactive power exchange by the power plants is interesting, the regulation of voltage at the HV busbar is not comparable with the contribution of a

programmable power plant connected at the transmission grid. The voltage trend shows a consequent delay and overshoot due to the inaccurate response of each Automatic Voltage Regulator controlled. Anyway, the coordination of the reactive trend of this kind of generators can help to support the voltage management avoiding waste of reactive power in internal loops, especially in future scenarios characterized by a reduction of available HV sources.

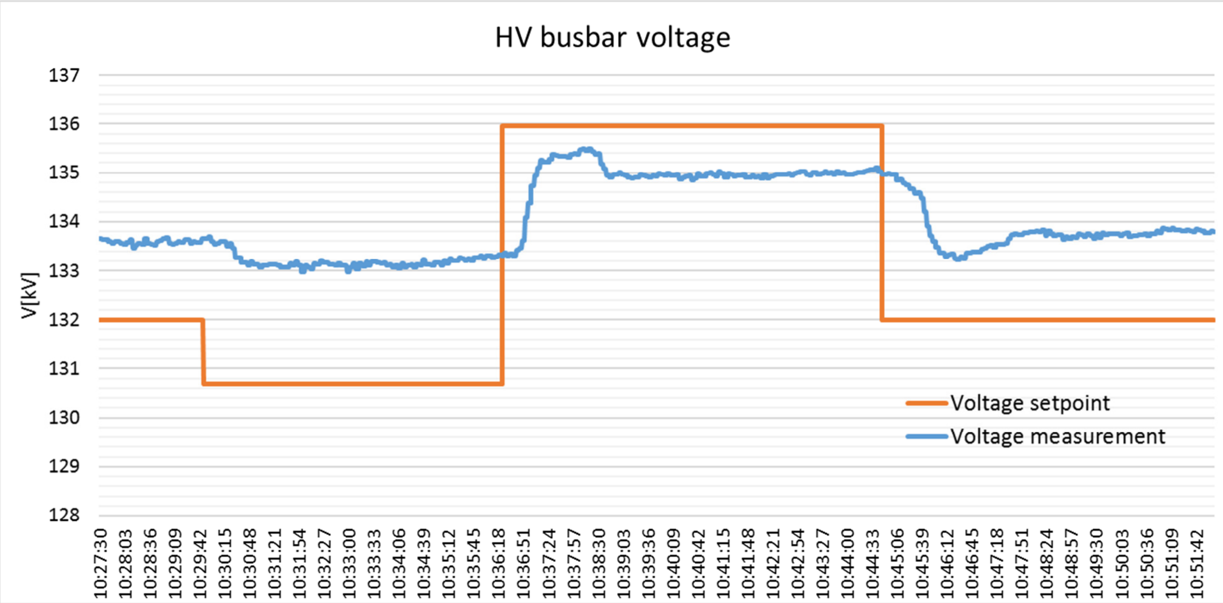

Figure 2.15 Effect of the regulation at the HV busbar

From the TSO's point of view, the possibility to know the accurate amount of the resources, split into generation and load at all times, leads to a more efficient and safe management of the transmission grid. Firstly, the observability functionality provided by the MVRS gives a better perception of the energy mix underlying the primary substation and, in particular, of the geographic allocation of the generation and the actual energy consumption of the load. It allows improving the grid calculation, where currently a gross estimate based on the installation is used, i.e. for state estimation and for static and dynamic simulations online and offline to individuate also critical constraints. It could enhance the Defence System, adapting the protection scheme of the system, and it could increase the adequacy of the Load Shedding Plan, providing the awareness of the real presumption disconnection. Moreover, it could support the TSO during the restoration of the service after a disconnection at the station.

Moreover, the acquisition of real-time data through the MVRS could improve the algorithms to calculate the consumption forecast in different time frames, processing this type of data with appropriate probabilistic methods. It allows to predict the evolution of the active and reactive power flows, which is especially useful when a high penetration of DER can lead to reverse flow from MV to HV grids. Another important application of the observability functionality in the MVRS is the identification of the capability of the virtual power plant connected to the primary substation and composed by MV plants. The calculation of the active and reactive power availability takes into account the distribution grid

constraints. It means that the observability provides the possibility to identify the potential contribution in the voltage and active power regulation.

It was demonstrated that the MVRS can be used to allow DG to provide voltage control to the TSO. The tests showed that activation of reactive sources at the distribution grid leads to the control of the voltage rise effect along the feeders of the DSO grid, usually subjected to over-voltages, in order to maintain the voltage within required limits. From the point of view of the management of the transmission grid, the field tests carried out have shown the technical feasibility of controlling the reactive power exchange of the power plants, although the behaviour of power plants connected at transmission grid is more prevalent than the contribution of DG. Figure 2.16 shows the trend of the voltage at the HV busbar during the tests: voltage reacts to the setpoints in the two feeders (red and green), although other elements of the grid may also affect the voltage, as happened at 15:55, when a decreasing of voltage was independent of any MV regulation.

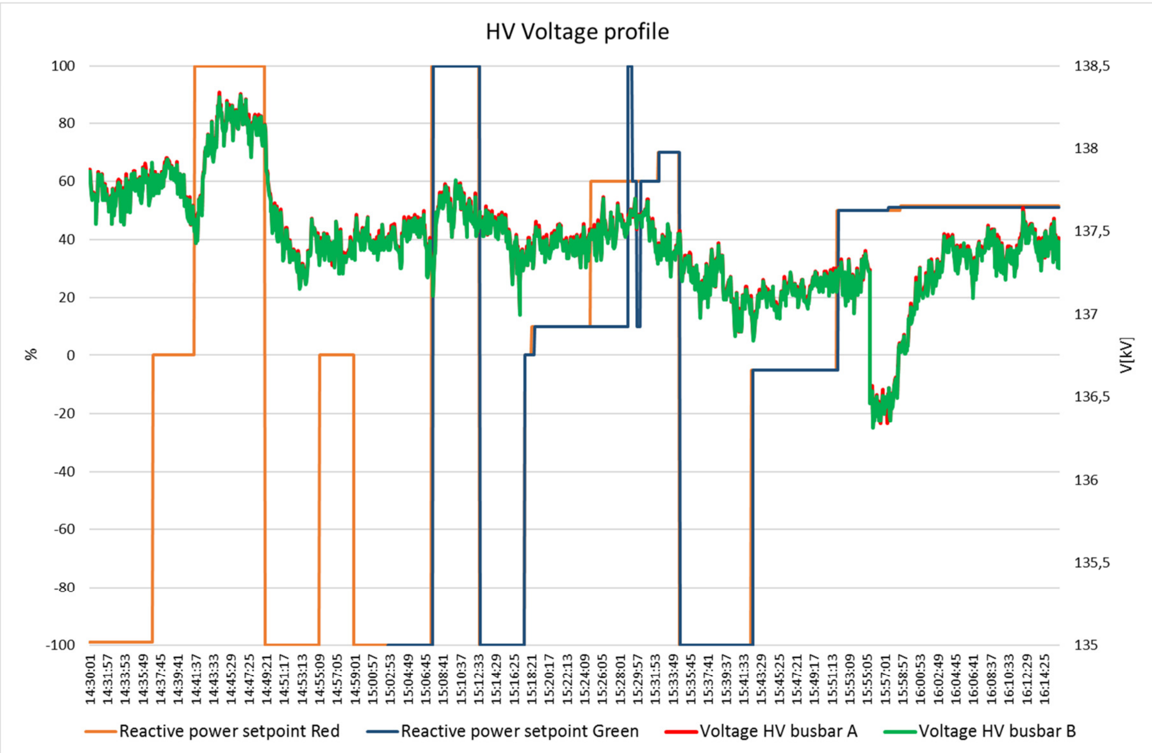

Figure 2.16 Trend of the voltage at the HV side of the primary substation during tests

At the moment, the involvement of DG in this service does not provide evident advantages in the management of the HV grid because the voltage trend follows the performance of the HV power plants. Nevertheless, the coordination of the reactive power exchange of these power plants can contribute to avoid wasting of sources that provide reactive power regulation. Moreover, it is very likely to have a big importance in the future as the contribution of RES increases.

Regarding the ability of MVRS to allow DG to provide frequency regulation, the tests provided promising results, with the activation of 7 power plants and a variation of the production of more than 6 MW. However, the dynamic response did not comply with the technical requirements of the service, due to delays in the communication and the inaccurate regulation of power plant controller. Moreover, the tests showed that the reliability and the quality of the regulation of the VPP at the interconnection point does not depend solely on the single power plant performance, but the trend is influenced by other elements of the grid, uncontrolled and unforeseeable. An example is reported in Figure 2.17, where the blue line is the expected contribution calculated from the percentage setpoint sent by the TSO and the red line is the real contribution of DG, calculated by subtracting an offset value to better appreciate the trend. In the lower part of the graph, the trend of the dynamic error has been reported in comparison with the limit value used for acceptance to the secondary frequency control service (10 %). The error increases with increasing response inaccuracy and delay.

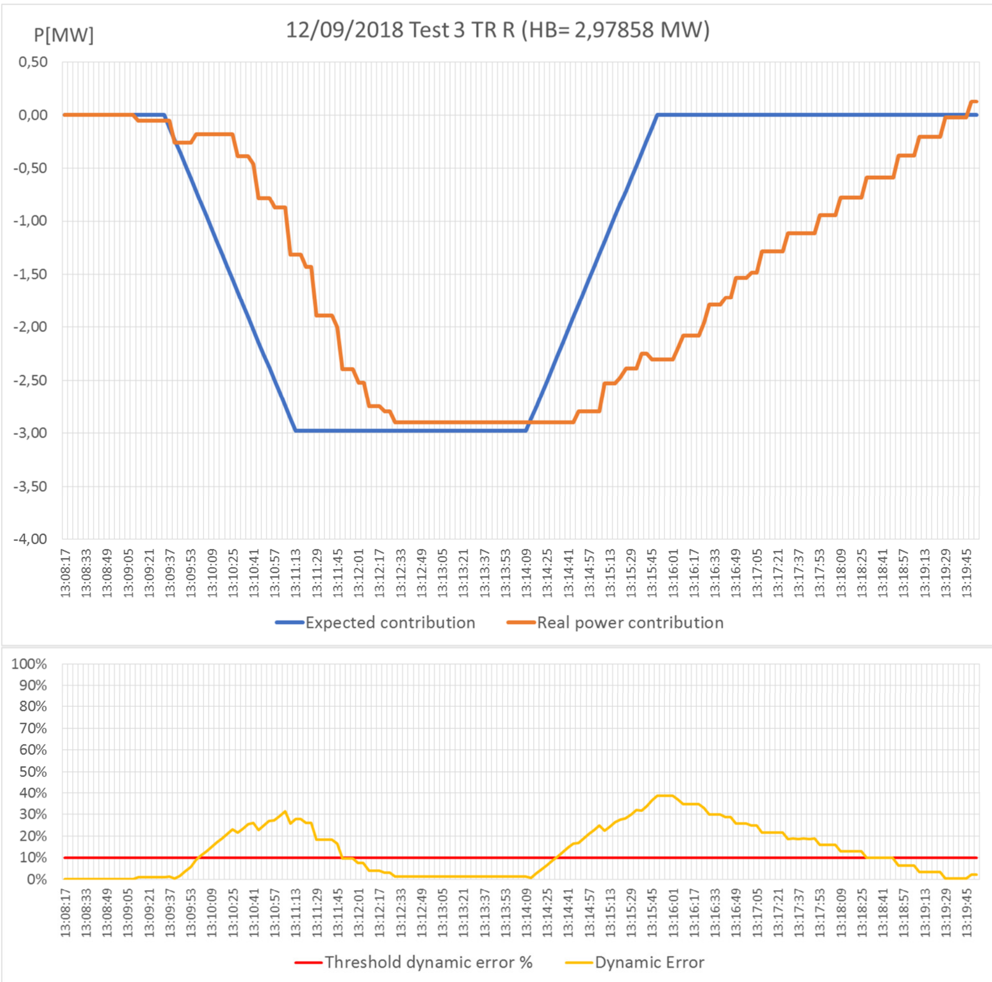

Figure 2.17 Example of trend and analysis of the HV contribution of the virtual power plant connected at the transformer

In general, an important value of the pilot is the results of tests and the detection of the aspects to be improved in order to integrate RES in the electrical grid. It is clear the need of further experimentations, some of which are already in place, in order to improve the performance and the reliability of the behaviour of RES. Moreover, the tests highlighted the importance of a continuous monitoring of the sources and of the actuation of the services so as to guarantee the efficiency, the safety, the adequacy and the quality of the dispatching.

3 Focus on information exchange between aggregators and DER: the Danish pilot

The second pilot [4], which was implemented in Denmark, focused on the information exchange needs between aggregators and DER and, in particular, how unidirectional price signals can be used to extract the flexibility in indoor swimming pools. Two different aggregators were defined within the pilot, one with a commercial responsibility (the Commercial Market Party, CMP) and another one receiving the price signals and sending the activation signals to the DER (the technical aggregator).

3.1 Pilot setup

The Danish power system is characterized by a high penetration of RES, mostly wind, but, increasingly, also solar (mostly PV) systems. Other highly-flexible DERs, such as Combined Heat and Power plants, waste treatment plants, as well as electric vehicles and heat pumps are also expected to have a significant role in the mid-term. Figure 3.1 shows the share of electricity originating from RES in Denmark in December 2018.

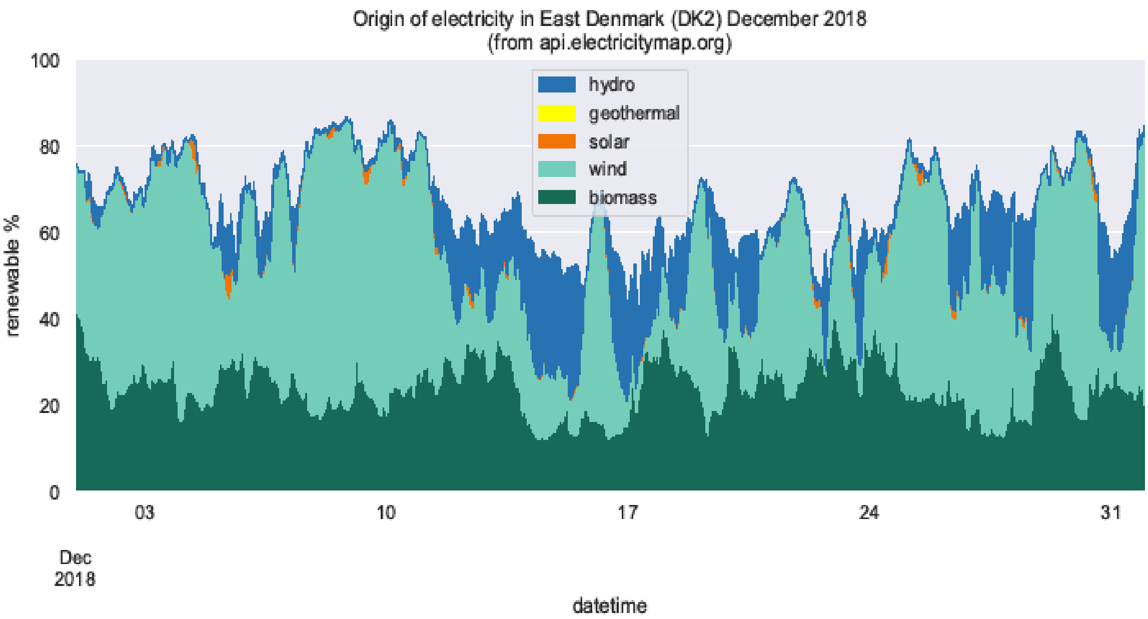

Figure 3.1 Share of electricity originating from RES in Denmark during December 2018

44% of the electricity load in Denmark was covered by the fluctuating and partly unpredictable wind power generation in 2017. This large penetration of the stochastic wind power often leads to balancing problems. Nowadays, these balancing problems are to some extend handled by the large thermal loads of the district heating systems.

The main purpose of the Danish pilot was to assess the opportunity of using predictable demand to contribute to the operation of transmission and distribution grids, by developing and demonstrating the models, technologies and algorithms to be used to provide the next generation of balancing services.

Summer houses with swimming pools consume substantial amounts of electricity for heating water and humidity control. The electricity demand from summer houses is particularly flexible. For example, swimming pools have a large thermal capacity and, therefore, the load to heat pool water can be disconnected or shifted with little consequences on the comfort of the occupants within given intervals that depend on the size of the heated environment and other factors. The Danish pilot assessed and demonstrated to which extent flexibility of summer houses can be exploited to provide ancillary services to both TSOs and DSOs.

Although the summer houses are not occupied permanently, they have a year-round base load, e.g., to guarantee that the pool water temperature does not fall below a certain threshold, should a customer wish to rent the house with short notice. The location of the houses, coupled with their thermal inertia, make their load a suitable candidate for the provision of grid services.

Indeed, as shown in Figure 3.2, many are in coastal areas of northern Jutland (in the DK1 control area of NordPool), where the distribution grid is weak. At the same time, a large capacity for wind power production is installed in the area, making summer houses a suitable candidate for the provision of congestion management services.

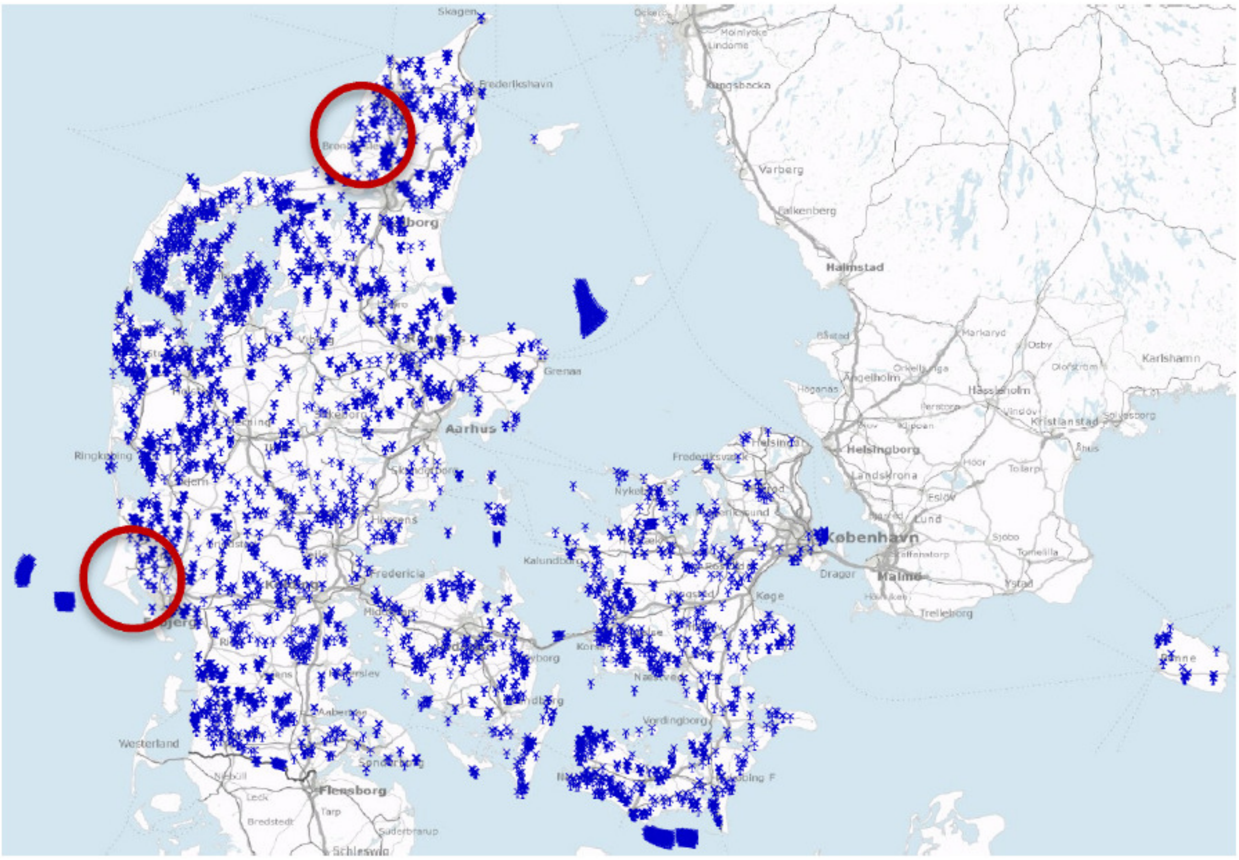

Figure 3.2 Geographical locations of summer houses in Denmark

For the purpose of the pilot, 30 summer houses were selected and provided flexibility. However, the concept is absolutely replicable to a much greater scale, as NOVASOL, one of the partners in the pilot, is a rental company that operates about 900 summer houses with an indoor pool in Denmark[1], holding an average annual power consumption of about 30.000 kWh per house. They also do pool inspections 55 000 times a year – this includes heating adjustment tasks prior and after arrivals/departures.

The selected 30 summer house were equipped with a dedicated communication gateway, temperature sensors and a smart controller that reacts to price signal from the market operators. This pilot benefited from deploying software solutions including cloud, server technologies and big data to ease the interaction among industry and research partners and to provide an agile environment where pilot partners could test various models, physical components and technologies in parallel.

Figure 3.3 illustrates the functionalities, communications, and ICT interfaces in the Danish pilot, which was divided into lower- and upper-levels, and the role of various partners in the pilot.

[1] NOVASOL is present in 26 countries across Europe (https://www.novasol.co.uk)

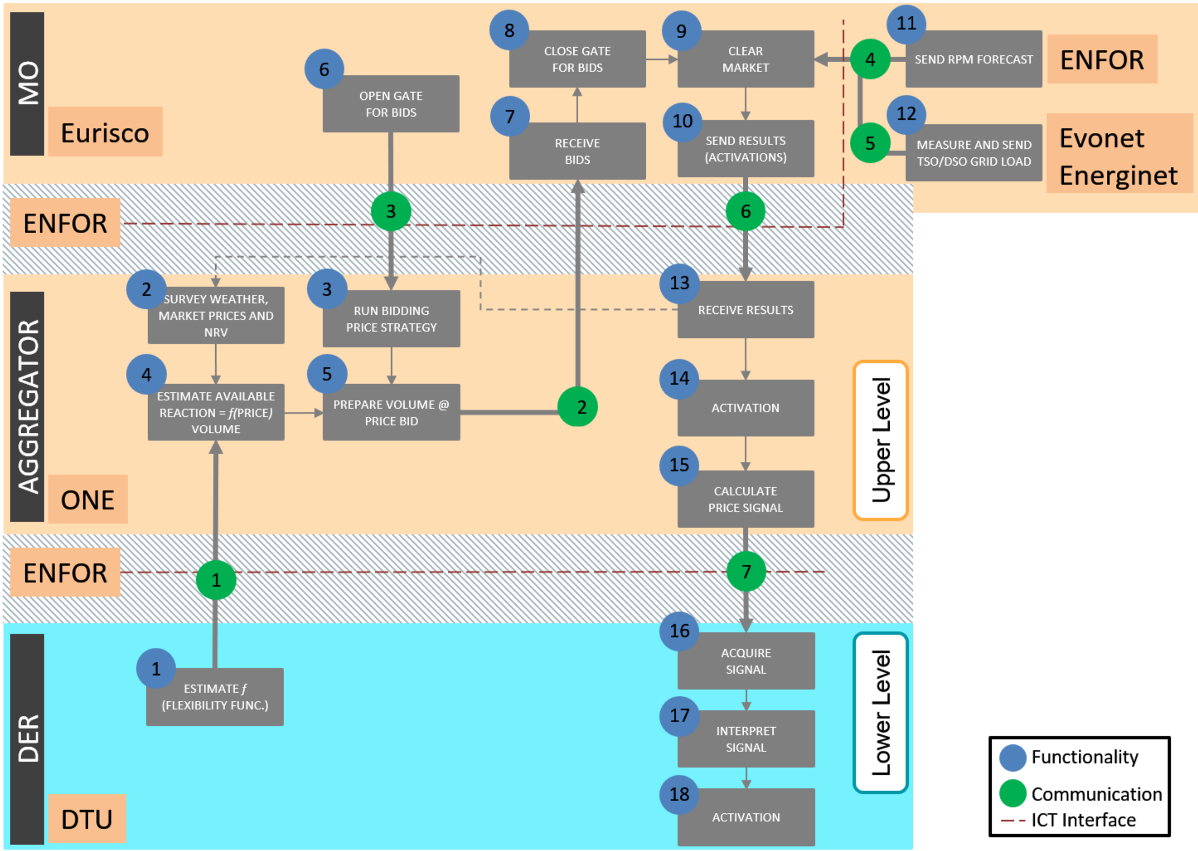

Figure 3.3 Communication and ICT interfaces in the Danish pilot

According to this structure, the TSO and the DSO send their requirements for balancing and voltage regulation to the market operator (MO), who interacts with the CMP to gather the required flexibility. The CMP uses a flexibility model developed within the pilot to predict the electricity demand as a function of prices and sends out both prices and price forecasts. Such communication intends to solve TSO and DSO needs for the next hours. The technical aggregator then receives two rates; one is the forecasted price, and the other is the actual price. In addition, it also collects weather forecasts and booking information, to calculate the optimal set points for the thermostats of all the summer houses. Measurements from the summer houses are then collected and used to feed price-responsiveness information in the flexibility model.

3.2 Main activities performed in the pilot: indirect control of DER

The goal of the pilot was to exploit the flexibility in summer houses but, since the CMP did not have a direct control over the energy usage, it needed to characterise the energy flexibility in terms of the penalty signals sent to the summer houses. From the perspective of the CMP, the aim was to test the feasibility of aggregation models in an indirect-control environment, aiming to schedule decentralized assets potentially by the thousands or millions through broadcasting signals.

Although different penalty signals are possible, the pilot used two of them: CO_2 and price. During the initial stage when the CO_2-penalty signal was used, the CMP broadcasted the CO_2-intensity of the energy mix and the DERs reacted to minimise total CO_2 emissions. In the second stage, the CMP broadcasted energy prices and DERs reacted to minimise the energy consumption cost. The reaction of DER to the penalty-signal was similar in both cases, but the creation of price-sensitivity curve requested a more profound analysis.

The price-based approach implemented an indirect control consisting of one-way communication from the CMP to the DERs, where the price signal was used to influence the whole load of the DERs during the activation period:

- After clearing the market, the MO sent the market clearing information to the CMP.
- In turn, the CMP calculated the price-based control signal estimating the flexibility function, in order both to provide the flexibility cleared in the market and to maximise the value for the DERs and the CMP during the next hours. The flexibility function predicted the electricity demand dynamically as a function of a time series of prices.
- Then, the CMP broadcasted control signals to the DERs, prompting a certain electricity consumption profile of the summer houses. These signals and the induced response may serve to reduce peak power consumption or to increase power consumption in case of available power surplus.
- After receiving the signals within a specific time resolution (for example 15 minutes), each DER used the information to plan the optimal consumption profile, i.e. the one which results in the lowest electricity bill, while staying within the boundary conditions, such as the pool temperature.
- Before reaching the next time step, the CMP sent the price for the next time step, including an updated price forecast.
- Each DER updated its consumption profile for each time step.

This results in a quite simple unidirectional communication system, which does not require the commitment of the DERs, as shown in Figure 3.4. One challenge is, however, for the CMP to predict the response from the DERs at a given price signal.

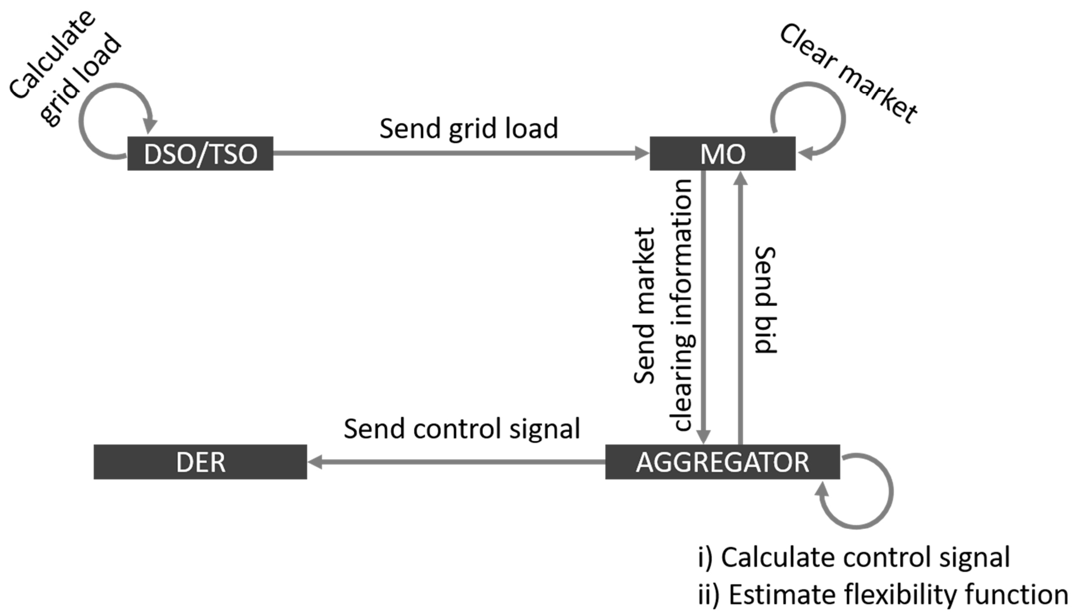

Figure 3.4 The main communications in controlling DERs indirectly through the CMP

The CMP issued prices to control the electricity consumption in the summer houses in a way, which was defined by specific cost functions. These cost functions can be constructed in several ways. One obvious choice is to define a cost function in which the load (partly) matches the wind and solar power production for the controller algorithm to control the power consumption. Another possibility is to define a cost function such that peak power consumption is reduced. The total price broadcasted to the summer houses might also partly consist of a grid-control related price, such that the TSO by altering the price, can avoid grid congestion and partly control the power load in various areas of the grid. For the summer houses, the control of the set-point of the thermostats was typically an economically-related cost function like those related to an economic Model Predictive Control (MPC).

By establishing a price generation mechanism, the CMP determined the optimal real-time price signal based on the estimations of the aggregated response of DERs, the so-called Flexibility Function. Such estimations were based on the historical data, although the characteristics of the response were tailored to the specific needs of the summer houses.

Figure 3.5 represents the conceptual dependency between a penalty generator and a potential DER including flexibility function.

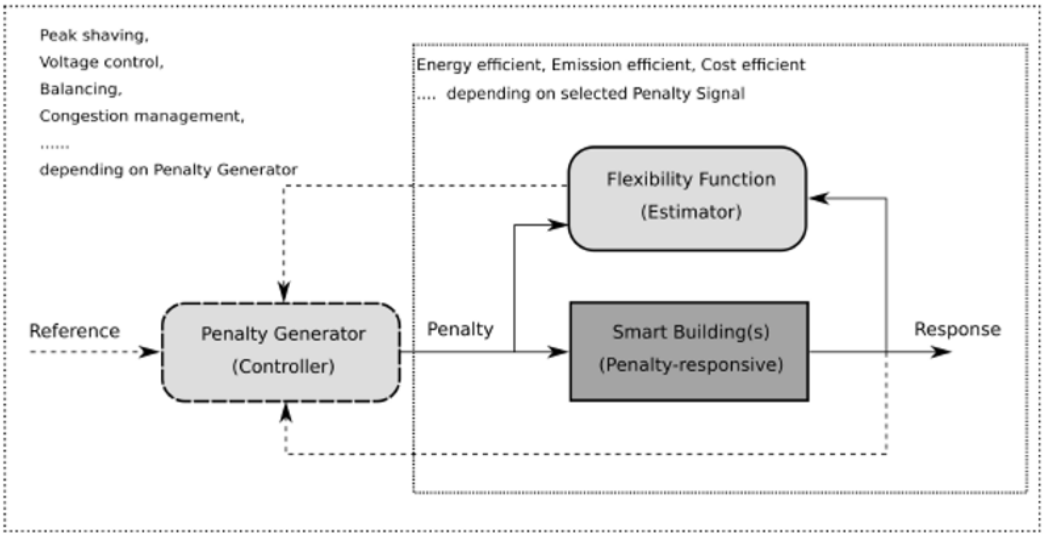

Figure 3.5 Dependency between a penalty generator and a potential DER

The relation between the penalty signal and the energy consumption was considered to be linear and time-invariant and, since the CMP did not measure the energy consumption in real time (time resolution was set to 5-minute), the finite impulse response was used to model the reaction to the penalty signal.

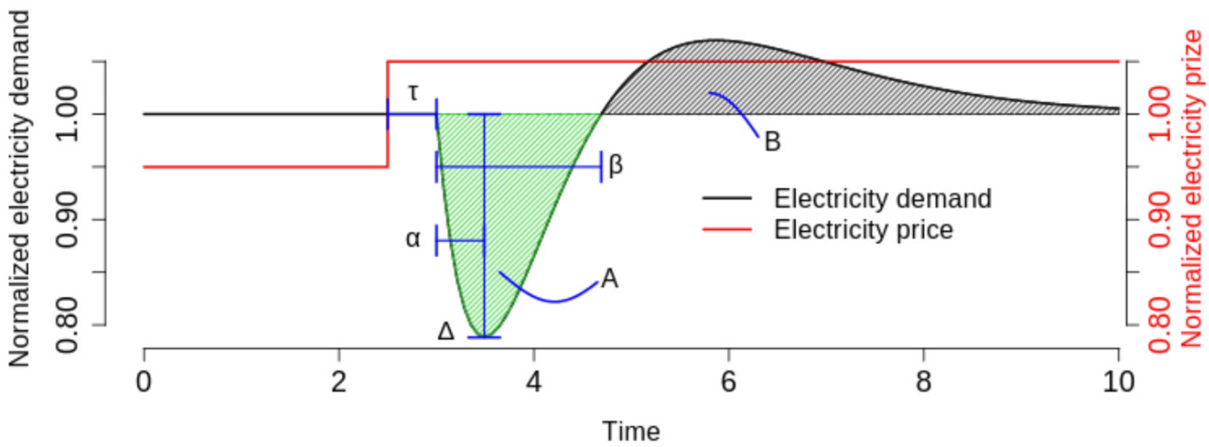

Figure 3.6 Example of a flexibility function

An example of this kind of response is shown in Figure 3.6, where τ is the delay from adjusting the electricity price and seeing an effect on the electricity demand, Δ is the maximum change in demand following the price change, α is the time it takes from the shift in demand starts until it reaches the lowest level, β is the total time of decreased electricity demand, A is the total amount of decreased energy demand (given by the green-shaded area) and B is the total amount of increased energy demand (given by the grey-shaded area).

Based on the price-signals received, the technical aggregator generated optimal temperature set-points for the summer houses, which were then sent to the local controllers. Figure 3.7 shows the structure of the control system of the technical aggregator.

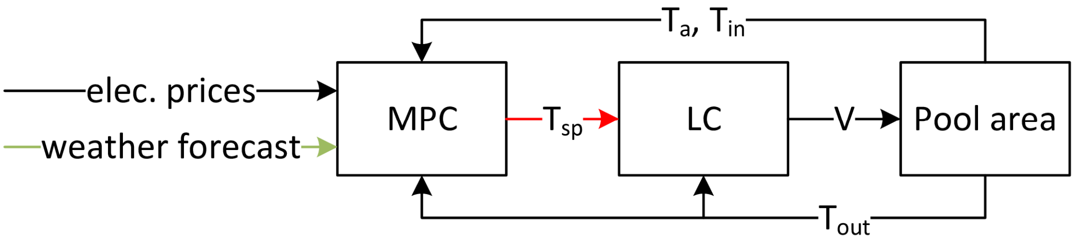

Figure 3.7 Control system of the technical aggregator

The technical aggregator aimed at minimising the operational cost of the swimming pool heating system installed in the summer house, by using on-site measurements, booking status, and forecasts for both electricity prices and weather. The algorithm for finding the optimal temperature set-point is divided into two stages:

- First, an economic MPC calculates the optimal valve position, which can only be ON (open valve) or OFF (closed valve). This status directly influences electricity consumption of the system.
- Then, the optimal temperature set-point (T_{sp}) is defined such that the obtained valve position is held during the sampling time of the controller.

Then, the local controller (LC in the figure) transformed the temperature set-point into a voltage signal to be sent to the pool area.

ICT deployment and digital communication was pivotal in this pilot to ensure both reliability of the service and the accurate output of DER controllers. Since there was no commercial product which could meet the requirements of the pilot, a controller was specifically designed, made and installed in the selected summer houses, the SN-10. These controllers were used as data communication interfaces from the technical aggregator to the summer houses. As can be seen in Figure 3.8, the SN-10 is a hardware component inside the system installed at the summer houses. The system also includes a 5 V/12 V DC power supply, a 230 V switch and sensors for temperature measurements. The SN-10 also has an interface and access to the electricity meter in the summer house to provide the total amount of electricity consumption in the property to the controller and forecast model.

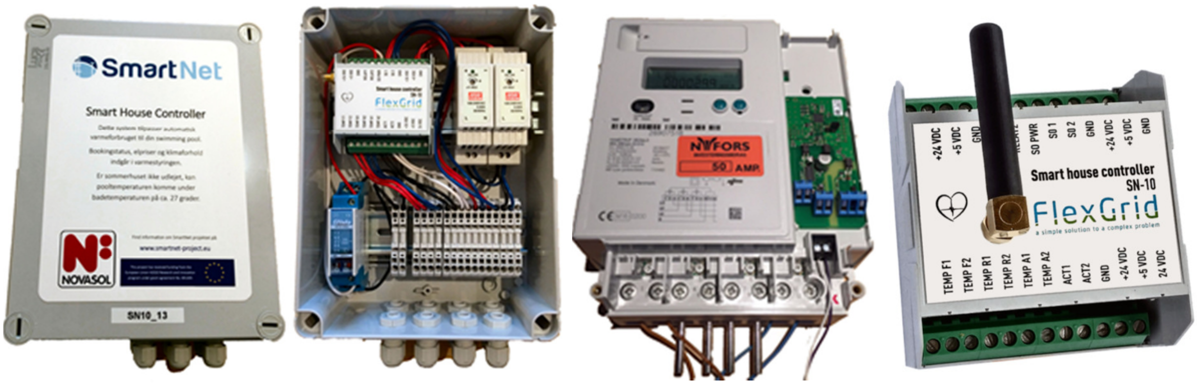

Figure 3.8 SN-10 Communication gateway and local controller

The actuators, labelled as ACT1 and ACT2 in Figure 3.9, are controllable thermostats, which opened or closed depending on a pulse-modulated signal (24 V DC) from the SN-10 controller. Water temperature was measured for the pool water going in and out of the pool and the air temperature sensor measured the heat from the pool room. The pool pump could be switched off during high-energy periods, but only for a limited time due to constraints in the water cleaning process. The power consumption was measured with an internal electricity meter (sub-meter) and with the household revenue meter.

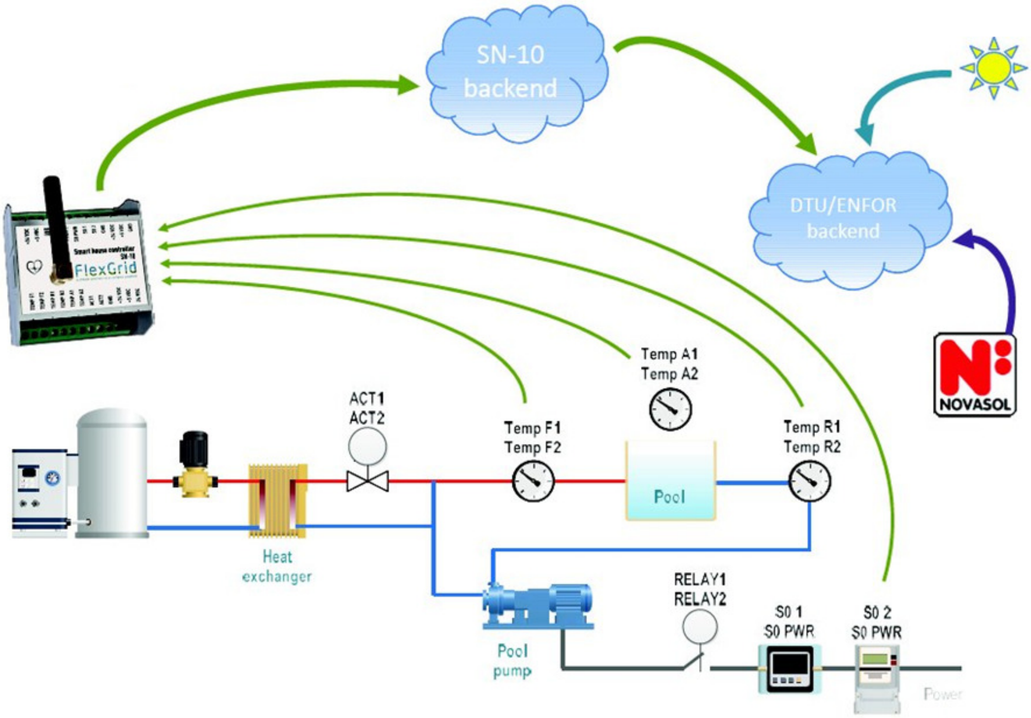

Figure 3.9 Data measurement and information gathering by the SN-10 controller

The SN-10 controller is an internet-of-things unit, which is connected to the internet via a 2G/3G communication and can collect the measurements and send the controlling signals received from the smart controller. Every 5 minutes, the SN-10 sent data to a cloud server and to the data management

system. Control signals were calculated and sent to the SN-10 unit on a 5-minute basis. The control signal was a temperature set-point, with which the SN-10 controller regulated the water temperature. Depending on the heating system of the house, two configurations were used:

- When the SN-10 was installed with an electrical boiler, it activated the relay when heating was needed and deactivated it when the set-point was reached. In order to prevent fast switches, a 1-degree Celsius hysteresis was used.
- On the contrary, when the SN-10 was installed in a house with a central heating system, a thermal actuator was used instead of the relay.

3.3 Other important activities: market interactions and clearing

As described in Figure 3.3 above, the Danish pilot was split into upper and lower levels. The lower level, which has been described in section 3.2, focused on computing the optimal heating schedules for the swimming pools and to activate them, while the upper level included all the interactions among the MO, the CMP, the DSO, and the TSO, including the market clearing process.

The architecture of the Danish pilot was been on the current situation in Denmark (in terms of DER penetration and uniform taxation scheme). The pilot assessed to what extent flexible summer houses could provide two ancillary services, namely balancing and grid congestion management, in 5-minute time steps.

The CMP estimated the available flexibility and its cost, decided on a bid strategy, and sent the bids to the MO. The bids contained price, quantity, and location of the bid, in order to enable the option of using the bids for grid congestion management on distribution level. The bids were placed for up to 12 time-steps, i.e. 60 minutes, and could include intertemporal constraints, [5].

Meanwhile, both grid operators (DSO and TSO) measured the grid load and sent the data to the MO along with the updates of the available grid capacities in case there had been changes. Then, the MO calculated the optimal dispatch, according to a rolling horizon optimization, and sent activation for the following 5-minute time-step and non-binding activations for the following 11 time-steps, i.e. for the next 55 minutes. The MO also estimated the need for balancing and solved all the requirements in one step.

The bids were updated every 5 minutes, which was also the market clearing frequency and, hence, the rate at which activations were sent. In order to clear the market, the MO had a model of the grid, including both transmission and distribution levels, which, along with the real-time grid load data from the DSO and TSO, was used to estimate grid congestions and the remaining grid capacity. Since the summer houses are connected to 400 V feeders, the DSO only monitored the load on the 10/0.4 kV stations and 60/10 kV stations directly above these summer houses.

As the market clearing algorithm implemented in SmartNet is far too complicated and the added value for the pilot would have been quite limited, it was not implemented in the pilot. On the contrary, the price formation was simulated from the forecasts of the manual Frequency Restoration Reserves (mFRR) market for the following hour. The technical aggregator forecasted the regulating power market price for Western Denmark for the following two hours with an update for every hour and sent it to the MO. The forecasted prices were converted to 5-minute prices to fit the temporal resolution of market defined in SmartNet. These 5-minute prices were taken as the market clearing price. The market clearing was simulated by comparing these market prices to the incoming bids from the CMP: bids with a lower price than the market price were activated, whereas bids with a higher price than the market price were not activated. The market result sent from the MO to the CMP was a binding activation of the next time-step and 11 non-binding activations for the following 11 time-steps, representing the rolling horizon optimization. These 11 non-binding market results were updated every 5 minutes with adjusted bids received from the CMP and market prices adjusted from the technical aggregator's conversion algorithm.

When there was no congestion in the distribution grid, the price at the distribution level was equal to the transmission level price. However, if there was a congestion in the distribution network, a different price was formed behind the congestion. Since no real congestions were expected, lower capacities of the stations were anticipated to provoke and demonstrate congestion management on distribution level in the pilot.

3.4 Main results and conclusions

In order to check how well the summer houses can be controlled through price-based control, different tests were performed, in different seasons of the year.

One of the tests is seen in Figure 3.10. The upper plot shows the measured active power for two summer houses (labeled C7224 and D7105). The middle plot shows the state of the pump for the heater of the swimming pools and the lower plot shows the activate bids from the market simulation.

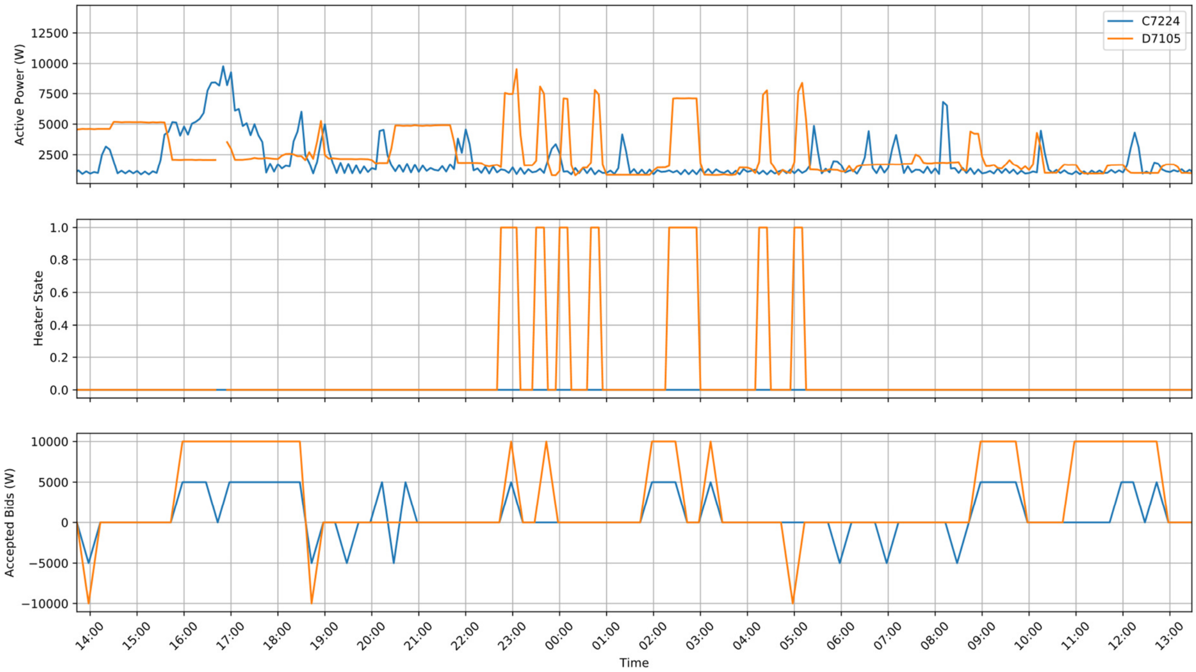

Figure 3.10: Test results for integration of price-based control in the Danish pilot (test started at 14:00 on 2018-07-25)

As can be seen in the figure, there is a certain mismatch between activated bids and actual activations of the swimming pool heaters. This is because the summer houses have multiple criteria for activating the heaters. Therefore, the heaters may also be activated without any activation signals coming from the market. Moreover, the tests were run in the middle of summer, with outside temperatures of around 30° C, so there was not much need for additional heating of the water. This is the reason for not activating the heating of C7224 at all during this period, because the temperature of the water was high enough and no heating was needed.

As comparison to the summer test seen in Figure 3.10, another test was made in December. The results from this test are shown in Figure 3.11. However, also in this case the activations of the swimming pool heaters do not follow the control signals from the simulation very well. One reason why little response is seen is that both pools were heated in the days prior to the test. Furthermore, summer house P32424 was neither booked for the period before, nor for the period after test. In such cases the setpoint for the water temperature is decreased, which prevents unnecessary heating. In order for the heating to be activated, the price offered by the CMP must be high enough, which it was not for this test.

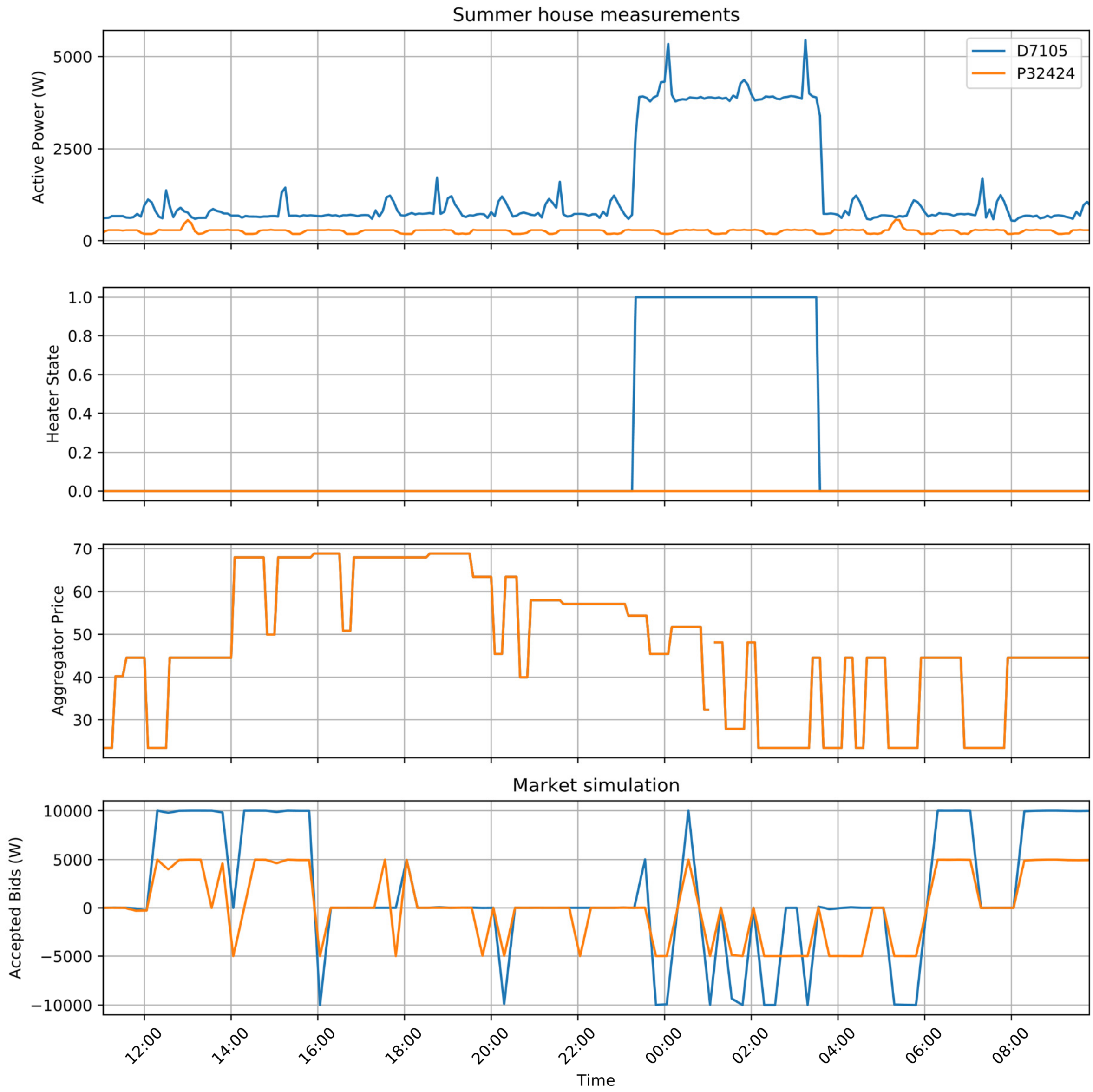

Figure 3.11: Test results for integration of price-based control in the Danish pilot (test started at 11:03 on 2018-12-17)

From these results it is clear that the price-based control developed in the Danish pilot can technically be used to exploit the flexibility of summer houses. On the one hand, the CMP was able to bid into the market, to receive market results and to create the price-signals to be sent to the technical aggregator. On the other, the technical aggregator was able to convert price-signals into activation orders for the thermostats, which reacted properly.

This effect was clearer in the period where CO_2-control was used. Figure 3.12 shows the control applied to a summer house for three weeks during October 2017, which was aimed at minimising CO_2 emissions. The top plot shows the temperature in blue and the state of the heating in red (1 if on, 0 if off). The bottom plot shows the CO_2-intensity for the same period. It is evident that the heating tends to be

turned on when the CO_2-intensity is low and off when it is high. With this control, CO_2 emissions were reduced by 9.6% compared to normal operation.

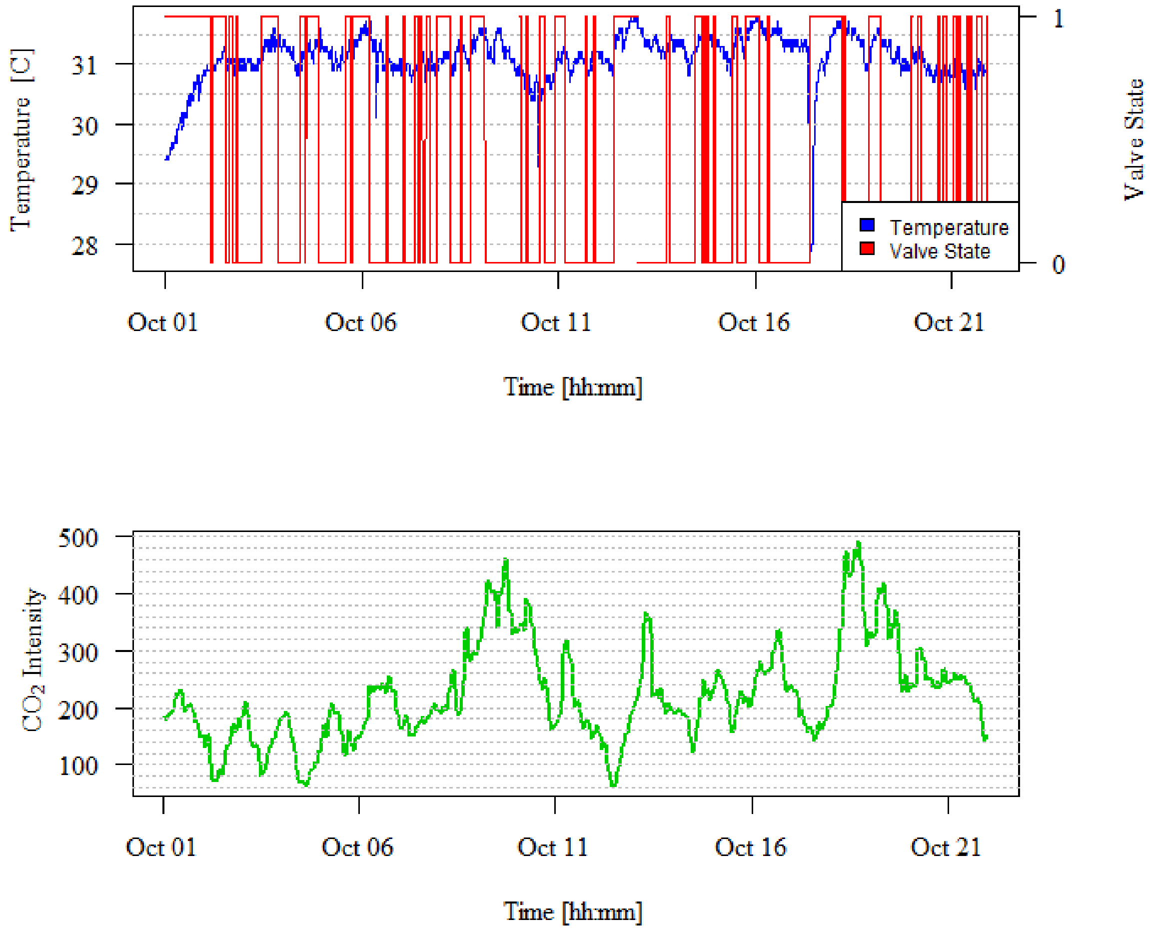

Figure 3.12 Three weeks of CO2-based control in October 2017

However, the results also show that, although this is technically feasible, the expected results will be something different than with a direct-control solution. It should also be pointed out that these tests were done with only two aggregated summer houses. Therefore, the impact of the price-based control is even more visible. With more houses, there is a higher probability that some of the houses react as expected, which also increases the chances for the CMP to make accurate bids.

In addition, several technical challenges appeared during the execution of the pilot. In particular, there was a major problem in maintaining good communication links to SN-10 controllers in the summer houses. The chosen communication form was GSM, which in city areas could easily solve the communication task, but which is very unstable in the rural areas where summer houses are located. Therefore, if electricity consumption is required to respond quickly to price signals, more stable communication connections are necessary in rural areas. Considering that, in general, heating a summer house with a heat pump is similar to heating an ordinary residential building, some of these approaches developed in the Danish pilot can also be applied to buildings too. Therefore, it is interesting to observe

the dynamics and reaction of the occupants of the summer houses to the changes triggered by the controllers; specially to see which parameters are involved when either the electricity consumption is to be started or exposed. An exposure to electricity consumption and knowledge of how long exposure can be without comfort reduction is especially valuable as it ultimately helps to reduce the peak load.

4 Focus on market participation of DER: the Spanish pilot

The third pilot [6], which was executed in Spain, focused on the participation of small-scale storage systems information in local flexibility markets, operated by the DSO both to solve constraints in the distribution grid and to maintain a scheduled exchange profile at the TSO-DSO interconnection. In this case, only one aggregator, the CMP, was considered.

4.1 Pilot setup

The Iberian Peninsula has two main specific challenges, when dealing with decarbonisation. On the one hand, an insufficient interconnection capacity with the rest of Europe is recognized for all network development scenarios in 2030 [7], as presented in Figure 4-1. This lack of capacity prevents the Spanish TSO to benefit from a larger regional market and its associated increase of balancing service providers to increase competition.

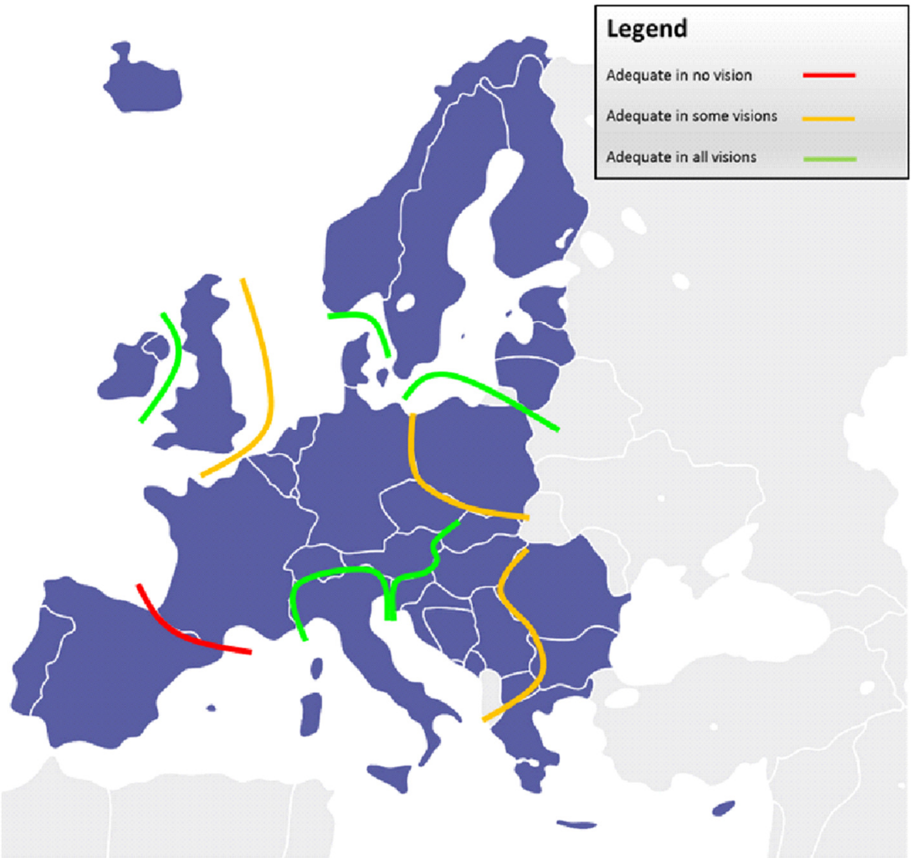

Figure 4-1 2030 Transmission adequacy [7]

On the other hand, balancing and associated AS become increasingly complex (and costly) activities in the Iberian market because the share of highly-variable production from RES in the Spanish generation mix is relatively large. In the presence of such RES technologies in the market, the need for reserves to

balance supply and demand increases. In addition, the increasing number of DER and consumers may lead to grid congestion issues.

As an example of the high variability of RES in Spain, wind power was producing roughly 2 GW at 14:40 (contributing to 6.7 % of demand) on 26/01/2019 and less than 12 later, at 02:10 on 27/01/2019, wind power produced almost 11GW (43.5 % of demand), as shown in Figure 4-2.

Figure 4-2 Variability of the generation mix in the Spanish power system [8]

Under this scenario of intermittent generation, with low interconnection capacity, the need for a more flexible demand is expected in the near future in Spain. However, demand flexibility programs have only been implemented at TSO level and applied to large industrial loads in Spain. The Spanish pilot aimed at demonstrating the technological feasibility of using the flexibility of demand connected at distribution level to provide ancillary services which can be used by the DSO, in particular, congestion management and balancing. Although the European Commission assigns the balancing responsibility to the TSO [1], the DSO can contribute to keeping system balance, by maintaining a scheduled exchange profile at the TSO-DSO interconnection, thus reducing the TSO need to procure balancing energy.

This TSO-DSO coordination is called “Shared balancing responsibility model” [9]. In this model, there are joint balancing responsibilities between the TSO and the DSO, according to a predefined schedule in the common border. The DSO monitors in real-time the exchanged power in each TSO-DSO

interconnection point to ensure the fulfilment of such profile. The DSO also monitors the status of the distribution grid and identifies potential constraints that may arise if demand flexibility is not used. Based on the requirements arising from both monitoring activities, the DSO requests the Local Market Operator (LMO) to open the local market. The LMO is a new regulated function located at the control centre of the DSO, to facilitate that CMPs become flexibility providers of aggregated DER and to allocate flexibility among them in a competitive manner. The LMO receives flexibility bids from CMPs, clears the market, while avoiding the creation of additional constraints in the grid and informs both the DSO and CMPs about market results. Finally, CMPs dispatch the flexibility and the DSO checks the actual delivery of the flexibility required.

On the contrary to the Danish case, the Spanish pilot aimed to implement balancing and congestion management (BCM) services for the distribution network through direct bidirectional signals to the CMP. These signals were pushed further downstream to the activation of DER, following the set-up described in Figure 4-3.

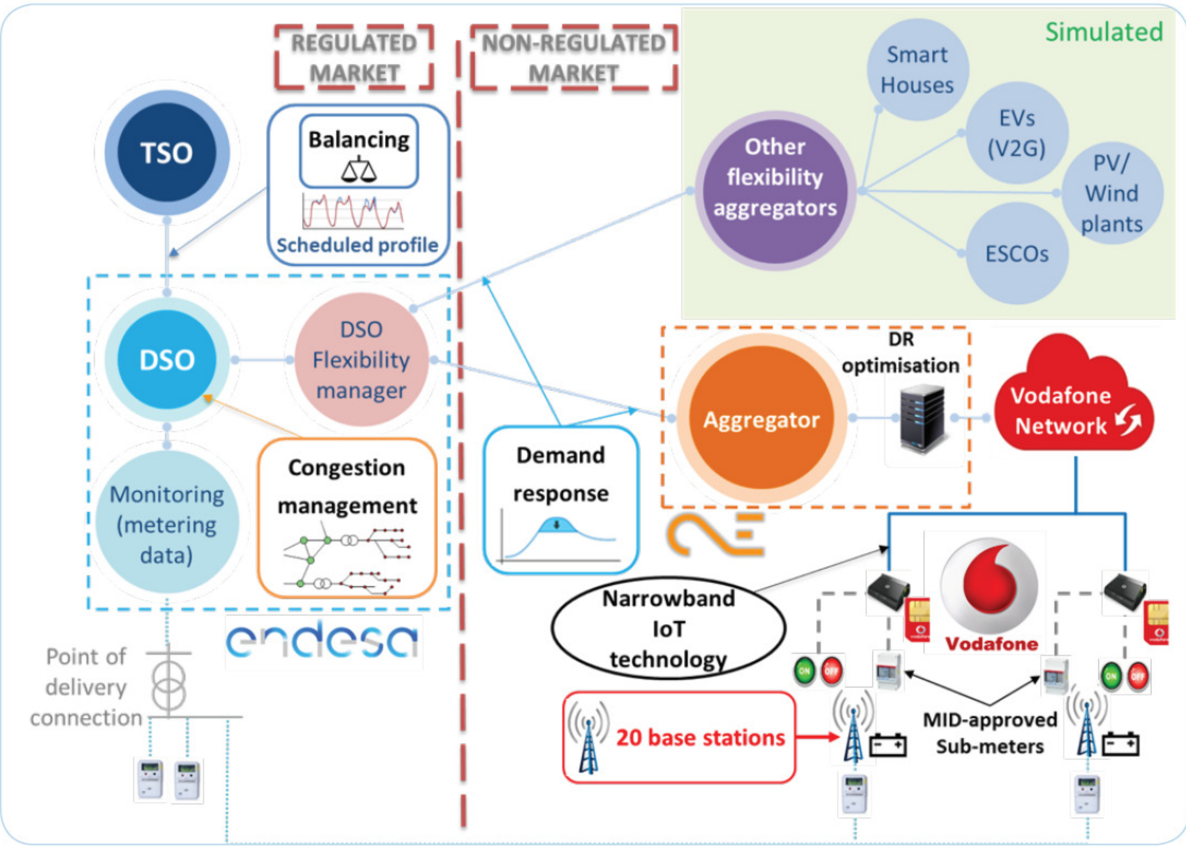

Figure 4-3 Functional architecture of the Spanish pilot

The DER involved in the pilot were radio base stations for providing communications services. Base stations are equipped with back-up batteries to maintain the communications service in the (rare) event of a blackout, as shown in Figure 4-4. Therefore, they could be disconnected from the grid on purpose to

provide AS to the DSO. This way, the DER owner exploited an underutilized asset and supported the operation of the distribution network.

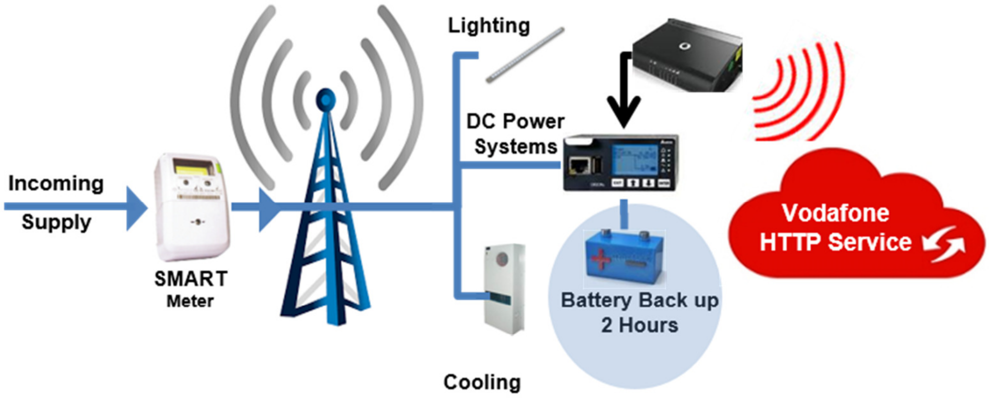

Figure 4-4 Functional architecture of the power supply of a base station

The scheduled profile was generated on a day-ahead basis and given as input data for the execution of balancing services the next day. The profile was created with a 15-minute resolution, based on 2015/2016 historical data archived by the DSO, and by clustering typical days per season and per weekdays/weekends.

The pilot involved five primary substations and 18 radio base stations in the city of Barcelona, as shown in Figure 4-5.

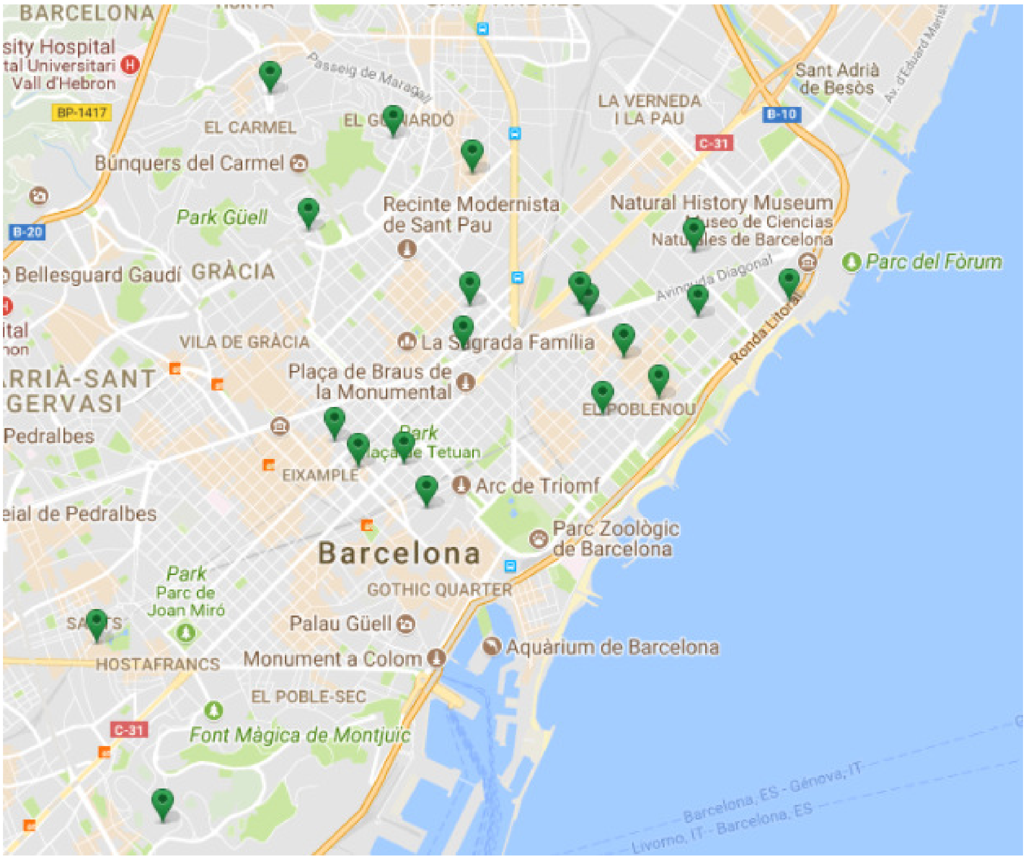

Figure 4-5 Location of the base stations in Barcelona

The distribution network downstream the TSO-DSO interconnection point was modelled with enough details so that balancing at the interconnection, congestions and activated flexibilities were observable. The grid involved in the pilot was strong enough to satisfy the existing demand, so there were no real congestion issues during the execution of the pilot. Therefore, the scenario considered in the pilot looked into a future situation, with a more electrified energy system, which may result in congestion problems at distribution level. In addition, it included simulated DERs that were not connected to the grid to increase the available flexibility in the pilot.

4.2 Main activities performed in the pilot: market bidding, clearing and DER operation

The aim of the local market was not only to gather balancing services but also to solve local congestions management at distribution level. As a result, the market clearing considered the network model and its related technical constraints, along with the flexibility bids. The key difference with respect to the flexibility activation when only balancing services are procured, was an optimisation algorithm, which allocated the flexibility volumes according to the minimum total flexibility activation cost. This optimisation algorithm was an optimal power flow (OPF).

Five different HV/MV primary substations were involved in the pilot. Due to their geographical closeness, the five of them were assumed to represent a single TSO-DSO interconnection point. Since no grid model was available at transmission/sub-transmission level, one separate MV network model was used per each TSO-DSO interconnection, i.e. five models in total.

The distribution system is a complex network with a lot of elements and ramifications, in order to model the grid mathematically some assumptions were taken:

- The grid topology was kept as simple as possible, but it was also developed enough to observe relevant line congestions.
- In principle, only branches with relatively high risk of congestions (based on historical data) were used in the definition of load areas (LAs). LAs were defined as portions of the grid where the allocation of flexibility resources for local congestion management purposes was easier.
- Only primary substations, MV feeders and MV nodes of secondary substations were explicitly included in the model. Points of delivery (PODs) of the real DERs participating in the pilot were implicitly represented inside lumped MV flexible loads of the model because there was no observability to the LV grid except for the meters.
- The DSO had observability at POD level by acquiring real-time data from smart meters. However, active power losses associated to flexibility deliveries at LV-level were not considered, because the LV part was not included in the model of the grid.

As presented in Figure 4-6, each primary substation had a radial topology with several MV feeders and three loads at the end of each feeder: an aggregated load (represented as “BL”), one load with real flexibility (represented as “Flex”) and another load with no flexibility (represented as “Non-Flex”). Furthermore, all the feeders were connected upstream in node 1, which was the MV side of the HV/MV transformer of the primary substation. Meanwhile, the TSO-DSO interconnection took place in the HV side of the HV/MV transformer. For simplicity reasons, the transformer was assumed to be ideal and, therefore, there were no losses, so the voltage was the only difference between both sides of the transformer.

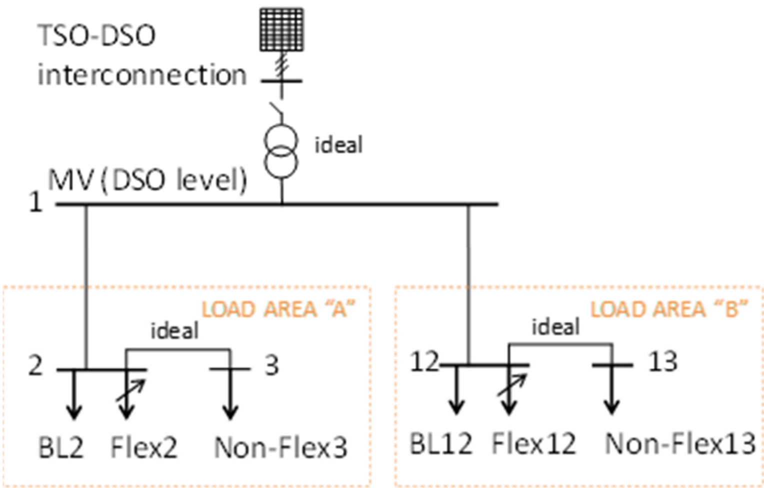

Figure 4-6 Example of grid model for one of the primary substations

As stated above, the real grid involved in the pilot was strong enough to satisfy the existing demand, so there were no real congestion issues during the execution of the pilot. Therefore, a virtual case was created, where additional DERs were assumed to be connected to the grid, both to create congestions in the distribution grid and to increase the flexibility available in the pilot. The virtual case combined real, metered data from the DSO's telemetry system, with virtual units, not existing at the moment, but included in the grid model.

The telemetry data, which were available per MV feeder, were used to build and allocate the non-flexible active power values per MV node ("Non-Flex" in Figure 4-6) and the baseline consumption of the DERs participating in the pilot ("BL" in Figure 4-6). Then, the virtual loads and the associated flexibilities were added to the real base case and allocated per node ("Flex" in Figure 4-6). As a final step, the power flow algorithm was used to obtain the operating conditions of the grid, which provides the information about the power exchange values at TSO-DSO interconnection points as well as congestions at distribution level.

Once the DSO requirements were calculated, the LMO opened a session of the local flexibility market to receive flexibility bids from CMPs. Since DERs were grouped in LAs along the distribution network in the grid model, CMPs considered the location of the different units when sending the bids to the market. These bids consisted of one or more blocks containing the flexibility volume quantity (Q) and their corresponding price (P). Then, the LMO ran the OPF to include the market constrains. The objective was to determine the optimal activation of bid blocks among all CMPs, considering that the clearing price would be set as the most expensive matched bid (pay-as-clear).

The objective function of the model was the minimization of the total flexibility activation cost, that is, the sum of all matched positive power bid prices for all nodes. Three main assumptions were made:

- For each node, the model included an active and reactive power balance constraint.

- For each line, active and reactive power flow constraints were stablished. Constraints were also included to set the operating limits both in voltages and flows in lines (i.e. line security limits).
- For each generator, the optimization model included constraints on generation limits.

In order to avoid abnormal prices in the market, it was assumed that the market was always cleared. For that purpose, the OPF always produced a feasible solution, even in the cases where there was not enough flexibility made available by CMPs or technical constraints in the grid made it impossible to reach the required active power exchange at the TSO-DSO interconnection point. Such feasible solution considered that the DSO had additional flexibility (e.g. in its own grid elements) to obtain a feasible solution, although such additional flexibility was not included in the market clearing process. Once the market was cleared, results were communicated to CMPs and to the DSO.

The market performed in the pilot had two major innovations: the time execution and the use of an OPF to clear the market. The time execution was set in 5 minutes, which is close to a real-time operation and, thus, it may provide more accuracy to balancing and to control activations. Using an OPF to clear the market allowed the LMO to evaluate the technical restrictions and, at the same time, dispatch the flexibility to achieve the balancing objectives.

In addition to the innovation on the DSO-LMO side, there was an important innovation in the CMP's role to perform the monitoring, bidding and activation of a portfolio of homogenous (from the flexibility point of view) batteries in radio base-stations.

In order to fulfil these duties, the CMP needed to communicate with the rest of the parties. In particular, communications were required with the LMO for bidding and clearing, with DER for managing and activating flexibility, and (indirectly) with the DSO for real-time information of the actual load per asset to guarantee the effective provision of the traded flexibility. These communication requirements were solved with a centralised asset gate hub model, which was the sole interface towards outside counterparties, as presented in Figure 4-7 below.

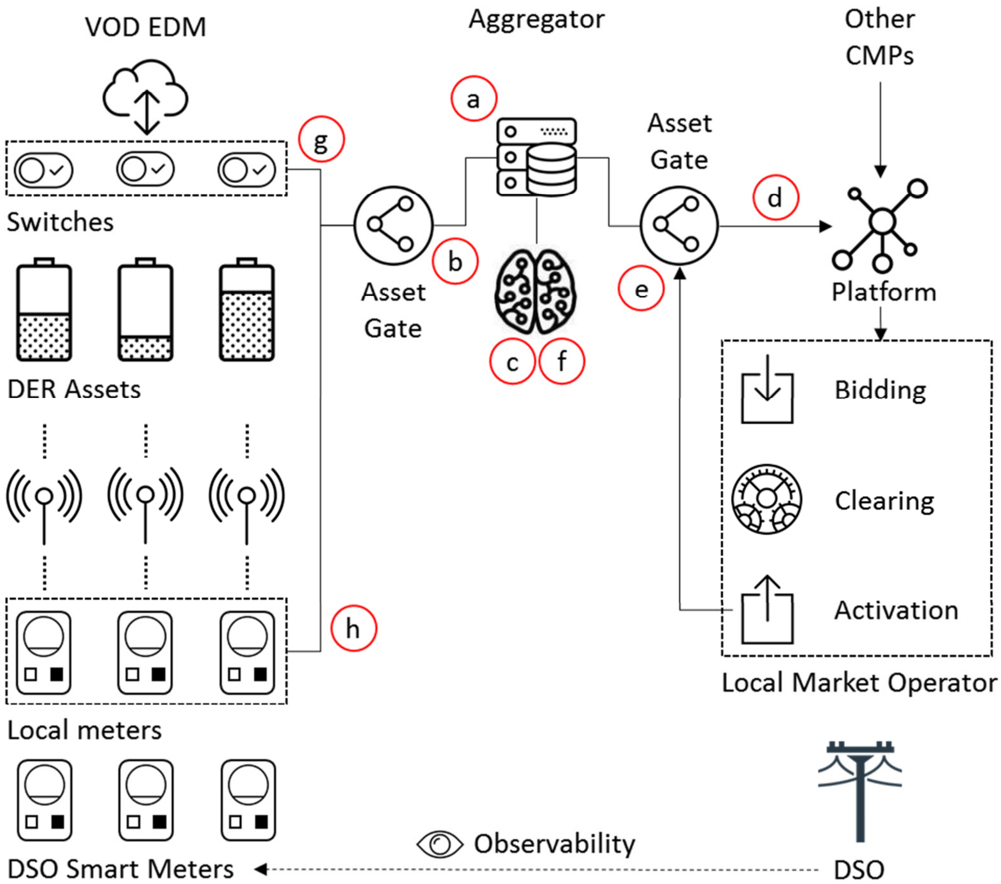

Figure 4-7 CMP's process flow

The main activities described in Figure 4-7 are:

a) Create a built-in database with pre-agreed logic on flexibility availability, portfolio size, scheduling profile, etc.
b) Receive constant feed from asset status (asset gates introduce input in the database).
c) Explore bidding opportunities in view of expected market results (run in Python).
d) Post bid to LMO (the Python-code creates objects in the database and sends them via asset gates).
e) If successful, receive activation from LMO (asset gates introduce input in the database).
f) Assignment of activation to assets (Python-code creates message in database).
g) Send activation / deactivation message to assets (database sends signal via asset gate).
h) CMP (Aggregator in the figure) observes and follows activations. If failure, repeat from step f.

In order to implement the aggregation algorithm, the CMP had to take into account the minimum allowed state of charge and the nominal charging power of the batteries and obtain in real-time both the state of charge of the battery and the load in the base station. The algorithm developed for this task

allowed the CMP to manage the different data and communication interactions, as well as to model the potential behaviour of the different assets.

4.3 Other important activities: communications, DSO's monitoring tool

Given the nature of the DERs in this pilot, a number of parameters and real-time information exchange were required between DERs and the CMP. For that purpose, the pilot took advantage of having Vodafone as a partner and the possibility to use the energy data management (EDM) system they developed to monitor the base stations, and which aggregates a number of operational parameters from the assets in one single platform. This solution allowed the CMP to communicate with an array of assets through one single communication channel, which simplified the process significantly, as most routines and processes were already designed.

Although the DSO could verify the activation of the base stations through the billing meters installed, these smart meters are designed to collect the consumption information in hourly periods and to send the data to the DSO's control centre on a daily basis. Therefore, the EDM system was also used to allow the CMP to send real-time data to the DSO. Figure 4-8 shows the overall communications architecture.

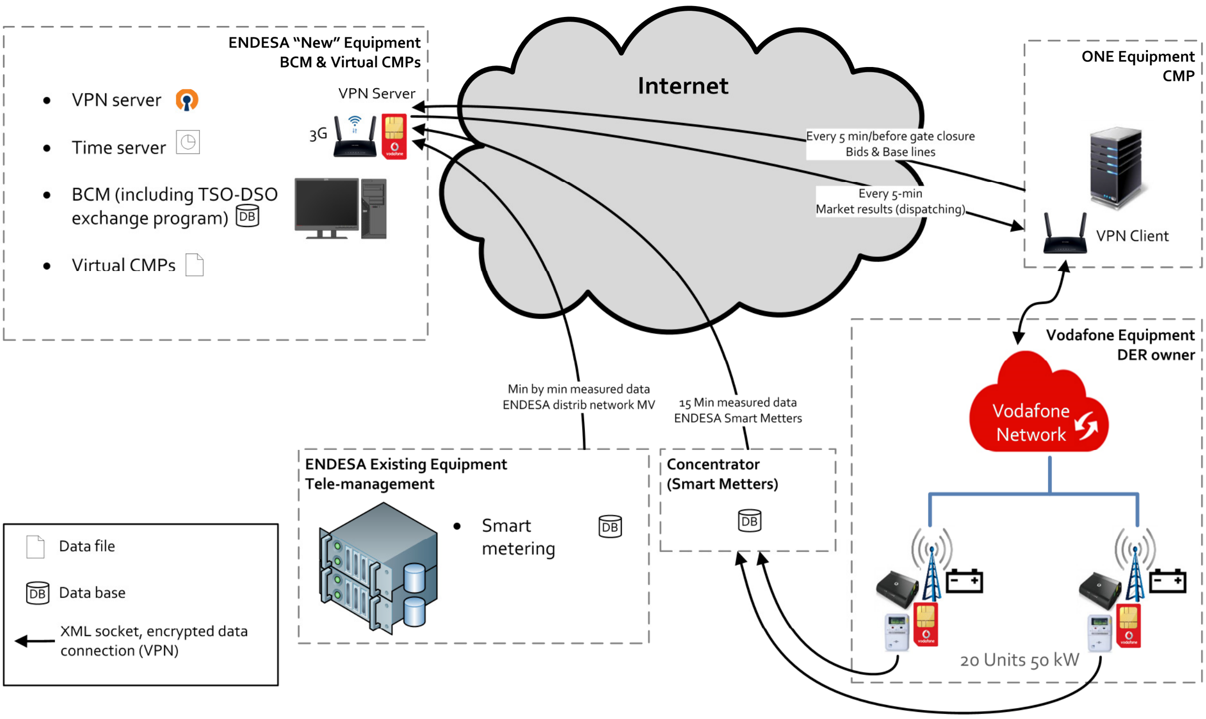

Figure 4-8 Overall communications architecture in the Spanish pilot

Another important development within the pilot was the creation of a visualisation environment, which could be used both by the DSO and by CMPs. The web server for visualisation was divided into four sections:

- "Home": a short introduction to the project SmartNet and to the Spanish pilot were provided, together with some presentations. The page included a short video presenting the project, a brief introduction and a link to the SmartNet web page. On the upper part of the page, a menu was included to navigate through the website, which allowed the visitor to visit the different sections described below.
- "Balancing & Congestion": the balancing functionality and the grid structure and measurements were included in this page. The upper part of the balancing and congestion page (Figure 4-9), showed the power exchanged at the TSO-DSO interconnection point and the scheduled profile. A filter was also made available to show a specific period of dates. At the lower part of the page (Figure 4-10), a snapshot diagram of the selected substation was included to show the power exchange on the interconnection point, the power passing through each main feeder, the level of congestion for each section and the status of the resources involved in the pilot. All the power values were provided in megawatts, except for the resources which were provided in kilowatts.

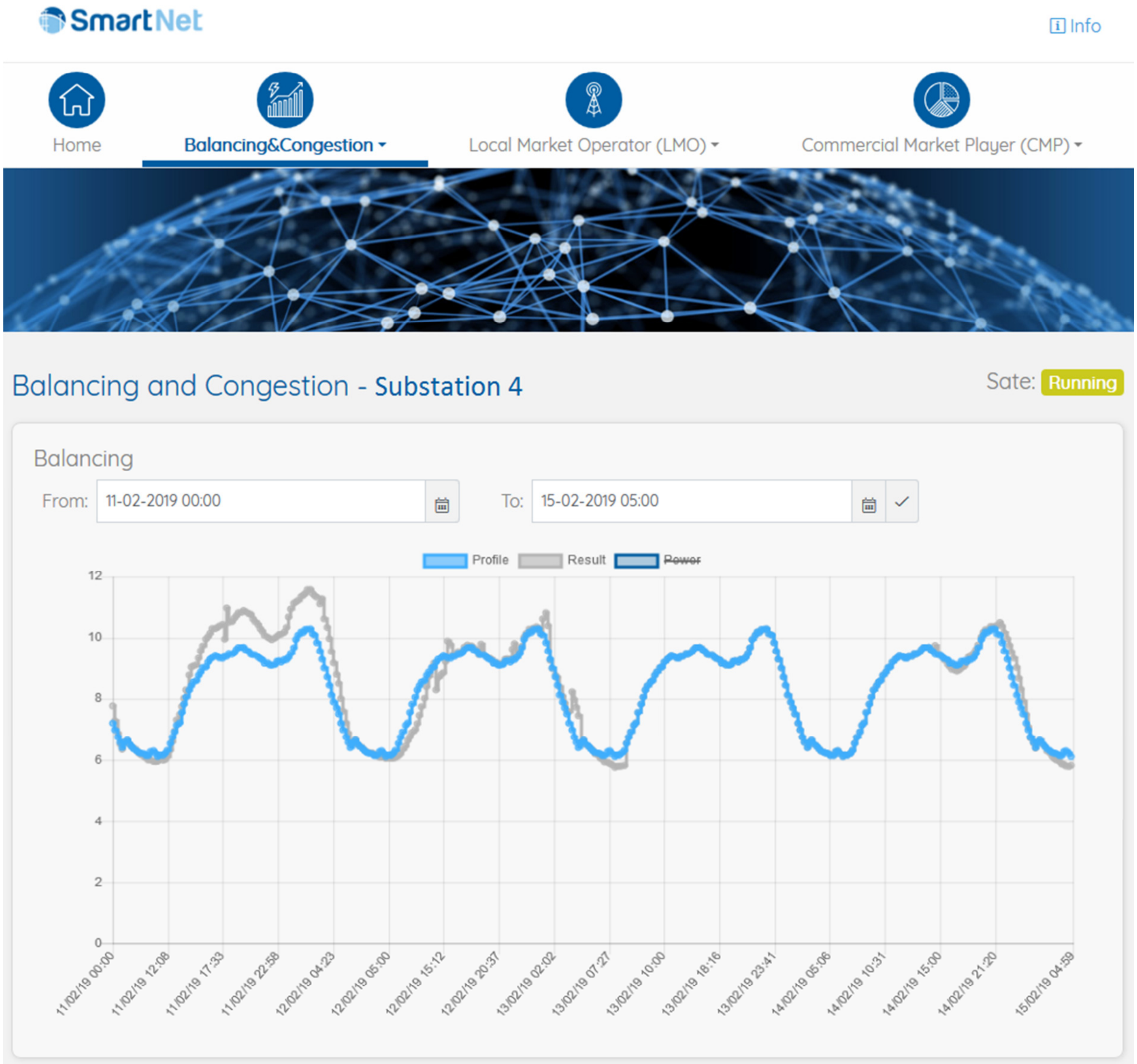

Figure 4-9: Balancing & Congestion page, top

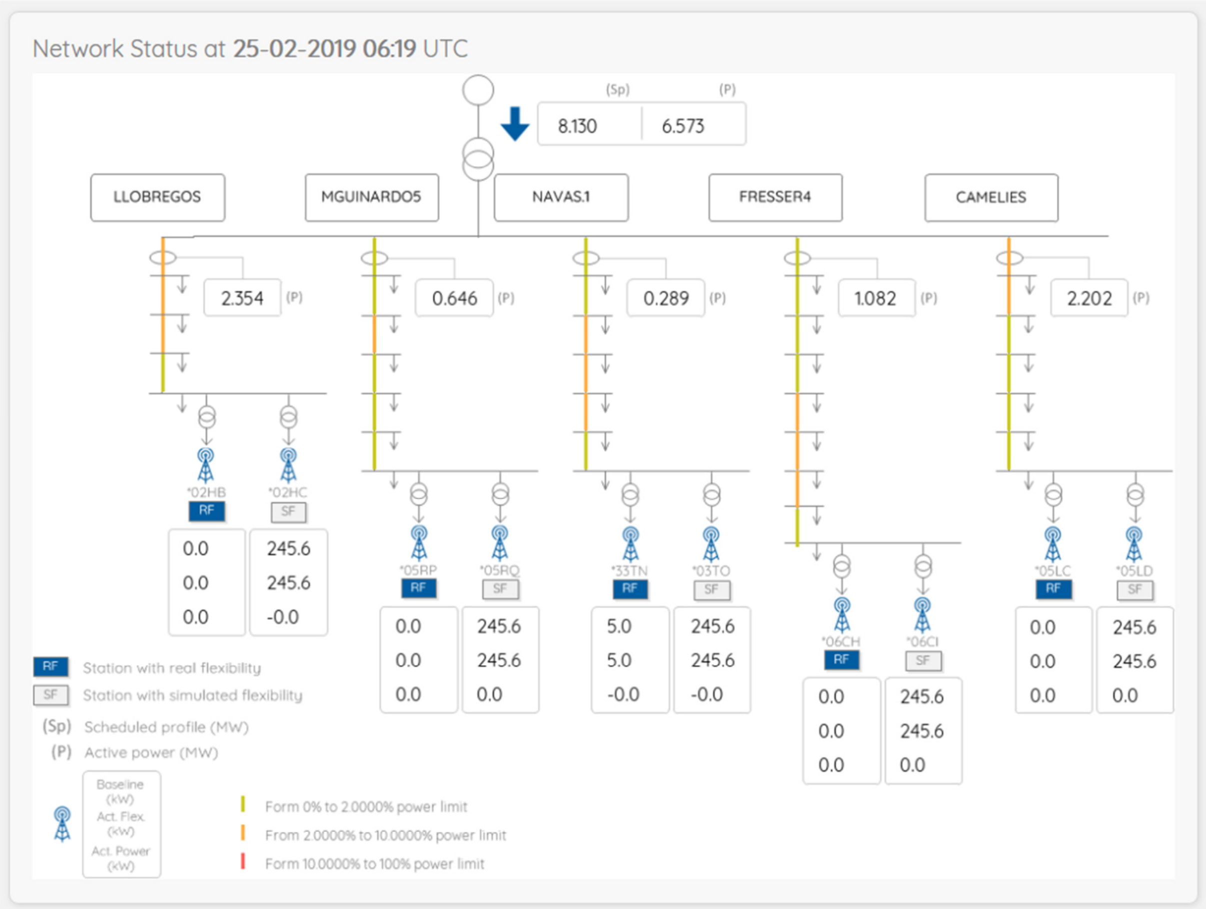

Figure 4-10: Balancing & Congestion page, bottom

- "Local Market Operator (LMO)": this page showed the status of the market the prices and the activations. A submenu with the different substations was included in the main menu and a filter was made available to select the time horizon shown in the charts. The upper chart (Figure 4-11) showed market prices (in blue) and the price of the most expensive bid sent by CMPs (in grey). The lower chart represented, for each time-period, both the amount of available flexibility and the dispatched flexibility.

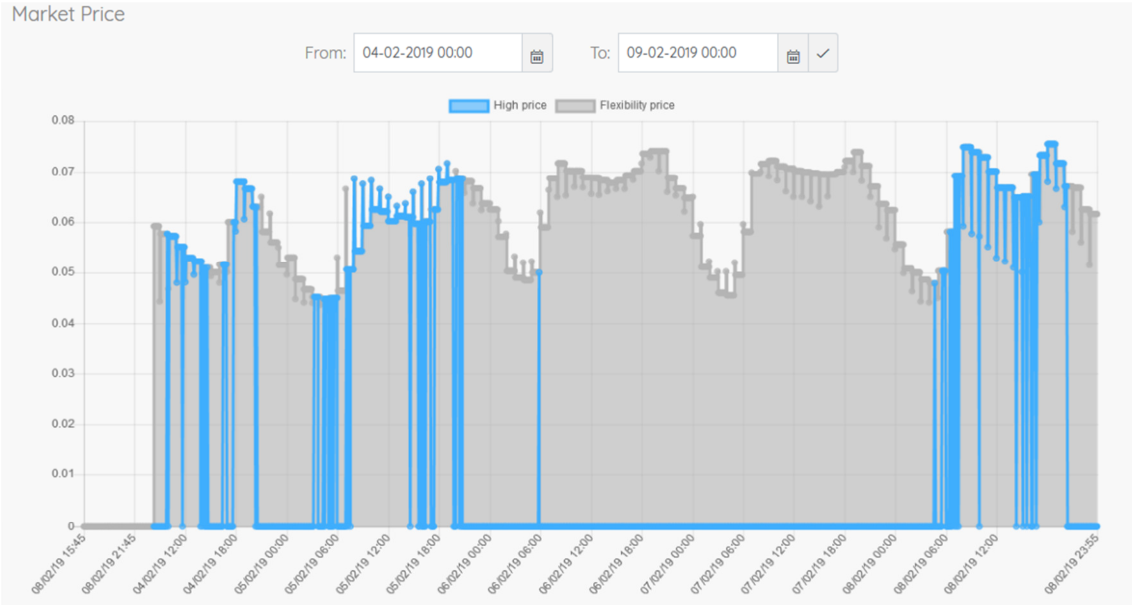

Figure 4-11: Local Market Operator page, top

- "Commercial Market Player (CMP)": this section shows the information regarding each CMP. In addition to the date filter included in the other sections, a submenu was included in the upper part of the page to select the CMP to be visualised, from the three ones involved in the pilot (ONE, TWO or Virtual). The upper chart (Figure 4-12), aimed at representing the amount of flexibility provided by the selected CMP, included the total flexibility available (grey line), the expected consumption (light blue line) and the real consumption (dark blue line). In the lower part of the CMP page, a table with each offer sent to the market was presented, including the information related to each station, the flexibility offered and its price.

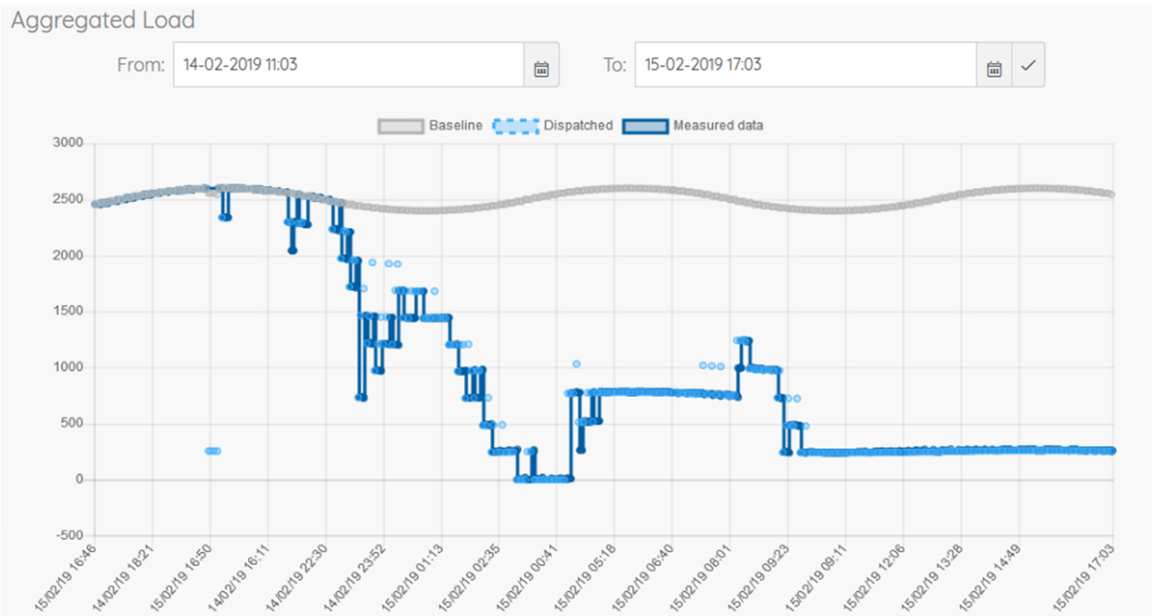

Figure 4-12: Commercial market party page, top

4.4 Main results and conclusions

The execution of the pilot was divided into three weeks of 24/7 operation. The first one, which took place in September 2018, was aimed at checking the frequency of activations and the pilot activity. The communications between the different agents were tested and the CMP designed and developed the bidding strategy. As a result of this first execution phase, some systems and communication processes had to be updated and the DSO developed all the tools to run the local market. Such local market was tested in January 2019. Again, some updates were needed before running the third test week, which was launched in early February 2019.

In this test, it was demonstrated that the DSO can meet the goals of maintaining the scheduled profile at the TSO-DSO interconnection, while avoiding congestions in the distribution grid. However, it is important to remind some considerations:

- The flexibility used in the pilot was provided only by reducing demand and, thus, no increase in consumption was made. As a result, the DSO could contract upward balancing (demand reduction), but not downward balancing (demand increase or generation reduction), because the types of DER to provide it were not included in the pilot.
- The scheduled profile was obtained from historical data and, hence, it may have been quite different to the real consumption in some cases. For example, one particular day may be usually very cold but, when executing the pilot, it may have been hotter than usual (due to specific weather conditions in 2019), hence affecting the real consumption in the distribution grid.

As an example of the success in the execution of the pilot, Figure 4-13 shows how the actual power exchange at the TSO-DSO interconnection (grey) was able to follow the scheduled profile (blue).

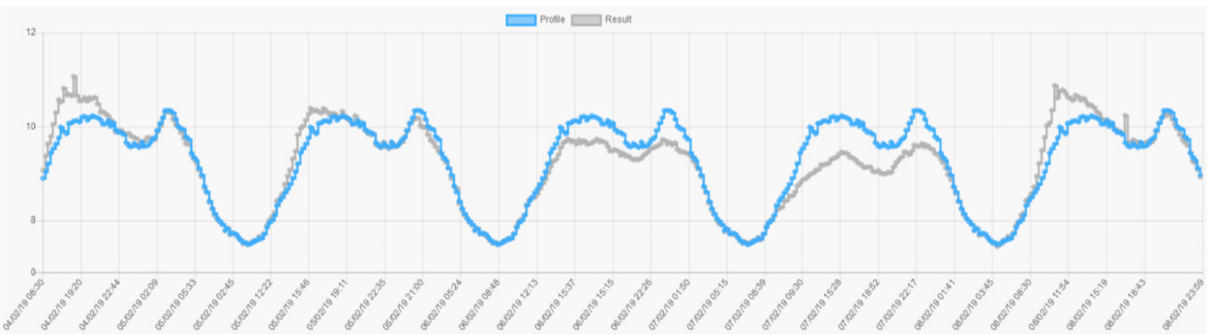

Figure 4-13 Balancing of one substation, during the execution between 4 and 8 of February 2019

The reason for having some periods in which the two lines are not in line is presented in Figure 4-14, which shows the flexibility available (light blue) and the flexibility required by the market (dark blue). When there is not enough flexibility available to meet all the requirements by the DSO (in the mornings of days 1, 2 and 5, when all the available capacity is used), the DSO cannot meet the scheduled profile and the exchanged power is lower than the schedule (blue line in Figure 4-13 is below the grey line).

Likewise, when the DSO needs downward balancing (in days 3 and 4, when flexibility is only dispatched during the night), batteries cannot provide it and, thus, the exchanged power is higher than the schedule (blue line in Figure 4-13 is above the grey line).

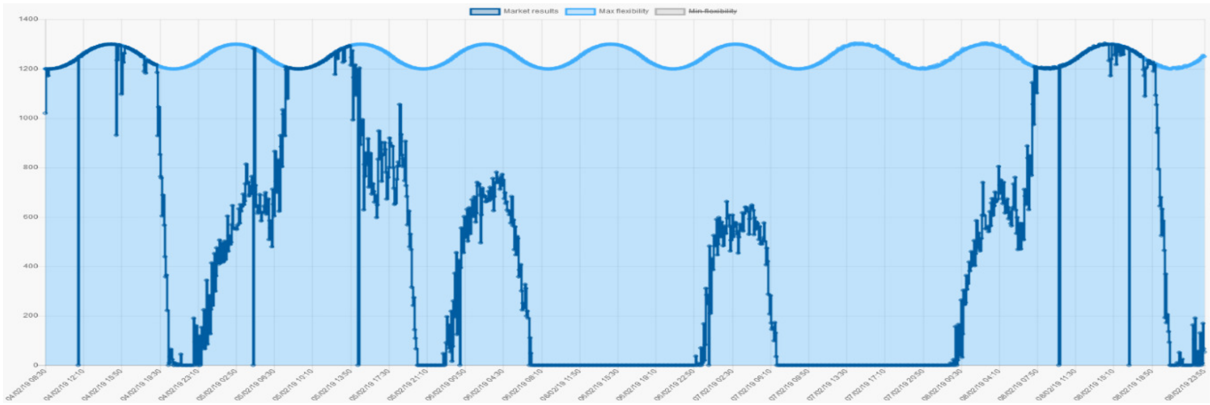

Figure 4-14 Flexibility of the same substation, during the execution between 4 and 8 of February 2019

Likewise, the congestion management process proved to be an alternative method to grid reconfiguration or reinforcement, when solving constraints in the distribution grid. This method also demonstrated to be useful to allow the DSO to run a "quasi-real time" market with technical constraints, in contrast to other approaches that solve technical restrictions after clearing the market for balancing. At the same time, the use of an optimization algorithm with two objectives, i.e. to comply with the balance and avoid the congestions, was successfully tested.

From a more practical perspective, it was learned that communications between the DSO and the CMP, and between the CMP and DER, are key elements for the success of the pilot. For that purpose, the use of standard communication protocols is of paramount importance to allow fast, transparent and non-discriminatory access to market information. Furthermore, it is worth underlying that the communication protocol and activation led to real activations in the physical assets, thereby seriously decreasing the implementation problems and resulting in a significantly high technology readiness level exercise.

From the DER owner perspective, the pilot paved the way for building a new business case, based on the provision of AS for grid operation and, hence, optimising asset usage. Under a near-future scenario in which the arrival of 5G technology may challenge the energy supply of telecom companies, the possibility of exploiting the flexibility of batteries for commercial applications opens new opportunities for them.

In addition, the execution of the pilot allowed for improving the asset management procedures:

- Several issues were found with the compatibility of DC power systems provided by certain vendors, which required the replacement and upgrade of a number of sites.
- A few sites were found to have faulty batteries, needing urgent replacement in the grounds of operational resilience, thanks to the remote connectivity.

- In addition, the remote connectivity also enabled identifying a number of maintenance issues, such as high temperature problems in some sites, system faults and issues with landlord power supplies.
- Thanks to a failure in sending the stop signal by the CMP, the remote battery test function was executed, which demonstrated the automatic reinstatement of the rectifiers to normal operation mode once the battery reached the bottom of the safety voltage (47.7 V). Figure 4-15 shows such event, triggered at 9:40 until 9:45. The green area shows the battery capacity recharging over time, reaching 90% of capacity in 2 hours. The remaining 10% took 8 hours more, due to the chemistry of the battery (currently, valve-regulated lead-acid).

But more important, none of the activities in the pilot had any impact on Vodafone's service: the staff in the operational division of Vodafone Spain was asking about the start of the pilot months after the activations had started, because they did not notice anything in the day to day operation of their network.

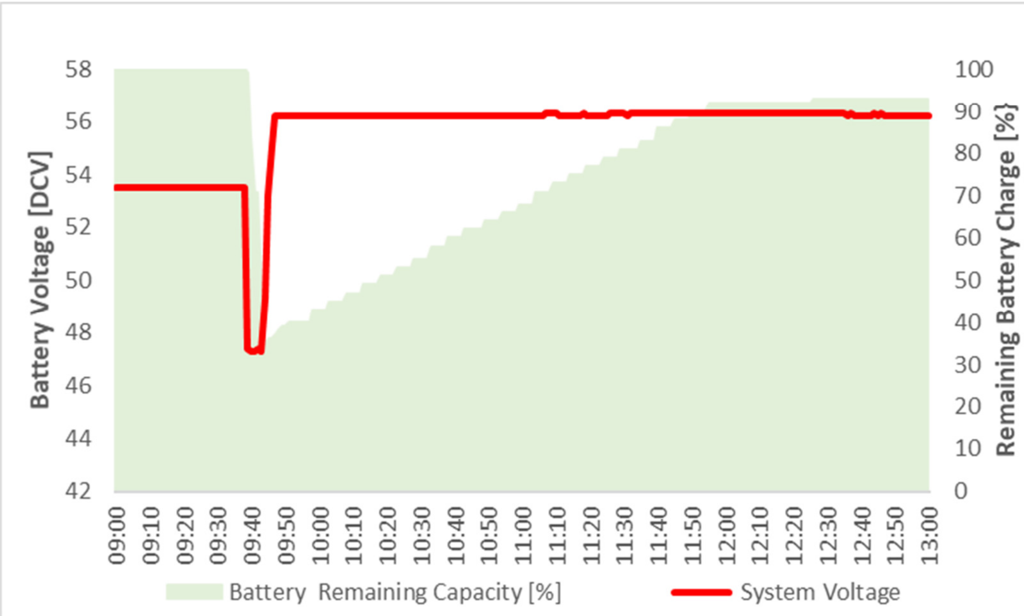

Figure 4-15 Sample DSR Event Showing Battery Voltage & Remaining Charge %

5 Lessons learnt

The three technological pilots deployed within the project SmartNet demonstrated that the TSO-DSO coordination schemes defined within the project are able to perform in real-life applications, as they do in the simulated environment. In particular, three different coordination schemes and market structures were tested, by focusing on different aspects of the AS procurement process and by using different types of DER technologies.

The results show that the three pilots were successful in procuring AS from DER. In spite of some minor issues resulting from the real-life implementation, were very useful lessons were learnt for the replicability of the solutions proposed.

5.1 Specific lessons from the Italian pilot

The purpose of the Italian pilot was to experience in field new technologies in order to explore new approaches for the management of the grid, considering also RES and DG, the amount of which are supposed to grow in the near future due to the adoption of a policy that aims to encourage the development of new and renewable forms of energy and the fossil fuel replacement.

The experimentation in field allowed to collect important resulting data to evaluate both the functioning of the devices and the quality of the ancillary services provision by RES and non-programmable energy sources.

The outcomes proved the possibility to control in real-time the active and reactive exchange of DG with the grid, through a centralized scheme controlled by the TSO taking into account the constrain of the whole grid to avoid voltage violation and congestions also in the distribution grid.

An important value of the pilot is the opportunity to detect the aspects to be improved in order to allow the integration of RES in the electrical grid.

Tests highlighted the clear need of further experimentations, some of which are already in place, in order to improve the performance and the reliability of the behaviour of RES to provide AS. First of all, the pilot highlighted the importance of an accurate and complete monitoring of the sources and of the provision of the services so as to guarantee the efficiency, the safety, the adequacy and the quality of the centralized activation of flexibility. The reverse engineering exercise, aimed at comparing the available measurements with the results of the estimation algorithms that were run simulating a reduction of the installed meters, showed that this accuracy is guaranteed by a high coverage-rate of direct measurements in field, to estimate the power production characterized by high unpredictability (at least the 60% of the installed production in case of hydro power plants). The outcomes also showed the dependence of the accuracy on the type of estimated resource (solar production seems easier to be estimated based on

weather data) and on the choice of the sentinel measurement that significantly influences the result and is not based solely on the size of the power plants.

It is important to consider that the observability functionality implemented in the pilot implies the transmission of the measurement aggregations differentiated by source to the TSO control system with a 20-second update. The analysis of the tests have highlighted that, in the provision of the AS, the data update rate of 20 seconds is not adequate to evaluate the dynamic response when DER are providing active power services like aFRR, since in the provision of aFRR, the power production varies rather quickly (about each 4 seconds and the calculation of the closed-loop amount of the aFRR activation is updated every 2 seconds).

Regarding the voltage regulation, tests showed that the effect of the behaviour of big-sized plants connected in the area prevails over the small-sized hydro contributions, especially considering the DG. Regardless, the advantage of a coordination of the reactive power between TSO and DSO, through coherent reactive power activations, is the possibility to reduce the recirculation of reactive power among generators and the waste of regulating resources. The pilot proved the possibility to coordinate the reactive power between TSO and DSO through coherent reactive power activations.

The experimentation was an interesting preliminary study considering that the national implementation of the new European Regulation (Requirement for Generators) in Italy provided an extension of the ability to regulate the voltage: new power plants shall be able to provide the voltage regulation and it has been investigated the possibilities for existing power plants to undertake modernization to adapt its performance with new requirements and provide voltage regulation. In this perspective, the results of the tests provide interesting data to know the possible applications that can be adopted to use the reactive power flexibility of the grid and the aspects to be improve (capability, accuracy, delays, mitigation of overshoots).

For the future, the purpose is to maintain in operation the devices: the HVRS installed in the HV substation for TSO's purposes, while the MVRS is currently mainly used by the DSO to locally control the voltage along the feeders of the distribution grid (due to the slight benefit to the HV grid).

Regarding the frequency regulation, the tests have led to the activation of 6 MW in distribution grid. Therefore, the experimentation has verified the possibility to activate services from DG in accordance with network constraints, because the system automatically and continuously evaluates the operational condition and calculates the real time capability of the VPP considering all the distribution grid constraints. The availability of the VPP for the provision of the service is defined by the MVRS in accordance with this capability. Moreover, the device gives priority to the violation on the network over the regulation because, in case of violation in the DSO grid, the MVRS interrupts the regulation and try to solve the potential violation acting on the power plants operating point and on the on-load tap changers.

Due to the complex communication chain and the limited power plants performance, the dynamic response of the DG aggregation did not comply with the technical requirements of the service in terms of both accuracy and delay. The project highlighted future opportunities for manufacturers to improve the performance of the regulation and of the communication chain (for instance, regarding information and communication technologies, as well as power plant controllers). Furthermore, it is evident the need to find a way to overcome the unpredictability of RES: it is not possible to guarantee a contribution in the service without a production plan or without considering the combination with other types of flexibility capable of compensating the performance errors presented during the tests. In the provision of the ancillary services.

In conclusion, the pilot provided an interesting preliminary study to evaluate feasibility of the project and it opened the door to future improvements to understand how to exploit new flexibilities of the electrical system to support the TSO in the grid management.

5.2 Specific lessons from the Danish pilot

The Danish pilot has shown the potential for a much more significant contribution to both industry and the research community to harvest energy flexibility. The energy flexibility could be provided to the grid using new and novel methodologies experimented and deployed in the pilot. A new flexibility function and an economical model-predictive control were implemented, designed and used in a new setup to demonstrate the potential of possible flexibility. Results and analysis show that using these new methods could reduce the CO_2 emissions by at least 10%. Besides, the solution has shown potential to complement existing markets for ancillary services.

The energy flexibility must be considered as a dynamic phenomenon. This contrasts with the classical problems related to production, transmission and distribution of power, where everything can be assumed static. Moreover, energy flexibility comes with stochasticity much larger than that experienced for power generators. The dynamics and stochasticity are especially pronounced when zooming in on few buildings and small time-scales, as was done in this pilot.

This means that bidding-clearing approaches are inappropriate for activating energy flexibility, which leaves CMPs in a poor position to participate in the current power markets. Control approaches are currently the only known solution to stochastic and dynamic problems. A restructure of power markets should be undertaken to allow such solutions. Moreover, a high time resolution (more than five minutes) has to be chosen to incorporate the energy flexibility on regulation markets. However, the summer houses initially chosen for the pilot were all heated by heat pumps, where turning them ON and OFF too frequently wears them down. Thus, the frequent flexibility activations requested by the CMP were often ignored to protect the heat pumps.

From a technical perspective, during the uninterrupted operation of the communication and bidding processes implemented by the CMP, some anomalies were found in the processing and adaptation of data at times when data from the NordPool API were not provided. Therefore, the use of this APIs proved to be very useful in enabling quick, transparent, and non-discriminatory access to market information. The CMP has also observed the necessity to implement additional code to write temporary extraction files and save the server database (offers, activations, activity logs, etc.) every 24 hours to provide memory optimization solutions on the server in order to feed auxiliary processes and free memory from the server. An optimization of the script to improve the use of memory to solve processing time problems on the server and maximize uptime was also performed.

The Danish pilot used a unidirectional communication between the upper and lower levels of the pilot. As a full real-time feedback was not required, the computational load and time declined considerably, thus allowing to broadcast signals from thousands or even millions of assets. The control for this system is decentralized (as stochastic controllers perform the control duties) and this scheme is more secure in case of a certain intrusion (e.g. a hacking attempt into the system), as the CMP does not read the available flexibility or bids anywhere, eliminating a significant communication risk. However, this system requires the CMP to implement a new way (the flexibility function) for the conjugation of the “deterministic” auction/bid/clearing mechanisms necessary at high level, for the “nondeterministic”. The exact reaction of the assets is unknown, as just models have been used for this purpose.

From the communications perspective, the pilot also provided several lessons to be learnt:

- Using 3G communication for remote, rural areas, where there is a limited coverage of communication networks, can be a challenge. This point is even more critical in the case of summer houses, because of the limited bandwidth in periods when there are many people in the summer houses using Wi-Fi and mobile phones. As a result, it is important to make sure that the data communication network has high quality of service and, to be on the safe side, include an off-line back-up solution for the periods with no communication.
- Some of the people renting the summer houses was shutting off the heating installation or the power to the control system, which gave some challenges when operating it automatically. Therefore, the access to on-site disconnection of the control system should be limited as much as possible (e.g. only to technicians or in emergency cases). This can be made by offering the IoT unit and the management system as an integrated part of the summer house rental service, so that the user comfort preferences can be a feedback to the energy management system
- A batch of SIM cards for the control unit (SN-10) had a problem with material it was made of, resulting in a small deformation and therefore unstable connection between the SIM-card and the SIM-card connector. This resulted in periodic disconnect from the network and unstable data communication, until the SIM-cards was replaced. Hence, it is important to remind that

low CAPEX can result in high OPEX - meaning that if the investment in IoT in the field (summer house) is to low, which will course frequent service and maintenance visits in the field, then the operation cost can be too high for the limited income from flexible load control.

As a summary, the Danish pilot paved the way for new developments and the creation of new technologies that help in providing extra flexibility to the energy sector. In addition, at the consumer level, they can gain additional benefits from such methodologies and set-up from some of the challenges this pilot has faced during the execution phase. In general, the Danish pilot achieved its objectives, in how to apply new control algorithms and defining new technologies for such systems.

Throughout the different implementation phases, both the obtained results and the advanced technologies developed in the Danish Pilot attracted the attention from all around the world. Results and analysis derived from the output of the experiments and test performed in the pilot showed that using these new methods could reduce the CO_2 emissions by at least 10%. Besides, the Danish pilot has provided indirect benefits that were not anticipated at the initial stages of the projects, such as remote control of the heating system and monitoring of the status of property occupancy by the house renters.

5.3 Specific lessons from the Spanish pilot

Within the Spanish pilot, the DSO developed new methods and performed innovative responsibilities for the grid exploitation. In particular, it was demonstrated that the DSO can run a "quasi-real time" market with technical constraints (in contrast to other approaches that solve technical restrictions after clearing the market for balancing) by running an optimisation algorithm that allows complying with the balance at the TSO-DSO interconnection, while avoiding congestions at distribution level. From the experience in the pilot, it can be concluded that the congestion management algorithms give an alternative method to solve the congestions into the grid versus other solutions such as grid reconfiguration. However, in order to be able to implement a shared balancing responsibility market model, enough available flexibility must be ensured in order to avoid situations where there is not enough offered flexibility in the market to get the balance. Moreover, the implementation of a local flexibility market by the DSO requires the existence of system to monitor both the power and voltages and, in order to meet the clearing frequency defined in the pilot, measurements must be made close to real-time. Although the smart meters deployed in Spain can measure with the required frequency, they are not configured to do so (due to more relaxed regulatory requirements), so existing smart meters had to be reconfigured for the purpose of the pilot.

During the uninterrupted operation of the communication and bidding processes implemented in the pilot, the CMP experimented several challenges. On the one hand, there were some anomalies in the processing and adaptation of data at times when no data is received from the DER, but the use of communication protocols proved to be really useful to allow fast, transparent and non-discriminatory access to market information. On the other hand, the CMP also observed the need to implement additional

code to write temporary extraction files and save the server database (bids, activations, activity logs, etc.) every 24 hours to provide memory optimisation solutions on the server in order to feed auxiliary processes and free up server memory. The reason is that it does not allow interference from, for example, hackers, since the CMP does not read the flexibility available or make offers anywhere, thus eliminating a significant risk of communication.

The pilot also allowed the DER owner to improve the asset management:

- Several issues were found with the compatibility of DC power systems provided by certain vendors, which required the replacement and upgrade of a number of sites.
- A few sites were found to have faulty batteries, needing urgent replacement in the grounds of operational resilience.
- In addition to discovering the battery issues described above, the remote connectivity enabled identifying a number of maintenance issues, such as high temperature problems in some sites, system faults and issues with landlord power supplies.
- Due to a failure in sending the stop signal by the CMP, the DER owner could also fully test the remote battery test function in full, hence demonstrating the automatic reinstatement of the rectifiers to normal operation mode once the battery reached the bottom of safety voltage (47.7 V).
- More generally, working in a live environment always requires integrating external planning constraints, such as customer service and 3rd parties' constraints, into the field operation. These constraints include the opening time for site access in premises of commercial landlords and residential areas, network freezing periods to maximize the communications network stability in peak periods (e.g. Christmas time), permits for crane set up when needed for equipment replacement on city centre rooftops, etc.

But more important, none of the activities in the pilot had any impact on the communications service: the staff in the operational division of Vodafone Spain was asking about the start of the pilot months after the activations had started, because they did not notice anything in the day to day operation of their network.

As many telecommunication operators, Vodafone manages a vast technical and multi-site estate, with installed energy backup to allow customer enjoying voice call and data speed in any circumstances. The Spanish pilot demonstrated that, in good grid conditions, the unused available capacity backup aggregated from bases stations can be reused by the DSO for congestion management, and eventually avoiding costly ignition of thermic power plants. Vodafone by itself in EU could represent more than 250 MW of flexible load.

In the future, the demand response concept should be integrated in the grid / telecom operator relationship from inception as to design the base stations accordingly (power control, back-up and

communication dimensioning) to get the sites “flexibility-ready”. Further studies to optimise the backup technology to this extend should be launched as soon as possible to complete the picture and optimize the requirements. The demonstration of the benefits envisioned in the Spanish pilot may contribute to a regulatory change in the next years to help unlock the value of small and multiple-site infrastructure assets owned by telecom operators (and other similar DER), while contributing to the social welfare of European citizens

5.4 Impact of pilots outside SmartNet

The SmartNet project in general and the pilots in particular were extensively disseminated to the stakeholders outside the SmartNet consortium since the very beginning of the project. Although it is not the aim of this deliverable to describe all the activities performed, it is worthwhile to mention the most relevant ones.

Each of the pilots organised a national workshop to disseminate the outcomes of the activities to the most relevant national stakeholders.

The Italian national workshop was held in Rome on the 6th of May of 2019, at the TSO headquarters. The workshop was focused on explaining the technical details of the pilot and the results of the experimentation to Italian stakeholders. Each partner of the consortium (Terna, RSE, Edyna, Siemens and Selta) had the opportunity to described part of the project and their role in the pilot. After a brief welcome, RSE presented a summary of the whole SmartNet project introducing the other activities provided for the project. Then, Terna described the Italian energy context and the characteristics of each service tested were illustrated in detail to complete the overview of the pilot and to explain the requirement for each ancillary service in Italian regulation. The functionalities implemented were described comparing the novelties introduced in this innovative experimentation with the actual rules of the Italian regulation. Edyna described the DSO’s grid and the power plants involved in the project, characterised by a reverse power flow due to the abundant production for almost all the year. The technological partners of the consortium, Siemens and Selta, illustrated the technical details of each device and each functionality implemented for the pilot (HVRS, MVRS). The conclusions showed the results of the tests carried out with the devices installed in field and the technical limits of RES and DG in the provision of the tested services. The participation was wide, also in terms of the variety of stakeholders: representatives of manufacturers, producers, DSOs, energy organisations, traders took, etc. The participants showed an interest both in the technical aspects of the project and in the importance of the results of the experimentation as a benchmark for future analysis and developments.

The Danish national workshop was arranged on the 20th of September of 2018 at the TSO premises. The workshop started with an introduction by DTU to both the SmartNet project and the Danish pilot in its context. Then, the rest of the partners in the pilot presented the work did they: representatives from SydEnergi and Energinet.dk presented the challenges and possibilities for use of the developments on the

DSO and TSO side, ENFOR presented the smart energy forecasting and control services used in the pilot, and ONE and Novasol described the activities and the lessons learnt from the CMP and end-user perspectives, respectively In total, around 60 people attended the national work, and this includes a number of people from Danish TSO, DSOs, BRPs, Energy-IT companies, and energy supply and smart grid companies in general. The workshop also created some attention from people outside Denmark, for example, people from National Renewable Energy Laboratory – NREL (USA), Argonne National Lab (USA), Korea (Grid planning people), Indonesia and Austria (AIT). It was mentioned several times that SmartNet project has really focused on some of the main challenges of the future smart grids, such as challenges the DSOs (and TSOs) will face given more EVs, PV, Heat Pumps, etc. For instance, NREL were interested in the mythologies used in the pilot whereas Argonne were more interested in the hardware implementations in the summerhouse and how the setup could also provide edge computing, similar to what they already have in Argonne labs. Denmark hosts almost 50% fluctuating renewables (wind + solar) in its power system, and the challenges will increase. However, it was also discussed that the fluctuations could potentially be balanced by Danish robust DH system. The knowledge on how to use the huge flexibility of the DH systems to provide grid services could benefit from what was learned in Danish Pilot of the SmartNet project. The conclusion from the national workshop is also that it will be tried to apply for further funding in order to be able to continue with the principles and methodologies developed in the Danish Pilot and SmartNet in general.

The Spanish national workshop took place on the 9th of April of 2019, at the premises of the Spanish Ministry for Science, Innovation and Universities. The date and the location were selected to coincide with a monthly meeting of the Spanish Smart Grid association (https://www.futured.es/), which allowed for having participation from Government agencies, the Spanish TSO, the Spanish market operator, DSOs, software companies, RES producers and associations, engineering companies, electrical equipment manufacturers, utilities, universities and research institutions. The workshop started with a welcome by Endesa, followed by a presentation about the importance of local markets by the Spanish market operator. Then, Tecnalia provided a detailed overview of the SmartNet project and the other two pilots, before the rest of the partners in the pilot presented the activities performed: Endesa presented the objectives of the pilot, the activities on the DSO side and the main conclusions of the pilot and Vodafone described the activities and the lessons learnt from the DER owner perspective[2].

In addition, the Italian pilot was publicly declared as of national interest by the Italian Regulator ARERA during the final SmartNet workshop (Arona). ARERA is presently financing national sandboxes ex deliberation 300/2017/R/EEL to promote access to the market to non-programmable resources and distributed generation. Presently, the only active pilots are about non-remunerated ancillary services

[2] Due to a last-minute event, ONE could not attend the workshop, but Endesa and Tecnalia answered to the questions made by the audience in relation to the CMP.

(voltage regulation) and resources aggregation for the ancillary services market MSD (mFRR and RR products). The results by the Italian Pilot are attentively scrutinized by ARERA as complementary to the ones obtained with the national sandboxes and a follow up at national level is not excluded.

The Italian pilot also received the award to one of the best papers of the 2018 CIGRE session, as shown in Figure 5-1below.

04 April 2019

Dear L. Ortolano,

As you know your paper has been selected as one of the "Best of" papers of the Paris 2018 Session.
In order to document this important achievement, please find attached a recognition certificate for the article "*Smart TSO-DSO interaction schemes and ICT solutions for the integration of ancillary services from distributed generation*".

Congratulations!

Robert Stephen
President CIGRE

Philippe Adam
Secretary General CIGRE

Konstantin O. Papailiou
Chief Editor
CIGRE Science & Engineering

Figure 5-1 Screenshot of the letter announcing the CIGRE award to the paper about the Italian pilot

As for the SmartNet project and the other two pilots, the results and status of the Spanish pilot was very frequently updated in the most relevant forums, both at European level (CIRED 2017 and 2019, CIGRE 2018, European Utility Week 2017 and 2018, and the GEODE Autumn Seminar 2018) and at national level (Spanish CIGRE sessions in 2018, Smart Grid Congresses in 2016 and 2018), as well as different collaboration agreements that Endesa has with Spanish universities (UPC seminar in 2017 and UIMP courses in 2018 and 2019). The Spanish pilot was also the seed for a follow-up project (see chapter 6 below).

6 Conclusions

Being in the forefront of technological implementation, the three SmartNet pilots revealed a number of issues, ranging from regulatory (such as impeding DER to participate in the AS markets organised by the TSO or having different metering requirements depending on the contracted consumption power) to technical (such as low mobile phone connectivity in remote rural areas or faulty back-up batteries, which, fortunately, never had to provide back-up power until the pilot started the testing phase) and even practical barriers (e.g. radio base stations are located in the roofs of residential buildings, so replacing their cabinets required obtaining permission from landlords and from municipalities, as they must be uploaded by huge cranes located in the streets).

The Italian pilot demonstrated that the information of the units located in the distribution grid can be aggregated and communicated to the TSO with a very high frequency (aggregated every 4 seconds and communicated every 20 seconds). Moreover, it was also demonstrated that DER can provide voltage regulation for the TSO, even if the capability of DER to regulate voltage at transmission level is significantly lower than the potential of big power plants. Likewise, RES can contribute to frequency regulation (probably, to mFRR), but their response time is not in line with the present requirements of the aFRR process.

The Danish pilot confirmed the technological feasibility of using unidirectional penalty signals to modify the consumption profile of summer houses and, hence, to provide AS which are useful for the TSO or the DSO. Indirect control through penalty signals proved to be a lightweight approach which, however, needs a strong communication network to have the system working and requires a deep knowledge by the aggregator to calculate the flexibility functions for the DER.

The Spanish pilot proved that the DSO can sustain a scheduled exchange program at the TSO-DSO interconnection, while avoiding congestions in the distribution grid, by running a local flexibility market. Furthermore, the pilot evidenced the capability of radio base stations to provide flexibility to be used for AS provision to the DSO, without any impact on their core business of providing communication service. For this purpose, the use of standard protocols and an appropriate vendor management showed to be of key importance.

An important attention point is that applying strict time specification (4 seconds for control) to machines that were not put into service for this can generate problems of slow response (Italian pilot). In addition, ICT readiness and response should also be tested (Danish pilot). In any case, it could be important to find a role for the new flexibility taking into account inherent limitations, which could call to restructure current reserves procurement modalities.

Based on the results of the pilots, there are no apparent implementation barriers which should prevent the implementation of the different coordination schemes. According to the results of the CBA [10], the most efficient coordination schemes may be the one with the centralised market model, in case

of low congestions at distribution level, or the one with common TSO-DSO market if congestions at distribution level are frequent. Both schemes were successfully tested in the Italian and in the Danish pilot. In addition, the Spanish pilot demonstrated the technical feasibility of the shared balancing responsibility market model, which resulted to be the least efficient coordination scheme in the simulated 2030 scenarios in the three countries.

Therefore, it can be concluded that the three pilots were successfully completed and resulted in several very important lessons learnt for the next step to be taken to deploy the concepts developed in SmartNet, which is the replication of these pilots in other regulatory environments, with different flexibility providers and at a larger scale.

An example of follow-up activities of these pilots is the demonstration being implemented in Spain in the CoordiNet project. CoordiNet (https://coordinet-project.eu/) is a 42-month long Horizon2020 project, which started in January 2019 and counts 33 partners (among which many in common with the SmartNet consortium) under the coordination by Endesa. Following the main objective of the SmartNet project, CoordiNet focuses on establishing different collaboration schemes between transmission system operators (TSOs), distribution system operators (DSOs) and consumers to contribute to the development of a smart, secure and more resilient energy system. Special emphasis will be made on the analysis and definition of flexibility in the grid at every voltage level ranging from the TSO and DSO domain to consumer participation. The coordination schemes proposed by CoordiNet are strongly derived from the ones analyzed by SmartNet. They will be tested in three large-scale demonstration projects across 10 different locations in Spain, Sweden and Greece. Such demos will apply different coordination schemes and test the complete set of products for grid services defined within the project.

The Spanish demo, also led by Endesa and with the participation of the SmartNet partners Tecnalia, ONE and N-SIDE, will proof the technical and economic viability of a system that enables flexibility services providers, regardless of their size and voltage level of the connection point, to provide flexibility services to DSOs to solve congestions, voltage and islanding operation problems and TSO to solve congestions, voltage and balancing problems.

The demo aims to demonstrate how DSOs and TSOs can act in a coordinated manner to provide a favourable framework to promote the participation of all agents (consumers and generators) in the ancillary services markets:

- Provide favourable cooperation conditions to all the actors while removing barriers.
- Analyse and define the flexibility grid services for both TSO and DSO.
- Propose new market mechanisms, which are more suitable for real time operations, under the premise to define requirements for a European standard platform.

Results of this demo will allow to integrate a higher share of renewables in the grid and the participation of demand-side resources on the provision of grid services.

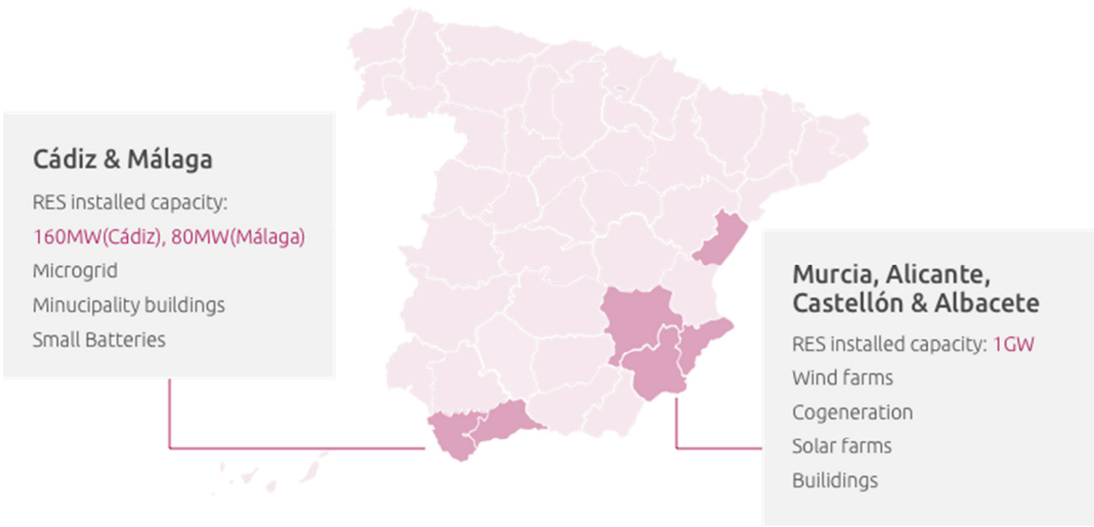

Figure 6-1 Location and units participating in the Spanish demo of the CoordiNet project (https://coordinet-project.eu/pilots/spain)

A second EU research project, which also started in January 2019, is INTERRFACE. INTERRFACE (http://www.interrface.eu/) is a 48-month long Horizon2020 project counting 42 partners and coordinated by European Dynamics (software developer). Among the partners in is worth mentioning ENTSO-E, many European TSOs and DSOs, one National Regulator (Romania) and one Market Operator (Bulgaria). INTERFACE aims at demonstrating the added value of sharing data among all participants in the electricity system value chain (customers, grids, market), from local, regional to EU level. It will also enable TSOs, DSOs and customers to coordinate their efforts to maximise the potential of distributed energy resources (DERs), demand aggregators and grid assets, so as to procure energy services in a cost-efficient way and create consumer benefits. This is carried out by designing, developing and exploiting an Interoperable pan-European Grid Services Architecture to act as an interface between the power system (TSO and DSO) and the customers and allow the seamless and coordinated operation of all stakeholders to use and procure common services. State-of-the art digital tools based on blockchain and big data management will provide new opportunities for electricity market participation and thus enlarge customers into the INTERRFACE proposed market structures that will be designed in order to exploit Distributed Energy Sources. Consequently, specific objectives are:

- to design an Interoperable pan-European Grid Services Architecture (IEGSA) that will connect market platforms in a transparent, non-discriminatory manner and will allow a pan-European electricity exchange that will link wholesale and retail markets and will enable the trading of energy services.
- to demonstrate the IEGSA components and architecture and the relevant IT infrastructure; IEGSA will be deployed in seven Demonstrations which will take place in nine countries (Greece, Bulgaria, Slovenia, Romania, Hungary, Italy, Finland, Estonia, Latvia), focusing on illustrating specific functions and serving real need and existing challenges, engaging different actors of the energy value chain.

RSE and Florence School of Regulation are the only SmartNet partners being present in the INTERFACE consortium. RSE, in particular, leads the task defining the services to be implemented into the IEGSA platform and will be involved in defining services market architectures. In doing that, the experience of the SmartNet project will be taken in full account along with specificities bound to the demos to be developed.

Finally, the newly awarded (not started at the time of writing this deliverable) Horizon2020 project FlexPlan, availing itself of the same coordinating person as SmartNet project (as well as many partners in common), will still tackle the topic of "flexibility" and "TSO-DSO cooperation", yet from a different angle point. The aim of FlexPlan will be to set up a new advanced grid planning methodology considering storage units and flexibility as an alternative to building new lines. This methodology will be applied to a domain including both transmission and distribution grids supposing that important flexibility contributions will come from distribution. Here, again, the experience derived from the SmartNet project will be fully valorised.

7 References

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