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

Results of Pilot C (Spain)

D5.3

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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

Table of Contents

List of Abbreviations and Acronyms

Acronym	Meaning
AC	Alternating Current
AF	Allocation Factor
API	Application Programming Interface
AS	Ancillary Services
AWS	Amazon Web Services
BCM	Balancing and Congestion Management
BSP	Balancing Service Provider
CMP	**Commercial** Market Party
DC	Direct Current
DER	Distributed Energy Resources
DG	Distributed Generation
DSM	Demand-Side Management
DSO	Distribution System Operator
EDM	Energy Data Management
HV	High Voltage
IMEI	International Mobile Equipment Identification
LA	Load Area
LAMP	Linux, Apache, MySQL and PhP
LMO	Local Market Operator
LV	Low Voltage
MFMD	Metered Feeder Maximum Demand
MV	Medium Voltage
NTP	Network Time Protocol
OPF	Optimal Power Flow
POD	Point of Delivery
RES	Renewable Energy Sources
RTU	Remote Terminal Unit
SNMP	Simple Network Management Protocol
TRL	Technology Readiness Level
TSO	Transmission System Operator
VPN	Virtual Private Network
ETL	Extract, Transform and Load procedure
ML4G	Mobile Link 4G

Executive Summary

This deliverable describes the realization of the Spanish Pilot under the H2020 SmartNet project. The main purpose of Spanish Pilot is to implement and evaluate the concept of shared balancing responsibility model for system balancing and grid congestion services between the Transmission System Operator (TSO) and the Distribution System Operator (DSO). The Pilot aims at assessing the potential of provision of ancillary services from an aggregation of radio base stations.

The radio base stations involved in the pilot are owned and operated by Vodafone to provide the mobile communications service. 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. In good grid conditions, the unused available capacity backup aggregated from bases stations can be reused by the DSO for congestion management and, eventually, by the TSO to avoid costly ignition of thermal power plants. These radio stations have a stable consumption with back-up batteries. The electricity stored in the batteries can be used to provide flexibility to the TSO or to the DSO. This pilot is a proof of concept for the estimation of the potential of batteries in the provision of ancillary services and for the capability of using this coordination scheme to allow small consumers to provide ancillary services.

The pilot is located in Barcelona, where 18 base stations have been used to provide ancillary services. The pilot's intelligence base is extracted from the models devised in several contributions from the partners involved in the Spanish pilot (Vodafone, ONE, Endesa) and, to validate the technologies developed and incorporated, several laboratory tests, simulations and real field tests were carried out.

The methodology used in the pilot tested and used the Optimal Power Flow (OPF) methodology to optimize the network management. At DSO level, one of the important points to focus on was the observability of the network, in order to make better decisions, as present metering systems have more relaxed time requirements than the market time operation requirements defined in the pilot.

From the functional point of view of an aggregator, the pilot has served to test the design, implementation and running-time errors, as well as to gain experiences under real world conditions, dealing with communication issues, standardization problems, asset constraints and the sort.

The demonstration of the benefits provided by flexible distributed energy resources (DER) to the operation of power systems and to social welfare of European citizens will be very useful for DER owners. In particular, it may provide the hints required by regulatory authorities to consider updating national regulation to allow both DSOs and DER owners to exploit the value of small-scale flexibility.

1 Introduction

The replacement of fossil-fuel-based generation by renewable 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, there is a growing penetration of medium and small-scale, flexible demand and storage systems in distribution networks. These resources could potentially be available to provide network services if they are aggregated effectively and there is an appropriate coordination between transmission systems operators (TSOs), distribution systems operators (DSOs) and aggregators.

Balancing refers to the situation after markets have closed (gate closure), in which a TSO acts to ensure that the demand for electricity is equal to the supply of electricity in and near real time [1], [2] or, alternatively, to all actions and processes, on all timelines, through which TSOs ensure, in a continuous way, the maintenance of system frequency within a predefined stability range [3]. As a result, TSOs are responsible for procuring balancing services from balancing service providers (BSPs) in order to ensure operational security. BSPs include generators but also demand response, which involves customers changing their operating patterns to aid system balancing. The larger the number of BSPs in a given market is, the higher the chance to increase competition among them will be and, thus, to reduce costs for society. However, in the Iberian market case, an insufficient interconnection capacity with the rest of Europe is recognized for all network development scenarios in 2030 [4], thus the transition of such market to a larger regional market (and its associated increase of BSPs to increase competition) is still limited.

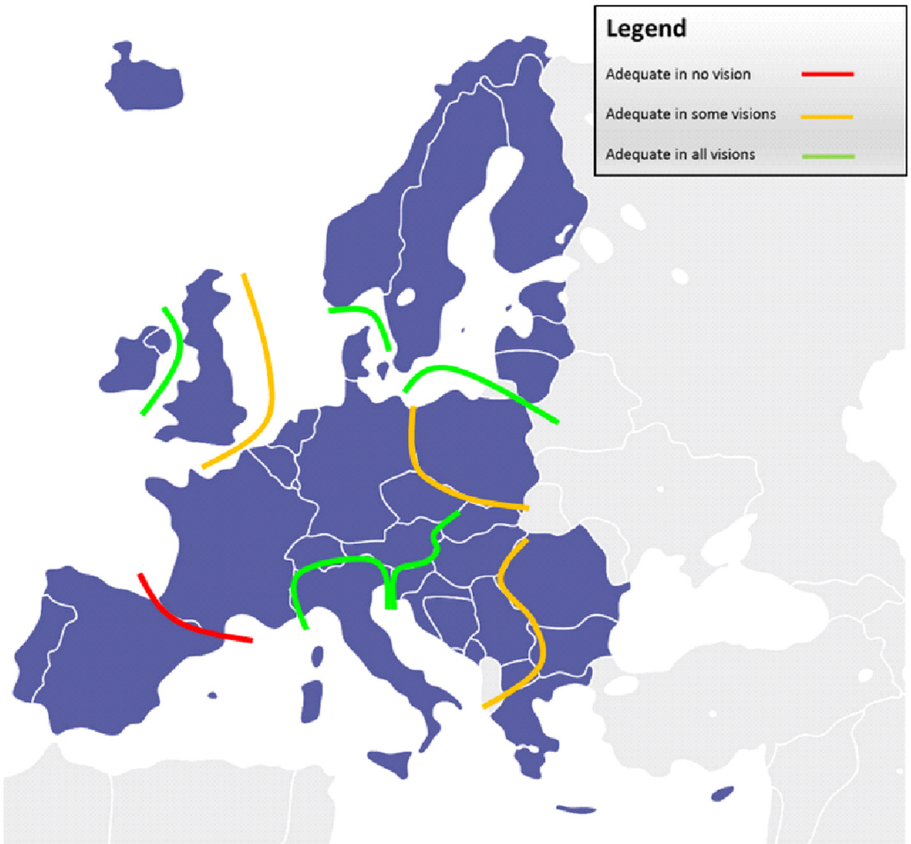

Figure 1-1 2030 Transmission adequacy [4]

Furthermore, balancing and associated ancillary services (AS) become increasingly complex (and costly) activities in the Iberian market because the share of highly-variable production from renewable energy sources (RES) in the Spanish generation mix is relatively large. In the presence of such RES technologies in the market, the need for reserves increases in order to balance supply and demand. In addition, the increasing number of distributed energy resources (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).

Figure 1-2 Variability of the generation mix in the Spanish power system [5]

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-side management (DSM) programs have only been implemented at TSO level and applied to large industrial loads in Spain, such as in the interruptibility service [6]. By assuming proper regulatory, economic and technology schemes, it is envisioned that sooner or later DSM will be applied at DSO level as well, following the trend in several European countries. As an illustration of this, specific provisions are included in the recently-enacted Law 24/2013 of 26 December 2013 of the Electricity Sector [11] and in the Royal Decree 216/2014 of 28 March 2014 which improves the participation of small consumers in system efficiency and Demand Response [12].

In order to manage these potential problems, a pilot has been designed and implemented to:

- Investigate the applicability of the "Shared balancing responsibility model" coordination scheme [9],
- Demonstrate DSO's ability to procure ancillary services from DER connected at distribution level, and
- Demonstrate that small-scale flexibility providers connected at distribution level can be aggregated effectively.

Therefore, this pilot is a step towards future Spanish scenarios with a contribution towards demand-side flexibility at distribution system level, following the roadmap for the implementation of the electricity balancing guideline [7] in Spain.

2 Description of the pilot

2.1 Concept

The project SmartNet [8] aims at providing architectures for optimized interaction between TSOs and DSOs for monitoring, acquiring and operating AS (frequency control, congestion management and voltage regulation) both at local and national level, taking into account the European context. This deliverable describes the outcomes of one of the three demonstration projects (pilots) within the project, the one implemented in Spain (the other two are located in Italy and in Denmark).

The need for increased cooperation between system operators is recognized by several stakeholders and the EU regulation provide a first basic framework to develop further collaboration strategies. Local needs for AS in distribution systems should be able to co-exist with system needs for balancing and congestion management. Resources located in distribution systems, like DSM and distributed generation (DG), are supposed to participate to the provision of AS both locally and for the entire power system in the context of competitive AS markets.

Within this framework, five coordination schemes that present different ways of organizing the coordination between system operators are proposed [9]. Each coordination scheme is characterized by a specific set of roles (taken up by system operators and AS providers) and a detailed market design. The coordination scheme used in the Spanish pilot is called "Shared balancing responsibility model". 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 organizes a local market to respect the schedule agreed with the TSO, while the TSO has no access to resources connected at the distribution grid. A new regulated function located at the control centre of the DSO, called Local Market Operator (LMO), is proposed to facilitate that Commercial Market Parties (CMPs) become flexibility providers of aggregated DER. This new function is designed to allocate flexibility among the different CMPs in a competitive manner.

The pilot, which is distributed along different points in the city of Barcelona, combines technical and economic aspects aimed at providing a flexible response to the needs of both the TSO (balancing) and DSO (balancing and congestion management).

It demonstrates the technical feasibility of using radio base stations to provide ancillary services for the DSO through DSM. In particular, the base stations are equipped with back-up batteries which ensure the continuity of communications service in the (rare) event of a blackout in the distribution grid. By using the back-up batteries, radio base stations can be disconnected from the grid on purpose when requested by the CMP. Therefore, a DSO-managed local market has been created, where different CMPs offer the flexibility of the DER in their portfolio, so that the DSO can procure balancing services and congestion management for the distribution network.

The main goals of the pilot are the following ones:

- Proof of concept of the "Shared balancing responsibility model" in a real demonstration environment, with the aim of:
  - Assessing the suitability of the coordination scheme to a real network operated by Endesa, and
  - Investigating the operational challenges that Endesa would face if the DSO should help the TSO to keep system balance, by taking the balancing responsibility for the distribution grid.
- Proof of concept of participation of back-up batteries to solve DSO issues, which provides useful hints to the DSO in terms of:
  - Testing the possibility to solve congestions or other issues at distribution level, by using flexible DER, and
  - Improving distribution system observability and controllability.
- Proof of concept of DER aggregation in a real demonstration environment, which is of particular interest for the aggregator because it offers the opportunity to:
  - Apply and test direct control actions on a distribution-connected portfolio of assets with direct observability over the loads,
  - Participate to a newly designed AS market which is meant to ease the participation of flexibility and enhance the opportunities for roles such as demand-response aggregation agents, and
  - Given the above set-up and timeframe, test in real-world conditions various bidding strategies according to a) the success in winning auctions in the AS market and b) subject to the real-life constraints of radio base-stations.
- Proof of concept of usage of back-up in base stations for DSM. The value for DER owners is to understand, both in real time and under real usage conditions:
  - The impact of random switching (versus normal operation of the backup solution) on:
    - The continuity of service to its customers (any mobile voice or data user), and
    - The base station equipment (batteries life time, rectifiers and radio equipment).
  - The technology readiness of:
    - Existing equipment controller software for data communication and
    - If needed, upgrade or transformation of existing software for further usage in other geographies where such scheme could be implemented.
  - The fit for purpose of hardware and software for remote communication, and

- Based on above, the optimal internal strategy for DSM development in countries where regulation allows small load aggregation.

Fundamentally, the pilot aims to implement balancing and congestion management (BCM) services for the distribution network through direct bidirectional signals to the aggregator. This is pushed further downstream to the activation of back-up capacities to reduce the consumption in selected grid regions of, in this case, the city of Barcelona, following the set-up described in Figure 2-1:

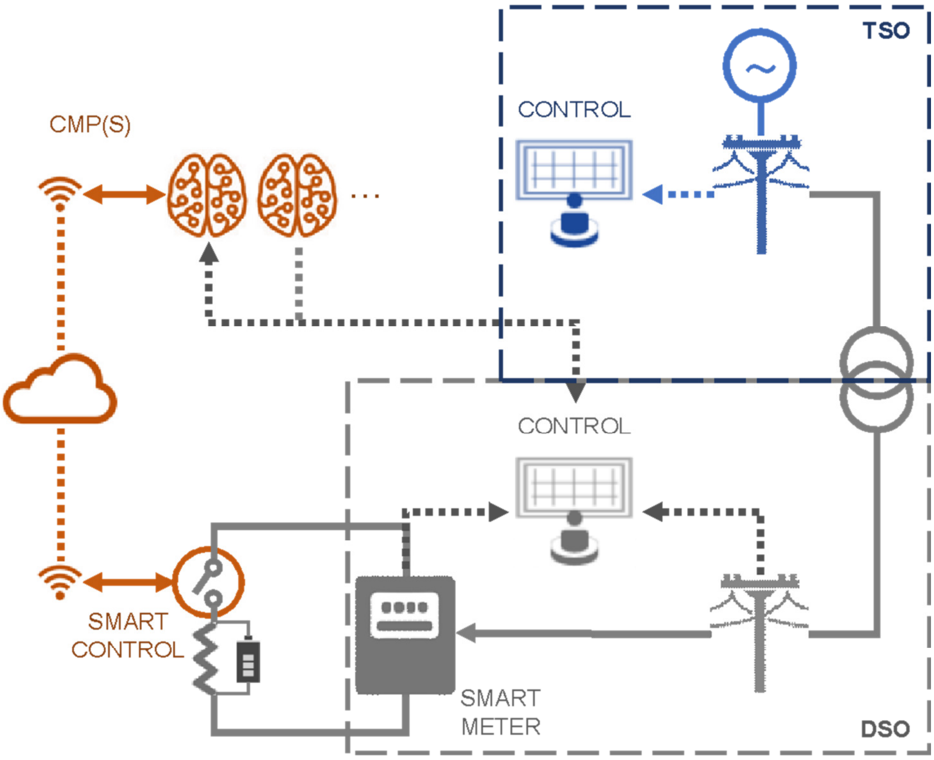

Figure 2-1 Functional architecture of the pilot

Therefore, the network model and its related technical constraints along with the flexibility bids are considered when performing the market clearing. The optimization algorithm, which is an optimal power flow (OPF), performs the allocation of flexibility volumes according to the minimum total flexibility activation cost.

Additionally, when insufficient flexibility is made available by CMPs or when technical constraints in the grid make it impossible to reach the required active power exchange at the TSO-DSO interconnection point, the OPF produces a feasible solution with the additional flexibility volume that the DSO should provide to comply with the balancing service. However, no additional flexibility sources have been made available by the DSO. For instance, no batteries have been installed in the network (such as in substations) as back-up devices for these cases. Hence, care has been taken to produce a virtual scenario for the pilot with enough flexibility provided by CMPs, in order to remove potential imbalances at TSO-DSO interconnections caused by low traded volumes.

The objective of including virtual DER in the pilot is twofold. On the one hand, these virtual DER can compete against the flexibility of radio base stations to provide the AS required by the DSO, in order to evaluate their competitiveness when this type of markets are more widespread. On the other, they can also be used to increase the capacity offered by CMPs, so that they reach 5 MW, which is the current minimum threshold in Spain to provide the interruptibility service [6], i.e. the only regulated product to provide DSM in Spain at the moment[1].

Endesa Distribución is the DSO in the area where the pilot has been implemented and leads the pilot. In addition, it plays the new role of the LMO, so that it uses an OPF to solve, in the same optimization process, both technical and market-related aspects of the balancing and congestion management services. In other words, technical constraints and bid prices are combined in the same optimization problem, which provides with an optimal *tecno-economic* solution, i.e. flexibility purchase cost minimization, while avoiding congestions at the distribution network.

Vodafone is the multi-site, small-scale DER owner, and provides the backup capability of 18 base stations amongst the 400 base station used for its mobile network multiband coverage in Barcelona city. Remotely piloted, the base stations are disconnected from the grid, releasing the flexibility required, while they make use of the energy stored in the batteries to continue providing the mobile communication service to Vodafone's clients.

Tecnalia provided technological consultancy to Endesa when designing and implementing the overall pilot architecture. It also contributed to ensuring the consistency of the pilot with the rest of the developments in the SmartNet project and the complementarity with the other two technological pilots.

ONE adopts the role of demand response aggregation, serving as a bridge between the physical flexibility and constraints and the organized market implemented by Endesa Distribución and assisted by Tecnalia just described above.

[1] The minimum bid size is one of the barriers for small-scale DER to participate in the provision of AS. However, the need to implement the Guideline on Electricity Balancing [3] is likely to remove some of them, as anticipated in the roadmap for its implementation (https://api.esios.ree.es/documents/480/download?locale=es), which is under public consultation when writing this deliverable.

2.2 Location

The pilot involves five primary substations and 18 radio base stations in the city of Barcelona, as shown in Figure 2-2[2]. The DSO (Endesa Distribución) is responsible for matching a scheduled active power profile at a virtual TSO-DSO interconnection point. This profile, which has a 24-hour horizon and a 15-minute resolution, is generated on a day-ahead basis and given as input data for the execution of balancing services the next day, based on historical data already archived by Endesa Distribución.

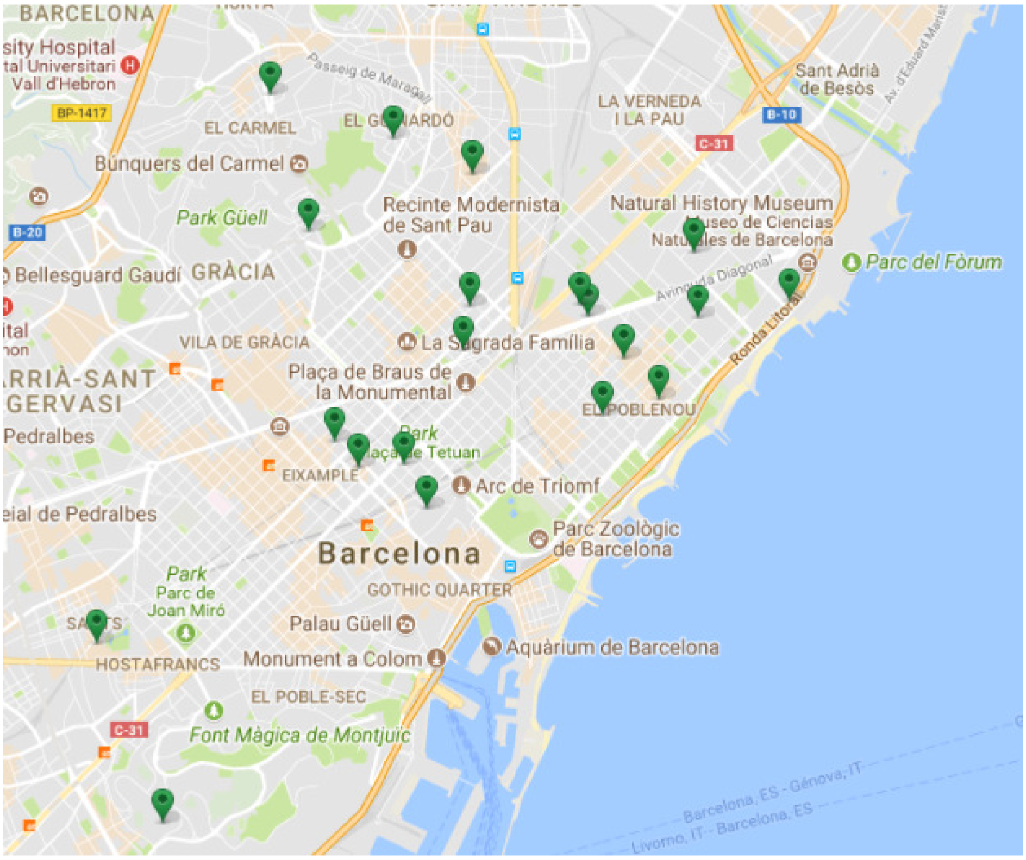

Figure 2-2 Location of the base stations in Barcelona

The distribution network downstream the TSO-DSO interconnection point has been modelled with enough details so that balancing at the interconnection, as well as congestions and activated flexibilities,

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[2] This picture shows the original set of 20 base stations. Due to operational requirements on Vodafone, 2 base stations have been dismantled during the execution of the pilot. However, the remaining base stations are more than enough to provide the target flexibility of 50 kW.

are observable. The grid involved in the pilot is strong enough to satisfy the existing demand, so there are no congestion issues today. Therefore, the scenario considered in the pilot is looking into a future situation, with a more electrified energy system, which may result in congestion problems at distribution level. In addition, it includes simulated DERs that are not currently connected to the grid to increase the available flexibility in the pilot. Therefore, part of the network model is virtual, in order to generate such a new scenario, with an effort being made to provide characteristics which could reasonably adapt to the current grid topology.

2.3 Roles and participants

The implementation of the pilot requires different roles to be performed by the partners involved, which are summarized in Table 2-1 below.

In addition, Vodafone is also responsible for the management of the connectivity services that allow ONE to interact with the radio base stations and Tecnalia has been the technological advisor to support Endesa in the definition of the scope and in the deployment of the pilot.

Table 2-1 Roles and partners in the pilot

Name	Market party description	Partner performing the role in the pilot	Partner role description
TSO	The TSO is responsible for balancing the Transmission System. The TSO operates the AS market at transmission level.	Endesa Distribución	Endesa Distribución simulates the creation of the TSO-DSO interconnection scheduled profile. Once the balancing responsibility has been shared, there is no further tasks to be completed by the TSO.
DSO	The DSO is responsible for balancing the local network on behalf of the TSO, by means of respecting a defined exchange profile. The DSO operates a local AS market and buys flexibility to deal with local grid congestion whilst adhering to the defined exchange profile. The DSO is also responsible for dispatching DERs which are not aggregated by CMPs.	Endesa Distribución	As the DSO, Endesa operates the distribution network in the pilot and monitors the provision of the requested AS, by means of the metered data management system.
CMPs	CMPs aggregate local DER resources. Hence, they are responsible for selling the flexibility of the DER in their portfolio on the local markets run by LMO and dispatching (and balancing) the DERs in their	ONE Endesa Distribución	ONE manages the flexibility of a portfolio of radio base stations owned by Vodafone. Endesa Distribución manages some virtual nodes emulating other CMPs participating in the local

	portfolios.		market.
LMO	An entity that operates a platform in which bids from CMPs are placed. In this case, the DSO is the operator of the local market, which is used to acquire the required ASs both to respect the scheduled exchange profile at the TSO-DSO interconnection and to solve local congestions in the distribution grid.	Endesa Distribución	Endesa Distribución plays the local market operator role at the local (distribution) level.
DER owner	A party that produces electricity via a flexible resource. The flexible resource is a unit connected to the grid which provides flexibility for one or more purposes.	Vodafone	Vodafone is the owner of the radio base stations, thus providing flexibility.

2.4 Functional description

The different functionalities carried out by the Endesa Distribución (DSO and LMO) are described in the subsections below.

2.4.1 Balancing and congestion management scheme

As described in section 2.1, the aim of the local market is not only to gather balancing services but to solve local congestions management at distribution level as well. To this aim, the network model and its related technical constraints along with the flexibility bids are considered when performing the market clearing. The key difference, with respect to the flexibility activation for only balancing services, is an optimisation algorithm (OPF) which performs the allocation of flexibility volumes according to the minimum total flexibility activation cost.

Up to five different high-voltage (HV) / medium voltage (MV) primary substations are involved in the pilot. Due to their geographical closeness, it is assumed that the five of them are a single TSO-DSO interconnection point. Since no grid model is available at transmission/sub-transmission level, one separate MV network model has been used per each TSO-DSO interconnection, i.e. five models total. As observed in Figure 2-3, each primary substation has a radial topology with several MV feeders and three loads at the end of each feeder: an aggregated load ("BL"), one load with real flexibility ("Flex") and another load with no flexibility ("Non-Flex"). Furthermore, all the feeders are connected upstream in node 1, which is the MV side of the HV/MV transformer of the primary substation. Meanwhile, the interconnection point between TSO-DSO takes place in the HV side of the HV/MV transformer. For simplicity reasons, the transformer is assumed to be ideal and, therefore, there are no losses, which

results in the voltage being the only difference between both sides of the transformer (it a step-down transformer, as voltage goes from HV to MV).

The electric grid is a complex network with a lot of elements and ramifications, in order to model the grid mathematically some assumptions has been taken:

- The grid topology is kept as simple as possible, but it is developed enough to observe relevant line congestions.
- In principle, only branches with relatively high risk of congestions (based on historical data) have been used in the definition of load areas (LAs). In this pilot, LAs correspond to portions of the grid which are defined to ease the allocation of flexibility resources for local congestion management purposes.
- Only primary substations, MV feeders and MV nodes of secondary substations are explicitly included in the model. Points of delivery (PODs) of the real DERs participating in the pilot are implicitly represented inside lumped MV flexible loads of the model because there is no observability to the low voltage grid except for the meters.
- Since the Spanish TSO is not involved in SmartNet, the profile at the TSO-DSO interconnection point is built up by using historical data from the years 2015/2016 and by clustering typical days per season and per weekdays/weekends.
- The DSO has observability at POD level by acquiring real-time data from smart meters. However, active power losses associated to flexibility deliveries at low-voltage (LV) level are not considered, because the LV part is not included in the model of the grid.

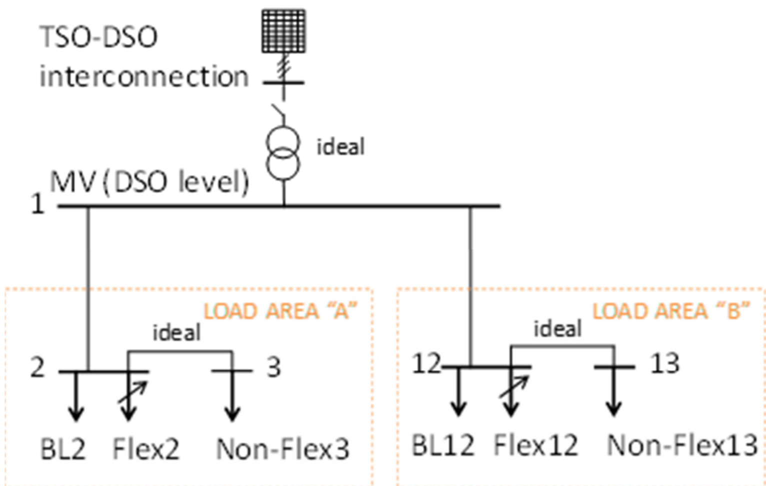


Figure 2-3 Example of grid model for one of the primary substations

Additionally, when insufficient flexibility is made available by CMPs or technical constraints in the grid make it impossible to reach the required active power exchanged at the TSO-DSO interconnection point, the OPF produces a feasible solution with an additional flexibility volume that the DSO should provide to comply with the balancing service. However, no additional flexibility sources have been made available

by the DSO, e.g. no batteries have been installed in the network (such as in substations) as back-up devices for these cases. Hence, care has been taken to produce a virtual scenario for the pilot with sufficient flexibility provided by CMPs in order to remove potential imbalances at TSO-DSO interconnections caused by low traded volume, as described in subsection 2.4.2.

2.4.2 Virtual case simulation

The objective of this functionality is to combine real, metered data with simulated data to build the grid model, which represents the current operating conditions.

During the pilot, real telemetry measurements have only been available per MV feeder (primary substation). However, such measured data must be modified in order to account for the penetration of virtual flexibility volumes in the model. To this aim, the "virtual" active (and reactive) power at the header of feeders have been calculated through power flow algorithms to take into account active and reactive power losses at MV level. This case represents the current network status with real and virtual activated flexibilities included in the model. The general methodology to build this case is divided in three steps: creation of the real base case, creation of virtual case and simulation of the current virtual case, which are described in next subsections.

2.4.2.1 Creation of the real base case

The aim of this first step is to derive reasonable non-flexible active power values per node. For that purpose, the MV active power telemetry data are received and loaded to the grid case. Then, a methodology adapted from the Metered Feeder Maximum Demand (MFMD) method is run to allocate active power load per node. It is assumed that such active power load represents non-flexible load, as well as the baseline consumption of real DERs participating in the pilot.

In the MFMD methodology, metered readings can be allocated to each MV/LV transformer based upon the transformer rating. An allocation factor (AF) can be determined based upon the metered three-phase demand and the sum of the kVA ratings of all transformers connected to the distribution grid (kVA_{total}):

$$AF = \frac{Metered\_feeder\_demand[kW]}{kVA_{total}}$$

2.4.2.2 Creation of the virtual activation case

This second step adds the virtual loads and their associated activated flexibilities to the real base case. Again, the MFMD method is used to allocate the baselines and associated activated flexibilities of virtual DERs per node but, then, activated flexibilities of real DERs are directly allocated to the corresponding

node (where applicable). The creation of the virtual activation case is finished by allocating the reactive power per node, assuming constant power factor values per node.

2.4.2.3 Simulation of current virtual case

Once the consumption per node has been calculated for all the network, including the virtual stations, the last step is to calculate the status of this new network. With that aim, the power flow algorithm is solved for the virtual activation case to obtain the current grid operating conditions, with provides the power exchange values at TSO-DSO interconnection points as well as congestions at distribution level. At this point, the virtual activation case is ready to provide observability of the distribution network.

Two different levels of load data granularities are identified in the grid model: (i) load per node (i.e. per MV/LV secondary substation) and (ii) load per LA. Each node is associated to a LA identification, so that the DSO is able to aggregate/disaggregate data for virtual DERs. On the other hand, the locational information of real DERs is directly associated not only to LA, but also to a specific node. When needed, data aggregated per LA can be calculated as a simple summation of individual nodal data.

2.4.3 Local market operator

The consumption is monitored at the TSO-DSO interconnection point, both to assess current imbalances by comparing it to the scheduled exchange profile and to forecast the grid status in the short-term horizon. All these results are introduced in an OPF model to clear the local market and provide the inputs for the flexibility dispatching, along with the clearing price.

The LMO implements local market clearing activities and is in charge of gathering and delivering information of local market rules.

Flexible resources are grouped in LAs along the distribution network. CMPs consider all these resources to offer bids which consists of one or more blocks containing the flexibility volume quantity and their corresponding price. As said before, the model developed, which is managed by the LMO, is a modified OPF optimization model. The objective is to determine the optimal activation of bid blocks among all CMPs and the clearing price is set as the most expensive matched bid (i.e. pay-as-clear or marginal pricing approach).

In the mathematical formulation of the developed model, LAs have been modelled as buses areas, represented as nodes in the distribution network model. The TSO-DSO interconnection point is considered as part of the distribution network too. This is due to the necessity of considering an artificial slack generator, characterized as an artificial slack node, in order to manage the resulting power imbalances. This slack generator participates as a flexible resource offering positive or negative power bid blocks, according to positive or negative imbalances, which are penalized in the model with high bid prices. This slack generator is added to the model to ensure a feasible solution of the model.

The objective function of the model is the minimization of the total flexibility activation cost, that is, the sum of all matched positive power bid prices for all nodes, except from slack node. Three main assumptions have been made:

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

Related to market clearing, there are two types of bids: curtailable and non-curtailable offers. The curtailable bids allow the market operator to accept them either totally or partially (to dispatch a flexibility volume which is the offered volume or lower), while for non-curtailable offers, the offered volume must be accepted completely (or otherwise, the offer should not be accepted). Furthermore, a bid block can only be activated in case of a previous bid block has also been activated.

In the TSO-DSO interconnection point, bid blocks can only be activated for dealing with positive or negative imbalance, but not both. If a negative imbalance has to be managed at the slack generator, the activated block in an upward flexibility bid cannot be higher than the total power of that bid. Similar to the previous case, power for negative imbalance bid blocks can only be activated if the previous bid block has also been activated.

The market performed in the pilot has two major innovations: the time execution and the use of an OPF to clear the market. The time execution is 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 allows the LMO to evaluate the technical restrictions and, at the same time, dispatch the flexibility to achieve the balancing objectives.

2.4.4 Aggregation of DER flexibility

In addition to the innovation on the DSO-LMO side, there is 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 needs to communicate with the rest of the parties. In particular, communications are 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.

In view of these characteristics, the wide variety of communication protocols between parties and the diversity of potential services to be provided, not only in the framework of SmartNet, but also in its commercial applications including voltage control, balancing, and congestion management, ONE has

opted out for a centralized asset gate hub model, which is the sole interface towards outside counterparties. The general schematics are presented in Figure 2-4 below:

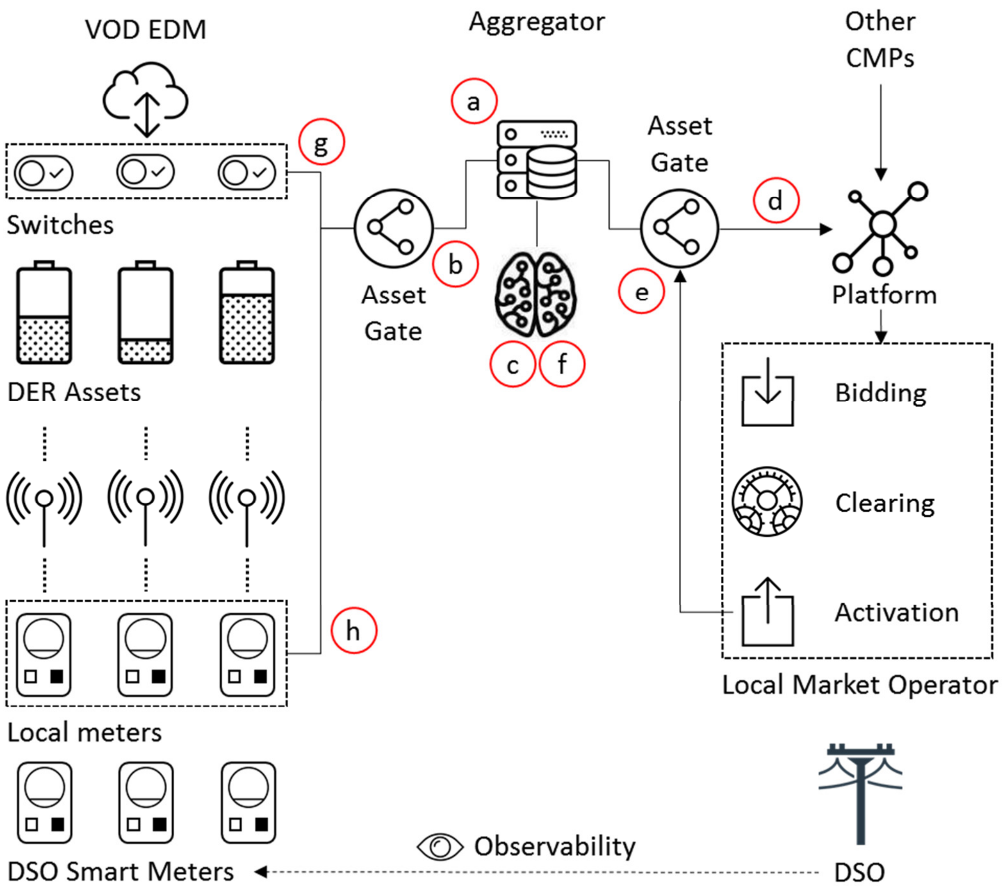


Figure 2-4 Aggregator's process flow

The main activities described in Figure 2-4 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) Aggregator observes and follows activations. If failure repeat from step f.

Given the nature of the DERs in this pilot, a number of parameters and real-time information exchange is required between DERs and the CMP, which is performed by means of a communication between

Vodafone's energy data management (EDM) system and ONE's asset gate. Furthermore, none of the aggregation model developed in the project [10] are completely applicable to the pilot (neither the one for atomic loads because batteries will need to be recharged again after service provision, nor the battery model because it will only be used for providing upward balancing). However, Tecnalia assisted ONE to develop new aggregation models for the pilot, which are compatible with the philosophy in [10].

In order to implement the aggregation algorithm, the following DER parameters for each battery must be received, either as static configuration or as real-time data-feed:

- State of charge of the battery, expressed as a percentage of the maximum capacity: This is required as it represents the main constraint to understand which battery can be activated or not at each time-step.
- Minimum allowed state of charge of the battery, as a percentage of maximum capacity: This is the threshold below which a battery cannot be activated until it is fully charged again.
- Nominal charging power of the battery, given in kW: This is needed in conjunction to the next one to understand the potential load management.
- Part of the load in base station that can be supplied by the battery, expressed in kWh: This is a factor applied to the previous parameter, in order to compute the actual available load-shaping available to the CMP.

The algorithm developed for this task allows the CMP to manage the different data and communication interactions, as well as to model the potential behaviour of the different assets.

The pilot also offered ONE the opportunity to test Vodafone's machine-to-machine technology, which aggregates a number of operational parameters from the assets in one single platform. This solution allows the CMP to communicate with an array of assets through one single communication channel, which simplifies the process significantly, as most routines and processes are already designed. Furthermore, it is worth underlying that the communication protocol and activation have led to real activations in the physical assets, thereby seriously decreasing the implementation problems and resulting in a significantly high technology readiness level (TRL) exercise.

3 Implementation

The functionalities described in section 2.4 have been implemented through three main applications:

1. **Balancing and Congestion Management (BCM) application**: Endesa Distribución developed the BCM application, which operates the local market and manages the communications between the local market and the other applications. The BCM is made of two different applications:
    a. The manager: this application manages the input and output messages form the other programs, resolves the correlations between POD and the LA and controls both the gate closure and the timings of the market. This program has been written in C#.
    b. The optimizer: this application contains the optimization algorithm, which is an OPF with the market clearing process included. It manages all the information of the network, including the available flexibility and the other constraints. This program is written in Julia, an open source language designed for computer science due the low learning curve and the interface with different solvers.
2. **Virtual CMPs application**: Endesa Distribución also developed this Virtual CMPs application, which emulates several CMPs to represent the bidding by other types of DERs and to provide the additional flexibility required by the local market when the real flexibility offered by ONE is not enough to meet DSO needs. The program can start several CMPs depending of the configuration file. The program consists on one thread to manage all the Virtual CMPs and one thread per virtual CMP to run the functionalities of each virtual CMP. This structure allows to start and stop virtual CMPs one by one. It has been implemented in C#.
3. **Aggregation application**: The implementation of the ONE aggregator has been managed from a single application with several communication networks, divided into several modules. All the components of this application have been implemented in Phyton:
    a. A module responsible for sending to and receiving messages from each of the interfaces, which manages the input and output of files that are processed in the management module. This section also manages the status of each of the available base stations, for further processing. The main challenge of this module has been to adapt its structure and functioning to the various requirements from both the DER's interface (Vodafone's EDM as described further below) and Endesa's market platform.
    b. A management module responsible for processing all data available (such as information from DERs, latest success in the local market and information about wholesale market prices) and which is the ultimate responsible for making the market price strategy for each of the base stations in each time stamp. This module is

also responsible of receiving the activation messages from the local market clearing, thereby activating the next module.

c. Finally, the activation module is in charge of activating the batteries, according to the activations received from Endesa's platform.

In addition, the Vodafone has also deployed hardware and infrastructure elements across the base stations to enable the data communication, remote monitoring and control of the batteries.

3.1 Technical details

This chapter describes the technical details related to the devices and the elements deployed or installed to perform the pilot tests.

3.1.1 Balancing and congestion management

During the pilot, the DSO has used the equipment and infrastructures described below:

- PC computer, to be used as a server to run the local market and the DSO applications. This computer is a Dell workstation with the next specifications: i7-7700 @3.60 GHz, 16 GB RAM, 256 SSD and Windows 10 Pro.
- Router 3G with a SIM card, for the communications to other devices.
- Medium voltage smart meters at the header of the feeders.
- Smart meters located in the different base stations, to measure and communicate the consumption of each base station.

A detailed architecture of the components required for the DSO/LMO is depicted in Figure 3-1. The devices provided by Endesa Distribución for the communications are:

- Tele-management: this agent provides observability on the distribution network, necessary for the pilot to check whether the stations work or not.
- BCM: This agent receives and sends the necessary data to execute Balancing and Congestion Management functionalities, i.e. to send and receive the messages in the established protocol and determine the operating time (bids and baseline reception, gate closure and sending market results). It also acts as a time server to synchronize ONE's equipment with Endesa's one.
- Virtual CMPs: as described above, this application simulates the behaviour of several virtual CMPs, in order to simulate the bids by other types of DERs and to create a more realistic bidding environment.
- Smart meter: these devices are used by Endesa Distribución for billing purposes but, in the pilot, they have also been used to obtain the status of each base station (voltage, current and state of charge) in real time. This information allows the DSO to check if the base stations are working properly and proving the flexibility acquired in the local market.

All the messages are in xml format and the communications go through a virtual private network (VPN) connection to ensure the security and availability.

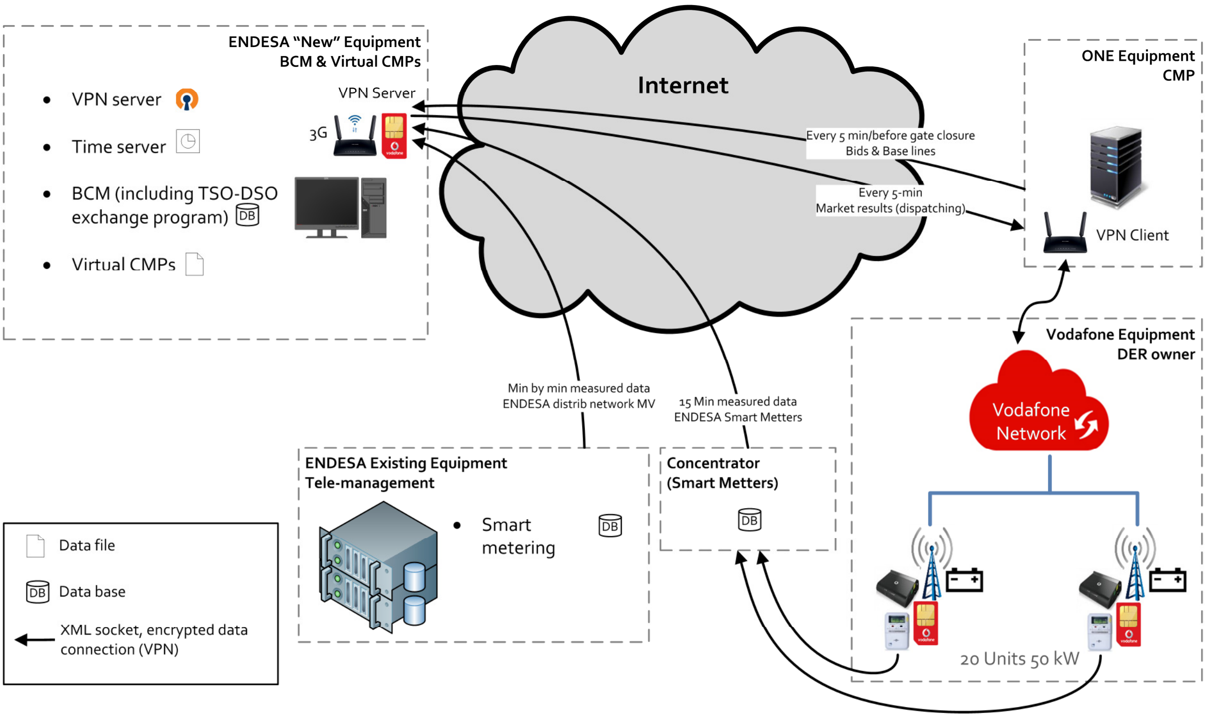


Figure 3-1 Architecture required for the DSO

3.1.2 Aggregation

During the pilot, the aggregator's applications and services were based on an infrastructure based on Amazon Web Services (AWS), which is depicted in Figure 3-2 and which includes:

- Implementation and maintenance of the AWS service: ONE has chosen to implement its algorithms and infrastructure on servers with AWS, instead of using own physical equipment, to enhance security, increase availability and reduce costs.
- Structuring of LAMP server into the AWS environment: ONE has opted to structure its information technology infrastructure in this pilot using a standard LAMP system (Linux, apache, MySQL and PhP) due to its proven robustness and simplicity, thereby aiming to prove that aggregation models could be easily replicated through these simple structures using Linux.
- A series of memory increases: This has been required in order to deal with the increasing amount of data in the server (partially resolved by daily data extractions). Also, several dynamic scripts have been created and executed on a daily basis, to sweep and clean the old files that are left in each execution of the system (Logs, activity records, etc).
- Optimization of runtime execution of the scripts for enhanced performance: For this specific application, a time-control system between each script was implemented in order to analyse and optimize the overall performance and running-time of the system.

- Update to the latest Linux version: In order to always keep the system running with the latest version of Linux available to avoid compatibility issues.
- Implementation of automatic clean-up routines: As explained above, in order to optimise system performance, several file cleaning routines have been implemented to keep the server memory always active for any use.
- Development of integrations with market Application Programming Interface (API): In order to access real wholesale market prices from the Iberian Market Operator (OMIE), some scripts were developed to communicate with OMIE's API to gain full access to the intraday wholesale prices.
- Management of connection errors with the server through Https messages, in order to obtain a logs system with each of the possible errors generated in the system.

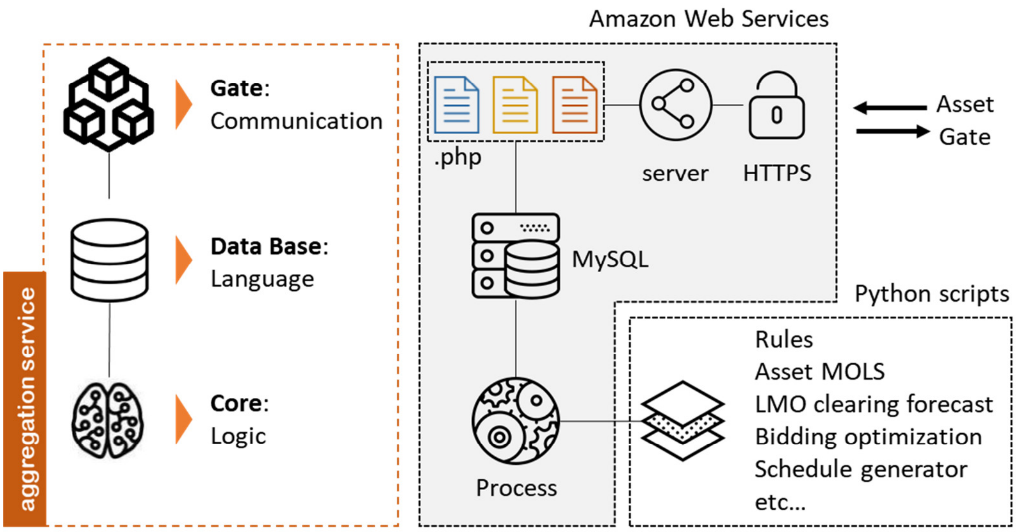


Figure 3-2 Architecture of the aggregation service

Based on the requests to accommodate an ease of the processes with the partners, some updates were further required:

- Undergo a modification of the script "edm.php" for a correct clean-up of data received from Vodafone in case of data flooding and ongoing adaptation to the latest data structure to be finally agreed with Vodafone. The script "edm.php" is a script developed in php language that is in charge of carrying out the Extract, Transform and Load procedure (ETL)[13] in our system. ETL is the process that allows organizations to move data from multiple sources, reformat and clean them, and load them into another database or data warehouse for analysis.
- Modification of the script "bids.py" to align with our mathematical model and provide a smoother bidding curve as a function of prices and availability of base stations. The script "bids.py" is a script developed in Python language, which is in charge of making the price offers for the different available base stations every 5 minutes. It is also fed with market price information from OMIE at all times.

- Furthermore, ONE had to create relational tables with the objective to establish a relationship between PODs[3], sites and International Mobile Equipment Identification (IMEI) codes, which are the different concepts used by different actors to singularly refer to a given DER.
- Creation of new python scripts:
  - Implementation of a new "listen.py" script to listen and receive the list of the available stations provided by Endesa, depending on the PODs sent. Note that the number and structure of these files has changed several times throughout the pilot project.
  - Creation of a new script "listenHttp.py" to listen to the files sent and received during communication with Endesa. This script is in charge of classifying the different types of files received (LAs and activations) and inserting them in a database for later consultation within the market process.
  - The script "SendPODS.py" is meant to provide Endesa with the list of PODs which will participate to the next round of bidding in order to receive the information about their respective LA. It is also in charge of reading the files (.json) that Vodafone sends to ONE in 1-minute periods, as well as of identifying each of the IMEIs collected and sending them to Endesa. It is also responsible for reading the state of charge of each of the batteries whose information is made available to ONE and for checking it with the rules agreed between ONE and Vodafone, so that we the offers to buy or sell energy (charge / discharge) can be built.
  - Creation of a new `BatteryActivation.py' script in charge of processing the market results received and activating the batteries in the base stations. To identify each of the activations with its corresponding battery, relational tables are used and stored in the database.

These scripts are required to ensure a correct communication with all counterparts. All communications through ONE's Asset Gate are done through the port 443 over HTTPS. The interpretation of all the communications that arrive to the server is done through the PHP management of the .json and .xml files attached to the HTTPS POST requests and through a VPN connection. The initial structure proposed for the communication architecture is presented in Figure 3-3.

[3] Each POD is identified through its CUPS, the Spanish term for the Meter Point Administration Number.

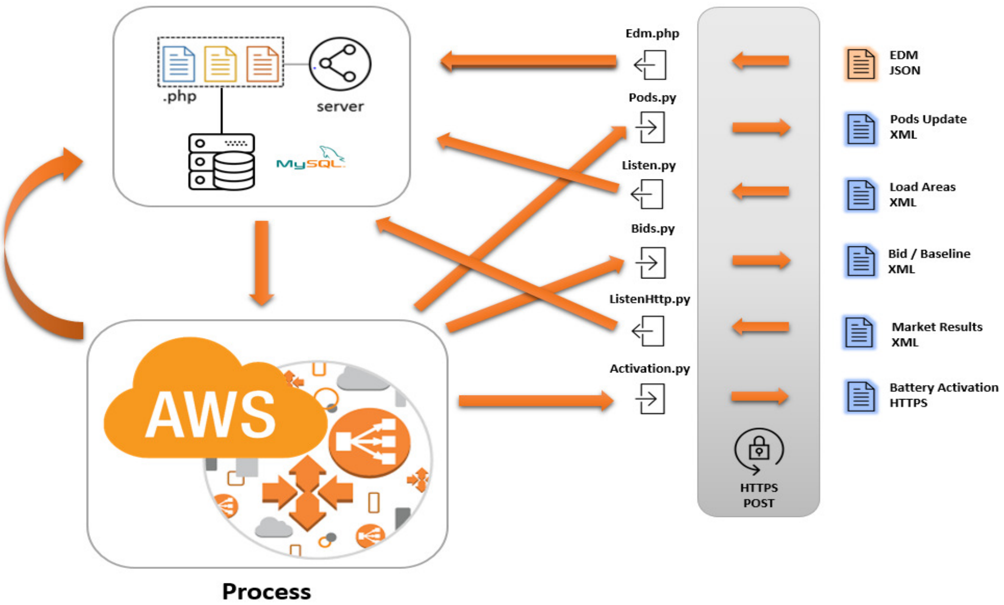


Figure 3-3 Communications Architecture

3.1.3 DER communication and management

Each site required the installation of an additional equipment interface enclosure, mounted within the sites shelter or cabinet and a sub meter to monitor the site consumption, as described in Figure 3-4. The main requirements of the equipment were:

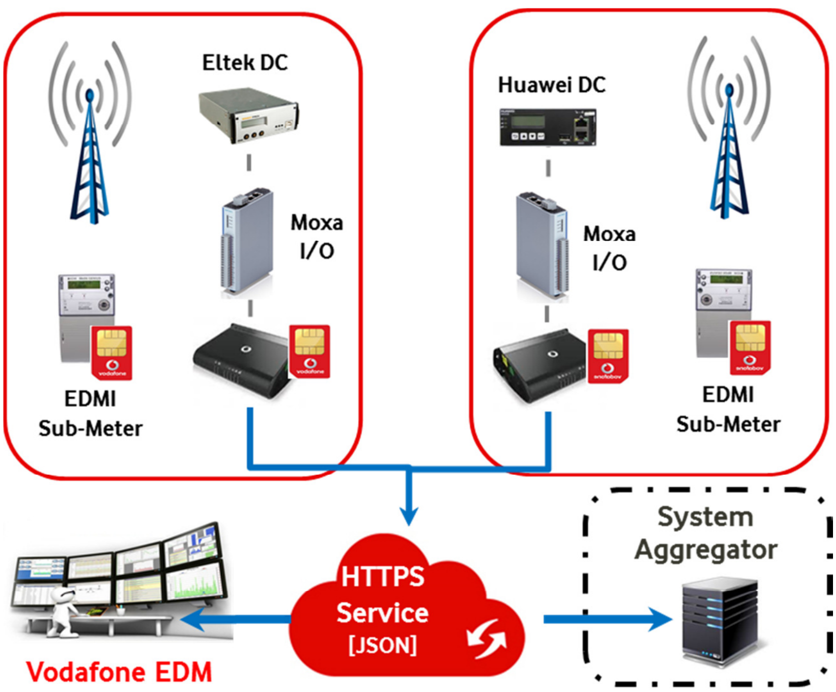


Figure 3-4: Site set up for DSR remote monitoring and control

- The contents of the equipment interface enclosure provided both external communication with Vodafone servers and internal communication with the sites' direct current (DC) power system. This equipment consists of the follow component parts:
    - Enclosure: IP66 rated lockable housing L 300mm x W 200mm x H 150mm.
    - ML4G+ Terminal Device: Vodafone 4G enabled data logger providing both serial and IP communications capability to the site and the connected devices, for remote communication.
    - Moxa ioLogik E1212: Remote Ethernet I/O with 2-port Ethernet switch, 8 Dis, and 8 DIOs to gather sensor information.
    - Power Supply: -48V DC to DC power supply unit.
- The submeter is installed separately nearby the alternating current (AC) electrical board. This submeter is a MID-graded (approved process for gas and electricity meters under the Measuring Instruments Directive) AC submeter, which is used to confirm the variation in site consumption and, simultaneously, send the data to Vodafone's existing EDM platform.
- The installed site hardware interfaces directly with the onsite DC power system over Simple Network Management Protocol (SNMP) open style communication, to enable real-time (minute by minute) read/write communications, providing both status information and remote control.
- This information is collected and presented in Vodafone's internal EDM platform for information and maintenance purposes.
- The same data sets, for each site, are automatically forwarded via a .json messaging service to the aggregator's servers every minute, to allow the CMP to act in real-time to switch the batteries on demand.
- The general speed of response is largely governed by network latency.

To provide more details, the submeter is an EDMI Mk10A, MID approved, Smart Sub Meter, the data from which is read every 60 seconds via an internal GPRS modem. The meter offers measurement connections via internal whole current sensor and is depicted in Figure 3-5.

- Figure 3-1 Overall dimensions of the meter

Height = 262 mm, Depth = 95 mm, Width = 175 mm

Figure 3-5: EDMI Mk10 sub meter

As shown in Figure 3-4, there are two manufactures of the DC power systems deployed across the pilot sites, each requiring a slightly different approach, in order to enable these services: Eltek and Huawei.

1. The current Eltek DC power system controller required upgrading to the latest version (SmartPack S), in order to enable the required battery test and communication functions. Once upgraded, key status and alarm information has been exchanged with the ML4G terminal device[4] using SNMP style communications. Wherein, the remote battery test function is triggered over the same SNMP style communications. This remote battery test function relies on the test results from the last battery test to determine if the batteries are healthy enough to start the test. Therefore, it is important that the test function in the SmartPack S is setup correctly according to the batteries used on each site (battery Ah rating, quantity, battery test end voltage, etc). Figure 3-6 shows the wiring diagram for the Eltek SmartPack S.

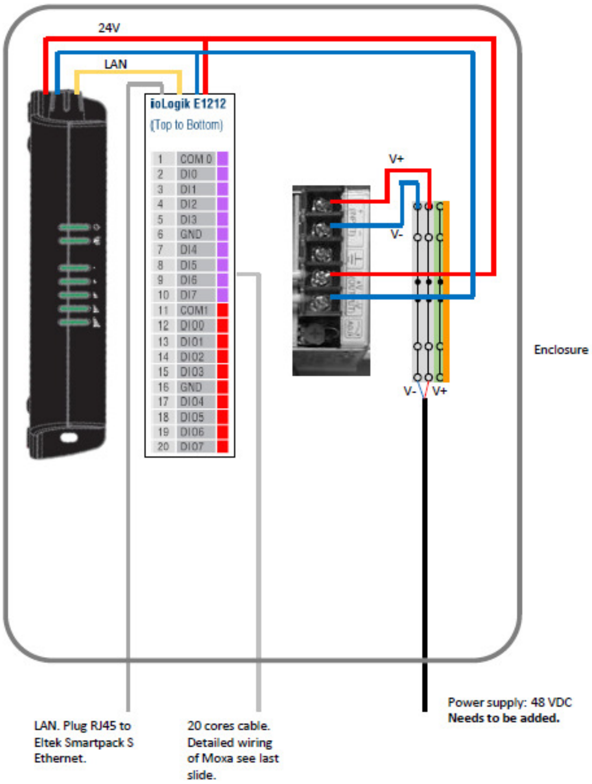


Figure 3-6: Wiring Diagram for Eltek SmartPack S DC Power System.

[4] https://www.vodafone.com/business/iot/iot-devices/integrated-terminals

2. Huawei DC Power System: The current installed Huawei DC Power system controller was suitable for this project, but required a software update to a higher version, details of which can be confirmed via the controller LCD screen. Once upgraded key status, alarm information and operational commends, could be exchanged with the ML4G terminal device using SNMP style communications. Again, the remote battery test function is triggered via the SNMP link command and this test function relies on the test results from the last battery test to determine if the batteries are healthy enough to start the test. Therefore, it is important that the test function in the SMU Controller is setup correctly according to the batteries used on each site (battery Ah rating, Qty, battery test end voltage, etc).

As described above, both DC power system controllers operates in the same manner in terms of the remote battery test function:

- Upon receipt of an event trigger, the output voltage of the rectifiers is lowered to a point just lower than the current battery voltage, thus placing the DC load onto the care of the batteries.
- Should the batteries become faulty, or stolen, the rectifiers remain in place and operational and available to take the DC load, thus avoiding and DC power cut and the loss of radio services.
- If the batteries are in good condition, the batteries will continue to discharge until they reach 47 VDC. At this point, the rectifiers are automatically reconnected, and the batteries recharged.

The battery autonomy (backup time) is governed by the battery capacity (in ampere-hours, Ah), DC load and health and age of the battery. Normally, Vodafone attempts to maintain between 1 and 2 hours of autonomy as standard, but due to the above factors these timing can vary across sites.

It is important to highlight that, during testing and operation of the pilot, three sites will faulty batteries were discovered, which, once replaced, avoided potential service losses, in the event of a mains failure.

3.2 Software

This chapter describes the software architectures, applications and interfaces developed for the pilot. In addition to the pieces of software developed for the two main applications described here, several scripts have been used that facilitate the obtaining of data in files (.csv) in a continuous way for its later representation, as shown in section 3.4.

3.2.1 Balancing and congestion management

The software architecture designed by Endesa for the BCM and the virtual CMPs' applications is depicted in Figure 3-7.

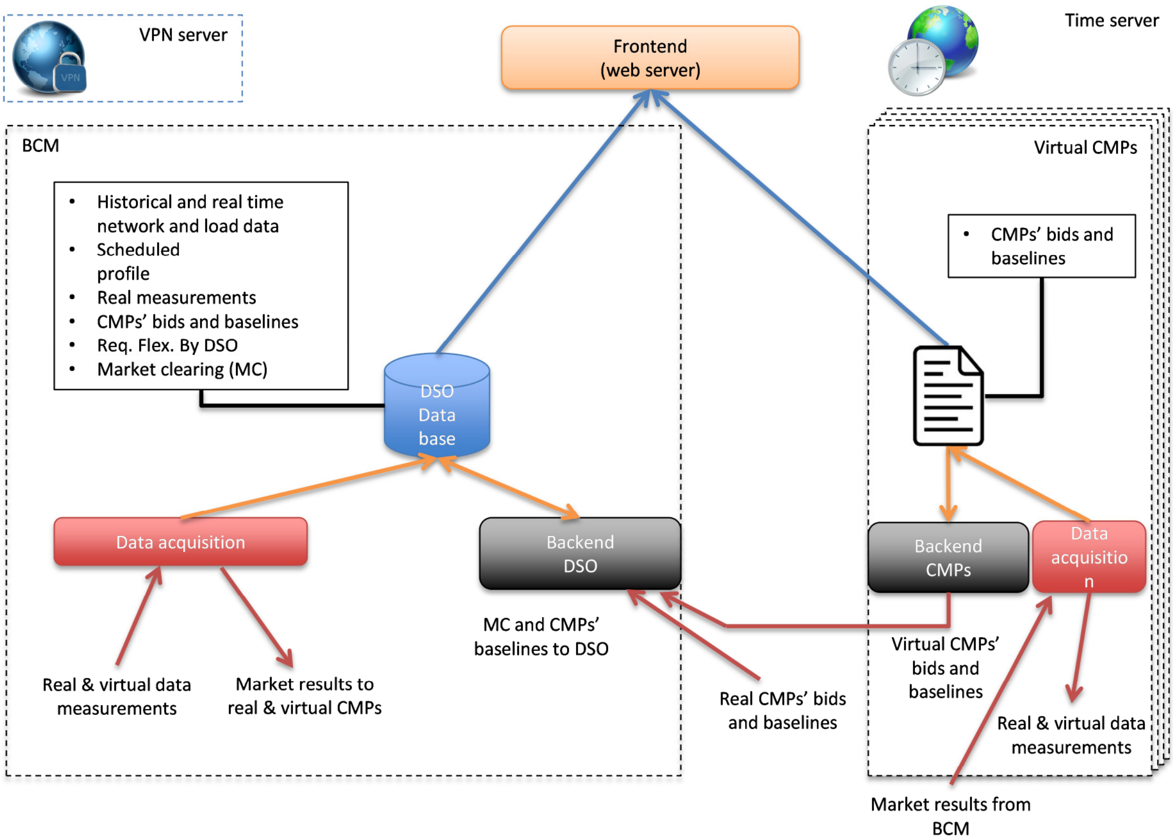


Figure 3-7 Architecture of BCM and virtual CMPs

The applications developed by Endesa are mostly written in C# language and executed in the Dell workstation. The reason to choose the C# programming language is that it is a high-level language, with an orientation to objects and high running speed. In addition, the development team has broad experience in its usage.

The different elements which build up the applications are:

- VPN server: this server provides a private network for the pilot to guarantee the availability and security for the communications among the three clients of the network (the VPN server, the Endesa server and the aggregator server) with an easy implementation.
- Data acquisition: this library was implemented in the two backend applications described below and contains a server implementation performing the reception of data from external sources, validation of the messages and saving into the database (in case of the BCM, and file directory, in case of virtual CMPs). The data acquisition allows Endesa to receive all the structured messages in xml for an easier readability, both for humans and machines.
- Backend: it processes data and performs calculations in accordance with the functional specifications of the BCM and the Virtual CMPs applications:
    - BCM (flexibility activation): this application is the optimization process, including the virtual case simulation, the OPF model generation and local market clearing, which

also manages the communications. As shown in Figure 3-8, this application shows the activated CMP, the last bids and baselines received, the next time to start the OPF and market clearing calculations and the time to send the results of the market.

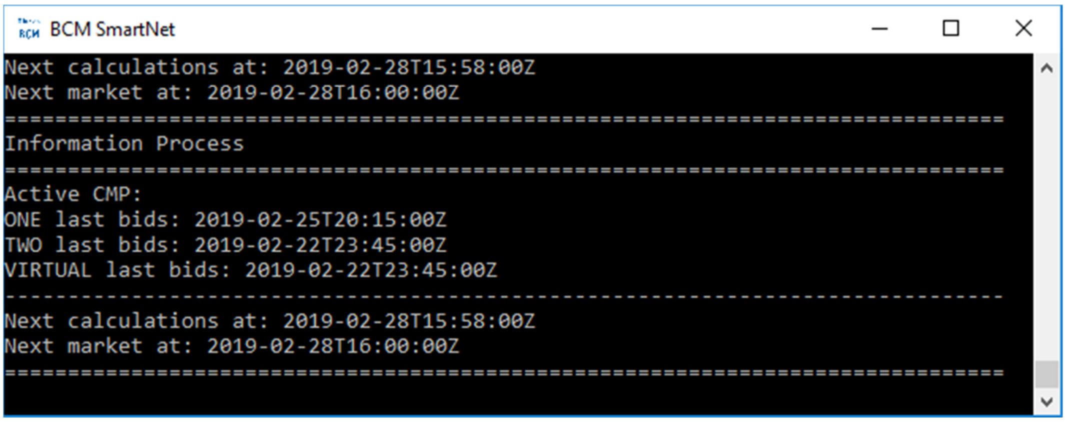


Figure 3-8 Screenshot of BCM application

- Virtual CMPs (flexibility aggregation). this application simulates a simple CMP aggregator, which can be configured with different files. As shown in Figure 3-9**,** the information displayed include the active CMPs (which, in this moment, were TWO and VIRTUAL), the status of each CMP and the next time to send the bids and baselines.

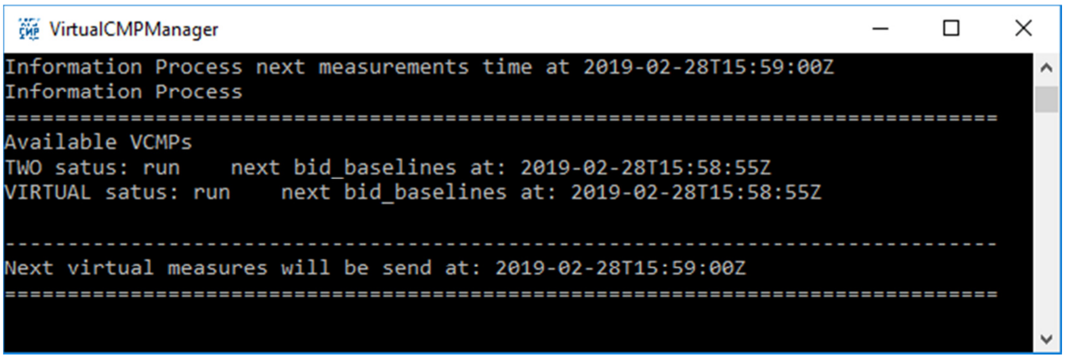


Figure 3-9 Screenshot of Virtual CMPs application

- Time server: this server works inside the VPN communications to guarantee time synchronisation with all the devices. For this application, the time server included in the Windows software was chosen, as it is already installed on the server.
- Database: the database is operated in the BCM application by a database management system to simplify the interaction with the user (frontend web server), the BCM backend and the data acquisition server. The selected application to store all the information is MongoDB. The main feature of this application is to have a NoSQL structure database; which provides greatest

flexibility to achieve the needs of the pilot than e.g. a SQL database, with a fixed structure with no possibility to include subarrays into the information.

- Frontend: this is a web server based on XAMPP with a web template based on bootstrap with a database connection. The aim of this fronted is to create an interface to facilitate the presentation of results. Although this web interface was initially published on http://77.211.26.180, it was unpublished for security reasons, after suffering an attack during the execution of the pilot, which pulled down the server. The web interface is divided in four sections:
    - “Home” (Figure 3-10): a short introduction to the project SmartNet and to the Spanish pilot is provided, together with some presentations. The content of this page is a short video presenting the project and a brief introduction and a link to the SmartNet official web page. On the top of the page, there is a menu to navigate through the website, which allows the visitor to visit the different sections described below.

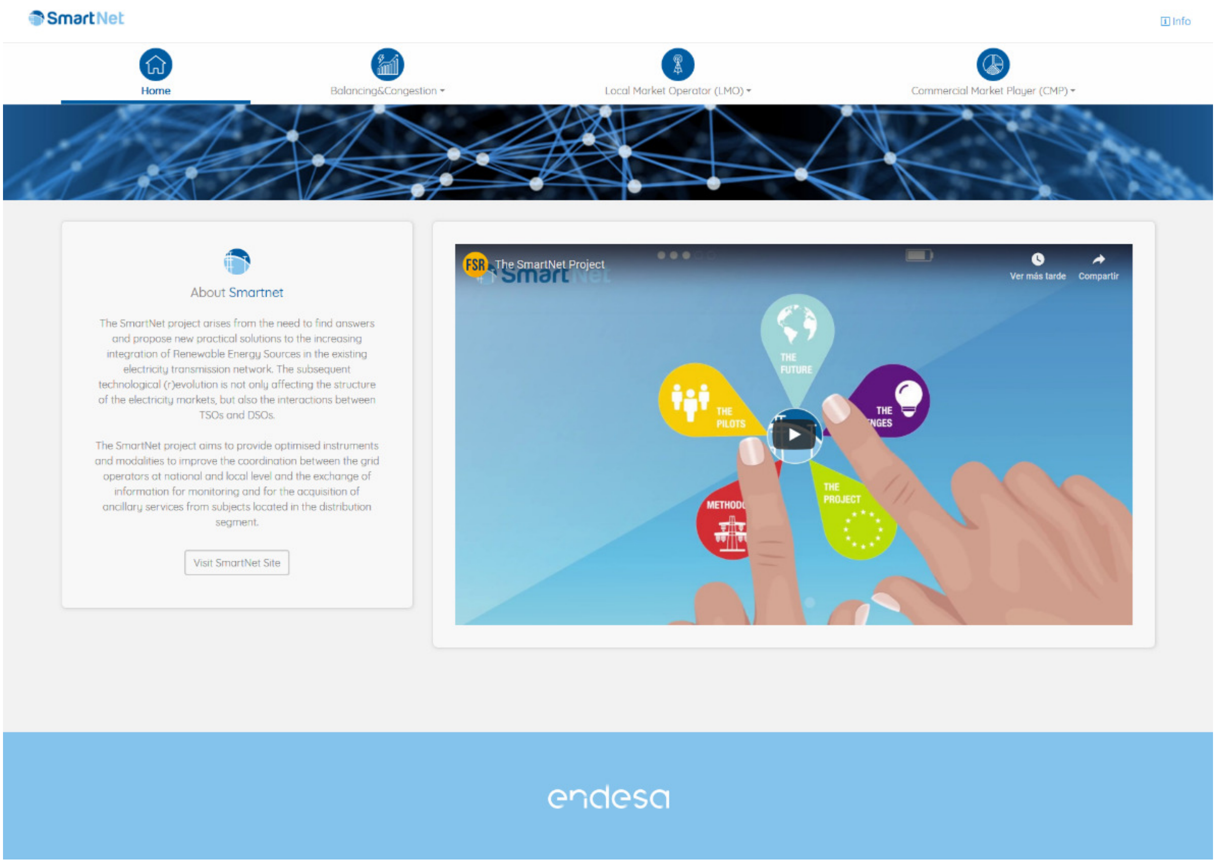


Figure 3-10: Home page

    - “Balancing & Congestion”: this page shows the balancing functionality and the grid structure and measurements. At the upper part of the balancing and congestion page (Figure 3-11), there is a chart which shows both the power exchanged at the TSO-

DSO interconnection point and the scheduled profile. This chart can be filtered to show a specific period of dates. At the lower part of the page (Figure 3-12), there is a snapshot diagram of the selected substation, showing 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 showed in this page are in megawatts, except for the resources which are provided in kilowatts.

Figure 3-11: Balancing & Congestion page, top

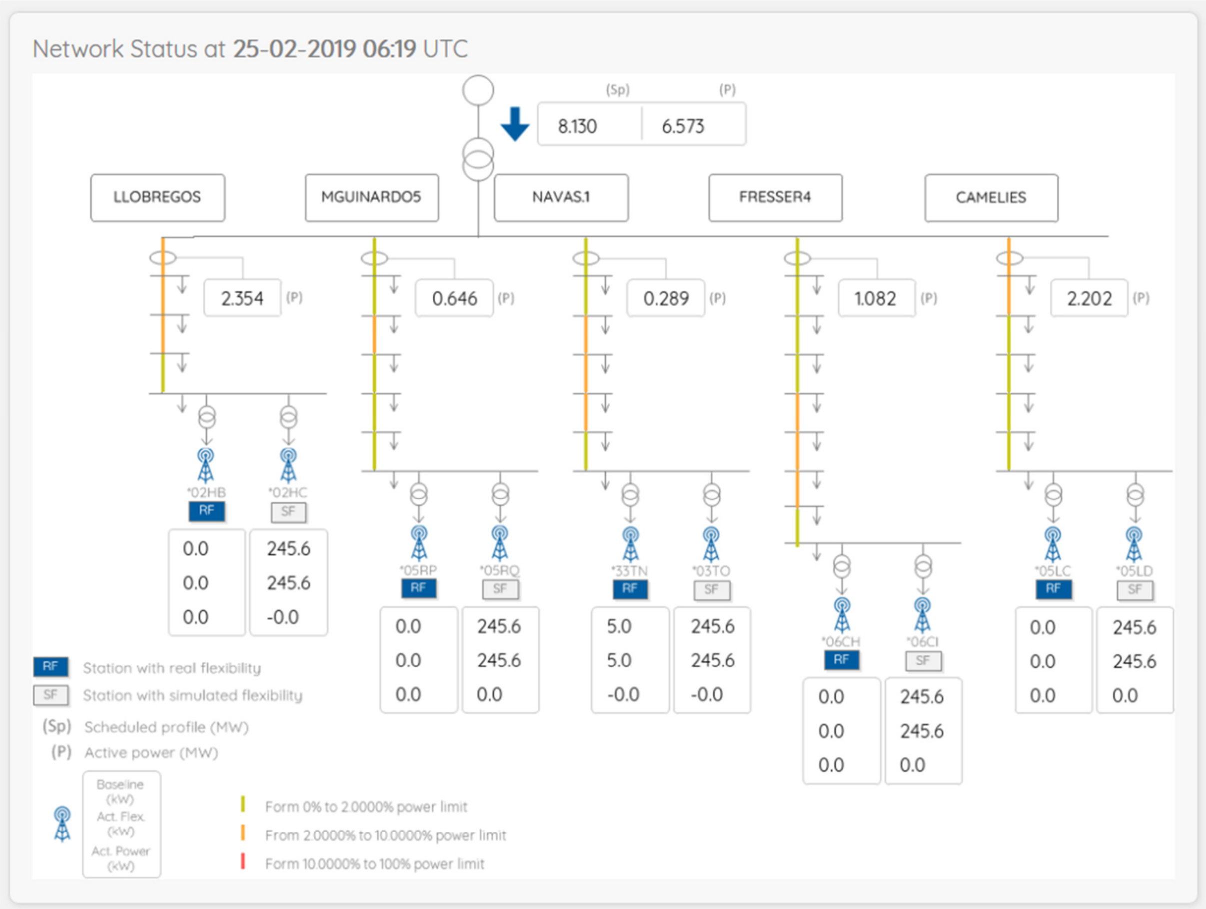


Figure 3-12: Balancing & Congestion page, bottom

- "Local Market Operator (LMO)": this page shows the status of the market the prices and the activations. The menu of this section shows up a submenu with the different substations. Like in the "Balancing & Congestion" page, there is a filter to select the time horizon shown in the charts. The upper chart (Figure 3-13) shows market prices, where the grey line represents the maximum bid price (the most expensive bid received among all the CMPs), and the blue line the resulting market price (the final price of the activated bids). As shown in the figure, when the market needs flexibility, market prices reach or get close to the maximum bid price, because there are small price differences between the CMPs. The lower chart (Figure 3-14) represents the amount of flexibility for each time period; the amount of available flexibility in light blue and the dispatched flexibility in dark blue.

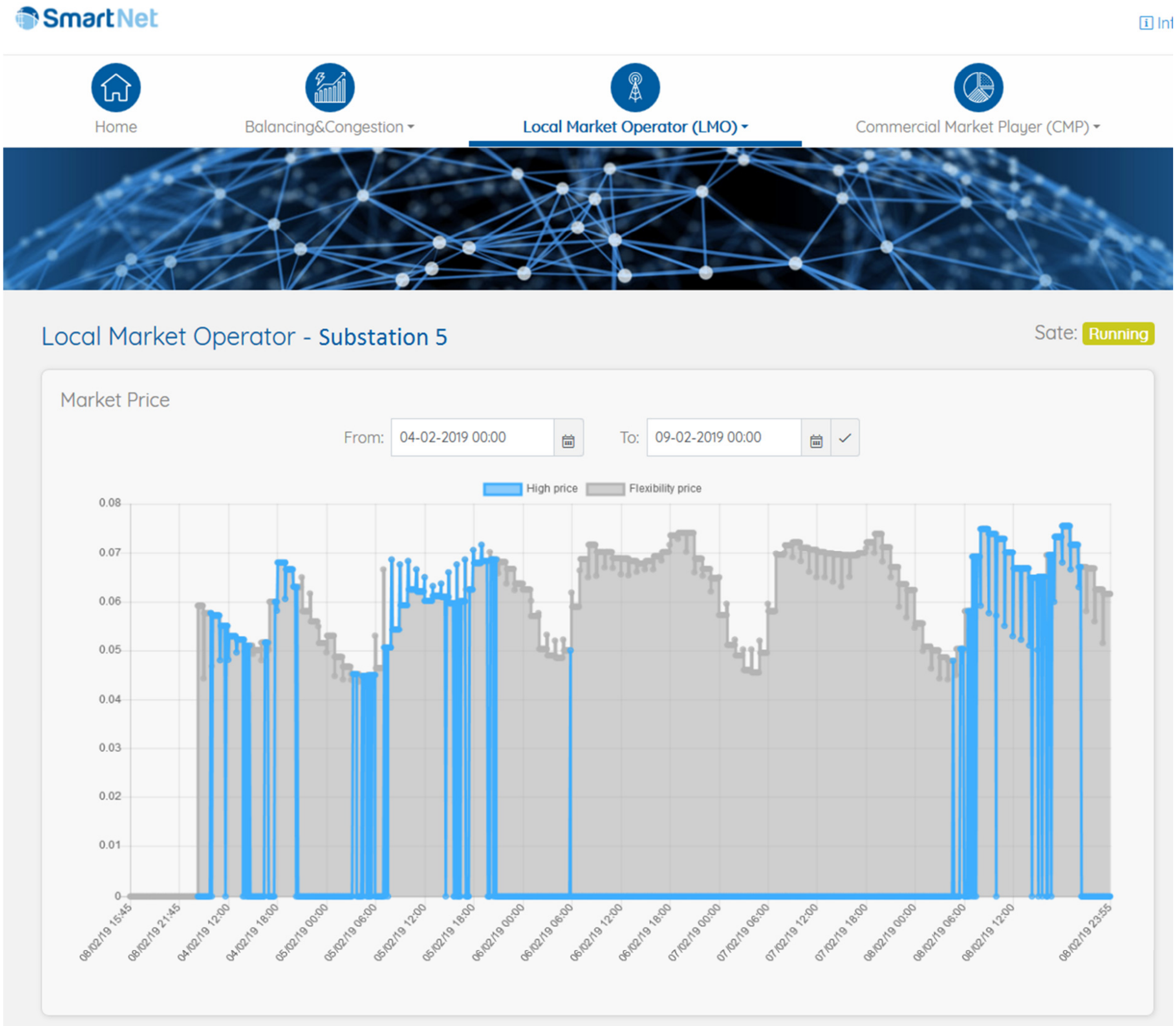


Figure 3-13: Local Market Operator page, top.

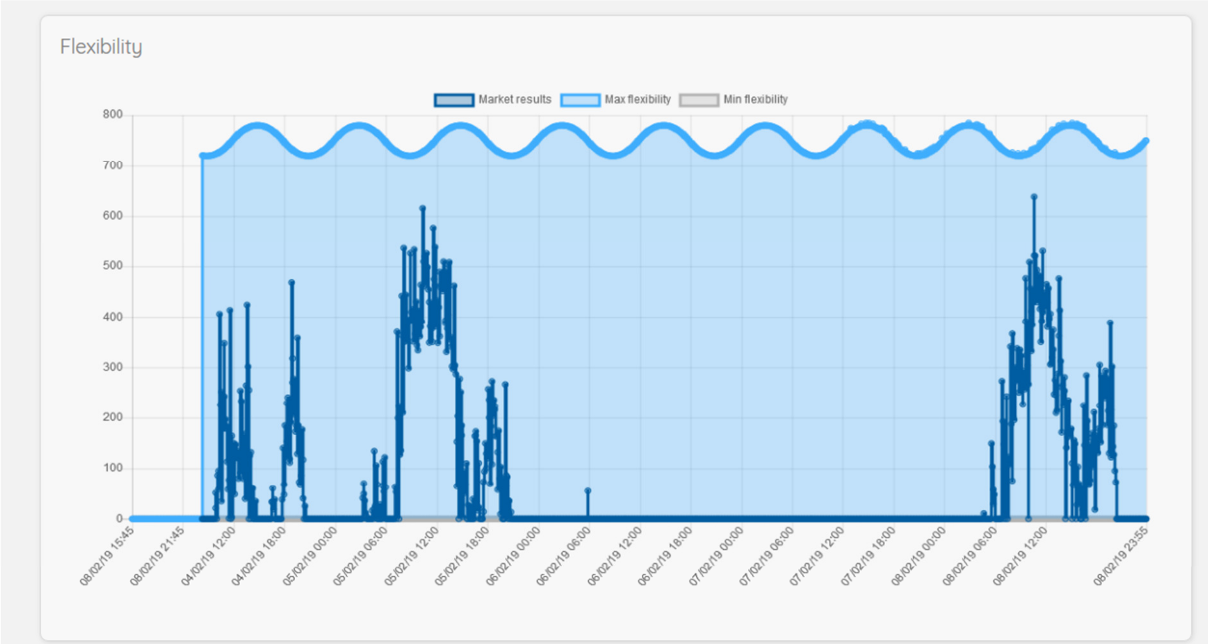


Figure 3-14: Local Market Operator page, bottom

- "Commercial Market Player (CMP)": this section shows the information regarding each CMP. On the top of the page, there is a submenu with the all the CMP involved in the pilot (ONE, TWO or Virtual) and, like in previous sections of the frontend, the time horizon to be shown can be filtered. The upper chart (Figure 3-15) represent the amount of flexibility provided by the selected CMP, where the grey line is the total flexibility available, the light blue line is the expected consumption and the dark blue line is the real consumption (which is the addition of all the measurements in each base station). In the lower part of the CMP page (Figure 3-16), there is a table with each offer sent to the market, including the information related to each station, the flexibility offered and its price.

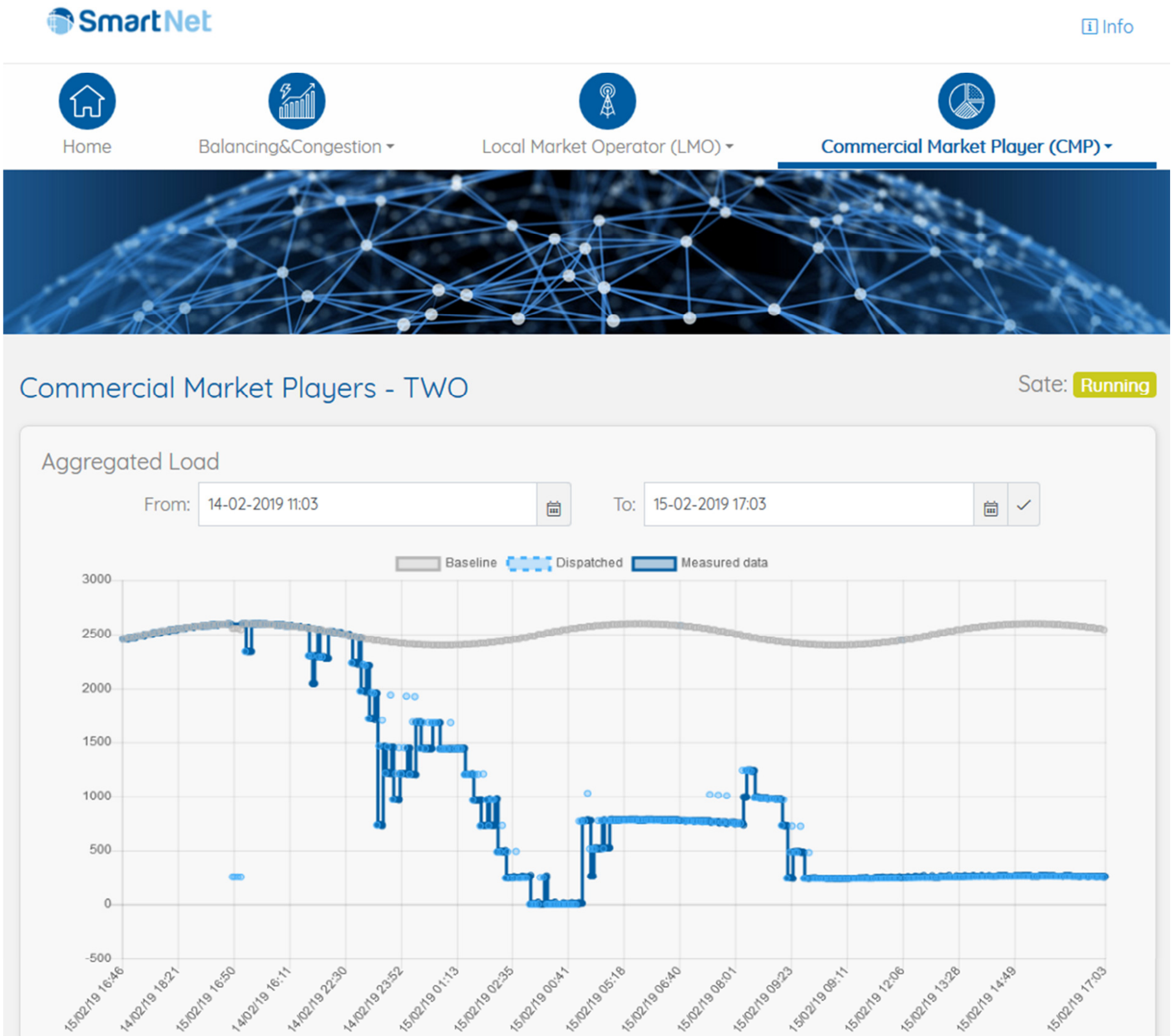
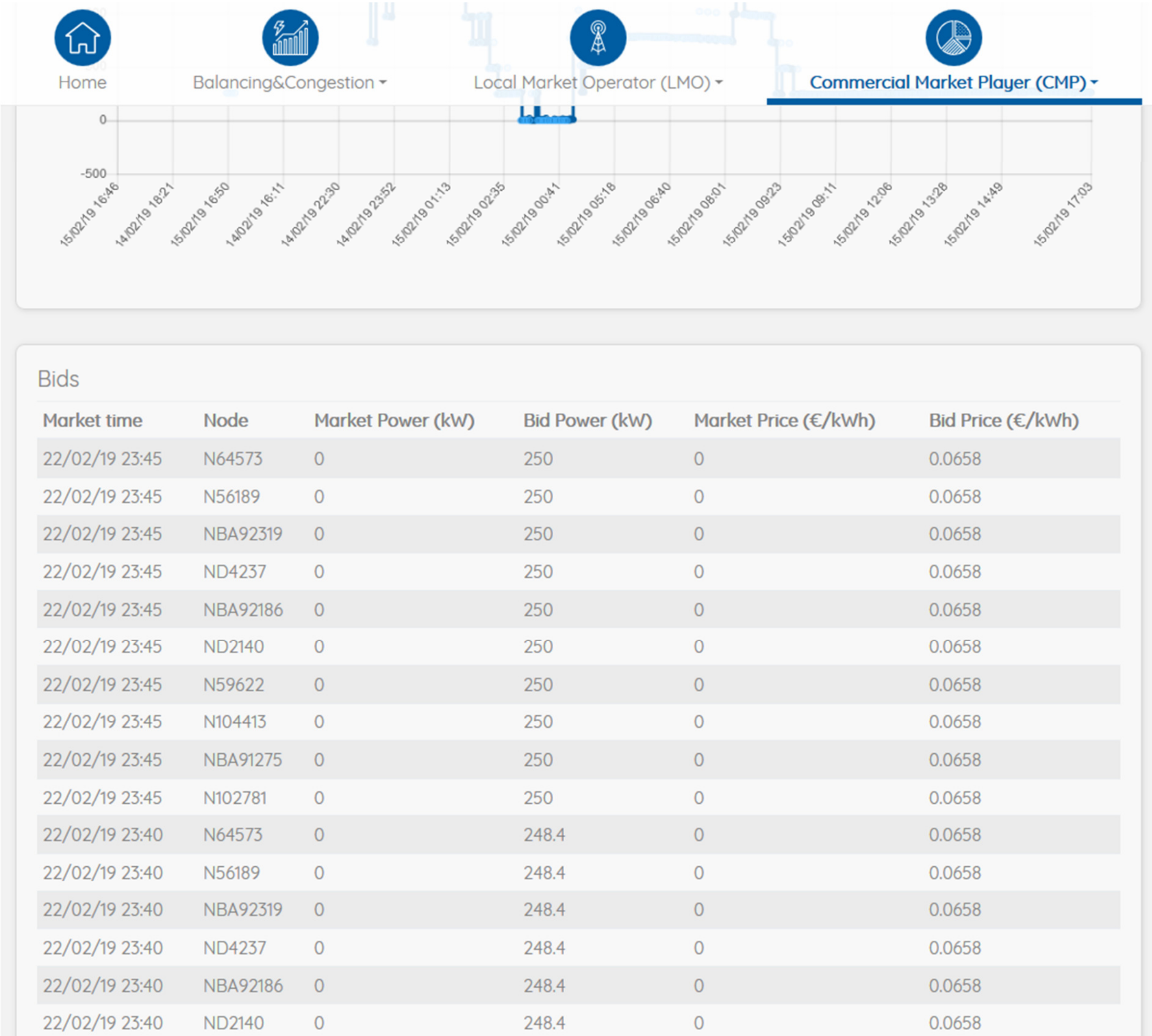


Figure 3-15: Commercial market party page, top



Market time	Node	Market Power (kW)	Bid Power (kW)	Market Price (€/kWh)	Bid Price (€/kWh)
22/02/19 23:45	N64573	0	250	0	0.0658
22/02/19 23:45	N56189	0	250	0	0.0658
22/02/19 23:45	NBA92319	0	250	0	0.0658
22/02/19 23:45	ND4237	0	250	0	0.0658
22/02/19 23:45	NBA92186	0	250	0	0.0658
22/02/19 23:45	ND2140	0	250	0	0.0658
22/02/19 23:45	N59622	0	250	0	0.0658
22/02/19 23:45	N104413	0	250	0	0.0658
22/02/19 23:45	NBA91275	0	250	0	0.0658
22/02/19 23:45	N102781	0	250	0	0.0658
22/02/19 23:40	N64573	0	248.4	0	0.0658
22/02/19 23:40	N56189	0	248.4	0	0.0658
22/02/19 23:40	NBA92319	0	248.4	0	0.0658
22/02/19 23:40	ND4237	0	248.4	0	0.0658
22/02/19 23:40	NBA92186	0	248.4	0	0.0658
22/02/19 23:40	ND2140	0	248.4	0	0.0658

Figure 3-16: Commercial market party page, bottom

3.2.2 Aggregation

As explained above, ONE has chosen to develop the logical unit in Python and to run it from an Ubuntu (Linux) desktop mounted on an Amazon Web Services server.

Figure 3-17 highlights the functional diagram originally discussed for the implementation of the pilot from the perspective of the aggregation. This diagram features the different processes taking place between and within each partner at the different stages of the bidding and activation process.

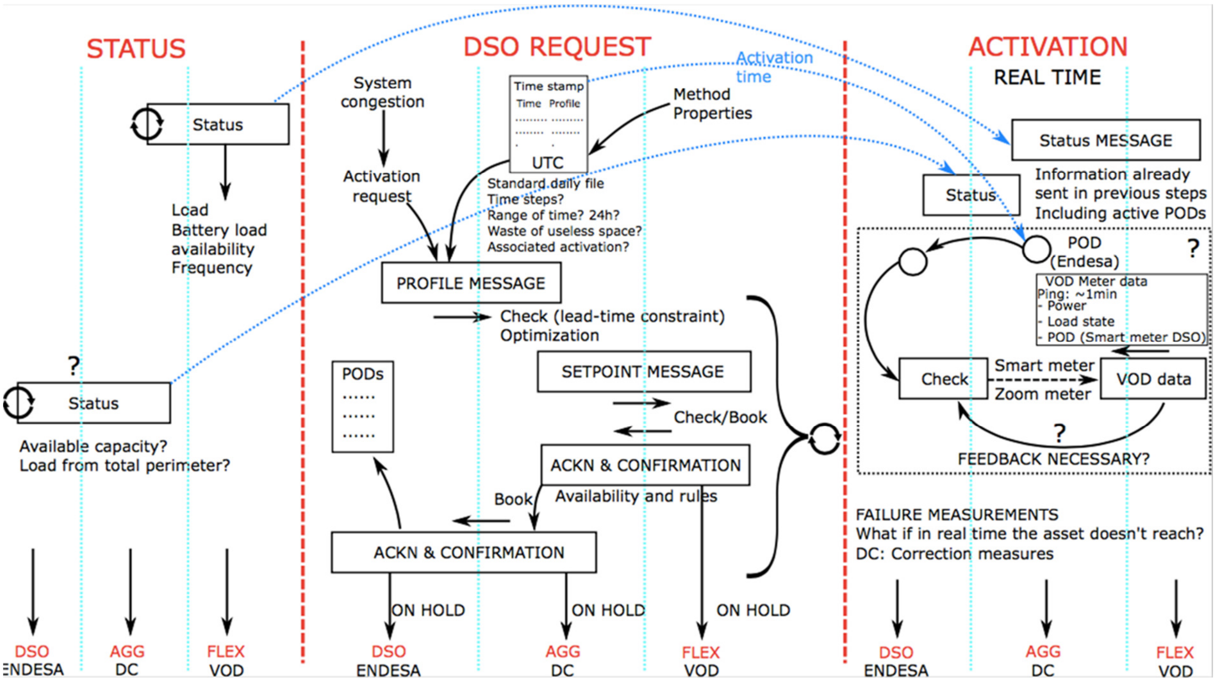


Figure 3-17: Original functional diagram of the from an aggregation point of view

Then, Figure 3-18 shows the initial map of communications, which was agreed amongst partners and which describes the various messages that were needed to fully implement the functional diagram of Figure 3-17.

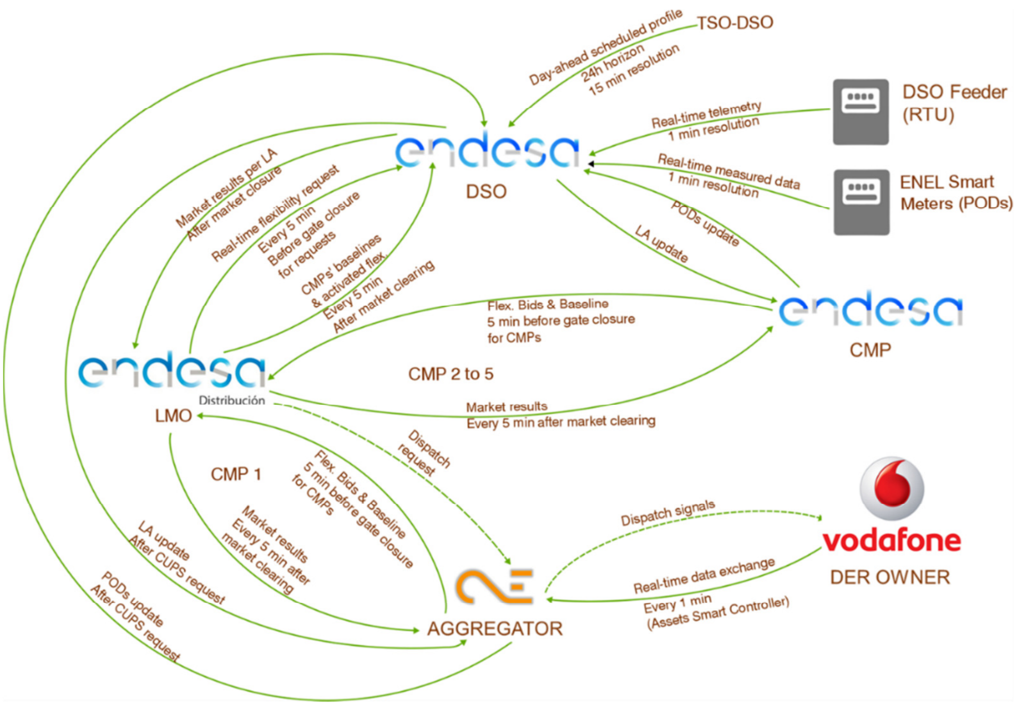


Figure 3-18: Original communications' diagram from a full process point of view.

The diagram in Figure 3-18 has been retained to a great extent during the whole execution of the pilot. Only ONE's data acquisition system had to de adapted, to satisfy the updated specifications of the status

.json files received from Vodafone. This also required ONE to implement new data acquisition and classification routines to sort the batteries by their state of charge.

In addition, some small code-structures in the data messages were implemented in each of the communications with Endesa and Vodafone to comply with the stipulated requirements in the technical specification document. Mainly, ONE checks the information about the available base stations received from Vodafone, to assess the status and provide the information to Endesa. All this process is executed through the script SentPods.py in Python language.

About the aggregated bidding strategy, an overall process has been implemented, which consists of the following steps (see Figure 3-19):

- Acquisition of spot (day-ahead) and intraday prices from the Iberian market operator (OMIE), in order to gather the data on how the market discounts the system stress via the market price signal. This information is used for the next steps.
- Calculation and characterization of the difference between these two prices for the current delivery hour. From this difference, a parameter called "alpha" is calculated, which characterizes the direction and the extent of the intraday price signal.
- Based on this characterization, two bidding curves are defined, up and down-regulation, in a form that enables to secure some cheap activations and, also, fish for extreme prices for maximizing the value of flexibility from the local market.
- A layer of activation appetite from the DERs for a given direction (up or down regulation) is also calculated, based on historical activations and on current state of charge:
    - The rebounds from previous activations are read the current baseline is read and, provided there is no activation, what the asset would intend to do).
    - This appetite is reflected by shifting the bidding curve up or down, so the activation for the asset in the right direction is eased.
- With the two layers above, an aggregated bid curve is generated and sent to the market for the auction. In parallel, the bidding curves are stored, with a characterization of which asset (battery POD) is behind each of the individual bidding points, so that the disaggregation process becomes a trivial consideration when an activation takes place.

Meanwhile, the script "listen.py" is run in the background. This script is responsible for listening to the ports of entry that have been configured to receive messages in the application (market results, load enabled areas and activations).

In case an activation is received:

- The activation is stored and the rebound effect of those activations that are stored in the baselines for the next market period is immediately processed (these rebound effects are added to the previous ones).

- The required batteries are activated, i.e. they have entered within the flexibility of the market. All this process is done through the execution of a script called “batteryactivations.py”.

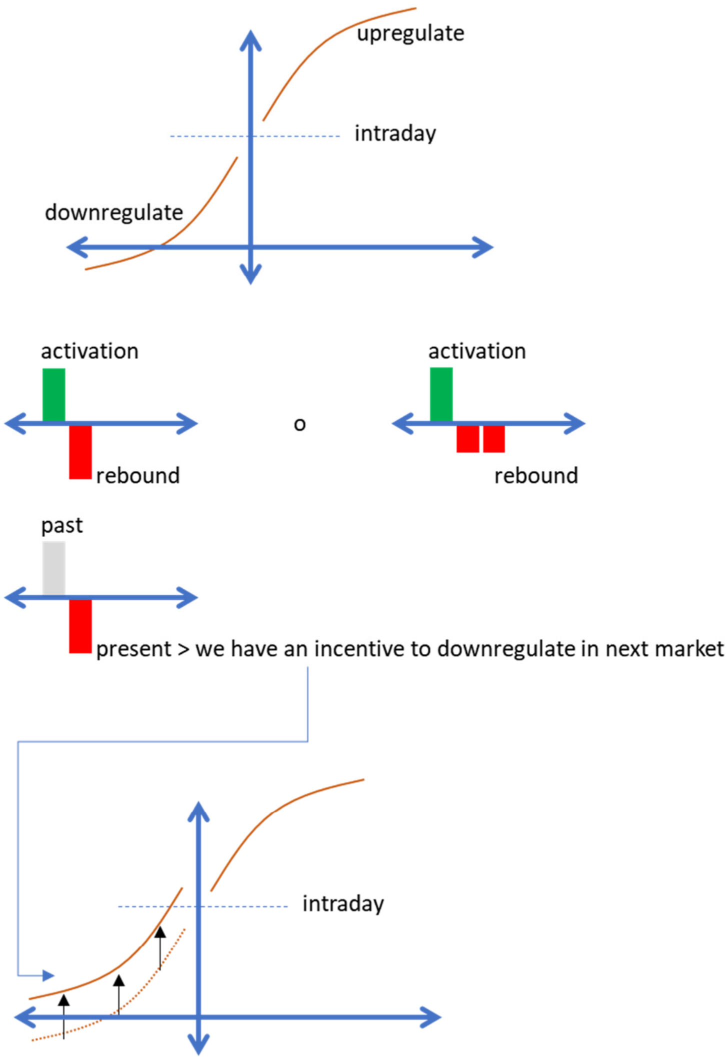


Figure 3-19 Schematic of flexibility activation and associated rebound effect

3.3 Tests performed

Before the execution of the pilot, the different components of the pilot, including the software modules developed and the communications between the different partners, were tested. Moreover, during the execution phase, different types of errors have been experienced in terms of communications, operations by the aggregator when carrying out the system of price auctions and data reception by all the partners or companies involved. When solving these additional issues, the components were also tested before continuing with the execution.

The different types of tests made during the pilot are described in this section.

3.3.1 Communication tests between ONE and Vodafone

For the communication between the CMP and the DER, a simple and adaptive network configuration (Http) was used, so that messages could be established continuously for sending and receiving files. Within the continuous testing process, several types of errors appeared:

- Files (.json) with incorrect structures.
- Lack of information and time lag in the received files.
- Communication problems.
- Input frequency of Vodafone files (.json).

In order to solve them, different types of tests have been applied:

- Check the stability of the requests and Http response through port 443 between both parties to see how often ONE receives files from Vodafone.
- Check the data structures of the battery stations (voltage, current, percentage of charge) supplied by Vodafone to adapt them to the system.
- Continuously adapt the system to avoid possible failures due to the several changes in the data structures received during the duration of the pilot.

3.3.2 Communication tests between ONE and Endesa

For the communication between the DSO/LMO and the CMP, a private communication protocol (VPN) was chosen, which allows for having a more exhaustive control of the status of the network at all times.

During these tests, different types of errors have been experienced:

- Communication errors and network stability.
- Communication failures due to an NTP (Netwok Time Protocol) server installed in the Endesa's internal network.

In order to be able to face this type of inconveniences, it has chosen to carry out the following tests:

- Stability of the VPN connection and execution times when transferring information.
- Perform a complete cycle of communications between ONE and Endesa, so that bids and activations are sent and received by both parties on a continuous basis.

3.3.3 Tests of the aggregation process

In addition to all the communication tests described in the previous subsections, all the processes related to the market strategy, flexibility of the aggregator, sending bids, reception of market results and battery activation had to be tested too.

During the testing period, the following errors or anomalies were experienced in the operation of the application:

- Errors in the data structures sent and received by both partners.
- Little market flexibility.
- Lack of information from base stations.
- Erroneous or unnecessary activations due to failures in the scripts used.
- Lack of available battery information.
- Delay in the reception of market results.

In order to cope with this type of inconvenience, the following tests were made:

- Checking and correcting scripts for proper operation.
- Execution of all aggregation processes on a continuous basis.
- Adjustment of the flexibility of the market to have a greater participation in the auctions of prices carried out.
- Verification and correction of all processes in which erroneous activations have been carried out by means of a predefined system of logs.
- Check that ONE receives the information about the available stations, sends the bids correctly and obtains Endesa's market results within 5 minutes to reach the objective.

3.3.4 Battery activation tests

The test to the battery activation process has also been performed by activating all the batteries that have entered the flexibility of the market. Throughout this process different types of errors have been experienced:

- Communication with Http requests to the server that Vodafone has implemented.
- Small updates that Vodafone applies to its systems without prior notice.

Therefore, an individual activation test had to be applied to each battery available within the infrastructure that Vodafone has provided to the pilot, followed by a deactivation test for each battery.

- Each site reports back the current energy consumption and the state of charge of the battery to the aggregator in real-time (minute by minutes) via pre-agreed JSON formatted messages.
- To trigger an event, the aggregators sends a “start” command via JSON, for each site, trigging the remote battery test function within DC power systems.
- At the end of the desired event, the aggregator sends a “stop” command again via JSON, for each site, to cease the battery test function and recharge the batteries.

- The DC Power Systems remote battery test function safely places the sites load onto batteries, by lowering the rectifier voltage so as to prevent a loss of service in the event the batteries are faulty.
- The remote battery test we continue until the battery voltage meets and pre-defined voltage of 47.7 VDC, the discharge however will vary based upon the load of the radio equipment and general condition.
- The DC power systems will prevent the execution of the remote battery test, if it detects that the condition of the batteries is in question or that they are not fully recharged above 90%.

Figure 3-20 below shows the DC system voltage in red, discharging below 48V, during a DSM 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).

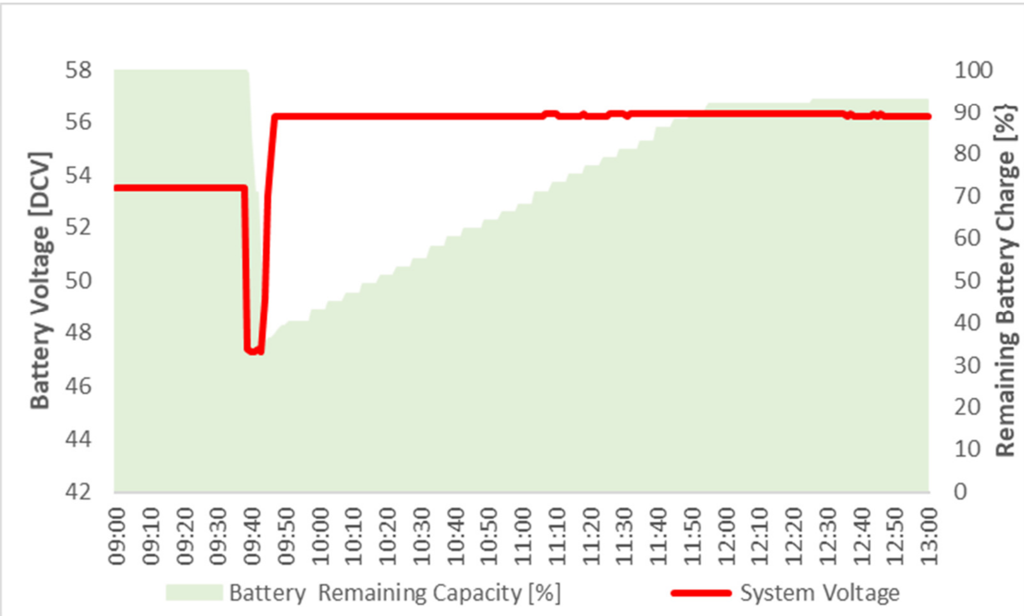


Figure 3-20 Sample DSR Event Showing Battery Voltage & Remaining Charge %

3.4 Results

The execution of the pilot was divided into three main phases of one week each. In each of these phases, the pilot was kept in operation continuously, i.e. Endesa calculated the flexibility required, ONE estimated the available flexibility in base stations and sent the bids to the local market, the market was cleared, and the clearing results communicated to ONE, who dispatched the base stations as required. As described in section 3.3, some updates to the applications and scripts were required after each phase, with the consequent testing phase.

The first execution week, which took place in September 2018, was aimed at checking the frequency of activations and the pilot activity. For that purpose, the steps in subsection 3.2.2 were taken and, as a

result, the day ahead and last intraday prices for one given day were gathered. As shown in Figure 3-21, the intraday prices swing around the day-ahead for different hours in the day, mainly due to expected changes in demand and RES generation forecast.

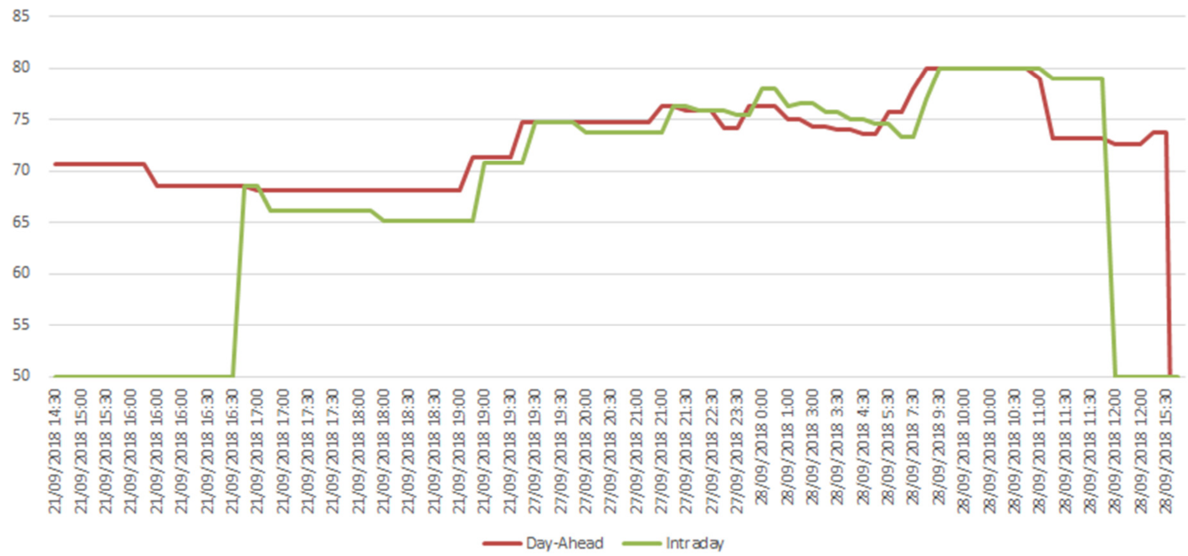


Figure 3-21 Wholesale Electricity Prices in Spain

As described above, the direction of the intraday price signal is characterised and compared to the day-ahead through the parameter "alpha", which in essence is the difference between those two prices but capped at +/- 10€/MWh. Figure 3-22 presents the difference between these two curves ('Raw Alpha') and this capped ('Alpha').

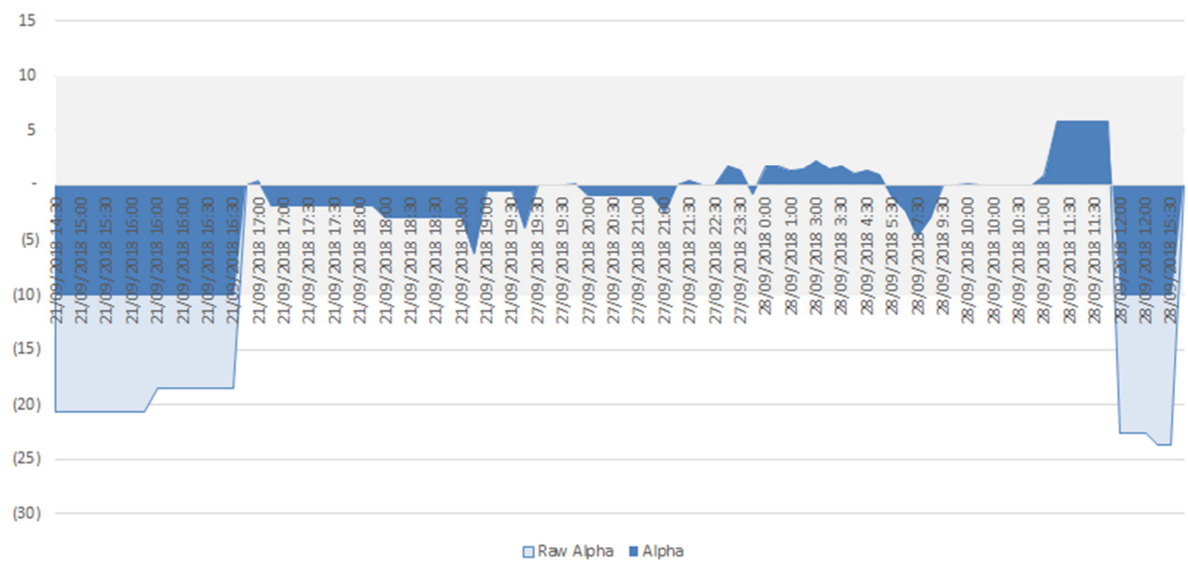


Figure 3-22 Model Alpha and Activation History

After some updates on the systems, the execution week in February allowed the pilot partners to evaluate all the elements and algorithms involved in the pilot. In particular, the aim was to check whether

the DSO could meet the goals of maintain the scheduled profile, while avoiding congestions in the distribution grid. However, some important considerations must be reminded:

- The flexibility used in the pilot is only provided by reducing demand and, thus, no increase in consumption is foreseen. Therefore, the DSO can contract upward balancing (demand reduction), but not downward balancing (demand increase or generation reduction), because the types of DER to provide it are not included in the pilot.
- The scheduled profile is obtained from historical data, so, in some cases, it may be quite different to the real consumption, because e.g. one particular day is usually very cold but, when executing the pilot, it was hotter than usual, hence affecting the real consumption in the distribution grid.

The result of the demand gathering by the DSO for balancing purposes is depicted in Figure 3-23 and Figure 3-25, where the blue line represents the scheduled profile and the grey line is the actual exchange. Likewise, Figure 3-24 and Figure 3-26 present the flexibility required by the market (dark blue) and the flexibility made available by CMPs (light blue). As shown in the figures, when there is not enough flexibility available to meet all the requirements by the DSO (e.g. on February 4 in the morning), the dark blue line and the light blue line get together in Figure 3-24 and the grey line is above the blue line in Figure 3-23. On the contrary, when the DSO needs downward balancing (e.g. in February 6), there is no available flexibility, so the dark blue line represents zero in Figure 3-24 and the grey line is below the blue line in Figure 3-23. In the rest of the cases, that is, when there is enough flexibility available to meet DSO's needs, the DSO meets the scheduled profile and, hence, the grey and the blue lines in Figure 3-23 get together.

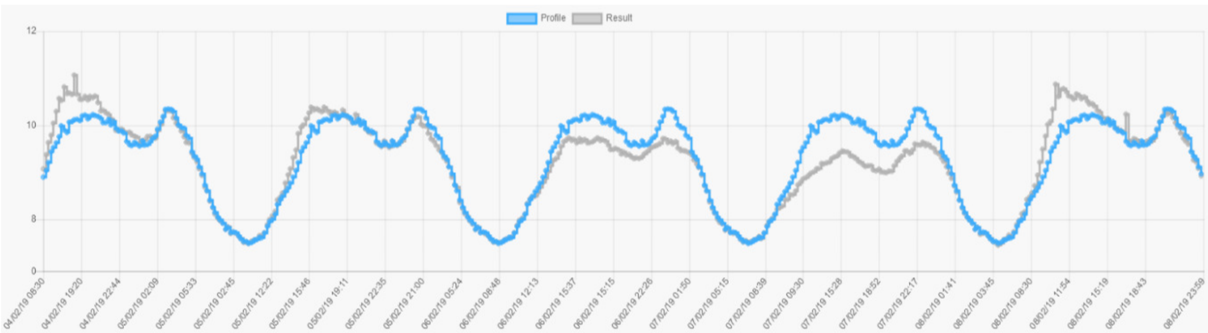


Figure 3-23 Balancing of Substation 3, during the execution between 4 and 8 of February 2019

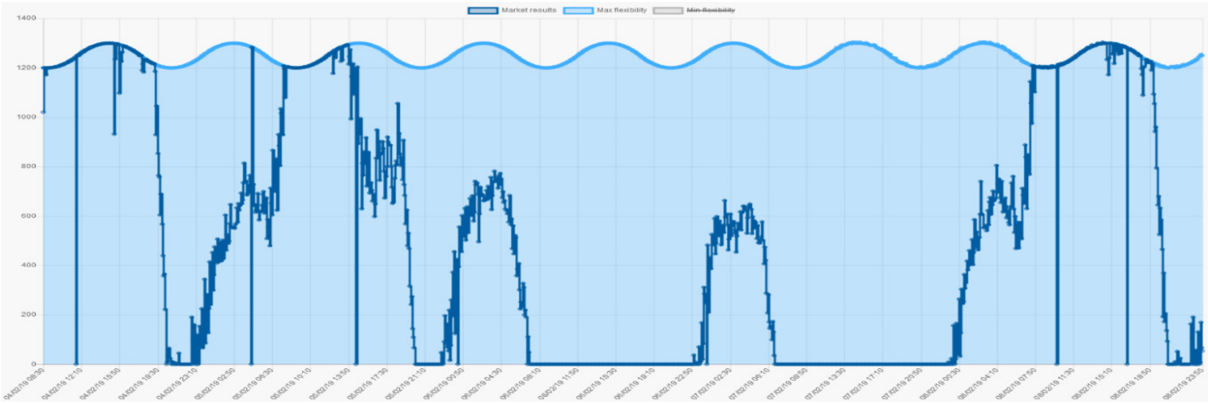


Figure 3-24 Flexibility of Substation 3, during the execution between 4 and 8 of February 2019

The behaviour discussed above appear not only in Substation 3, but also in the rest of substations involved in the pilot, as shown in Figure 3-25 and Figure 3-26.

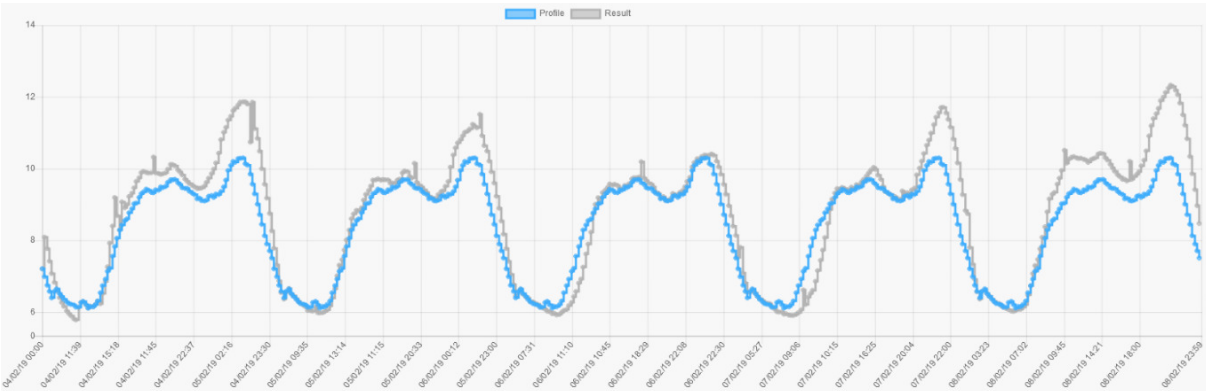


Figure 3-25 Balancing of Substation 4, during the execution between 4 and 8 of February 2019

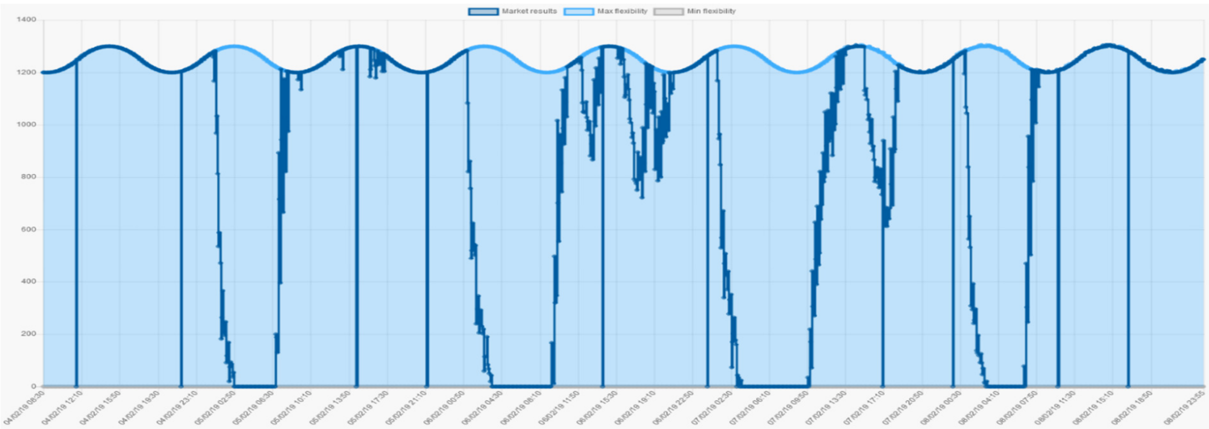


Figure 3-26 Flexibility of Substation 4, during the execution between 4 and 8 of February 2019

Regarding the avoidance of congestions, Figure 3-27 shows a screenshot of the status below Substation 4. In this screenshot, there is a real base station providing 5 kW of flexibility (in feeder 3) and other virtual stations and lines are coloured to show the loading rate of the lines. In each DER, the number above represents the baseline consumption, the number in the middle the activated flexibility and the number below the actual power consumption, all of them in kW.

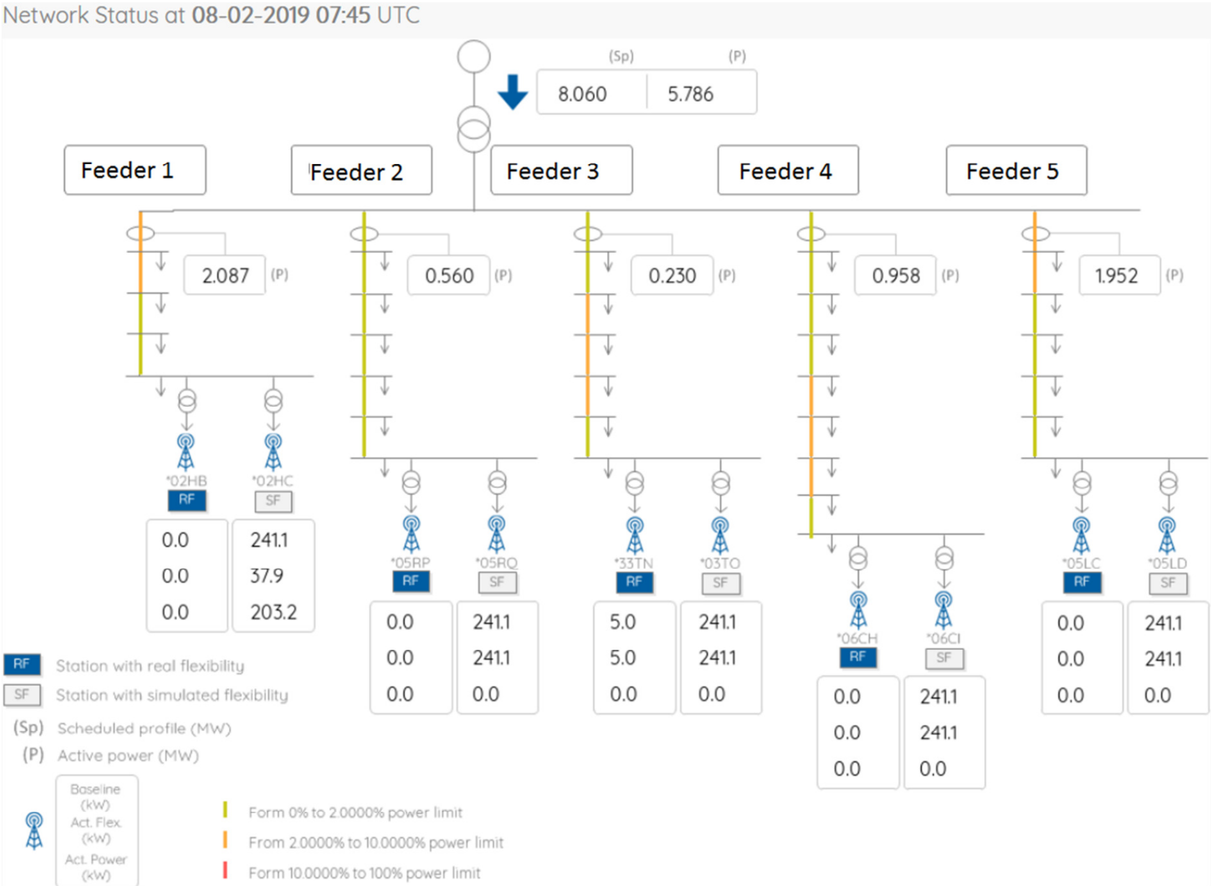


Figure 3-27 Substation 4, market dispatch at 08-02-2019 07:45 UTC

In this case, all the available flexibility in feeders 2, 3, 4 and 5 has been dispatched (as active consumption in all of them is zero), while the flexibility in feeder 1 has been only partially activated.

Figure 3-28 shows two snapshots of substation 5. In the first snapshot, it can be seen that feeder 3, which is not making use of any flexibility, is the most loaded one. The second snapshot shows the situation 5 minutes later, after the clearing of the next market session. As expected, the market dispatches all the flexibility on this feeder 3, trying to resolve the congestion, but, in this case, the flexible power at this point was not enough to solve the congestion.

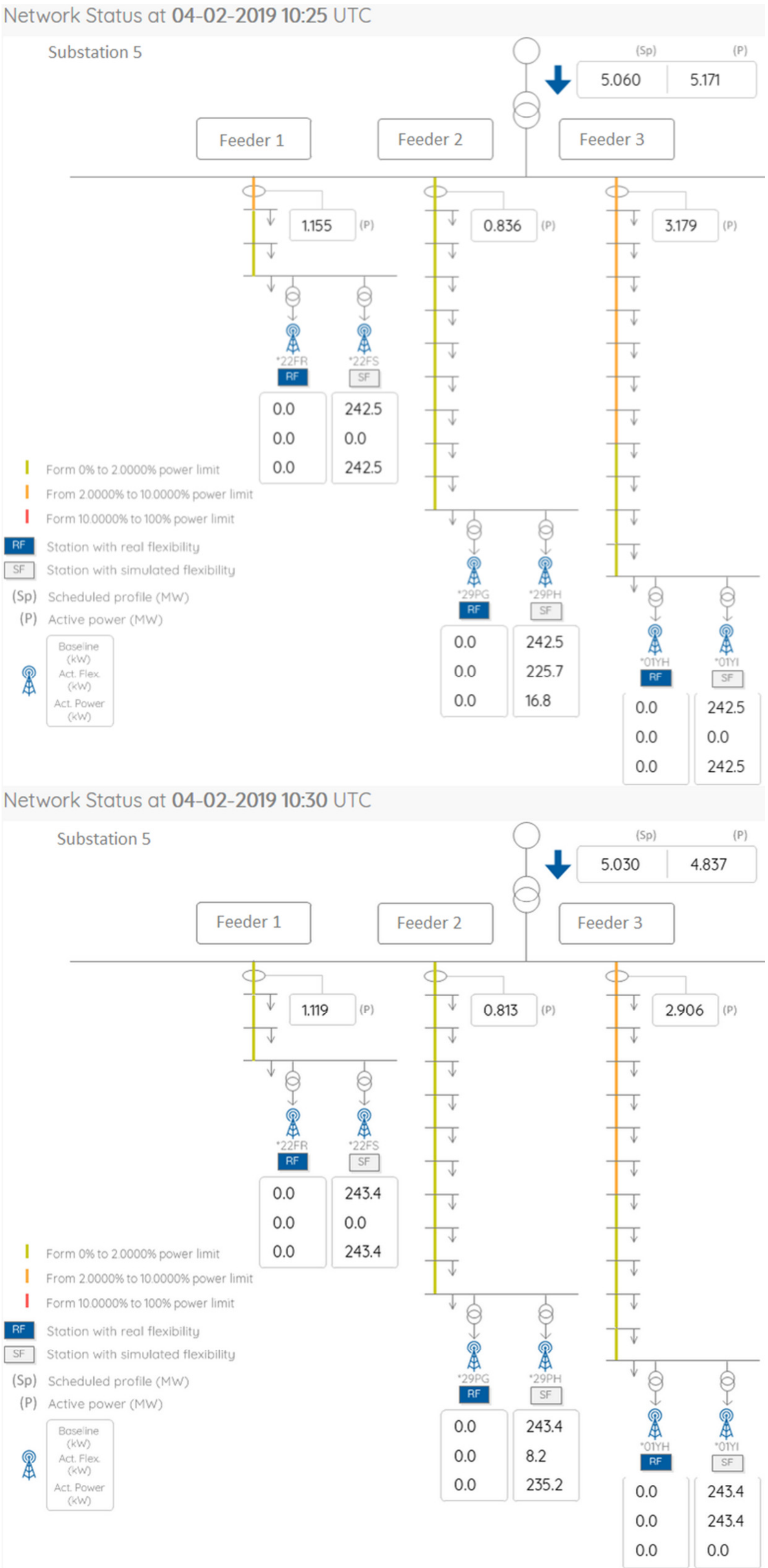


Figure 3-28 Screenshot of the Substation 5 network, 04-02-2019 (up) 10:25 (bottom) 10:30

3.5 Implementation problems

In addition to the software issues identified in section 3.3, further operational problems were identified during the preparation and execution of the pilot. These problems are described in the list below:

- Endesa and ONE made a different interpretation of the documentation about the specifications for the communication protocol for the DSO-CMP information exchange. Frequent meetings allowed for having a common understanding between both parties and, after making some tests and changes, the communications finally worked.
- The VPN server could not be installed in the DSO's computer, because the operative system installed had some unsolved issues related to VPN server application. After having considered buying the service of a VPN server or using a small device to allow that kind of communications, the external device with the capabilities to run as a VPN server at the same network was used.
- The configuration file of the VPN server had to be updated to ensure a stable communication. During the tests, some clients of the VPN were disconnected spontaneously due to the lag in communications. This problem was solved by changing the configuration of the VPN server to allow a greater communications lag.
- Time server did not work properly. This server is installed in Endesa's computer, but a non-standard application was used, because the NTP server provided by the operative system is not compatible with all the operative systems, such as GNU/Linux. During the tests, some timeout problems with this server arose. This problem was fixed by creating a scheduled restart every 6 hours with the windows task scheduler.
- The optimization module needed a solver with the capabilities to solve a mixed-integer nonlinear programming. After an exhaustive search, the Bonmin solver was selected to program the optimization problem, because it was the only open-source program which could solve mixed-integer nonlinear problems. Julia language was used to integrate the optimization problem, providing an easy interface to Bonmin. Julia language is a new, open-source language focused in data science and high-performance numerical analysis.
- The grid of the Barcelona is meshed and quite complex, which caused two main issues: it was very hard to model it because it took very long to follow all the wires and ramifications, and, in addition, the complexity of the network made the optimization problem more complex, taking to account that the optimization problem must be solved in less than one minute. For these reasons, the network was simplified, by dividing the network into five substations and aggregating the loads in nodes, focusing only in the areas where flexibility was available and assuming that there is no reconfiguration of the grid.
- An adaptation of the communication protocols between ONE-Endesa and ONE-Vodafone was carried out to solve the communication problems and to align with the protocols and

specifications agreed with both Endesa (in its role as Local Market Operator or LMO) and Vodafone (in its role as Distributed Energy Resource or DER).

- Implementation of 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. The aggregator's server had long processing times, due to memory use issues. Therefore, the sequence of commands was optimised to improve the use of memory.
- The auction system was updated, after having been implemented, to improve the operating dynamics of the entire pilot. This way, a continuous flexibility of the pilot (bids, market results) was obtained.
- The data acquisition and classification method (available base stations, bids, activations, loading zones, etc.) also was adapted, to stabilize the file transmission times between ONE, Endesa and Vodafone.
- In some periods, the scenarios created for simulating the DSO's needs resulted in low flexibility requests by the market and, hence, the batteries were not activated during long periods of time. In order to avoid this type of anomalous behaviour, the operational dynamics of the entire pilot were improved, both on Endesa's clearing mechanism and in ONE's bidding strategy. In its role as aggregator, ONE's dynamic bidding strategy consists of checking the prices of a previous offer accepted by the local market, thereby adapting the baseline for ONE's bidding strategy upwards or downwards according to recent history: for an upward regulation bid the next price that is going to be offered will be increased by 10% in the case that the previous bid has been accepted and 5% less of the price in the case that the last bid was rejected.
- Several changes in structure and frequency were identified in the reception of files by Vodafone, which led to multiple adjustments in the structure of the communication scripts to avoid unexpected behaviours in the system. For that purpose, ONE modified several scripts to perform a filtering of base stations and batteries, which discards any base station that does not meet the stipulated requirements.

4 Lessons learnt

4.1 Technical benefits

In terms of the DSO, Endesa has performed new methods and responsibilities for the grid exploitation in this pilot. These new experiences allowed for detecting the possible benefits or lessons learned to apply in the future to the grid. The main lessons learned by the DSO are listed below:

- The congestion management algorithms give an alternative method to solve the congestions into de grid versus other solutions such as grid reconfiguration. At the end, this method offers the DSO more options to solve grid congestions.
- The scheme implemented in the pilot assigns part of the balancing responsibility to the DSO. This new responsibility requires the existence of more available flexibility in order to avoid situations where there is not enough offered flexibility in the market to get the balance.
- The DSO monitoring system at consumer level in low voltage is used for biding. During this pilot, the necessity to use this system to monitor both the power and voltages in close to real time was discovered. Although the installed smart meters are capable to perform these measurements, they are not configured to do so. Endesa realized that smart meters need to be reconfigured to allow these new functionalities.

Also, this pilot allowed 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 DSO has tested an optimization algorithm with two objectives: comply with the balance and avoid the congestions.

During the uninterrupted operation of the communication and bidding processes implemented in ONE's algorithms within the pilot, the aggregator has experimented and applied several lessons learned. There have been some anomalies in the processing and adaptation of data at times when no data is received from Vodafone. The use of communication protocols has proven to be really useful to allow fast, transparent and non-discriminatory access to market information. However, it was not the only corrective action, as listed below:

- The data acquisition and classification method had to be adapted (available stations, bids, activations, loading zones, prices, etc.), to stabilize file transmission times between ONE, Endesa and Vodafone.
- The communication protocols were adapted for the correct resolution of problems, and for the alignment with the protocols and specifications detailed during the execution period of the pilot. In addition, the scripts had to be adapted to obtain a more flexible and dynamic system in sending the offers.

- The configuration file of the AWS server was modified to establish a stable and continuous communication in the VPN network of interconnection between ONE and Endesa, because the stability of the processes in execution time is vital to obtain reliable results for the project.

ONE has 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 optimization 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 aggregator does not read the flexibility available or make offers anywhere, thus eliminating a significant risk of communication.

Regarding DERs, Vodafone identified the following faults, issues and observations as part of the project implementation:

- 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 Vodafone to identify a number of maintenance issues, such as high temperature problems in some sites, system faults and issues with landlord power supplies.
- 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.

This pilot also enabled Vodafone to fully test the remote battery test function in full, due to a failure in sending the stop signal by the aggregator (see Figure 3-20), hence demonstrating the automatic reinstatement of the rectifiers to normal operation mode once the battery reached the bottom of safety voltage (47.7).

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.

4.2 Commercial benefits

From the role of ONE as aggregator, the experience provides a first step in the direction of evaluating the commercial opportunity to propose aggregation of flexibility as a service to third parties. The results from the pilot are yet non-conclusive, given the limited scope of the experience and the potential impact from market design in the real value of flexibility in these to-be new markets, thereby limiting the economic opportunities and appetite from DERs and subsequently value to be shared (or captured) by aggregators.

Yet, ONE full recognizes the opportunity to structure such services by means of the market price signal alone, in opposition to capacity markets and the sort. As proven during the pilot, adapting bidding strategies can offset the lack of performance in the auctions.

At the light of this pilot, Vodafone has also experienced primary benefits related to DSM impact on their infrastructure design and behaviour, but also for some key components of the DSM chain:

- Time to market for Vodafone to be part of DER landscape, due to the non-impact on telecom service delivery security. Prove the mobile communication network is not at risk when DSM activities are running.
- Marketing material: Additional case study for Vodafone branded Mobile link 4G data terminal in the utility sector.
- Management of vendors: Push technology suppliers, both HW and SW, to deliver their promises and test in real site remote management/maintenance for future feature deployment. This may eventually impact operational expenditures and the sustainability agenda.
- Revenue/cost offsetting opportunity sustainability: Prepare future mass market DSM deployment program set up, i.e. lessons learnt: what to do and what not to do.
- Introduction of a new element in the power back-up business case: Test DSM impact on batteries' life time and support site design required changes for mass usage, in combination with the introduction of new (energy-intensive) telecom technologies such as 5G, which in return impact the base station backup capacity.
- Optimize both capital and operational expenditures, defining synergies between telecom and energy management operations.
- Creativity for managing savings management creativity: Expected reduction of the energy bill, by offsetting part of the energy non-commodity costs in providing DER services to DSOs.
- Internal promotion of DSM in (still) the short list of countries where aggregation for demand is possible.

All above elements converge to reinforce Vodafone strategy in term of sustainability targets and cost management effectiveness, while supporting technical and commercial strategy to address 5G network needs, energy and IoT sector demand.

4.3 Additional benefits

Alongside the duration of this pilot Vodafone have experienced several additional benefits, aside from those already described in previous sections. These include, but are not limited to, the ones described below. The pilot enabled Vodafone to:

- Test the DC power system functionality, which uncovered a few software floors that have since been rectified,
- Identify a few obsolete DC power systems that prompted upgrade and replacement,
- Identify several sites with faulty batteries, enabling replacement before impacting the services,
- Identify extended mains failure (enabling Vodafone to dispatch an engineer to resolve, before a loss of service), and
- Identify maintenance issues which could be dealt with before they escalated to a service-impacting event.

These factors have resulted in building a business case for remote management of sites, including options for implementation of DSM on a network-wide basis, to be activated within the next 2 years, depending upon the evolution of regulation and energy markets.

5 Conclusions and recommendations

This deliverable presented in detail the Spanish pilot developed within the project SmartNet, together with its key functionalities, valuable results and lessons learned. The pilot assessed the extent to which batteries had flexibility or could provide ancillary services, such as balancing services and voltage regulation, to be used by system operators. This was a good proof of concept for the estimation of the potential of batteries in the provision of ancillary services in Europe.

The pilot's intelligence base is extracted from the models devised in several contributions from the partners involved in the Spanish pilot (Vodafone, ONE, Endesa). To validate the technologies developed and incorporated, the Spanish pilot carried out laboratory tests, simulations and real field tests. Throughout these validation phases, the Spanish pilot faced several challenges, most of which were successfully resolved, and which will be considered for improvement in future projects.

With the new technologies and the penetration of RES, power systems will need to be updated to accommodate the new methods of generation. This pilot tested some improvements to give more flexibility to the network in order to overcome the system security challenges derived from the energy transition.

This kind of projects are a good opportunity to test and use an OPF to find the best decision. At DSO level, one of the important points to focus on is the observability of the network, in order to make better decisions. Compared with the pilot, the present metering systems have more relaxed time requirements than the operation requirements of the pilot. Based on the results of the pilot, it may be worthwhile to consider a regulatory change to fix faster communications parameters.

As shown by results, the amount of flexibility was not enough to fix the problems in some cases. However, this is due to the limited scope of the pilot and to the method selected to generate the scheduled profile.

One point to take into consideration is the distance of the base stations in electric terms. In order to avoid interfering the quality of the communication service provided by Vodafone, the base stations involved in the Spanish pilot had to be relatively spread across the city of Barcelona. The distance between the real stations required that the electric network was split into different substations. In a real application, the base stations should be located in the same area in order to use a small network, easy to monitor and control.

From the functional point of view of an aggregator, the pilot served to test the design, implementation and running-time errors and experiences under real world conditions, dealing with communication issues, standardization problems, asset constraints and the sort. In spite of some implementation issues, ONE obtained many of the expected results in terms of flexibility and stability by participating in each of the test periods performed over the active lifetime of the pilot.

ONE had access to a level of flexibility (from currently installed batteries) which presents a number of operational limitations in terms of number and depth of activations. However, a positive business case for Vodafone and similar players in the market could represent an opportunity for the commercial deployment of aggregation as a third-party service.

One last consideration from ONE with respect to the mathematical model developed for the bidding strategies is that there is significant space for exploring different techniques, especially in the context of enhanced flexibility (more base stations and/or more flexible batteries) and also aggregation of various types of assets thereby inter-linking their flexibilities to form complex bidding strategies.

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 250MW + of dispatchable load.

In the future, the DSM 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 "DSM-ready". Further studies to optimize 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.

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