21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

C5-309

CIGRE 2018

Exploiting flexibility of radio base stations in local DSO markets for congestion management with shared balancing responsibility between TSO and DSO

C. MADINA*, J. JIMENO, J. MERINO, M. PARDO, M. MARROQUIN, E. ESTRADE
Tecnalia Endesa Our New Energy Vodafone
Spain Spain Spain Luxembourg

SUMMARY

Electric power systems are facing major challenges as fossil fuel generation is replaced by renewable generation, which is often characterised by variable behaviour. This increases the need for resources to be used to guarantee voltage and frequency stability and to ensure power quality. At the same time, an increasing number of flexible demand and storage systems are being located at distribution level. All these resources can potentially provide network services if they are aggregated effectively. To achieve this, however, the roles of the diverse network stakeholders –transmission systems operators (TSOs), distribution systems operators (DSOs) and aggregators– should be reshaped. Together, the way real-time electricity markets are organised must also be adapted to reflect the new operating environment.

The project SmartNet (http://smartnet-project.eu/) compares five TSO-DSO coordination schemes and different real-time market architectures with the aim of finding out which one could deliver the best compromise between costs and benefits for the system. An ad-hoc-developed platform is used to carry out simulations on three benchmark countries –Italy, Denmark and Spain– whose results are used to perform a cost-benefit analysis. This analysis compares the benefits drawn by the system with the ICT costs needed to implement each coordination scheme. In parallel, three demonstration projects (pilots) are deployed for testing specific technological solutions to enable monitoring, control and participation in ancillary services provision from flexible entities located in distribution networks.

This paper summarises the achievements of the Spanish pilot during the first two years of operation. The pilot includes technical and economic aspects, under the "Shared balancing responsibility model", to demonstrate the feasibility of using urban, distributed radio base stations to provide ancillary services for the DSO through demand side management. In this model, the balancing responsibility is divided between the TSO and the DSO, so that each of them must ensure a predefined schedule in the common border. With that aim, the DSO organises a local market to respect the schedule agreed with the TSO, while the TSO has no access to resources connected to the distribution grid. Commercial market parties such as aggregators become flexibility providers of aggregated distributed energy resources at the local market and the DSO allocates flexibility among them in a competitive manner. Additionally, the local market is used also by the DSO for managing the congestions in its own grid.

KEYWORDS

ancillary services, TSO-DSO interaction, distributed energy resources bidding and aggregation.

*** carlos.madina@tecnalia.com**

1 INTRODUCTION

The contribution of intermittent renewable energy sources (RES) to the European electricity supply is steadily increasing in the last years [1]. On the one hand, the variability resulting from this new paradigm requires a growing reserve to be used for providing ancillary services (ASs) –in particular, system balancing, congestion management and voltage control– so as to maintain system stability. On the other hand, RES plants are replacing big power plants, based on coal and gas technologies, which were the traditional providers of such reserve. Therefore, the management of ancillary services markets by the national Transmission System Operator (TSO) is becoming increasingly complex.

In addition to RES generation, Distributed Energy Sources (DER) –distributed generation and flexible loads, very often connected to distribution grids– are also becoming important actors in the electricity sector. Hence, an important question to be answered is whether DER might replace large generation sets in the provision of ancillary services to the system through an increasing level of cooperation between TSO and the different Distribution System Operator (DSOs).

The Clean Energy Package proposal issued by the European Commission in November 2016 assigns a role to DSOs for local congestion management but not for balancing, whose management would remain in the hands of the TSOs [2]. It can be questioned whether maintaining a rigid decoupling between balancing and congestion management potentially risks leading to inefficient system operation. The European research project SmartNet (http://smartnet-project.eu) aims at investigating how the TSO-DSO interaction for the acquisition of ancillary services (AS) from DER connected to distribution networks can be optimised, by defining and comparing five potential coordination schemes [3], [4].

One of the countries where the project SmartNet is focusing is Spain. Balancing and associated ASs become increasingly complex –and costly– activities in the Iberian market because the share of highly-variable production from RES in the Spanish generation mix is relatively large. As an example of the high variability of RES in Spain, on 19/11/2015 at 11:50, wind power was producing 1 350 MW (contributing to 4.2 % of demand) and less than 48 hours later, on 21/11/2015 at 04:50, wind power produced 15 293 MW (58 % of demand) [5].

In the presence of such RES technologies in the market, the need for reserves to balance supply and demand increases. In addition, the increasing number of DER and consumers may lead to grid congestion issues. However, demand-side management programs have only been implemented at transmission level and applied to large industrial loads in Spain, such as in the so called "interruptibility service". By assuming proper regulatory, economic and technology schemes, it is envisioned that demand-side management will be applied at distribution level as well, following the trend in several European countries. As an illustration of that, specific provisions are included in the Electricity Act [6] and in the Royal Decree 216/2014 [7], which improves the participation of small consumers in system efficiency and demand response. Hence, this pilot is a step ahead towards future Spanish scenarios with contribution of demand-side flexibility at distribution system level.

2 DESCRIPTION OF FUNCTIONALITIES

In order to assess the potential participation of DER connected at distribution level in the provision of ASs, a pilot project is being implemented. The pilot aims to implement balancing services and congestion management for distribution networks through direct bi-directional signals coming from an aggregator. This is pushed further downstream to the activation of back-up batteries to reduce the consumption in selected grid regions of, in this case, the city of Barcelona. The pilot involves six primary substations and 20 radio base stations, which are equipped with back-up batteries, and, thus, can be disconnected from the grid when required.

In this pilot, the "Shared balancing responsibility model" coordination scheme is considered. Under this scheme, the TSO transfers the balancing responsibility of the distribution grid to the DSO. As a result, the DSO must respect a pre-defined schedule at each interconnection point between distribution and transmission networks. Within the pilot, the six primary substations are assumed to be only one interconnection point between the transmission and the distribution networks. The pre-defined schedule is based on the nominations of the Balancing Responsible Parties (BRP), in combination with historical forecasts at each HV/MV interconnection point.

In order to maintain such scheduled exchange profile and to avoid congestions in the distribution grid, the DSO observes the status of the grid in real-time by receiving real-time tele-metered data from remote terminal units (RTUs) located in the relevant primary substations. The scheduled profile at the TSO-DSO connection point has 24-hour horizon with 15-minute resolution. RTU metered data should be refreshed every 1 minute.

The DSO takes a new role, called Local Market Operator (LMO), to fulfil its balancing responsibilities by acquiring the flexibility of local DER. Based on the grid status, the DSO calculates the flexibility requirements and organises a local market, where different aggregators offer their flexibility. Once the market is cleared, aggregators perform direct control over the DERs they manage -–base stations in this pilot– and check their real-time consumption, since DER's real-time performance will be used by the DSO to settle imbalances and to pay for the services after flexibility activation. The DERs participating in the pilot have relatively fast response times so that their ramp-up events are not significant related to the total activation period. In this design, the activation period is 5 minutes, thus consecutive markets are also organized every 5 minutes. Accordingly, 1-minute maximum response time has been set so that aggregators and their associated DERs reach the final value within that time.

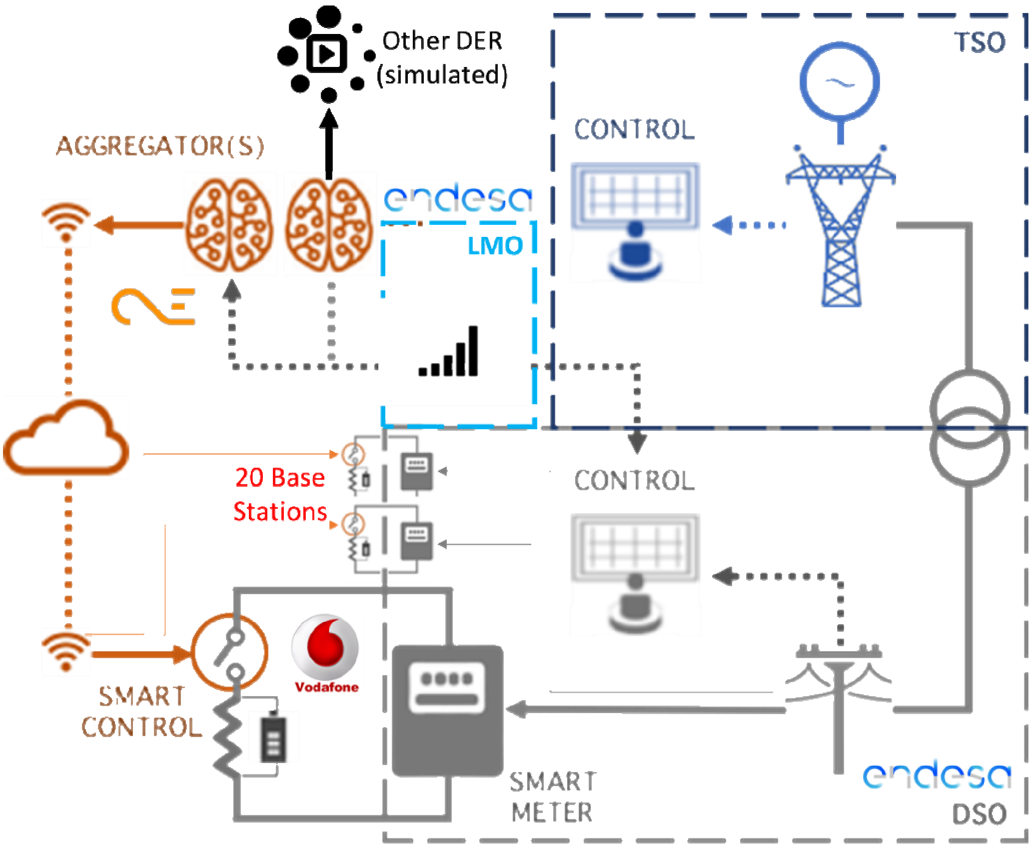

Figure 1. General scheme of the Spanish pilot

As described in Figure 1, the DSO and the LMO in the pilot is Endesa Distribución, the aggregator is ONE and the DER are radio base stations owned by Vodafone, which is also the provider of the connectivity service –on-site kits and the platform for the aggregator to monitor and control remotely the DER flexibility. In order to represent the effect that competition will have in the acceptance of bids by the aggregator of base stations, the bids that other aggregators can present will be simulated and included in the local market clearing process.

3 RESPONSIBILITIES AND ROLES OF PARTICIPANTS

The pilot involves three main participants: the DSO, the aggregator and the DER owner. Each participant has some responsibilities to perform the attributed role, as described below.

The DSO must ensure that the scheduled exchange profile at the TSO-DSO border is respected. For that purpose, it needs to perform several activities:

1. First, the DSO acquires real measured data from the distribution grid and combines them with some simulated data to build the grid model representing the operating conditions before the activation of flexibility (virtual case simulation). Real data are used to represent a situation which is as close as possible to reality, but, since there are very few local congestion problems, some simulated data are needed to represent a likely situation in the future, where the creation of a local market for balancing will be required.

2. Then, the output of the virtual case simulation is compared to the power of the scheduled profile at the TSO-DSO interconnection point to assess existing imbalances and the forecasted status of the grid for the subsequent time steps. The DSO sends this information to the LMO. In parallel, the LMO receives flexibility bids from aggregators.

3. All this information is then used by the LMO to perform an Optimal Power Flow (OPF) calculation, which ensures the fulfilment of all DSO requirements (compliance with the scheduled profile, while avoiding grid congestions). In addition, it also provides the market clearing results, which are communicated to aggregators, so that they can appropriately dispatch the DER units.

Figure 2 shows the DSO's monitoring system, where the baseline load (yellow), the new schedule after clearing the local market (green) and the real-time consumption (red) are depicted.

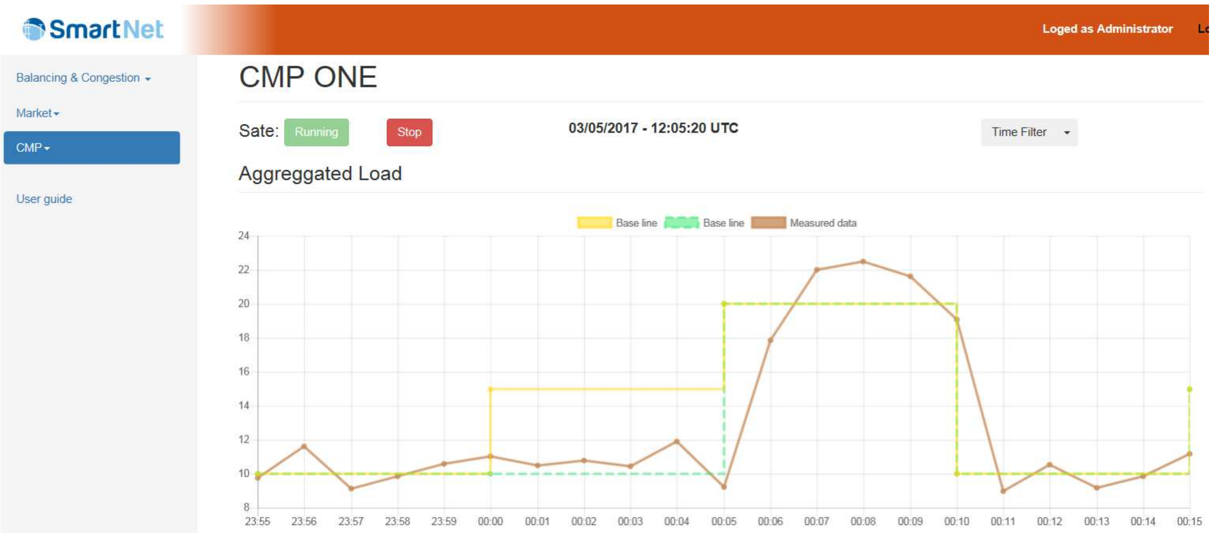

Figure 2. DSO's monitoring system

The aggregator must define the bidding strategy and perform the management and activation of the flexibility available in the batteries of a portfolio of radio base-stations. In order to fulfil these duties, the aggregator needs to communicate, mainly, with DER assets –through Vodafone Energy Data Management (EDM) systems– to acquire real-time status and to manage activations and with the LMO's market platform to submit bids and receive LMO clearing results. In addition, it also gathers real-time information from the wholesale market operator and the system operator to select the most interesting bidding strategy.

For the communications and processes in the Spanish pilot, a centralised middleware model has been selected, so that there is a sole interface towards outside counterparties. These communications and processes are depicted in Figure 3 and described below:

a. The aggregation algorithms are based on the work on battery aggregation models performed in previous phases of the SmartNet project, which yield a foundation for the optimisation of storage units in bidding into SmartNet-alike markets.
b. There is a constant real-time update on the status from the assets (the batteries from radio base-stations). A number of parameters are received from each battery, allowing the aggregator to understand its status and availability for activation.
c. Based on the information from b), opportunities arise to bid upward and/or downward flexibility. This is put into the context of wholesale market prices and grid status to devise an optimised bidding strategy, i.e. to decide to use the flexibility for market arbitrage in the wholesale market or to bid it into the local market.
d. When the bidding strategy is set, a formal bid is sent to the market platform in due format and timing.
e. In case of bid acceptance, a message is received from market platform to generate a given flexibility activation.

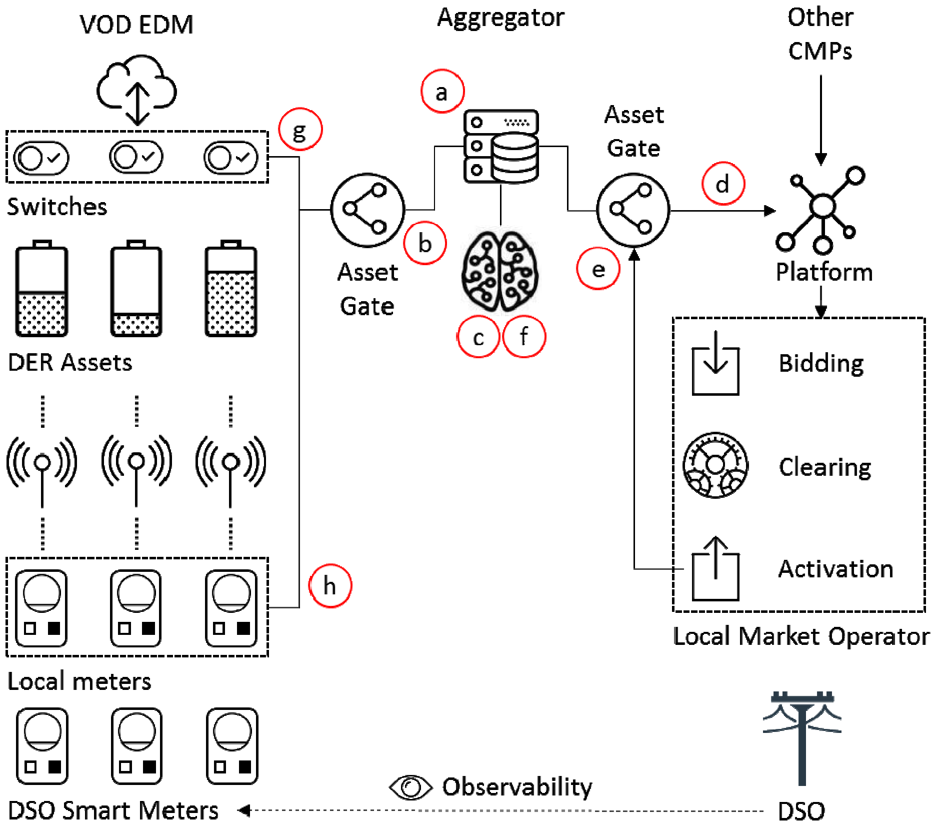

Figure 3. Process Flow from Aggregator's point of view

f. The aggregator, who has received an activation for a given volume, performs the disaggregation of the accepted bid, that is, to assign individual activations to each DER to obtain the successful aggregated behaviour. In this case, the aggregator uses direct control of the batteries, which makes the disaggregation process rather trivial since every bid in process d) represents a cluster of individual activations, thereby rendering the simplest form of disaggregation. In order to avoid issues if any of the batteries that must be activated changes its availability, a risk-neutral cost minimisation approach is taken.
g. Based on the disaggregation process of the successful bids, an activation message is sent to the relevant assets via Vodafone EDM.
h. Thanks to the real-time asset status update described in b), the aggregator has a good observability on the assets and can, thus, verify the activation schedule of each of them.

All these processes are supported through Amazon Web Services through a LAMP (Linux, Apache, MySQL, Python [8]) server, which allows for a fast development and deployment of the functionalities. Figure 4 presents the schematics of the aggregator architecture. The asset gate immediately processes incoming information storing it in the database. From time to time, processes are run in the background to react to new information (be it an activation, a new asset status file, etc). These processes include offline rules to estimate assets' flexibility, an asset merit-order list system (MOLS), a local-market clearing price forecast (based on statistical inference) and, based on them, an optimised bidding strategy and scheduling of flexible loads.

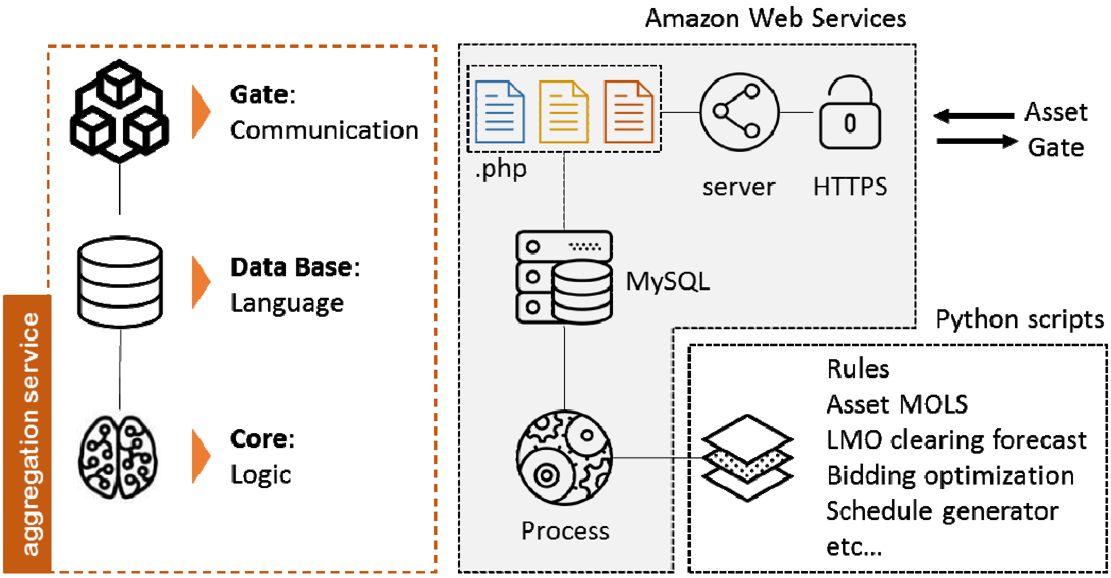

Figure 4. Architecture of the Amazon Web Services used for aggregator's communications

The DER owner must be able to provide the offered flexibility when requested by the aggregator. In this case, the flexibility is obtained from back-up batteries installed in base stations used for mobile phone communications. Base stations consume electricity to ensure the continuity of the communications service and for some ancillary systems (lighting, cooling of the enclosure for communication systems…). The nominal capacity of the battery, which determines the duration of the back-up energy, depends on the relative importance of the radio site. The critical load is the one for communication systems, so some back up batteries are included in the base station to be able to keep supplying such load in case there is a black out in the main grid. Since it is very unlikely that a black out happens, batteries are almost never used and, thus, become an under-utilised asset. In order to extract some economic profit from those batteries, the base station can be disconnected from the grid on purpose to provide grid-support services to the DSO, while guaranteeing the continuity of the communications service thanks to the batteries.

Taking into account that Vodafone has more than 100 000 base stations in Europe, representing an equivalent load of around 400 MW –about 200 MW of which corresponds to the flexible part in this pilot, i.e. to load that could be supplied through electric storage systems–, the success of the pilot and the possibilities to scale it up can be a very important step towards the flexibilization of demand to facilitate the integration of RES in power systems.

However, the pilot cannot affect the quality of supply of the communications service during the execution phase. Therefore, three main limitations are applied to the pilot. First, it is limited to having 20 base stations within the city of Barcelona, where Vodafone has more than 400 base stations. Second, the base stations have been selected to be spread enough, so that, in case one of the is disconnected during the pilot and the batteries cannot supply the required load, neighbouring base stations can take the traffic of the disconnected base station and guarantee the communications service. And third, base stations cannot be disconnected for more than 1 hour and the initial state of charge of the battery must be, at least, 95 % to avoid depleting the battery.

As described above, the aggregator needs real-time data about the consumption in DER. Therefore, it uses an Internet-of-Things (IoT) solution installed in each base station to monitor the status of the batteries and to receive real-time consumption measurements from the base stations. Moreover, the aggregator can also trigger conditional commands to switch the electricity supply of base stations from the grid to batteries.

4 MAIN CHALLENGES FOR SETTING UP THE DEMONSTRATION PROJECT

The project initiated the execution phase in early 2018, but several challenges had to be overcome before the experimentation started.

One of the major challenges faced so far is linked to the metering requirements of the pilot. The market setup defined in the project SmartNet considered a higher resolution –it proposes a market setup with a time-step of 5 minutes– than existing market. Moreover, the monitoring requirements by the DSO in order to dispatch the local market every 5 minutes set the metering resolution even at a shorter time frame, e.g. 1 minute. Therefore, metering requirements are more demanding in SmartNet than what is required today and, thus, existing regulation posed some constraints to the deployment of the pilot.

The first challenge was to deal with the metering requirements of consumption points. Regulation defines five types of categories for consumption points, based on the contracted power. The meters in three biggest ones –those above 50 kW– must be able to take measurements on a 5-minute basis and to communicate with the DSO's control centre, the meters in the smallest one –those up to 15 kW– must be able to take measurements on an hourly basis and to communicate with the DSO's control centre, but the meters for consumption points between 15 kW and 50 kW only need to be able to register the consumption in the three periods defined in the grid access tariff. Some base stations have contracted powers between 15 and 30 kW, so existing meters cannot be used, neither for metering nor for communication. The solution to deal with this problem was to reduce the contracted power of the base stations below 15 kW whenever the electricity consumption profile of the base stations allowed to do so.

However, a second issue, linked to the possibilities to change the contracted power arose. In order to prevent consumers from changing the contracted power to adapt to the usual changes in demand along the year –as the grid capacity, which is designed to meet the annual peak demand, is available throughout the year– the contracted power can only be changed after, at least, 12 months from the latest change. Several base stations were re-dimensioned in 2016, so they could only be downsized after the 12-month period expired in 2017.

Once the base stations were equipped with the regular billing meters, the third challenge appeared. At the moment, billing meters register consumption on an hourly basis –although they can also register shorter time frames– but they only send the data to the DSO on a daily basis. The reason is that, for billing purposes, the DSO only needs to receive data every day and having a more frequent communication period would require much higher communication requirements. Although the DSO can ask for real-time consumption at will, it was discovered that billing meters could not be used to monitor the progress of the pilot in real-time. Therefore, the meters used by Vodafone to monitor the status of the base stations are used as the main source of information for pilot participants. Consequently, Vodafone monitors the real-time consumption of base stations and provides the data to both the aggregator (ONE) and the DSO (Endesa). In any case, the billing meters are used to check ex-post whether the data provided by Vodafone are consistent with the daily measurements by the DSO.

Additional challenges related to the physical implementation relate to the possibilities to use the base stations. Obviously, base stations are facilities used to provide a real commercial service by the DER owner. Therefore, all the activities related to the pilot must take into account the limitations of such commercial service. On the one hand, physical access to the DER sites for operations is not an easy task, because it is a very highly scrutinised live commercial activity and it has strict security rules – base stations are located in residential building blocks, so the transit of people must be minimised to avoid complaints by residents.

Moreover, the existence of multiple proprietary software systems in the 48V controllers created challenges to ensure full interoperability of the Energy Data Management platform and to obtain a smooth communication with the aggregator's platform. On the other hand, all the activities in the pilot must be consistent with the commercial activity of the DER owner and, hence, certain periods of the year (Christmas, big events such as the Mobile World Congress, etc.) cannot be used for testing or on-site operations.

Figure 5. Outdoor and indoor equipment of a base station

5 CONCLUSIONS

Although the pilot has just started its operation and most of the conclusions will be obtained at the end of the experimentation period, there are some very useful experiences for the different participants in the demonstration project.

From the DSO's perspective, it is very important to demonstrate that the new LMO functionality is technically feasible. This way, the DSO will be able to solve congestions in the distribution grid without the need to reconfigure or expand it, while also being able to provide balancing to the TSO if needed.

From the aggregator's point of view, the pilot is very useful to test the flexibility that batteries can provide in real-life operation, as well as to enhance the understanding of the patterns of electric flow congestion in urban areas. As a result, the aggregator can, on the one hand, redefine the mathematical models of the batteries and, on the other, improve the forecasting of the need for grid services. Accordingly, the aggregator will be able to refine and optimise his bidding strategies.

As for the DER owner, the real-life experience of using batteries for providing flexibility results in two main potential benefits. In fact, a single investment –battery cost– can provide two values: security of supply and incomes from provision of grid-support services. Therefore, the DER owner can perform a strategic re-thinking of both the optimal battery size required –and, thus, of the required capacity for base stations– and the battery technology that best fits the new requirements –in terms of number of charge-discharge cycles and/or lifetime.

Additionally, the knowledge and first-hand experience obtained through direct participation in programs such as SmartNet, is of great value in the development of demand response activities for the industrial partners in the project.

6 ACKNOWLEDGEMENTS AND DISCLAIMER

The research leading to this publication has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691405.

7 BIBLIOGRAPHY

[1] Eurostat. "Share of electricity from renewable sources in gross electricity consumption, 2004-2015". Available on-line at: http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Share_of_electricity_from_renewable_sources_in_gross_electricity_consumption,2004-2015_%25_T2_New.png (last accessed: 22 January 2018).

[2] European Commission. "Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal market in electricity". COM(2016) 864 final. Brussels, 30 November 2016.

[3] G. Migliavacca, M. Rossi, H. Gerard, M. Dzamarija, S. Horsmanheimo, C. Madina, I. Kockar, G. Leclerq, M. Marroquin, H. Svendsen, "TSO-DSO coordination and market architectures for an integrated ancillary services acquisition: the view of the SmartNet project". CIGRE Session 2018 Paper C5.306

[4] G. Guida G. Bruno, L. Ortolano, G. Migliavacca, D. Moneta, C. Arrigoni, F. Zanellini, G. Della Croce, M. Baldini, A. Bridi "Smart TSO-DSO interaction schemes and ICT solutions for the integration of ancillary services from distributed generation". CIGRE Session 2018 Paper C5.307

[5] Red Eléctrica de España. “Demanda de energía eléctrica en tiempo real, estructura de generación y emisiones de CO2”. Available on-line at: https://demanda.ree.es/demanda.html (last accessed: 22 January 2018).
[6] Spanish Government, “Ley 24/2013, de 26 de diciembre, del Sector Eléctrico”. State Official Gazette 310, pp.105198-105294. Madrid, 27 December 2013.
[7] Spanish Government, “Real Decreto 216/2014, de 28 de marzo, por el que se establece la metodología de cálculo de los precios voluntarios para el pequeño consumidor de energía eléctrica y su régimen jurídico de contratación”. State Official Gazette 77, pp.27397-27428. Madrid, 29 March 2014.
[8] Wikipedia, “LAMP”. Available on-line at: https://en.wikipedia.org/wiki/LAMP_(software_bundle) (last accessed: 23 January 2018).