Vodafone Base Stations

More than 400 units just in Barcelona

Contracted Power of each one from 5kw to 15kw
Vodafone Base Stations
Flexibility by Storage Capacity

- Back Up Batteries - Base Station of Vodafone
Spanish pilot

DER Owner side. Demand Response Technology over VF Base Stations

Pilot flexible aggregation capacity: around 100 kW
To proof in real field the feasibility of the *Shared balancing responsibility model* of SmartNet project

**Spanish pilot**

**Pilot realisation**

- **Italian Pilot (A)**
- **Danish Pilot (B)**
- **Spanish Pilot (C)**

**Motivation**

**Goal achievements**

- Validation of TSO-DSO interactions
  - (TSO level)
- Balancing
- Congestion management
  - (DSO level)

- Flexibility Aggregation
- Demand Response
  - (Base stations)
- ICT communications

**Layers**

- Market layer
- Physical network layer
- ICT layer
Coordination scheme

Shared balancing responsibility model
Shared balancing responsibility model

Two different markets
- Ancillary Service market for resources connected at TSO-grid
- Local Market for resources connected at DSO-grid

Ancillary services
- Balancing in the interconnection point by respecting schedule profile (on behalf of TSO)
- Congestion management in the distribution grid

How?

By using flexibility from DER owners through Commercial market parties

Coordination scheme
## Roles in the project

<table>
<thead>
<tr>
<th>Role</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission System Operator</td>
<td>Balancing at interconnection level</td>
</tr>
<tr>
<td></td>
<td>Developing the TSO-DSO interaction</td>
</tr>
<tr>
<td>Distribution System Operator</td>
<td>By doing congestion management services for itself at local network</td>
</tr>
<tr>
<td>Commercial Market Party</td>
<td>Virtual nodes emulating other CMP’s (Smarthouses, PV’s, BSs)</td>
</tr>
<tr>
<td>Market operator</td>
<td>Local market operation</td>
</tr>
<tr>
<td>Commercial Market Party</td>
<td>Managing the portfolio of Vodafone radio base stations</td>
</tr>
<tr>
<td>DER owner</td>
<td>Owner of the base stations (flexible resource)</td>
</tr>
<tr>
<td>Consulant</td>
<td>Provider of connectivity services to CMP’s</td>
</tr>
<tr>
<td></td>
<td>DR providers</td>
</tr>
</tbody>
</table>
Pilot C: Setup

Local market
Local market operator: ENDESA DISTRIBUCIÓN

DSO
ENDESA DISTRIBUCIÓN

Balancing & Congestion Management

CMP 1
ONE

DER owner
Vodafone

CMP 2
ENDESA

VIRTUAL CMP

Radio base station 1
Vodafone

Radio base station 2
Vodafone

Radio base station n
Vodafone

RTUs

Tele-management
ENDESA DISTRIBUCIÓN

Scheduled profile (day ahead)
ENDESA DISTRIBUCIÓN
Endesa Distribución will play the market operator role at the local (distribution) level by means of the market clearing algorithm, which at the end is an OPF (Optimal Power Flow).

The OPF solves in the same optimization model 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 optimisation problem, which provides an optimal economical outcome.
Local Market Operator

Main LMO Functionalities

• DSO transfers their needs to solve congestion issues from the d-grid
  - Facilitates flexibility to solve congestion issues from the DSO
  - Local congestion management

• Comercial market participants send their bids and Baselines to the LMO
  - Performs market clearing
  - Market clearing

• DSO transfers their needs to solve congestion issues from the grid
  - Facilitates flexibility for balancing at the TSO-DSO interconnection

• Acquires information from participants and broadcasts market results
  - Balancing at TSO-DSO level

Balancing at TSO-DSO level
Web interface architecture

- **Balancing and Congestion Management**
  - Balancing
  - Network status

- **Market**
  - Market price
  - Flexibility
  - Market results
  - CMP bids

- **CMP**
  - CMP ONE (real)
  - CMP TWO (virtual)
  - CMP V2G (virtual)
    - Aggregated load (per CMP)
Pilot C: Balancing & Congestion Management

Local market
Local market operator: ENDESA DISTRIBUCIÓN

Balancing & Congestion Management

DSO
ENDESA DISTRIBUCIÓN

BCM

DB

Manager

Optimization

Information Process

Active CMP:
ONE last bids: 2018-03-21T15:30:00Z
VCMP01 last bids: 2018-03-21T15:10:00Z

Next calculations at: 2018-03-21T15:14:00Z
Next market at: 2018-03-21T15:15:00Z
Pilot C: BCM - Manager
Pilot C: BCM - Optimization

**BCM**

Manager

Optimization

mongoDB

**Start Optimization**

- **Network**(t-dmc..t) → **Load the network status**
- **Sch.Prof.(MC)** → **Evaluate consumption with Sch.Prof. (TSO-DSO)**
- **Sch.Prof.(MC–dmc)** → **Optimal Power Flow + Market Clearing**
- **Bids**(t) → **Send dispatch orders**
- **Baseline**(t)
- **marketresults**(t)
- **marketresults**(t)

MC = Market Clearing Time

dmc = 5 min

**Messages**

**Connections to DB**

MC = Market Clearing Time
dmc = 5 min

**Messages**

**Connections to DB**
Pilot C: BCM - Opt. – OPF + MarketClearing

\[
\min \sum_{g \in G} \sum_{k \in K_g} lb_{gk}^+ P_{gk}^+ + \sum_{k \in K_{G_0}} lb_{0k}^- P_{0k}^- + \sum_{(i,j) \in \mathcal{L}} C_{ij}
\]

s.t.
- Power Flow technical constraints
- Balancing constraints
- Congestion constraints
- Market Clearing constraints
Pilot C: BCM - Opt. – OPF + MarketClearing

Balancing

- $P_{0k}^+ > 0 \ \exists k \in K_{G_0}$
- $P_{0k}^- > 0 \ \exists k \in K_{G_0}$

Demand surplus

Insufficient generation

Congestion

- $C_{ij} > 0 \ \exists (i, j)$

Congestion in line $(i, j)$

Market Clearing

- $k : \begin{cases} \ell b_{gk}^+ = 1 \\ \ell b_{gk+1}^+ = 0 \end{cases}$

Price bid block $k \in K_g$ for generator $g$
Balancing

- Time plot of active power exchanged at TSO-DSO interconnection points
  - Scheduled profile (MW)
  - Actual active power measured data (MW)
  - 1 plot per each TSO-DSO interconnection point in Pilot C
  - Adjustable time filter (window)
Network status

- Diagram of the distribution network downstream each TSO-DSO interconnection point
  - Voltage levels per node
  - Branch loadings (lines/cables, transformers)
  - Actual delivery of flexibility resources of the Pilot C (VODAFONE and virtual)
  - Updated every 1 minute
Market price

- Time plot of the clearing price per market session at each TSO-DSO interconnection point (cent/kWh)
  - 1 plot per each TSO-DSO interconnection point in Pilot C
  - Adjustable time filter (window)
Flexibility & Market results (dispatching)

- Flexibility:
  - Time plot of **total flexibility volumes** per market session at each TSO-DSO interconnection point (kW)
    - Dispatched flexibility
    - Available flexibility volumes
    - Time window with few recent market sessions

- Market results (dispatching):
  - Table of **dispatched flexibility volumes per CMP** per market session and node at each TSO-DSO interconnection point (kW)
Table of submitted flexibility bids per CMP per market session and node at each TSO-DSO interconnection point

- Curtailable/non-curtailable bid blocks
- Real/virtual CMP

<table>
<thead>
<tr>
<th>CMP</th>
<th>Market time</th>
<th>Curtailable</th>
<th>Node</th>
<th>Price (€/kWh)</th>
<th>P (kW)</th>
<th>Virtual</th>
</tr>
</thead>
<tbody>
<tr>
<td>ONE</td>
<td>2017-02-13T23:55:00Z</td>
<td>no</td>
<td>6</td>
<td>0.32</td>
<td>2.5</td>
<td>No</td>
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<tr>
<td>TWO</td>
<td>2017-02-13T23:55:00Z</td>
<td>no</td>
<td>10</td>
<td>0.28</td>
<td>7.5</td>
<td>Yes</td>
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<tr>
<td>V2G</td>
<td>2017-02-13T23:55:00Z</td>
<td>yes</td>
<td>7</td>
<td>0.28</td>
<td>50</td>
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<td>ONE</td>
<td>2017-02-14T00:00:00Z</td>
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<td>6</td>
<td>0.32</td>
<td>2.5</td>
<td>No</td>
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<tr>
<td>TWO</td>
<td>2017-02-14T00:00:00Z</td>
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</tr>
<tr>
<td>V2G</td>
<td>2017-02-14T00:00:00Z</td>
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<tr>
<td>V2G</td>
<td>2017-02-14T00:00:00Z</td>
<td>yes</td>
<td>7</td>
<td>0.28</td>
<td>-10</td>
<td>Yes</td>
</tr>
</tbody>
</table>
CMPs (aggregated load)

- Time plot of aggregated load of customers’ portfolio of each CMP
  - Baseline (yellow)
  - Dispatched power, i.e. (baseline + dispatched flexibility) (green)
  - Delivered (measured) power (brown)
Consumption = Baseline (network consumption)

Consumo 0 → Battery consumption
Pilot C: Virtual CMP

Information Process Send virtual measurements 21-Mar-18 15:11:00 time now 21-Mar-18 15:11:00 processing message...
VCMP01 Information Process Loaded VCMP01_info.xml
Information Process next measurements time at 2018-03-21T15:12:00Z
Information Process

Available VCMPs

Next virtual measures will be send at: 2018-03-21T15:12:00Z
Progress so far

Local market
Local market operator: ENDESA DISTRIBUCIÓN

DSO
ENDESA DISTRIBUCIÓN

Scheduled profile (day ahead)
ENDESA DISTRIBUCIÓN

Balancing & Congestion Management

CMP 1
ONE

DER owner
Vodafone

CMP 2
ENDESA

VIRTUAL CMP

Radio base station 1
Vodafone

Radio base station 2
Vodafone

Radio base station n
Vodafone

Real time power measurements on 10 Bss

Power measurements at the head of each feeder

RTUs

Tele-management
ENDESA DISTRIBUCIÓN
Progress so far

- **Local market**
  - Local market operator: ENDESA DISTRIBUCIÓN

- **DSO**
  - ENDESA DISTRIBUCIÓN

- **CMP 1**
  - ONE

- **CMP 2**
  - ENDESA

- **DER owner**
  - Vodafone

- **Communications between ONE and ENDESA working. Dispatch orders working**

- **Radio base station 1**
  - Vodafone

- **Radio base station 2**
  - Vodafone

- **Radio base station n**
  - Vodafone

- **RTUs**

- **Tele-management**
  - ENDESA DISTRIBUCIÓN

- **Scheduled profile reception OK**

- **Scheduled profile (day ahead)**
  - ENDESA DISTRIBUCIÓN

- **Virtual CMP**
Progress so far

Local market
Local market operator: ENDESA DISTRIBUCIÓN

DSO
ENDESA DISTRIBUCIÓN

Scheduled profile (day ahead)
ENDESA DISTRIBUCIÓN

OPF + Market clearing working for Tanger substation

CMP 1
ONE

DER owner
Vodafone

Virtual CMP working. Preprogramed flexibility and prices.

CMP 2
ENDESA

VIRTUAL CMP

Radio base station 1
Vodafone

Radio base station 2
Vodafone

Radio base station n
Vodafone

Tele-management
ENDESA DISTRIBUCIÓN

RTUs
What has been done from the aggregation part

**General WP5 tasks:**
- AWS Server Maintenance
  - Memory increase
  - Execution time optimization
  - Latest Linux update
- Automatic clean up routines
- Database optimization
- Integration of market APIs
- Integration of REST server

**Pilot Specific:**
- Update communication scripts
- Re-work scripts’ to adapt to align with updated Pilot considerations
- Introduction of dynamic bidding strategy
- Script optimization
- Resolution of communication issues
Status

- VOD EDM
- Aggregator
- Asset Gate
- Other CMPs
- Platform
- Bidding
- Clearing
- Activation
- Local Market Operator
- Observability
- DSO
Status – Day Ahead  June 15th 2018

![Graph showing energy prices and forecasts for the day ahead.](image-url)
Status – Real Time  June 15th 2018

The chart shows the price of energy in €/MWh over time from H7 to H20. The data includes Day-Ahead, Intraday, Forecast, and Real price information.
Status – Real Time  
June 15th 2018
Pilot C - Physical Layer
Vodafone BTS transformation into DER plants.

- **Curtailment principle**: Integrate the remote battery test functionality to pilot the radio equipment switch to back up batteries on demand.

- **Scenario**: 20 Radio Base stations equipped with
  - 48V controller SW: 2 brands – Eltek and Huawei
  - SNMP connection
  - Mobile Link 4G modem+ Moxa gateway
  - 4x12 V 100amph VRLA Batteries
  - 1 smart meter with 1mn slot readings
Test preparation – 12 months on a bumpy road....

Sensitive context to manage operation in 20 different locations

1. **Live business**: BTS’s are delivering service to the public - > 0 impact rule
2. **Private location**: The BTS’s are located on commercial or private premises - > logistic required for non permanent access authorization– e.g 6 months to get access for 48V cabin swap with cranes
3. **DER internal Quality of Sce**: Vodafone Network is submitted to freezing period for quality management - Regulator audits, Christmas period, etc … - > no site access at all during 2 periods of 4 weeks within the last 6 months
4. **SW stability**: 48V controller software releases and unequal performances requiring unexpected manufacturers deep dive and solving patches delivery
5. **DER resource reliability**: Batteries back up requirement to be adjusted with pilot rules (95%) and obsolescence triggering physical change requests and potentially technology evolution from VRLA to Lithium batt. To follow-up
6. **Monitoring continuity**: Monitoring systems cabling sensitive requiring maintenance personal training and clear verification process.
Field test: 80 to 95% operational

Feb 2018

Jun 2018: 90 to 100 Kw curtailable
Next: flexibility usage for the DER

As many telecoms 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.

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.

SmartNet benefits demonstration allowing a regulation change in the next years will help unlock the value of Vodafone small infrastructure power assets while contributing to the social welfare of European citizens.