Real proven solutions to enable active demand and distributed generation flexible integration, through a fully controllable Low Voltage and medium voltage distribution grid

WP4 - Demonstration in real user environment: EDPD - Portugal

Evaluation of Demonstration Results and Data Collection

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EXECUTIVE SUMMARY

The Portuguese demonstrator of the UPGRID project targeted all the clusters of the European Technology Innovation Platform Smart Networks for Energy Transition - ETIP SNET – Roadmap. Having developed functionalities that respond to present Distribution System Operators (DSOs) challenges arising from the new roles that DSOs must play in the future energy system, the UPGRID Portuguese demo was built to add field experience on topics like Flexibility, Data Management and Market Facilitation, as depicted in Figure 1. Having as a building block the evolving smart grid infrastructure that is being deployed, this new level of integration allows the DSO the ambition to collect and manage data, which will ultimately benefit the consumer, by an improved grid flexibility, which can establish a stronger link between renewable generation and consumption, considering all the electricity value chain market actors.

![Portuguese Demo Framework](image)

**FIGURE 1: PORTUGUESE DEMO FRAMEWORK**

The Portuguese demo has benefited from the developments made by several partners of the project, namely EDP Distribuição (demo coordinator), INESC TEC, NOS and WithUS, which together formed the Portuguese demonstrator partners. These partners brought a set of competences and knowledge that was combined to enhance all areas under demonstration, contributing to significant beyond state of the art results under UPGRID.

**EDP Distribuição** (EDPD) as the demo leader, together with its 3rd parties EDP Inovação and Labelec, has prepared the demonstration area and assembled the enabling infrastructure that allowed the implementation and testing of several functionalities and developments of the UPGRID project, such as:
Centralised Low Voltage Grid Operation & Control tool – UPGGRID Control (UGC);
- TelCo component - Sinapse;
- UPGGRID Mobility tool;
- Advanced Metering Infrastructure (AMI) integration;
- Street Light Flexibility Management;
- Planning tool for LV grid with Distributed Energy Resources (DPLAN UPGGRID);
- Consumption profiling;
- Energy losses and dynamic tariffs evaluation studies;
- In-line power regulator for LV advanced operation;
- Automatic Feeder Mapping (AFM);
- Smart grid infrastructure and power quality monitoring dashboards;

INESC TEC was responsible for the conception, development and testing of several demo components, giving their contributions in laboratory testing of several functionalities, as well as validation under real site operation, where components like State Estimation, Market Hub Platform (MHP) and Forecasting were integrated in the demo ecosystem allowing to obtain impactful results in the demo.

WithUS, brought innovative solutions for the energy management at the customer’s premises – Home Energy Management System (HEMS), as well as the development of the retailers’ platform, which functioned as the interface between the HEMS and the Market Hub Platform, allowing to demonstrate end to end solutions to integrate Demand Response (DR) in EDPD grid operation tools.

NOS, acting as a telecommunication operator, has enabled the development of innovative communication technologies, such as Narrow Band Internet of Things (NB IoT), interfaces and monitoring tools for the smart grid infrastructure, facilitating new channels for Smart Grid information management, and increasingly sharing relevant information between companies, to improve both the telecom and the electric grid operations.

The Portuguese demonstrator was implemented in an urban area of Lisbon with over 20.000 consumers – Parque das Nações – and allowed EDP Distribuição to integrate several functionalities, which, on one hand enhanced the DSO grid operation, and on the other hand brought a positive impact on the social
and economic aspects of this part of Lisbon. This environment allowed for developing, implementing and validating advanced tools and prototypes, spanning the 5 clusters of the Portuguese demo framework.

The UPGRID Portuguese demo main results and innovative solutions are highlighted below:

Cluster 1: Integration of Smart Customers

- First ever end-to-end Demand Side Management (DSM) operation integrating over 50 residential consumers;
- Incorporation of consumers’ flexibility in DSO operation through HEMS;
- Over 5,000 customer’s consumption information enabled with a web portal;

Cluster 2: Integration of DER and new uses

- Pioneering integration of public lighting as a flexible distributed energy resource;
- In depth evaluation of EV public charging stations consumption profiles;
- Demonstration of LV connected Distributed Energy Resources (DER) in grid operation;
Cluster 3: Network operations

- Ground-breaking integrated LV grid management prototype “UPGRID Control”;
- Disruptive NB-IoT communication technology implemented in smart meters (SMs);
- Innovative automatic voltage control prototype deployed;

FIGURE 4: PUBLIC LIGHTING SOLUTION

FIGURE 5: UPGRID CONTROL
Cluster 4: Network planning and asset management

- LV Power Flow prototype “DPLAN UPGRID” integrating forecasts and SM data;
- Advanced mobility prototype to support field teams “UPGRID MOBILITY”;
- Automatic feeder mapping prototype based on smart grid assets;

Cluster 5: Market design

- Development and operation of a market hub platform connecting DSO and consumers through market agents;
- Implementation of a Retailers Platform to manage consumers HEMS;
- Integration of LV consumers’ consumption data in grid congestion analysis for dynamic tariff construction;

FIGURE 6: UPGRID MOBILITY SOLUTION
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# ABBREVIATIONS AND ACRONYMS

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<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFM</td>
<td>Automatic Feeder Mapping</td>
</tr>
<tr>
<td>AMI</td>
<td>Advanced Metering Infrastructure</td>
</tr>
<tr>
<td>API</td>
<td>Application Programming Interface</td>
</tr>
<tr>
<td>BaU</td>
<td>Business as Usual</td>
</tr>
<tr>
<td>CSS</td>
<td>Customer Secondary Substation</td>
</tr>
<tr>
<td>DER</td>
<td>Distributed Energy Resources</td>
</tr>
<tr>
<td>DR</td>
<td>Demand Response</td>
</tr>
<tr>
<td>DSM</td>
<td>Demand Side Management</td>
</tr>
<tr>
<td>DSO</td>
<td>Distribution System Operator</td>
</tr>
<tr>
<td>DSS</td>
<td>Distribution Secondary Substation</td>
</tr>
<tr>
<td>DTC</td>
<td>Distribution Transformer Controller</td>
</tr>
<tr>
<td>EAC</td>
<td>Economic Activity Code</td>
</tr>
<tr>
<td>EDPD</td>
<td>EDP Distribuição</td>
</tr>
<tr>
<td>EV</td>
<td>Electrical Vehicle</td>
</tr>
<tr>
<td>FW</td>
<td>Firmware</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>HAN</td>
<td>Home Area Network</td>
</tr>
<tr>
<td>HEMS</td>
<td>Home Energy Management System</td>
</tr>
<tr>
<td>ICMP</td>
<td>Internet Control Message Protocol</td>
</tr>
<tr>
<td>ICT</td>
<td>Information Communication Technologies</td>
</tr>
<tr>
<td>IMSI</td>
<td>International Mobile Subscriber Identity</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
</tr>
<tr>
<td>LV</td>
<td>Low Voltage</td>
</tr>
<tr>
<td>M2M</td>
<td>Machine to Machine</td>
</tr>
<tr>
<td>MNO</td>
<td>Mobile Network Operator</td>
</tr>
<tr>
<td>MV</td>
<td>Medium Voltage</td>
</tr>
<tr>
<td>NB-IoT</td>
<td>Narrow Band – Internet of Things</td>
</tr>
<tr>
<td>NMS</td>
<td>Network Management System</td>
</tr>
<tr>
<td>OMS</td>
<td>Outage Management System</td>
</tr>
<tr>
<td>OSS</td>
<td>Operation Support Systems</td>
</tr>
<tr>
<td>PF</td>
<td>Power Flow</td>
</tr>
<tr>
<td>PI</td>
<td>Public Illumination</td>
</tr>
<tr>
<td>PS</td>
<td>Primary Substation</td>
</tr>
<tr>
<td>RP</td>
<td>Retailer’s Platform</td>
</tr>
<tr>
<td>RTU</td>
<td>Remote Terminal Unit</td>
</tr>
<tr>
<td>SDP</td>
<td>Service Delivery Point</td>
</tr>
<tr>
<td>SEP</td>
<td>Special Energy Producers</td>
</tr>
<tr>
<td>-------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>SLV</td>
<td>Special Low Voltage</td>
</tr>
<tr>
<td>SM</td>
<td>Smart Meter</td>
</tr>
<tr>
<td>SNMP</td>
<td>Simple Network Management Protocol</td>
</tr>
<tr>
<td>SS</td>
<td>Secondary Substation</td>
</tr>
<tr>
<td>UDM</td>
<td>Unified Data Model</td>
</tr>
<tr>
<td>UGC</td>
<td>UPGRID Control</td>
</tr>
<tr>
<td>WAN</td>
<td>Wide Area Network</td>
</tr>
<tr>
<td>WFM</td>
<td>Work Force Management</td>
</tr>
<tr>
<td>WP</td>
<td>Work Package</td>
</tr>
<tr>
<td>WS</td>
<td>Web Service</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

1.1 SCOPE OF THE DOCUMENT

Following “Guidelines for Field Testing” - Deliverable 4.2 [1], this document, entitled as “Evaluation of Demonstration Results and Data Collection” aims at presenting the results of the functionalities developed and validated in the Portuguese demonstrator as well as to evaluate its impact for the stakeholders involved, namely the DSO and its customers. This deliverable is therefore the aggregation of the technical and social learnings which are the result of the work developed, from the functionalities specification until its testing and benefit analysis.

1.2 STRUCTURE OF THE DOCUMENT

The present document is composed by four main sections:

1. Introduction – it aims at giving a short overview on the scope of the document and the structure of the document.

2. Deployment of Portuguese Demonstrator – in the first part, this section presents a summarised review about the deployment of the Portuguese demonstrator, namely about its enabling market and DSO infrastructure. In the second part of this section the reader is presented with the reference architecture.

3. Section three presents the results of all the tests performed in Portugal. This section goes through the succinct description of each functionality objectives, the description of the used test bed (systems, networks, consumers, etc...), the presentation of the tests performed and data collected and finalizes with the results' analysis and main conclusions for each functionality.

4. Section four wraps up the Portuguese demonstrator with the main conclusions of the work performed from the beginning of the demonstration stage.
2. DEPLOYMENT OF PORTUGUESE DEMONSTRATOR

This chapter introduces the demonstration phase, considering the suggested approach on D4.2 [1] (same structure with different specificities to each functionality).

The different functionalities required a different number of tests and complexity, due to the involved systems, actors and collection of needed information. The tests were performed with the aim of collecting the required information to calculate the demonstrator/project Key Performance Indicators (KPIs) to have measurable conclusions.

2.1 MARKET & DSO INFRASTRUCTURE

In the last years, the energy sector has changed considerably, being the distribution sector one of the most affected. Although not involved in the management of the distribution networks, the energy consumers are nowadays asked and incentivised to play a more active role on it.

The UPGRID Portuguese demonstrator aimed at presenting the end-users as crucial stakeholders in the operation and management of the LV networks. With that in mind, several sub-functionalities and components were designed to leverage their participation and operational value.

FIGURE 7: HEMS FRAMEWORK EXPOSED IN A COMMUNITY DISSEMINATION EVENT
In addition to the engagement and awareness creation, strategies to address energy efficiency, decarbonisation and costs reduction was put in place, to empower the consumers. This could only be achieved through the development of an adequate Information and Communications Technology (ICT) infrastructure at the residential level, allowing the integration with the DSO infrastructure and the exchange of information between the two parties. The framework of interaction between market domain and distribution grid is depicted in Figure 8.

![Figure 8: Market Hub Platform and Interconnected Stakeholders](image)

With that in mind and through the strategy described in D4.2, 55 residential energy consumers had a direct participation in the demonstrator, through the installation of HEMS at their premises.

The installation of the HEMS (Gateways and Smart plugs), more than getting these consumers to be more familiarized with new Home Automation solutions, allowed them to better perceive its energy consumption patterns. The most ambitious goal of enabling this group of consumers with HEMS was to allow the exploitation of the energy consumption flexibility of each one of them. By understanding the criticality of the operation of each electrical load (operation period and cost), these group of consumers could define flexibility periods for the loads connected to the smart plugs, allowing the participation and testing of Demand Side Management schemes developed by the DSO.

The reference architecture of the Portuguese demonstrator, including both EDPD corporate systems of support and those developed on the scope of the project is depicted in Figure 9. For a detailed explanation of the architecture, please refer to D4.2 [1].

### 2.2 Demonstrator Reference Architecture
FIGURE 9: PORTUGUESE DEMONSTRATOR REFERENCE ARCHITECTURE
3. EVALUATION OF FIELD TESTS’ RESULTS

This section describes the results and developments made in the UPGRID Portuguese demonstrator. As explained before, given the high number of functionalities tested, the utilisation of assets/area/number of customers in the demonstrator was adjusted to the needs and objectives of the test to be performed to a specific tool or functionality.

3.1 INTEGRATION OF SMART CUSTOMERS

One of UPGRID’s primary goals is to promote the participation of LV customers and improve their ability to monitor and control their own energy consumption. In the past, due to technical limitations, similar functionalities to these were solely available to the DSO. With UPGRID, a further step is given towards the wider availability of these tools to the customers.

3.1.1 END USER ENGAGEMENT TO IMPROVE NETWORK OPERATION

3.1.1.1 TEST OBJECTIVES

The testing of this functionality aims to prove that it is possible to resort on consumers’ consumption flexibility and consumers’ engagement in DR strategies to manage the LV network operation during periods of constrain. More information can be found in section 2.3.1 of deliverable D4.2.

To test this functionality, we relied on the ICT infrastructure that was deployed on the field to perform data collection and DR. The overall system architecture is presented below.

FIGURE 10: SYSTEM ARCHITECTURE – DEMAND RESPONSE SCHEME TO MANAGE LV NETWORK CONSTRAINTS
The Retailer’s Platform (RP) consists of a web application that communicates with HEMS gateways to collect metering information as well as to provide DR features as described in section 2.3.1 of deliverable D4.2. Data collection and actuation is ultimately performed by smart devices located within communication range of the gateway.

Upon the completion of both the first version of the cloud and HEMS, the physical installation of devices began on the houses of 55 demonstrator participants.

The web application provides a user interface with the following features:

- Energy consumed over time as read from the smart meter
- Peak power in 1 hour intervals as read from the smart metering
- Current power consumption as read from the smart meter
- Instantaneous power measured by the smart devices attached to circuits
- Energy consumed over time by each circuit, as measured by the smart plugs
- Peak power in 1 hour intervals on each circuit as measured by the smart plugs
- Configuration to assign names and rated power to circuits
- Configuration to assign flexibility periods on a weekly schedule
Each user registered on the RP is assigned a Service Delivery Point (SDP), which uniquely identifies him. The SDP is used by upstream systems to trigger DR action as defined in the use cases described in deliverable D2.2 [2].
3.1.1.2 TEST BED AND CONFIGURATION

As described in Deliverable D4.2 [1], this test intended to demonstrate the integration of DR customer requests and the consequent power consumption reduction for LV network operation when dealing with LV network constraints.

3.1.1.3 PERFORMED TESTS AND COLLECTED DATA

The following tables describe the several tests performed to analyse this functionality under different network operation scenarios and different consumer engagement scenarios.

**TABLE 1: SET DEMAND RESPONSE REQUESTS FOR HEMS CLIENTS**

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV Grid A with constrains associated to high demand</td>
<td>Set Demand Response requests for customers in impact area, in order to stabilize grid operation</td>
</tr>
</tbody>
</table>

**Actions**

<table>
<thead>
<tr>
<th>Begin</th>
<th>End</th>
<th>Power [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:14</td>
<td>12:30</td>
<td>12</td>
</tr>
<tr>
<td>12:31</td>
<td>12:35</td>
<td>20</td>
</tr>
<tr>
<td>12:45</td>
<td>12:55</td>
<td>70</td>
</tr>
<tr>
<td>12:56</td>
<td>13:05</td>
<td>2,000</td>
</tr>
<tr>
<td>13:15</td>
<td>13:45</td>
<td>4,000</td>
</tr>
<tr>
<td>14:00</td>
<td>14:28</td>
<td>2,500</td>
</tr>
<tr>
<td>14:31</td>
<td>14:57</td>
<td>150</td>
</tr>
</tbody>
</table>

**Results**

In the tests conducted seven clients were selected to reduce and increase their consumption and five abide the order. Take for example, the period between 12:00 and 12:30. The feeder load reduced from 4,03 kW to 3,31 kW due to the actuation in the clients load for that period. Through Figure 12, it is possible to observe that the actuation in the load of the HEMS clients to reduce their consumption is reflected in the secondary substation (SS) total power.
FIGURE 12: LOAD PROFILE FOR HEMS AND SS

The picture below presents the load diagram of one of the house circuits for one of the clients that have participated in this test. It is possible to observe that the flexibility requests sent had an impact in the circuit diagram.

FIGURE 13: LOAD DIAGRAM FOR THE HEATING SYSTEM CIRCUIT

As an example, for the period between 12:00 and 12:45 it is possible to observe the actuation in the load of the client in the heating System circuit through the figure below.
3.1.1.4 EVALUATION OF RESULTS

The tests were a success, since it was possible for the DSO to control the customers’ load during periods of LV network constraints, through the HEMS installed in 50 customers’ premises. The results obtained validated the reference architecture and the agents involved (MHP, HEMS, RP and DSO). It was possible to verify the use of the customer’s pre-defined flexibility. The activation of the customer’s flexibility reduced the power consumption of a given consumer by 18%.

The use of the demand flexibility as a resource for the DSO, can have great operational benefits such as reduced peak demands or mitigate overloads, consequently improving the network efficiency and potentially avoiding outages.

3.1.2 CALCULATION OF NON-TECHNICAL LOSSES

3.1.2.1 TEST OBJECTIVES

To leverage the data available from the UPGRID Portuguese demonstrator, the non-technical losses for the Parque das Nações township were assessed.

The development of this functionality is an important step to gaining insight into the value of increased data consumption information through the energy distribution value chain. This enables the DSO to create a reference of the evolution of calculating and estimating the losses.

The increased data availability adds more accuracy into the calculations, seeing as less estimation is needed, which leads to a better insight to the global losses. It is important to refer that with less data available, the best resource is the usage of estimated data which inherently adds a higher error to the
calculations. Data availability is a work in progress, but great gains have been observed recently and this demo is creating a path to a more connected and information based grid.

This study calculated the global losses (i.e., the global effect of technical and non-technical losses) from both Medium Voltage (MV) and Low Voltage (LV) grid of Parque das Nações. The visibility of the LV grid is a challenging task, with the increased amount of data, associated with a lower reliability on the grid configuration and how the end points are currently being fed. These challenges affected how the study was conducted, and will be explained with more detail in the section below.

### 3.1.2.2 TEST BED AND CONFIGURATION

The key systems used for the calculation of the losses in the Parque das Nações township were:

- **The Unified Data Model (UDM);**
- **Grid Infrastructure:** Primary Substation (PS), Distribution Secondary Substation (DSS), Customer Secondary Substation (CSS); Special Energy Producers - SEP Medium Voltage – MV, Special Low Voltage – SLV, Low Voltage – LV, Public Illumination PI).
- **InovGrid infrastructure (Sysgrid):** Main system for collecting the LV consumption data from the Distribution Transformer Controller (DTC) (Aggregator of Smart meter data).
- **DPLAN Upgrid:** Grid planning tool that allows for an accurate calculation of the normal power flows quantifying the technical losses for localized grids. On the framework of UPGRID project, a new module was developed in this tool.

For the calculations performed:

The system global losses are calculated from the injected energy ($E_i$) and the consumed energy ($E_c$) from the voltage level in study:

$$
\text{Losses}(t) = \sum_{t=0}^{n} E_i(t) - E_c(t)
$$

(1)

The value of the losses in percentage can be calculated from the ratio between the global losses and the total consumption ($E_T$):

$$
\text{Losses} \% = \left( \frac{\text{Losses (GWh)}}{E_T} \right) \times 100
$$

(2)

### 3.1.2.3 PERFORMED TESTS AND COLLECTED DATA

The following tables describe the analysis performed for the MV network and for the LV network.

The study comes from the best practices in place at EDPD and as an exploration of the increased detail that is possible to obtain from the increased data availability allowing for a more detailed calculation of the energy transited through the distribution secondary substation.
Observations

Calculate the global losses in the MV grid, considering the grid topology and the state of grid exploration in place.

For the northern PS, there was missing data in the load diagram for a universe of 27 SS, for the month in analysis which leads to more uncertainty inherent to the process of using estimated data. There is also a MV special producer, with cogeneration, connected to the northern PS which adds another component to be considered in the energy transits.

Results for the northern PS

<table>
<thead>
<tr>
<th>PS EXPO NORTE</th>
<th>Quantity (#)</th>
<th>Energy (kWh)</th>
<th>Estimated component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entered Energy</td>
<td>2</td>
<td>10.181.910</td>
<td>0,0%</td>
</tr>
<tr>
<td>PS</td>
<td>1</td>
<td>9.287.180</td>
<td>0,0%</td>
</tr>
<tr>
<td>PRE MV</td>
<td>1</td>
<td>894.730</td>
<td>0,0%</td>
</tr>
<tr>
<td>Exiting Energy</td>
<td>151</td>
<td>9.657.208</td>
<td>8,0%</td>
</tr>
<tr>
<td>PTD(^1)</td>
<td>101</td>
<td>5.281.622</td>
<td>14,6%</td>
</tr>
</tbody>
</table>

\(^1\) 27 PTD’s with estimated data
WP4 – DEMONSTRATION IN REAL USER ENVIRONMENT: EDPD - PORTUGAL
D4.3 EVALUATION OF DEMONSTRATION RESULTS AND DATA COLLECTION

<table>
<thead>
<tr>
<th></th>
<th>Quantity (#)</th>
<th>Energy (kWh)</th>
<th>Estimated component</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTC</td>
<td>50</td>
<td>4.375.586</td>
<td>0,0%</td>
</tr>
<tr>
<td>Losses</td>
<td></td>
<td>524.702</td>
<td></td>
</tr>
<tr>
<td>% Losses</td>
<td></td>
<td>5,43%</td>
<td></td>
</tr>
</tbody>
</table>

Energy curve

FIGURE 16: ENERGY CURVE FOR THE MONTH UNDER ANALYSIS

<table>
<thead>
<tr>
<th></th>
<th>Quantity (#)</th>
<th>Energy (kWh)</th>
<th>Estimated component</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS EXPO SUL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entered Energy</td>
<td>1</td>
<td>11.818.005</td>
<td>0,0%</td>
</tr>
<tr>
<td>PS</td>
<td>1</td>
<td>11.818.005</td>
<td>0,0%</td>
</tr>
<tr>
<td>SEP MV</td>
<td>0</td>
<td>0</td>
<td>0,0%</td>
</tr>
<tr>
<td>Exited Energy</td>
<td>133</td>
<td>11.590.563</td>
<td>1,2%</td>
</tr>
<tr>
<td>DSS²</td>
<td>89</td>
<td>5.925.369</td>
<td>2,3%</td>
</tr>
</tbody>
</table>

² 4 DSS’s with estimated data
<table>
<thead>
<tr>
<th>CSS</th>
<th>44</th>
<th>5,665,194</th>
<th>0,0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losses</td>
<td>227,442</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Losses</td>
<td>1,96%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 17: ENERGY CURVE IN THE PS SUL FOR THE MONTH UNDER ANALYSIS**
TABLE 3: LOW VOLTAGE GRID LOSSES

<table>
<thead>
<tr>
<th>Losses from the secondary substations to the end consumers</th>
</tr>
</thead>
</table>

LV grid under analysis

FIGURE 18: LV GRID ANALYSED

Objectives

The set of installations in the LV grid (including adjacent areas to the demo site), used to assess correctly the energy consumed in the LV installations, are as follows:

<table>
<thead>
<tr>
<th>DSS</th>
<th>LV</th>
<th>SLV</th>
<th>PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>190</td>
<td>21532</td>
<td>476</td>
<td>236</td>
</tr>
</tbody>
</table>

For this study, 3 different trimesters of the year were considered. Along time, there was an increase of available data which is directly translated with the addition of more DSS’s to the pool under analysis, as shown in the figure bellow. Another gain from using more DSSs and the associated installations is a mitigating effect of the errors in installation mapping. As such, having a more robust and complete portfolio of information for the LV grid allowed the calculation of the energy transits with better accuracy.
3.1.2.4 EVALUATION OF RESULTS

The evaluation performed at the MV level shows that:

- The necessary data for calculating the losses at the MV level of the PS is increasing in availability, which enlarges the set of data feeding the study. From just few meters in the beginning of the project moving to tens of thousands of meters, supplying quarterly-hour readings.

The evaluation performed at the LV level shows that:

- Enhanced by the project demonstrator, the amount of data available for this study in the LV level has increased substantially (from 1 reading per month to 96 readings per day), which feeds more confidence on the results. It is worth stressing that such work hasn’t been done in Portugal before.
- The grouping of DSSs allowed to calculate the losses in areas where the objects’ mapping was not fully reliable, thus allowing to obtain results even for these areas.
- Considering that before UPGRID, any loss calculation was greatly dependent on timing factors and data availability, UPGRID helped us to prove that it’s possible to simply pick up the data and do the maths. It’s a great step forward.

As a final remark and for a possible follow-up, developing applications for calculating the global losses on a larger scale for the MV grid can bring even further benefits to EDP Distribuição.
3.2 INTEGRATION OF DER AND NEW USES

UPGRID Portuguese demonstrator has developed solutions to promote the integration of DER, to test and validate DR schemes, using, for instance, the street light circuits. Furthermore, a public lighting cabinet with an improved urban integration was implemented in the demonstration area.

In this demo, other two initiatives were implemented, one concerning consumption profiling (section 3.2.2) which was important to assess the type of customers present in the demonstrator, according to their habits and behaviours; the other one was the development of communication technologies, which presents better performances for the smart meters.

3.2.1 REMOTE MANAGEMENT OF DER

An underground prototype cabinet was implemented in the demo area. This prototype allowed the DSO to assess a set of features that were different from the Business as Usual (BaU) scenario, namely: exposure to different weather conditions (humidity, floods, temperature); reading communication of the smart meters; urban integration. Secondly, this installation also aimed at a smoother urban integration and an increased comfort for the citizens circulating in the sidewalks.

![Image of underground cabinet](image-url)

FIGURE 20: UNDERGROUND CABINET INSTALLED IN THE UPGRID PORTUGUESE DEMO (CABINET IN THE CENTRE)

The front-end system for network operations was UPGRID Control (UGC enabling the DSO to send set points to active loads which allow solving of present or future LV network constraints).

On a background level, UGC will communicate with ECCOS CITY (Arquiled monitoring application to monitoring and control street light Luminaries).

In the Portuguese Demo, 30 LED luminaires of 64W and 18 of 103W were installed in the Parque Nações area.
The solution developed to monitor and control the street light is composed by LED luminaires with cellular mobile communication, the Gateway and Arquiled Management Application.

To enable the dispatch operator to monitor and control the electric network, an interface between UGC and Arquiled management application was developed, to exchange alarms and set-points.

The Arquiled application presents an integrated central console on top of a geographic information system GIS with the following functionalities:

- Control (individually or group) the luminosity flux;
- Communicate with the luminaries through GPRS;
- Report of events and alarms in “real-time”;
- Configure the luminaries’ profile;
3.2.1.1 TEST OBJECTIVES

Validate the integration of active loads control, such as public light circuits, in the LV network operation, when dealing with LV network constraints.

Regarding the installation of the underground cabinet, a primary objective for the installation of this prototype, and to enhance its replicability in the future, was the incorporation of standardised equipment in the final product, namely: the SM for public illumination, contactor, command frequency relay (as backup), fuse bases, etc.

3.2.1.2 TEST BED AND CONFIGURATION

The current Test involves the following Equipment/Systems/tools:

- UGC;
- ECCOS CITY (Arquiled application to monitor and control street light luminaries);
- Smart Grid infrastructure;

The test bed for the installation of the underground cabinet was the place of a former on the ground cabinet.

3.2.1.3 PERFORMED TESTS AND COLLECTED DATA

The results demonstrated a correct behaviour of the interface between UGC and the Arquiled application.
TABLE 4: STREET LIGHT MONITORING AND CONTROL

<table>
<thead>
<tr>
<th>Test IDNU 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test Scenario</strong></td>
</tr>
<tr>
<td><strong>Objective</strong></td>
</tr>
<tr>
<td><strong>Actions</strong></td>
</tr>
</tbody>
</table>

**FIGURE 24: UPGRID CONTROL SNAP SHOT – GEOGRAPHIC REPRESENTATION**
The UGC receive “real time” alarms from Arquiled luminaires, to monitor and be aware if there is a constraint.

Results

The performed tests allowed validating the correct behaviour of the implemented functionalities. Furthermore, it was possible to conclude that an improved monitoring of the streetlight makes it possible to give more reliable information to the dispatch centres.
TABLE 5: CONTROL OF ACTIVE LOADS

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Based on a network constraint detected in the DPLAN Upgrid or a LV alarm received from a DTC, the Dispatch Operator performs a network analysis and sends a set point to a specific street light circuit to help solving the network constraint, acting on an active load.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Validate the integration and activation of active loads control in a demand response scheme, to deal with LV network constraints.</td>
</tr>
</tbody>
</table>
| Actions       | Triggered by the occurrence of a network constraint, the Dispatch Operator performed the following steps:  
  - The Dispatch Operator confirmed the network constraint and sent a set point to a specific street light to set luminaries’ profile in the economic mode. |

FIGURE 27: UPGRID CONTROL SNAP SHOT: FUNCTIONALITIES OVER AN ASSET
Results

The results allowed validating the integration of DER. Through the actuation over the load profile of the street light circuits, it is possible to have a more proactive approach over the LV management and operation and solve some load restrictions during a specific period.
<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Installation of the equipment, using standardised equipment.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TABLE 6: UNDERGROUND CABINET</strong></td>
<td><img src="image.jpg" alt="Image" /></td>
</tr>
<tr>
<td><strong>FIGURE 29: UNDERGROUND PUBLIC LIGHTING CABINET</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Objective</strong></td>
<td>Assess the performance and evolution of this asset in what concerns the following features:</td>
</tr>
<tr>
<td></td>
<td>• Safety</td>
</tr>
<tr>
<td></td>
<td>• Overall Dimensions</td>
</tr>
<tr>
<td></td>
<td>• Casing sealing</td>
</tr>
<tr>
<td></td>
<td>• Air ventilation</td>
</tr>
<tr>
<td></td>
<td>• Protection against corrosion</td>
</tr>
<tr>
<td></td>
<td>• Installation procedures</td>
</tr>
<tr>
<td></td>
<td>• Reduce need for maintenance</td>
</tr>
<tr>
<td><strong>Actions</strong></td>
<td>Check one by one, the evolution of the features enumerated above.</td>
</tr>
<tr>
<td><strong>Results</strong></td>
<td>The preliminary results are very positive, although the relative little time the prototype has in the field does not allow for a correct evaluation of most characteristics above. Nevertheless, the urban integration, the installation process and dimensions have revealed to be important enhancers for its future replication.</td>
</tr>
</tbody>
</table>

3.2.1.4 EVALUATION OF RESULTS

This solution allowed testing new technologies of street light control and monitoring that have resulted in more data and new operational functionalities available from the operation stand point, for the first time in EDPD dispatch centre (with this configuration). Furthermore, it is possible to conclude that the
streetlight circuits can be a useful resource as a flexible load, helping to solve network constraints, by remotely acting in load without affecting domestic customers and consequently to have a more proactive approach in the LV operation.

Regarding the underground cabinet, the municipality of Lisbon was involved in the process of installation and has showed a special interest in the prototype, through its replication in other parts of the city, namely in historical areas where electrical infrastructures confer high visual impact and sidewalk space is usually limited. The underground cabinet prototype has been installed successfully and has had a very good behaviour until now (although no severe weather events have occurred yet, namely floods).

### 3.2.2 CONSUMPTION PROFILING OF LV CONSUMERS AND CHARACTERISATION OF ELECTRICAL VEHICLE (EV)

The UPGRID project makes extensive use of the Smart Metering infrastructure, enabling the DSO to better understand and monitor the LV grid and consumption behaviour of LV customers. A study has been performed to determine the consumption patterns and clusters associated with it. The idea is to understand if there is any relationship between the consumption 15-minute meter readings of LV customers and any set of characteristics of the LV customers, including contractual power, cumulated consumption, contractual tariff and other variables. Then, the same was done for EV charging points. Since there is no information gain or statistical significance in performing segmentation analysis (such as clustering) for the EV charging stations (given their low number), the analysis is focused on residential delivery points and non-residential delivery points consumption patterns.

#### 3.2.2.1 TEST OBJECTIVES

There are 2 mains objectives:

i. Find if there is any relation between 15-minute energy consumption data and technical/contractual characteristics of the Customers/EV charging stations. If so, it should be possible to determine population clusters and define them.

ii. Calculate the aggregated 15-minute curve consumption for each of the clusters identified.

#### 3.2.2.2 TEST BED AND CONFIGURATION

The information used in this study consisted of the quarter hourly meter readings of LV customers and EV charging stations, as well as the characteristics of those type of service delivery points, which are the following:

- Number of phases supplied;
- Contractual Tariff and Cycle;
- Industrial sector;
- Annual consumption (2016);
- Contractual Power;
- Economic Activity Code (EAC);
- Postal Code;
• MV/LV Substation code;
• Creation date of the delivery point;

Data gathered in 3 databases:
• Customers at demo site (13,494 delivery points);
• 15-minute energy data from residential customers (94,177,599 registers);
• 15-minute energy data from EV charging stations (143,889 registers);

The energy 15-minute consumption data must go through a process of validation, to detect abnormal values. It is a usual process ensuring the quality of the information supporting the studies, which otherwise can be biased due to abnormal data. Mains sources of abnormalities are:
• Inconsistent data residing on IT systems;
• Missing data;
• Abnormal values;

Hence, a validation process was built and all situations not meeting the following requirements are abnormal:
• Contractual power higher than 20,7kVA and Tariff other than Triple;
• Energy consumption above contracted power;
• Missing data for any of the master data (customer characteristic data);
• Having in mind that energy data will be used to build consumption profiles based on seasonality, it was decided not to include delivery points with more than 20% of missing data (consumption measurements);

Registers within those conditions are considered invalid and not included in the study. Total excluded delivery points were 3,723 out of the total population of 13,494. Among all valid delivery points, the percentage of missing interval data revealed itself to be less than 6%. These 6% were replaced by estimation data calculated through statistical modelling: average fluctuation considering the different seasonality³. The regression model also allowed the calculation for each delivery point, of the deviation between energy consumption and the estimated ones, considering the normal behaviour pattern of the same delivery point. Extreme deviation cases, 4,9% of the total registers, were replaced by estimation based on the normal consumption behaviour on that period.

3.2.2.3 PERFORMED TESTS AND COLLECTED DATA

Monthly profile for each delivery point is calculated as the monthly consumption for each month $m$, by day type $D$ (working day, Saturday, Sunday/holiday) and by each 15-minute interval, which is then normalized (i.e., the ratio of the total consumption of that particular delivery point) and multiplied by 1000 (for scale reasons only), as follows:

$$ P_{h,D,m} = \frac{\sum_{d=1}^{D} \sum_{m=1}^{M} C_{h,d,m}}{\sum_{d=1}^{D} \sum_{m=1}^{M} C_{h,d,m}} \times 1000 $$

$P_{h,D,m}$ – Profile based on 15-minute interval, at the D day and month M.

$C_{h,D,m}$ – 15-minute interval consumption at day D and month M.

Some delivery points show a steady consumption for long periods of time. These are explained by households without occupation, small business shut down or unrented offices. As such their respective profiles have a differentiated behaviour and it should not be included on the aggregated profile to avoid biasing the result. These delivery points are identified by looking at the standard deviation of the individual profile. We have excluded delivery points with standard deviation less than 0,1 for at least 2 month, as well as standard deviation higher than 1 on any day and month. This way, we mitigated the effect on both the individual and aggregated profiles, respectively.
Residential and non-residential have been analysed separately. For each delivery point, the clustering algorithm variables are the profile values for every month and day type. Knowing that a workday has a frequency 5 times higher than Saturday or Sunday/holiday, it means that a deviation between the profile and the real during workdays has also an effect 5 times higher on the error of the segmentation model. Hence, it’s necessary to include in the model this 5:1:1 ratio coming from the calendar.

The K-Means algorithm was applied to several clusters as to identify what was the number of clusters (NC) where the $R^2$ (explained variance) growth slows down. The algorithm shows that around 3 it slows down.

Thus, the number of clusters to consider is 3. The K-Means algorithm also outputs clusters with profiles that standout towards the profile population. The clusters with few individuals (less than 1% of the total population) reflects a cluster of outliers. Clustering algorithm was therefore applied recursively removing the outliers on every iteration, following these steps:

1. Defining number of clusters NC, by applying the K-Means algorithm;
2. Building NC clusters using the K-Means algorithm;
3. Removal of the delivery points falling into clusters with less than 1% of the total.
It has been found no outlier in the residential group. The non-residential customer’s analysis, however, showed 5 outliers.

The clusters allow identifying customer groups with similar behaviour. These clusters allow characterizing the customer’s patterns by the following variables:

- Activity Sector;
- Cycle;
- Tariff;
- Power;
- Consumption;
- Zone.

First, it is necessary to understand those variables’ distribution through the clusters. Then, using a decision-tree, it is important to determine how explanatory those variables can be to characterize the clusters and measuring the relevance of each one of them. The most relevant variables can be combined to define groups.

The decision-tree explanatory ability is measured through quality measures:

- Average Square Error (EQM);
- Percentage of wrong classifications (CE);
- Entropy;
- Gini index;
- Sum of Square Residues.
It was concluded that the Residential Customers are very similar between themselves, the consumption variance explained by the clusters is relatively low ($R^2$ is 10.8%).

The resulting clusters are then as follows:

- **Cluster 1** (693 elements) typical residential, consumption peak occurs at early morning and another at the evening. Both peaks get higher during winter. During weekends, the morning peak occurs a few hours later;
- **Cluster 2** (1,419 elements) – also has peaks like Cluster 1, but the curve is more flattened, more constant consumption around the year;
- **Cluster 3** (102 elements) – consumption follows the working hours, instead of early morning and evening peaks.

### TABLE 7: RESIDENTIAL CUSTOMER’S DESCRIPTIVE STATISTICS

<table>
<thead>
<tr>
<th></th>
<th>Cluster 1</th>
<th>Cluster 2</th>
<th>Cluster 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olivais I</td>
<td>12</td>
<td>19</td>
<td>5</td>
</tr>
<tr>
<td>Olivais II</td>
<td>248</td>
<td>572</td>
<td>51</td>
</tr>
<tr>
<td>P Nacoes</td>
<td>433</td>
<td>828</td>
<td>46</td>
</tr>
<tr>
<td>Consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 500kWh</td>
<td>12</td>
<td>83</td>
<td>34</td>
</tr>
<tr>
<td>Between 500 and 1500kWh</td>
<td>87</td>
<td>357</td>
<td>17</td>
</tr>
<tr>
<td>Between 1500 and 3000kWh</td>
<td>252</td>
<td>560</td>
<td>13</td>
</tr>
<tr>
<td>Between 3000 and 7140kWh</td>
<td>282</td>
<td>374</td>
<td>23</td>
</tr>
<tr>
<td>More than 7140kWh</td>
<td>60</td>
<td>45</td>
<td>15</td>
</tr>
<tr>
<td>Contractual Power</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 3.45kVA</td>
<td>56</td>
<td>225</td>
<td>37</td>
</tr>
<tr>
<td>Between 3.45 and 6.95kVA</td>
<td>372</td>
<td>698</td>
<td>28</td>
</tr>
<tr>
<td>10.35kVA</td>
<td>189</td>
<td>323</td>
<td>16</td>
</tr>
<tr>
<td>13.80 kVA</td>
<td>47</td>
<td>102</td>
<td>8</td>
</tr>
<tr>
<td>More than 17.25kVA</td>
<td>29</td>
<td>71</td>
<td>13</td>
</tr>
<tr>
<td>Contractual Tariff</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double</td>
<td>192</td>
<td>347</td>
<td>7</td>
</tr>
<tr>
<td>Simple</td>
<td>494</td>
<td>1042</td>
<td>92</td>
</tr>
<tr>
<td>Triple</td>
<td>7</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>Contractual Cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily</td>
<td>130</td>
<td>244</td>
<td>8</td>
</tr>
<tr>
<td>No Cycle</td>
<td>491</td>
<td>1040</td>
<td>92</td>
</tr>
<tr>
<td>Weekly</td>
<td>72</td>
<td>135</td>
<td>2</td>
</tr>
<tr>
<td>Supply Phases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 phase</td>
<td>477</td>
<td>955</td>
<td>62</td>
</tr>
<tr>
<td>3 phase</td>
<td>216</td>
<td>464</td>
<td>40</td>
</tr>
</tbody>
</table>

The success rates obtained by the decision tree algorithm are not sufficient to conclude that they have explanatory power to classify individuals based on their characterization variables. Hence, clustering the customers must be done solely by considering its energy consumption pattern.

Non-Residential customers are far more heterogeneous than residential ones. The variance is now 27.4%

The resulting clusters are as follows:
• Cluster 1 (185 elements) – typical office pattern, consumption concentrated during office hours and on work-days;
• Cluster 2 (128 elements) – typical shop pattern, consumption high growth early morning and softly decrease at the evening, mostly steady along every day of the week and month of the year;
• Cluster 3 (318 elements) – very few variances on consumption pattern throughout the year, but higher in winter.

### TABLE 8: NON-RESIDENTIAL CUSTOMER’S DESCRIPTIVE STATISTICS

<table>
<thead>
<tr>
<th></th>
<th>Cluster 1</th>
<th>Cluster 2</th>
<th>Cluster 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Zone</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olivais I</td>
<td>4</td>
<td>2.2%</td>
<td>2</td>
</tr>
<tr>
<td>Olivais II</td>
<td>93</td>
<td>50.3%</td>
<td>98</td>
</tr>
<tr>
<td>P Naciones</td>
<td>88</td>
<td>47.6%</td>
<td>28</td>
</tr>
<tr>
<td><strong>Consumption</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 500kWh</td>
<td>10</td>
<td>5.4%</td>
<td>7</td>
</tr>
<tr>
<td>Between 500 and 1500kWh</td>
<td>27</td>
<td>14.6%</td>
<td>13</td>
</tr>
<tr>
<td>Between 1500 and 3000kWh</td>
<td>42</td>
<td>22.7%</td>
<td>4</td>
</tr>
<tr>
<td>Between 3000 and 7140kWh</td>
<td>51</td>
<td>27.6%</td>
<td>16</td>
</tr>
<tr>
<td>More than 7140kWh</td>
<td>55</td>
<td>29.7%</td>
<td>88</td>
</tr>
<tr>
<td><strong>Contractual Power</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 3.45kVA</td>
<td>32</td>
<td>17.3%</td>
<td>16</td>
</tr>
<tr>
<td>Between 3.45 and 6.95kVA</td>
<td>60</td>
<td>32.4%</td>
<td>26</td>
</tr>
<tr>
<td>10.35kVA</td>
<td>28</td>
<td>15.1%</td>
<td>32</td>
</tr>
<tr>
<td>13.80 kVA</td>
<td>19</td>
<td>10.3%</td>
<td>10</td>
</tr>
<tr>
<td>More than 17.25kVA</td>
<td>46</td>
<td>24.9%</td>
<td>44</td>
</tr>
<tr>
<td><strong>Contractual Tariff</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double</td>
<td>7</td>
<td>3.8%</td>
<td>9</td>
</tr>
<tr>
<td>Simple</td>
<td>155</td>
<td>83.8%</td>
<td>93</td>
</tr>
<tr>
<td>Triple</td>
<td>23</td>
<td>12.4%</td>
<td>26</td>
</tr>
<tr>
<td><strong>Contractual Cycle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily</td>
<td>15</td>
<td>8.1%</td>
<td>13</td>
</tr>
<tr>
<td>No Cycle</td>
<td>155</td>
<td>83.8%</td>
<td>93</td>
</tr>
<tr>
<td>Weekly</td>
<td>15</td>
<td>8.1%</td>
<td>22</td>
</tr>
<tr>
<td><strong>Supply Phases</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 phase</td>
<td>80</td>
<td>43.2%</td>
<td>59</td>
</tr>
<tr>
<td>3 phase</td>
<td>105</td>
<td>56.8%</td>
<td>69</td>
</tr>
<tr>
<td><strong>Activity Sector</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sector 1</td>
<td>25</td>
<td>13.5%</td>
<td>12</td>
</tr>
<tr>
<td>Sector 2</td>
<td>126</td>
<td>68.1%</td>
<td>80</td>
</tr>
<tr>
<td>Sector 3</td>
<td>27</td>
<td>14.6%</td>
<td>33</td>
</tr>
<tr>
<td>Sector 4</td>
<td>7</td>
<td>3.8%</td>
<td>3</td>
</tr>
</tbody>
</table>

The decision tree’s success rates indicate that the most relevant variables are, by order: Cycle, Consumption and Activity Sector. These are therefore the variables that explain the belonging of each delivery point to each of the clusters.

### 3.2.2.4 EVALUATION OF RESULTS

After a first step validating the data, outlier correction and estimating missing data, the monthly profiles were determined for each delivery point. With these profiles, it was possible to identify homogeneous
groups of customers through cluster analysis. These groups were then sorted based on the characteristics of the population such as Tariff, Activity, etc., using descriptive statistics and decision-trees.

Cluster analysis found out that 3 clusters can represent the residential population and another 3 represent the non-residential. Regarding the residential clusters, it was found that the characteristic variables of the population did not reveal enough explanatory capacity to classify the individuals in the clusters. The explanatory capacity resides therefore on the consumption pattern only. Nevertheless, for non-Residential delivery points, the profiles are more heterogeneous and the characteristic variables can explain the clustering as well as the consumption pattern. This explanatory capacity goes by the following order of importance: Cycle, Consumption and Activity Sector.

This study is fundamental for the DSO, allowing it to know the diversified consumption pattern of the demonstrator (data for every 15mins) and categorize it into groups with similar behaviour. Getting insights from consumption patterns not only enables the DSO to better plan and manage the distribution grid, but also to discover, create and promote enhanced services to the energy market (e.g. such as energy efficiency promotion to end clients and providing more data to market players), enhancing its role as a market facilitator.

The most natural step further after this study is to see how and if it maps onto Energy Efficiency programs. Naturally, these studies can become services to other market players as well (Retailers, ESPs, etc) creating an augmented role of the DSO as Data Provider.

### 3.3 NETWORK OPERATIONS

The UPGRID project focuses on the use of the smart grid infrastructure and associated information for the benefit of network operation. The Portuguese Demo enhanced the monitoring and control of the LV Network through the correlation of events and alarms from the AMI infrastructure and other external entities (telecommunication operators).

Additionally, the functionalities developed allowed the Dispatch Operators to receive information from the power simulation tool when technical network constraints were detected.

#### 3.3.1 IMPROVEMENT OF LV NETWORK MANAGEMENT SYSTEM VISUALIZATION BY INTEGRATING DATA MEASUREMENTS FROM INSIDE SS

##### 3.3.1.1 TEST OBJECTIVES

To validate the LV NMS.

##### 3.3.1.2 TEST BED AND CONFIGURATION

This functionality allows the dispatcher to visualize historic and real time information, to compare the asset performance. This test can be triggered in four different ways:

1. The operator receives an alarm from a DTC located at the demonstrator site.
2. The operator initiative, based on his experience in network management.
3. The operator analyses network constraints, supported by the following information:
   - LV events and alarms
     - Automatically available to the operator when received by Alarm View
   - Transformer three-phase voltage and current measurements
     - Real time measurements manually requested by the operator
   - Power factor
     - Real time measurement manually requested by the operator
   - Active and Reactive Power
     - Real time measurement manually requested by the operator
   - Load Diagram
     - Historic measurements manually requested by the operator
4. The operator creates an outage register directly in the Outage Management System (OMS)

### 3.3.1.3 PERFORMED TESTS AND COLLECTED DATA

#### TABLE 9: SET OF TESTS PERFORMED TO THE UGC

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Objective</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection of transformer Phase Down</td>
<td>Following the reception of an overvoltage event in Alarm View, the operator must, in a geographical context, collect information about the current state of the Grid. Requesting voltages and currents and analysing the load diagram.</td>
<td>- Receive overvoltage event in Alarm View</td>
</tr>
</tbody>
</table>

**FIGURE 35: UPGRID CONTROL – ALARM LIST VIEW**

- The operator, upon receiving the overvoltage event communicated by the DTC, can select the "Ir para MAP View" option that will redirect to a geographical context.
In MAP View, it is possible to obtain several information from the network elements being analysed, such as:
- SS and associated DTC;
- Number of customers fed by the SS;
- Geographical coordinates;
- Network hierarchy (top right corner);
- Events associated with the SS (lower left corner).

It is possible to validate the event previously presented.

Following the event received in Alarm View window, the operator validates the voltages and currents of each of the phases of the transformer, requiring that data in the tool.

By analysing the result of the request, the operator validates that there is indeed a phase failure.
The operator may also evaluate the load diagram.

**FIGURE 38: PHASE FAILURE IN A SS**

- After analysing all the information provided by the infrastructure to the operator via the UGC, it is possible to register an occurrence in the OMS, directly through the UGC;

**FIGURE 39: LOAD DIAGRAM**

Results

In this test scenario, we demonstrated the ability of the UGC to support the operator with information acquired through the LV infrastructure.

### 3.3.1.4 EVALUATION OF RESULTS

The geographic representation and associated processes enabled by UGC, such as events and measurements from the whole smart grid infrastructure in demo, allow the operator to anticipate fault reports and to assess the occurrence with a wider range of data, all in a centralised way. The average response time by the Dispatch Operator in a phase failure situation using the UGC system is 7 minutes. This time corresponds to sending the event for the infrastructure, applications request measurements, load diagrams and creating occurrence in OMS.

The increased sensorisation of the LV network integrated in the UGC improves the observability and actuation of the Dispatch Centres. This allows the DSO to have a more proactive approach, avoiding to wait for the customers’ call to be aware of the problems in the LV Network.
### 3.3.2 IMPROVEMENT OF LV NETWORK MANAGEMENT SYSTEM VISUALIZATION BY INTEGRATING DATA MEASUREMENTS FROM LV NETWORK DEVICES (E.G. CUSTOMERS SM, EV CHARGING POINTS, DER)

#### 3.3.2.1 TEST OBJECTIVES

The aim is to validate that UGC allows the Dispatch Operator’s to have access to the LV network devices (SMs and DTCs), their state and measures. It aims to validate the integration of the smart grid infrastructure data in the UGC system.

#### 3.3.2.2 TEST BED AND CONFIGURATION

The tests conducted involved the following equipment and systems:

- UGC
- Smart Grid infrastructure: DTC, smart meters

To validate this functionality, the dispatch operator sent measurement requests to the smart grid infrastructure.

#### 3.3.2.3 PERFORMED TESTS AND COLLECTED DATA

The following table describes the several tests performed to validate how the information of the smart grid infrastructure can help the network operation.

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Objective</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requesting DTC and smart meter measurements</td>
<td>Using the information from the infrastructure to confirm or to validate the real extent of an outage in the LV network.</td>
<td>LV network status and measurements — DTC measurements – Real time and historic measurements manually requested by the operator.</td>
</tr>
</tbody>
</table>

**TABLE 10: ENHANCEMENT OF THE OUTAGE INFORMATION USING SMART GRID DATA**
FIGURE 40: SNAPSHOT UGC – SS ELECTRIC MEASURES VIEW OPTION

FIGURE 41: SNAPSHOT UGC – LOAD DIAGRAM VIEW OPTION

FIGURE 42: SNAPSHOT UGC – GEOGRAPHIC VIEW OPTION
- Smart meter measurements – Real time and historic measurements manually requested by the operator.

![FIGURE 43: SNAPSHOT UGC – SM ELECTRIC MEASURES VIEW OPTION](image)

- LV events and alarms

Through the alarm view of the UGC the Dispatch operator can check the events and alarms of the DTC and smart meters. If the alarms confirm to be related with an outage, it can be the trigger for the Dispatch Operator start of the DTC and smart meters’ information requests (as referred previously in this test - LV network status and measurements subsection).

![FIGURE 44: SNAPSHOT UGC – EVENTS VIEW OPTION](image)

**Results**

The tests performed allowed to validate that the smart grid data measurements and events can be useful to enhance the information of an outage.
3.3.2.4 EVALUATION OF RESULTS

The solution developed allows to have a more proactive approach in the outage treatment. The data from the smart grid infrastructure such as measurements, load diagrams and events can help the operators to anticipate or confirm faults, instead of sending a crew to the field to analyse the problem which is the DSO actual procedure. This will contribute to the quality service improvement and the reduction of operational costs.

3.3.3 INTEGRATION OF MEASUREMENT DATA TO SUPPORT POWER FLOW ANALYSIS IN LV NETWORK MANAGEMENT SYSTEM

3.3.3.1 TEST OBJECTIVES

Several objectives can be enumerated for this functionality:

- Test the integration in DPLAN UPGRID of metering and telemetry information of SMs (D4.2 [1], section 2.3.3.1);
- Compare the result of Power Flow (PF) with data from SM and DTC and with load adjust algorism, with the PF without these data, to analyse the potential benefits of this new tool;
- Test the error topology sub-functionality (D4.2 [1], section 2.3.3.2.2) in the two components, voltage measurements inconsistencies and deviations of the integrated energy balance;
- Also, test the integration of load forecast specified and developed in WP2 (T2.1.3) and the SM historical data to run PF in the present day and in the future to predict constraints in LV network.

3.3.3.2 TEST BED AND CONFIGURATION

Equipment/Systems/Tools under test:

- DPLAN UPGRID;
- Unified Data Model (UDM) database;
- UPGRID Control.

The data to be imported (integrated quantities with a 15-minute resolution) has the following attributes:

- Identifier (CPE, installation code or counter code);
- Measurement Timestamp (date / time);
- Measurement variable;
- Unit of measure;
- Measured value.

Also, import DTC data from the UGC: this data is used to compute the power flow of the present day.

The network of the all area of Parque das Nações has been imported from technical information system.
3.3.3.3 PERFORMED TESTS AND COLLECTED DATA

Testing and comparing PF in the past with load values of DTC’s and SM

This test aims to compare the results of two PFs of the same network with different customer data. The comparison has been made between the currently used PF which considers typified values of load, and the LV PF performed with the real values of power and voltage from SM and DTC’s.

PF without SM data (PF1)

The current PF is performed with values typified for each type of customer (housing, commerce, industry) considering the contracted power of each client. The PF is calculated for maximum peak hours.
PF with load values of DTC’s and SM (PF2)

The PF developed in this functionality uses the real data (load diagrams) of the SM in the calculation. In the case of SM without any type of data, the load diagrams are estimated considering the load diagrams of the DTCs in such a way that the results of the power flow match the aggregated load at the DTC. This feature is incorporated in the DPU and has the designation of "Set load".

![Site Load Diagram](image)

**FIGURE 48: SITE LOAD DIAGRAM**

To evaluate the differences between the two PFs, the following parameters were compared:

- Maximum active power per LV feeder;
- Maximum current per LV feeder;
- Maximum voltage drop per LV feeder;
- Power losses per LV feeder.
To compare the two PFs, the actual values chosen from the EBs and DTCs were the peak day of the year (23/01/2017).

In the following tables data of 2 different SS is shown. The criterion for their choice was their high percentage of SM measurements.

**TABLE 11: TESTS FOR THE INTEGRATION OF MEASUREMENTS IN PF ANALYSIS**

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Objective</th>
<th>Actions</th>
<th>Results</th>
</tr>
</thead>
</table>
| PF in the past with real values of DTC’s and SM | Check difference between methods (with and without SM) | • PF without SM data on peak day of the year (01/23/2017) - Estimation  
• PF with load values of DTC’s and SM on peak day of the year (01/23/2017) - Chronologic  
• Perform “Set Load”  
• Comparing the results of the two PFs | ![FIGURE 49: SS LSB-D-9990](image) |
FIGURE 50: SS LSB-D-8594

<table>
<thead>
<tr>
<th>LSB-D-9990</th>
<th>LV Feeder 1</th>
<th>LV Feeder 3</th>
<th>LV Feeder 4</th>
<th>LV Feeder 6</th>
<th>LV Feeder 7</th>
<th>LV Feeder 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum active power [kW]</td>
<td>39,8</td>
<td>33,6</td>
<td>44,8</td>
<td>46,5</td>
<td>30,7</td>
<td>43,8</td>
</tr>
<tr>
<td>Maximum current [A]</td>
<td>61,8</td>
<td>52,1</td>
<td>69,6</td>
<td>72,2</td>
<td>47,6</td>
<td>67,9</td>
</tr>
<tr>
<td>Maximum voltage drop [%]</td>
<td>0,72</td>
<td>0,13</td>
<td>0,56</td>
<td>0,49</td>
<td>0,24</td>
<td>0,34</td>
</tr>
<tr>
<td>Power losses [kW]</td>
<td>0,28</td>
<td>0,04</td>
<td>0,24</td>
<td>0,22</td>
<td>0,07</td>
<td>0,14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LSB-D-8594</th>
<th>LV Feeder 4</th>
<th>LV Feeder 5</th>
<th>LV Feeder 6</th>
<th>LV Feeder 7</th>
<th>LV Feeder 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum active power [kW]</td>
<td>30,9</td>
<td>36,0</td>
<td>26,0</td>
<td>52,8</td>
<td>25,6</td>
</tr>
<tr>
<td>Maximum current [A]</td>
<td>48,0</td>
<td>55,9</td>
<td>40,3</td>
<td>81,8</td>
<td>39,8</td>
</tr>
<tr>
<td>Maximum voltage drop [%]</td>
<td>1,12</td>
<td>0,93</td>
<td>0,80</td>
<td>1,97</td>
<td>1,97</td>
</tr>
<tr>
<td>Power losses [kW]</td>
<td>0,37</td>
<td>0,32</td>
<td>0,22</td>
<td>1,09</td>
<td>0,12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LSB-D-9990</th>
<th>LV Feeder 1</th>
<th>LV Feeder 3</th>
<th>LV Feeder 4</th>
<th>LV Feeder 6</th>
<th>LV Feeder 7</th>
<th>LV Feeder 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum active power [kW]</td>
<td>27,5</td>
<td>17,7</td>
<td>20,5</td>
<td>25,0</td>
<td>19,2</td>
<td>38,4</td>
</tr>
<tr>
<td>Maximum current [A]</td>
<td>39,7</td>
<td>25,5</td>
<td>29,7</td>
<td>36,1</td>
<td>27,7</td>
<td>35,2</td>
</tr>
<tr>
<td>Maximum voltage drop [%]</td>
<td>0,43</td>
<td>0,06</td>
<td>0,23</td>
<td>0,22</td>
<td>0,13</td>
<td>0,27</td>
</tr>
<tr>
<td>Power losses [kW]</td>
<td>0,12</td>
<td>0,01</td>
<td>0,04</td>
<td>0,05</td>
<td>0,02</td>
<td>0,10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LSB-D-8594</th>
<th>LV Feeder 4</th>
<th>LV Feeder 5</th>
<th>LV Feeder 6</th>
<th>LV Feeder 7</th>
<th>LV Feeder 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum active power [kW]</td>
<td>10,7</td>
<td>8,8</td>
<td>13,8</td>
<td>6,6</td>
<td>24,1</td>
</tr>
<tr>
<td>Maximum current [A]</td>
<td>15,5</td>
<td>12,9</td>
<td>19,9</td>
<td>10,3</td>
<td>25,6</td>
</tr>
<tr>
<td>Maximum voltage drop [%]</td>
<td>0,36</td>
<td>0,21</td>
<td>0,39</td>
<td>0,25</td>
<td>0,36</td>
</tr>
<tr>
<td>Power losses [kW]</td>
<td>0,04</td>
<td>0,02</td>
<td>0,06</td>
<td>0,03</td>
<td>0,08</td>
</tr>
</tbody>
</table>

TABLE 12: PF1, RESULTS OF PF WITHOUT SM AND DTC

TABLE 13: PF2, RESULTS OF PF WITH SM AND DTC AND “SET LOAD”
In this test, it is possible to verify the discrepancy between the PF1 (without SM) and PF1(field test values).
Due to the difficulty of estimating the behaviour of different type of clients, and therefore a typical load diagram of LV clients, the DPU by default uses a more conservative criterion for estimation.

It was expected a higher maximum active power of the LV feeders in PF1, however, the results obtained in these particulate networks and the field test confirmed it.

The time to perform the “set load” algorithm is approximately of 10 seconds with DTC, except when there is some inconsistence of values between DTC and the corresponding SM: in these cases, the algorithm must perform more iteration for the PF to converge, resulting in a delay of more than one minute.

To perform a “set load” of all the SS in the demonstrator, the PF takes approximately 1 hour; this time was reduced during the field test, by adjusting the algorithm, so that it deals with different data scenarios of SM and DTC.

**Conclusion**
The test with field values was a success. The algorithm for “set load” needs to be adjusted to converge more quietly.

**Prediction of “Near real-time” PF and Future PF with historical and forecasted data**

With this feature, it is intended to obtain the power flow of the LV network related to each MV/LV transformer for the present day and for the upcoming days, based on the near real-time DTC load profile and the estimated load of SMs and DTCs.

The DTC load profile is sent to UDM every 6 hours (near real-time). Therefore, from 0h to the end-date of the last communication, the available load profile is the real one. From the end-date of the last communication to 24h of the present day, the DTC load profile is estimated based on historical data weighted by the real energy of the measured profile already available for that day. The load profile of the present day is thus composed of two distinct parts, one with real values and the other with estimated values - Figure 51. For the upcoming days, the load profile is estimated based purely on historical data.
The power-flow performed on a LV network is based on load profiles measured by customer SMs. Because in near real-time these data are not available, they need to be estimated. The estimation of SMs load profiles for the present day is based on three levels, indicated below in order of priority:

1. Forecast, for the SMs that have this functionality associated (~1,000 SMs);
2. For SMs without forecasted data, the load profile is estimated based on valid historical data;
3. For SMs without any data type (neither forecast nor historical), load profiles can be estimated iteratively so that the results of the power flow match the DTC load profile less technical losses.

This feature is included in the DPLAN software and is called "set load".

**FIGURE 51: EXAMPLE OF A NEAR REAL-TIME DTC LOAD PROFILE**

The power-flow performed on a LV network is based on load profiles measured by customer SMs. Because in near real-time these data are not available, they need to be estimated. The estimation of SMs load profiles for the present day is based on three levels, indicated below in order of priority:

1. Forecast, for the SMs that have this functionality associated (~1,000 SMs);
2. For SMs without forecasted data, the load profile is estimated based on valid historical data;
3. For SMs without any data type (neither forecast nor historical), load profiles can be estimated iteratively so that the results of the power flow match the DTC load profile less technical losses.

This feature is included in the DPLAN software and is called "set load".
As an alternative to point 3, there is also available in DPLAN the feature "adjust load", in which DPLAN iteratively modifies SMs load profiles (either obtained from forecast or historical data, 1 and 2 respectively) and doesn’t assign any consumption to SMs without any data type.

The procedure for evaluating the assignment of load profiles in near real-time is intended to compare the results of power flow with two different input data:

1. Estimated customer load profiles obtained with forecast data, historical data and set/adjust load;
2. Real customer load profiles of the same day, available in UDM the day after.

It should be noted that there may also be historic based and “set load” estimations in the day after, due to communication failures.

The variables to compare are the following:

- Maximum active power per LV feeder;
- Maximum current per LV feeder;
- Maximum voltage drop per LV feeder;
- Power losses per LV feeder;
- Maximum active power of MV/LV transformer.

This test was performed for an LV network selected for having a superior communications success rate, so that the estimation in near real time is compared to the largest amount of real data possible.

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Prediction of “Near real-time” PF and Future PF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Near real-time power flow and real power flow of SS 1106D1999000.</td>
</tr>
<tr>
<td>Actions</td>
<td>Compare power flows resulting from estimated data (forecast and historical) with power flows resulting from real values</td>
</tr>
<tr>
<td></td>
<td>● For the LV network selected:</td>
</tr>
<tr>
<td></td>
<td>o Estimation of DTC load profiles with near real-time data and historical data</td>
</tr>
<tr>
<td></td>
<td>o Estimation of customer load profiles with forecast data and historical data</td>
</tr>
<tr>
<td></td>
<td>o Estimation of the remaining consumption with “set load” feature</td>
</tr>
<tr>
<td></td>
<td>o Power flow calculations with the above estimated data</td>
</tr>
<tr>
<td></td>
<td>o Acquisition of real customer load profiles for the same day analysed above</td>
</tr>
<tr>
<td></td>
<td>o Estimation of the remaining consumption with historical data and “set load” feature</td>
</tr>
<tr>
<td></td>
<td>o Power flow calculations with the above real and estimated data</td>
</tr>
<tr>
<td></td>
<td>o Comparison of both power flow results</td>
</tr>
</tbody>
</table>
Results

<table>
<thead>
<tr>
<th>LSB-D-9990</th>
<th>LV Feeder 1</th>
<th>LV Feeder 3</th>
<th>LV Feeder 4</th>
<th>LV Feeder 6</th>
<th>LV Feeder 7</th>
<th>LV Feeder 8</th>
<th>MV/LV Transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum active power [kW]</td>
<td>12.9</td>
<td>4.2</td>
<td>7.8</td>
<td>12.1</td>
<td>5.1</td>
<td>10</td>
<td>52</td>
</tr>
<tr>
<td>Maximum current [A]</td>
<td>18.3</td>
<td>5.9</td>
<td>11.1</td>
<td>17.1</td>
<td>7.2</td>
<td>14.5</td>
<td>73.9</td>
</tr>
<tr>
<td>Maximum voltage drop [%]</td>
<td>0.20</td>
<td>0.01</td>
<td>0.09</td>
<td>0.11</td>
<td>0.03</td>
<td>0.07</td>
<td>2</td>
</tr>
<tr>
<td>Power losses [kW]</td>
<td>0.02</td>
<td>0</td>
<td>0.01</td>
<td>0.01</td>
<td>0</td>
<td>0</td>
<td>0.05</td>
</tr>
</tbody>
</table>

TABLE 14: NEAR REAL-TIME ESTIMATED POWER FLOW

<table>
<thead>
<tr>
<th>LSB-D-9990</th>
<th>LV Feeder 1</th>
<th>LV Feeder 3</th>
<th>LV Feeder 4</th>
<th>LV Feeder 6</th>
<th>LV Feeder 7</th>
<th>LV Feeder 8</th>
<th>MV/LV Transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum active power [kW]</td>
<td>10.1</td>
<td>3.8</td>
<td>8.2</td>
<td>8.4</td>
<td>5.4</td>
<td>8.0</td>
<td>44</td>
</tr>
<tr>
<td>Maximum current [A]</td>
<td>14.4</td>
<td>5.4</td>
<td>11.7</td>
<td>11.8</td>
<td>7.7</td>
<td>11.7</td>
<td>62.4</td>
</tr>
<tr>
<td>Maximum voltage drop [%]</td>
<td>0.16</td>
<td>0.01</td>
<td>0.09</td>
<td>0.07</td>
<td>0.04</td>
<td>0.06</td>
<td>0.16</td>
</tr>
<tr>
<td>Power losses [kW]</td>
<td>0.02</td>
<td>0</td>
<td>0.01</td>
<td>0.01</td>
<td>0</td>
<td>0</td>
<td>0.03</td>
</tr>
</tbody>
</table>

TABLE 15: REAL POWER FLOW OBTAINED WHEN REAL LOAD DATA IS AVAILABLE

Conclusion

The test demonstrated the good performance of the near real-time power-flow estimation. To achieve better results, the algorithm of obtaining DTC and SM historical data should be improved.

Topology errors detection

When the physical and the ICT topologies are congruent, DPLAN UPGRID power flow results on nodal (SM) voltages, which can be compared with the existing nodal SM voltage measurements to evaluate possible inconsistencies - Voltage consistency. Other tests to detect topology errors can be done, such as comparison of the aggregated SM loads with the DTC metered load/energy.

Topology errors detection (Energy balance) scenario 2

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Analysis of Energy Report in simulation scenario.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Check LV network with topology errors</td>
</tr>
<tr>
<td>Actions</td>
<td>• Simulate a topology error in 2 SS LV network</td>
</tr>
<tr>
<td></td>
<td>• Run energy and voltage compare report</td>
</tr>
<tr>
<td></td>
<td>• Analyse performance of the reports</td>
</tr>
<tr>
<td>Results</td>
<td>To verify the functionality, a change was forced in the DPU network, with no representation in the field: disconnection of the SS 8495, and putting the SS 8496 feeding the LV network of the SS 8495. This way we simulate an inconsistency between the total load of the DTC in SS 8496</td>
</tr>
</tbody>
</table>
and the sum of the SMs of 9485 and 9486 network, leading to a higher current and voltage drop in the LV network.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8594</td>
<td>1290924487</td>
<td>631.0</td>
<td>428.9</td>
<td>202.1</td>
</tr>
<tr>
<td>8595</td>
<td>1290930107</td>
<td>707.0</td>
<td>627.2</td>
<td>79.8</td>
</tr>
</tbody>
</table>

**TABLE 16: TOPOLOGY REPORT BEFORE SIMULATION**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8594</td>
<td>1290924487</td>
<td>631.0</td>
<td>1064.8</td>
<td>-433.8</td>
</tr>
<tr>
<td>8595</td>
<td>1290930107</td>
<td>707.0</td>
<td>0</td>
<td>707.0</td>
</tr>
</tbody>
</table>

**TABLE 17: TOPOLOGY REPORT AFTER SIMULATION**

In Figure 52, it is visible that the sum of the SM's (dash line) and the respective PF calculation is greater than the DTC measure (full line), so DPU confirms that we are in the presence of an error in the network topology situation, which the report detects.
with a negative delta - Figure 53.

FIGURE 54: VOLTAGE COMPARE REPORT OF SIMULATION SCENARIO

As expected, in Figure 53, it is possible to verify the correct operation of the voltage report and PF calculations.

**Conclusion**

The test demonstrated that the DPLAN UPGRID can detect topology errors in LV network studies. This feature makes it possible to correct errors in the existing infrastructure record.

### Topology errors detection (Energy balance and Voltage Comparison) – scenario 1

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Analysis of topology Reports – in all SS in Parque das Nações</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Verify LV network with topology errors</td>
</tr>
</tbody>
</table>
| Actions       | • Run energy and voltage report for all DTC in normal LV network configuration  
                 • Verify the cases where energy balance is negative  
                 • Analyse deviation of real voltage and PF calculation  
                 • Analyse reasons for error of topology               |
<p>| Results        |                                                            |
|                | <strong>SS</strong> | <strong>DTC (Ref, Ext)</strong> | <strong>Energy Measures [kWh]</strong> | <strong>Power Flow Energy [kWh]</strong> | <strong>Delta Energy [kWh]</strong> |
|                |        |                   |                           |                           |                         |</p>
<table>
<thead>
<tr>
<th>Date Code</th>
<th>Code 1</th>
<th>Code 2</th>
<th>Code 3</th>
<th>Code 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1106D1024600</td>
<td>1290931972</td>
<td>859</td>
<td>345,7</td>
<td>513</td>
</tr>
<tr>
<td></td>
<td>1290932031</td>
<td>564</td>
<td>911</td>
<td>-347</td>
</tr>
<tr>
<td></td>
<td>1290932607</td>
<td>235</td>
<td>199,8</td>
<td>35</td>
</tr>
<tr>
<td>1106D1024600 Total</td>
<td>1.658</td>
<td>1.456,5</td>
<td>201</td>
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<tr>
<td>1106D1025100</td>
<td>1290931449</td>
<td>491</td>
<td>491</td>
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<td>1290931468</td>
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<td></td>
<td>1290932632</td>
<td>1.012</td>
<td>1.391,6</td>
<td>-380</td>
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<tr>
<td>1106D1025100 Total</td>
<td>1.782</td>
<td>1.391,6</td>
<td>380</td>
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<td>1290924467</td>
<td>589</td>
<td>410,9</td>
<td>178</td>
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<td>1290924483</td>
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<td>1106D1030100 Total</td>
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<td></td>
<td>1290930113</td>
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<tr>
<td>1106D1033200 Total</td>
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<td>521,5</td>
<td>62</td>
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<tr>
<td>1106D1034900</td>
<td>1290924411</td>
<td>1.385</td>
<td>1.824</td>
<td>-439</td>
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<tr>
<td></td>
<td>1290924627</td>
<td>1.273</td>
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<tr>
<td>1106D1034900 Total</td>
<td>2.658</td>
<td>1.824</td>
<td>834</td>
<td></td>
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<tr>
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<td>1290930144</td>
<td>562</td>
<td>899,3</td>
<td>-337</td>
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<td></td>
<td>1290930172</td>
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<td>583</td>
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<tr>
<td>1106D1035800 Total</td>
<td>1.145</td>
<td>899,3</td>
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<td>1106D1036700</td>
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<td>1290925254</td>
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<td>815,9</td>
<td>1.088,1</td>
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<td>1106D1046100</td>
<td>1290923811</td>
<td>419</td>
<td>526,5</td>
<td>-107,5</td>
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<td>1106D1046100 Total</td>
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<td>526,5</td>
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<td>1106D1097300</td>
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<td>1290931523</td>
<td>45</td>
<td>11,1</td>
<td>33,9</td>
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<td></td>
<td>1290931543</td>
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<td></td>
<td>1290931578</td>
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<td>206,6</td>
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<tr>
<td>1106D1097300 Total</td>
<td>1.363</td>
<td>589,9</td>
<td>773,1</td>
<td></td>
</tr>
<tr>
<td>1106D1165400</td>
<td>1290930663</td>
<td>707</td>
<td>943,3</td>
<td>-236,3</td>
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<td></td>
<td>1290931526</td>
<td>573</td>
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<td>573</td>
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<tr>
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<td>1290931905</td>
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<td>1106D1165400 Total</td>
<td>2.164</td>
<td>943,3</td>
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<tr>
<td>1106D1860400</td>
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<td>156,7</td>
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<tr>
<td></td>
<td>1290924527</td>
<td>270</td>
<td>296,4</td>
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</tr>
<tr>
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</tr>
<tr>
<td>1106D1861000</td>
<td>1290931531</td>
<td>166</td>
<td>221,3</td>
<td>-55,3</td>
</tr>
<tr>
<td></td>
<td>1290932046</td>
<td>1.114</td>
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<td>1.114</td>
</tr>
<tr>
<td>1106D1861000 Total</td>
<td>1.280</td>
<td>221,3</td>
<td>1.058,7</td>
<td></td>
</tr>
<tr>
<td>1106D1861500</td>
<td>1290930129</td>
<td>2.006</td>
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<td>1.991,7</td>
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<td></td>
<td>1290930135</td>
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<td>50,7</td>
<td>-12,7</td>
</tr>
<tr>
<td>1106D1861500 Total</td>
<td>2.044</td>
<td>65</td>
<td>1.979</td>
<td></td>
</tr>
<tr>
<td>1106D1865900</td>
<td>1290931436</td>
<td>782</td>
<td>60</td>
<td>722</td>
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<td></td>
<td>1290932503</td>
<td>268</td>
<td>559,3</td>
<td>-291,3</td>
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<tr>
<td>1106D1865900 Total</td>
<td>1.514</td>
<td>970</td>
<td>544</td>
<td></td>
</tr>
<tr>
<td>1106D1953900</td>
<td>1290931966</td>
<td>46</td>
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<td>46</td>
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<tr>
<td></td>
<td>1290931971</td>
<td>1.792</td>
<td>648,4</td>
<td>1.143,6</td>
</tr>
</tbody>
</table>
Table 18 shows the DTCs where negative energy balances were found, and their associated SS.

Using this report, solutions were identified where LV feeders of SS are incorrectly linked to TRF’s and in some cases an incongruence in the relation between LV branch and number of building.

One of the new features installed in the DPU is the use of the real voltage of DTC to calculate PFs, which makes the calculation of the voltage drops closer to reality, so the comparison between the voltage calculated in the PF and the actual measurement of the SM is more accurate, and in the case, that no topology errors should be near zero.

The results demonstrated that there are several SM with considerable voltage deviations and this does not always represent an error in the LV topology.

There are several reasons that justify the abovementioned errors:

- Most SMs installed are single-phase. Since DPU does not do an accurate mapping of the SM with the respective phase, it performs the calculations considering they are a balance three phase load;
- Both SM and DTCs have a class of precision around 1%;
In the case of an error of a measurement, or a dip in voltage in one of the 96 points of a voltage profile, the report detects a deviation of voltage (Figure 56).

**FIGURE 56: EXAMPLE OF SM VOLTAGE**

| Conclusion | The good performance of the energy balance report was confirmed, there is a possibility to generate automatic topology alarm. The voltage compare report is a useful tool to analyse the LV network, but can’t generate an automatic topology alarm event. |

### 3.3.3.4 EVALUATION OF RESULTS

The results shown in the previous section demonstrated the good performance of the integration of SM and DTC in a Power Flow tool, validating the defined architecture and the interfaces created between UGC and DPU. The field test validates the option and effort required to incorporate the SM and DTC in the network study, allowing a higher visibility of the LV network. In the first test field (PF in the past with real values of DTCs and SMs), demonstrated that there is an improvement of results in the inclusion of real data from SM and DTC.

With incorporation of the forecast and historical data in DPU, the chronological analysis indicates potential operational risks in “near-real-time” and in the future.

The next steps for this feature will be the test in larger network studies to better understand the impact of these new elements in the studies. After this, it will be possible to integrate this module into the corporate system of the company and implement at the national level in the studies of LV networks.

### 3.3.4 LV NETWORK RESILIENCE - REMOTE AND FULLY AUTOMATIC IN LINE VOLTAGE AND POWER FACTOR CONTROL

#### 3.3.4.1 TEST OBJECTIVES

To enable a more flexible and resilient distribution network two In-line Power Regulators (IPR) were installed in critical grid locations. The use of this equipment provides the DSO with a tool for dynamically
controlling voltage, power factor and harmonics in response to: high levels of Distributed Energy Resources (DER equipment and regulatory focus on reliability and energy efficiency)

The objective of this functionality is to assess the benefits of IPR usage on critical grid locations as they are a fast to install and easy to maintain equipment that helps solving grid voltage constraints.

3.3.4.2 TEST BED AND CONFIGURATION

In the scope of the project, two locations were chosen to install the IPR, based on voltage field measurements. In these locations, high voltage variations where measured throughout the day and there were times where voltage level was near the acceptable minimum. In these locations, voltage profile is also very important as there are several customers with sensitive equipment.

FIGURE 57: EQUIPMENT INSTALLED IN THE DEMONSTRATOR

Below are the connection schemes of the equipment that was deployed. With this mounting scheme, it is ensured in-line mounting with an external bypass for extra safety.

FIGURE 58: ASSEMBLY DIAGRAM OF IPR IN LISBON, RUA FERNANDO BENTO;
3.3.4.3 PERFORMED TESTS AND COLLECTED DATA

Although both pieces of equipment were tested, as the results have proven to be identical, for simplicity reason, we have chosen the results for one of them to be presented in the present report.

For performance assessment, high precision power quality equipment has been used to measure voltage, power factor and harmonic distortion throughout the grid. 3 points of measurement were chosen, as shown in the picture below. The first location for measurements acquisition was on the secondary substation bus bar. The second place (point 1) was right next to the IPR output. The third place (point 2) was near the network far end to correctly assess the equipment benefits.

For this document, three test scenarios were made to demonstrate the equipment’s main functionalities. The results are shown in the same image for each measurement point.
FIGURE 60: MAP CHARACTERISATION OF IPR EQUIPMENT
## TABLE 19: TEST PERFORMED IN 16-05-2017

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>LV Network Voltage Control and Harmonic Compensation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective</strong></td>
<td>Assess IPR simultaneous capability to regulate voltage and do harmonic compensation.</td>
</tr>
<tr>
<td><strong>Actions</strong></td>
<td></td>
</tr>
</tbody>
</table>
| - Load Voltage Regulation  
|   - Status: Enable  
|   - Mode: Set point  
|   - Regulation Set point: 235 V  
| - Harmonic Compensation  
|   - Load Voltage: Enable  
|   - Source Current: Enable  
| - Source Reactive Power  
|   - Status: Disable  |
| **Results**   | Confirmed the capability of the IPR equipment to maintain a steady output voltage profile independently of the source voltage profile.  
|               | A major reduction in harmonic content was measured when the IPR equipment harmonic distortion compensation functionality was enabled. |

## TABLE 20: TEST PERFORMED IN 06-06-2017

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>LV Network Voltage Control and Power Factor Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective</strong></td>
<td>Assess the IPR’s simultaneous capability to regulate voltage and maintain a steady output power factor.</td>
</tr>
<tr>
<td><strong>Actions</strong></td>
<td></td>
</tr>
</tbody>
</table>
| - Load Voltage Regulation  
|   - Status: Enable  
|   - Mode: Set point  
|   - Regulation Set point: 225 V  
| - Harmonic Compensation  
|   - Load Voltage: Disable  
|   - Source Current: Disable  
| - Source Reactive Power  
|   - Status: Enable  
|   - Reactive Power Mode: DPF  
|   - DPF Set point: 0,98  
| - DPF Direction: Lead  |
Results

Confirmed the capability of the IPR equipment in maintaining a steady output voltage profile independently of the source voltage profile with simultaneous reactive power control for power factor regulation.

### TABLE 21: TEST PERFORMED IN 09-06-2017

<table>
<thead>
<tr>
<th>Test NO 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Scenario</td>
</tr>
<tr>
<td>Objective</td>
</tr>
</tbody>
</table>

### Actions

- **Load Voltage Regulation**
  - Status: Enable
  - Mode: Deadland
  - Regulation Set point: 225-235 V
- **Harmonic Compensation**
  - Load Voltage: Disable
  - Source Current: Disable
- **Source Reactive Power**
  - Status: Disable

### Results

Confirmed the capability of the IPR equipment in maintaining the output voltage profile within the defined dead band.

![FIGURE 61: SECONDARY SUBSTATION ANALYSIS](image)
3.3.4.4 EVALUATION OF RESULTS

As seen above, in the chosen location, for load voltage regulation, sag/swell mitigation, reactive power compensations and harmonic cancellation, the proposed objectives were met. The use of IPR proved to be very useful for grid operation flexibly as it enables dynamic and precise control of electric variables in maintenance free and high availability equipment.
The picture below sums up the voltage regulation capabilities of the IPR equipment throughout one month. Thus, proving this type of equipment benefits LV grid resilience and flexibility – voltage input (red) and voltage output (green).

In the scope of the project, it was developed an interface between the Automatic in line Voltage and Power Factor Control Equipment installed in the demo site and UGC. This integration allows the Dispatch operator to receive real-time alarms of the installed equipment in the UGC, to have more observability and a more proactive approach over the LV network.

The integration of In-line power regulators in critical grid locations enables a more flexible and resilient distribution network, as this new agile grid equipment allows dynamic control over voltage, power factor and harmonics in response to high penetration levels of Distributed Energy Resources, increasing capacity constraints, sensitive costumer equipment and regulatory focus on reliably and energy efficiency.

In the past, the previous listed constrains could only be solved with large grid infrastructures investments. Now with this easy to install, cost-efficient, multi-function and maintenance free solution we can delay grid infrastructure investments and increase the level of control and supervision over the Low Voltage Grid.

### 3.3.5 LV MESHED NETWORK OPERATION - IDENTIFYING THE OPTIMUM TOPOLOGICAL CONFIGURATION

#### 3.3.5.1 TEST OBJECTIVES

The test validates the DPLAN UPGRID’s network topology recommendation changes and alarms of grid constrains sent to UGC, and thereby to the Dispatch Operator, to optimize the network performance and reduce the technical losses.

#### 3.3.5.2 TEST BED AND CONFIGURATION

Systems under test:

- DPLAN UPGRID;
At a given LV meshed network, where the normal isolation point between two circuits distributes the load between them, DPLAN UPGRID detects a considerable load deviation that justifies the change of the open point location, moving the open point to different equipment, changing the network configuration and therefore optimizing the load distribution between the circuits.

Test trigger:

- DPLAN UPGRID initiative - The network optimal condition is calculated by the DPLAN UPGRID, using an OPF algorithm running by an operator trigger, and when detected the need of a network reconfiguration to perform the respective optimization, it sends that information to the UGC, and the UGC thereby notifies the Dispatch Operator by showing an alarm.

Afterwards, the Dispatch Operator decides the best action to minimize the technical losses that ultimately may lead to the network topology’s change and sends to the UGC a plan of manoeuvres that reduces the technical losses.

### 3.3.5.3 PERFORMED TESTS AND COLLECTED DATA

#### TABLE 22: LV NETWORK GEOGRAPHIC REPRESENTATION

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>LV network’s geographic representation and location on DMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Geographic representation of the network</td>
</tr>
<tr>
<td>Actions</td>
<td>• MAP without Geographic context</td>
</tr>
</tbody>
</table>
FIGURE 65: ASSETS (NETWORK) IN GEOGRAPHIC REPRESENTATION

- MAP without Geographic context
Figure 66: Geographic excerpt of demo and respective network

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPF algorithm run by operator trigger</td>
<td>Recommended network topology optimizations</td>
</tr>
</tbody>
</table>

- Result of OPF algorithm run

![Figure with the electric scheme and comparison of losses costs](image)

- Acceptance of the manoeuvres due to the reduction of technical losses
In this test the operator decided to perform 4 manoeuvres in the fuses, leading to a reduction of 70€ on total of 1926€ of technical losses for the network under analysis. Obtaining a 3% reduction of technical losses in annual financial.

### Test Scenario

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Interface with UGC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Validate web service (WS) built between DPLAN UPGRID and UGC</td>
</tr>
<tr>
<td>Actions</td>
<td>• DPLAN UPGRID tab with the functionality of sending alarms and manoeuvres</td>
</tr>
</tbody>
</table>
Reception of the alarms resulting from the OPF, sent manually to the UGC

Reception of the manoeuvres resulting from the OPF, sent manually to the UGC

- 4 manoeuvres in the fuses with ID and action
3.3.5.1 EVALUATION OF RESULTS

Through the implementation of this functionality it was proven that DPLAN UPGRID can help detecting an optimal reconfiguration of the LV Network to reduce financial and technical losses.

For each of the DPU’s optimisation recommendation, the Dispatch Operator conducts a qualitative analysis and sends to UGC a plan of manoeuvres, with the purpose of reducing the technical losses. For the situation under analysis, it was possible to reduce 70 € in fuses, with 4 manoeuvres, on a total of 1926€ of technical losses for the network under analysis. It is then possible to obtain a 3% reduction in annual financial.

This feature provides a faster provision of information to the DSO, depending on the interface created with UGC. The alarms generated by Virtual Client suggest to the DSO an analysis of the detected constraints, after assessing the constraints and if the he intends to make a network configuration, the DSO has a suggestion in the UGC of manoeuvre orders with the aim of suppressing it.

Due to the existence of a more informed customer and a greater number of sensitive Dispatch Centres to rapidly assess network availability and mitigate technical losses. The solution developed in this project may be a starting point for use in a Portuguese LV Dispatch Centres.

3.3.6 IMPLEMENTATION OF NETWORK MANAGEMENT SYSTEM (NMS) BASED ON SIMPLE NETWORK MANAGEMENT PROTOCOL (SNMP) AT SS LEVEL

3.3.6.1 TEST OBJECTIVES

To ensure connectivity with all smart grid assets with increased requirements for online availability and transaction intensity, utilizing a complex heterogeneous underlying telecom platform that comprises and
integrates private technologies and third party services, requires new and adapted Operation Support Systems (OSS) strategy to attain the required service assurance and quality.

Within this scope, the pilot addressed the telecom’s infrastructure that comprises remote wireless routers and WAN connectivity supplied by a Mobile Network Operator (MNO) with the following objectives:

- Feasibility of using an Open-source platform to monitor connectivity quality of routers that use a MNO WAN service;
- Capability to drive a service incident resolution workflow;
- Develop MNO interface to support service incident debug and repair decision.

### 3.3.6.2 TEST BED AND CONFIGURATION

The test bed used three basic components, a NAGIOS/ICINGA open-source platform in a decentralized architecture with two probing engines and a central reporting engine, MNO manual queries into its existing service metrics and an operational team to drive the incident procedures.

![Diagram](image)

**FIGURE 72: M2M ARCHITECTURE FRAMEWORK**

### 3.3.6.3 PERFORMED TESTS AND COLLECTED DATA

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Objective</th>
<th>Actions</th>
</tr>
</thead>
</table>
| Scale Probes to monitor 14 k wireless routers | Evaluate scalability and applicability of Nagios and ICINGA | • Deploy two Internet Control Message Protocol (ICMP) and Simple Network Management Protocol (SNMP) Engines  
  ○ Define sampling window of 5 minutes  
  ○ Define rules for unavailable condition  
• Deploy Master collector |
Develop monitoring Dashboards
Develop web service to trigger external incident workflows

Results
The objective functionality was achieved, demonstrating that market proven open source tools can be deployed in smart grid operational scenarios capturing its economic benefit.

**FIGURE 73: INSTANT SUMMARY STATUS DASHBOARD**

**FIGURE 74: HOST EVENT AND STATUS DETAILS**
### Test MNO Service Interface

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Develop an interface that can on-demand supply status of MNO Service</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective</strong></td>
<td>Get MNO information to feed the debug and repair action plan, building the basis for further development of an Application Programming Interface (API) that can support automatic debugging for M2M.</td>
</tr>
</tbody>
</table>
| **Actions**         | • MNO information database  
|                     |   o Determine which internal counters should be used as service proxies  
|                     |   o Detect and store serving cells for each served terminal  
|                     | • MNO consulting interface  
|                     |   o Develop a webpage that can be used to query MNO service status  
|                     |   o Queries by International Mobile Subscriber Identity (IMSI) or Internet Protocol (IP) address |
| **Results**         | It is now possible to query on-line the MNO on any IMSI/IP supported on its network, receiving information on register status of the terminal, historical serving cells and their current operational status.  
|                     | This information is an important first step for service management improvement, contributing to the incident action plan, namely on a first decision on MNO service status and the need to trigger field intervention. |

### 3.3.6.4 EVALUATION OF RESULTS

The results prove the ability to develop assurance practices addressing the high volume of assets that characterise the Smart Grid environment, applying open-source tools to optimise the economic effort and capturing the abundant know-how on these resources.

In its aftermath, the demonstrator will now progress to leverage on open-source reporting and automation components, testing the ability to monitor in an as-needed-basis, further increasing the monitoring and debugging technical and economic efficiencies.

On the MNO management interface, this test opened and developed an important requirement area, demonstrating that, although MNOs do not monitor or collect individual service instance related information, the existing infrastructures and applicable standards support its implementation, with EDPD and the MNOs agreeing on further developing a service support API that can automate service impairments, minimising human intervention and producing analytic evidence of root causes as well as corrective actions.
3.3.7 VISUALIZATION OF DATA FROM LV MANAGEMENT SYSTEM IN A GEOGRAPHICAL CONTEXT

3.3.7.1 TEST OBJECTIVES

The geographic representation of the LV network, smart meters and DTCs in the UGC system, as well as validating the possibility of sending smart grid information requests directly in the map/geographic view, are the main objectives of the following tests.

3.3.7.2 TEST BED AND CONFIGURATION

1. Check the LV network geographic representation and location;
2. Check the Smart meters’ geographic representation and location and if the following services are available for the Dispatch Operator:
   a. Instant measurements – voltage, current, active and reactive power, power factor
   b. Load diagrams
   c. Events and alarms
   d. Turn ON/OFF command
3. Check the DTCs geographic representation and location and if the following services are available for the Dispatch Operator:
   a. Instant measurements – voltage, current, active and reactive power, power factor
   b. Load diagrams
   c. Events and alarms
   d. Internal schematic
   e. Internal view 360º

3.3.7.3 PERFORMED TESTS AND COLLECTED DATA

| TABLE 23: SET OF TESTS FOR THE REPRESENTATION OF LV NETWORK OVER GIS PLATFORM |
|---------------------------------|----------------------------------------------------------------------------------|
| **Test Scenario**              | LV network geographic representation and location                               |
| **Objective**                  | Geographic representation of the network based on Google Maps                     |
| **Actions**                    | • MAP View with the map option active                                             |
Figure 75: Excerpt of demo and respective network (geographic view)

MAP View with the satellite option active

Figure 76: Excerpt of demo and associated assets (satellite view)

<table>
<thead>
<tr>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure and grid integration in a geographic context, using Google Maps</td>
</tr>
<tr>
<td>Test Scenario</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>Objective</td>
</tr>
<tr>
<td><strong>Actions</strong></td>
</tr>
<tr>
<td><strong>Results</strong></td>
</tr>
</tbody>
</table>

**Figure 77: List of Actionable Options Over A SM**
<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>DTCs geographic representation and location and checklist a set of services are available for the dispatch operator (represented in the figure below)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Geographic representation of the DTC based on Google Maps and WS available for the DSO</td>
</tr>
<tr>
<td>Actions</td>
<td>• MAP View Detail select one DTC with right click</td>
</tr>
</tbody>
</table>

![FIGURE 78: LIST OF ACTIONABLE OPTIONS OVER A DTC/SS](image)

| Results       | WS available for the DSO in a geographic context, using Google Maps                                                                                                                                                                                         |

### 3.3.7.4 EVALUATION OF RESULTS

After completing the developments in the UGC, it was possible to validate the features that were proposed in D4.2 [1]. The geographic representation of the LV network including the smart meters and DTCs in the UGC improves the analyses performed by the Dispatch Operators. Furthermore, the information requested/send by the smart meters can help not only to confirm the outages extension but also to have a more supported and informed decision.
3.3.8 LV STATE ESTIMATION – SITUATION AWARENESS

3.3.8.1 TEST OBJECTIVES

The main purpose of the tests described below is to evaluate the performance of the LV State Estimation tool (LV SE) in terms of accuracy and computational time at different network operational scenarios. More information can be found in section 3.3.9 of the deliverable D4.2 [1].

3.3.8.2 PRELIMINARY ANALYSIS AND CONFIGURATION

At the time when these tests started to be carried out there were almost 3 months of historical measurement data available in the Cassandra DB, which were gathered by all the Smart Meters (SM) installed on the demonstrator site. From the raw SM data analysis, it was possible to conclude that:

- Only 54 out of the total SM installed (see deliverable D4.2 [1] for more details) had less than 10% of missing data (the percentage of missing data of the remaining SM was considerably larger), from which 53 SM belong to the same SS. For this reason, the tests performed took only into account the historical data of these SM.
- The consistency of the active (and reactive) power records gathered by the SM was very poor, i.e., there were a lot of missing values, much more than the verified for the voltage data. In this sense, the power measurements were not considered. As the main goal of the tests is the assessment of the voltage magnitudes estimation accuracy, the inclusion of power measurements is not mandatory, although it could contribute to improve the estimation accuracy of such variable. In fact, the voltage measurements, in a highly resistive LV grid, are the main variable to detect potential technical problems and provide voltage alarms to the operator.
- The DTC installed on the referred secondary substation was not configured to record voltage magnitude values. Thus, such data was not considered in the tests performed.
- The customers’ connection phase was only known for the three-phase customers. Nevertheless, the connection phase determination for single-phase customers was possible to be performed through a correlation analysis between the voltage magnitudes data of both types of customers.

Taking in consideration what was stated before, Table 24 summarises the customers’ distribution (represented by their meters ID) across the 6 feeders of the secondary substation and their connection phase.

**TABLE 24: CUSTOMERS DISTRIBUTION**

<table>
<thead>
<tr>
<th>Feeder ID</th>
<th>Meter ID</th>
<th>Phase</th>
<th>Feeder ID</th>
<th>Meter ID</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SM001</td>
<td>CN</td>
<td>6</td>
<td>SM028</td>
<td>CN</td>
</tr>
<tr>
<td>1</td>
<td>SM002</td>
<td>BN</td>
<td>6</td>
<td>SM029</td>
<td>BN</td>
</tr>
<tr>
<td>1</td>
<td>SM003</td>
<td>BN</td>
<td>6</td>
<td>SM030</td>
<td>AN</td>
</tr>
</tbody>
</table>
Although the 53 SM referred are the ones with less percentage of missing data, the time instants with inconsistencies were not the same for every SM considered. Thus, the historical database was processed to synchronise the voltage measurements of all SM, which consisted of the intersection of all time instants.
with available data. After this process, the synchronised historical database was composed by 3,393 time instants (time steps of 15 minutes), which would be used for training purposes.

Before training the state estimation model, the SM with the capability of transmitting data in real-time (SM\(_\text{RT}\)) had to be defined. In general terms, the criterion behind the choice of SM\(_\text{RT}\) was to ensure the existence of electrical information, at least, in all the network feeders and in all phases. In this sense, after a correlation analysis between the voltage magnitude values available in the historical database, 1 SM\(_\text{RT}\) per phase was selected for monitoring at a given customer’s premise voltage magnitudes in each one of the network feeders, making a total of 10 SM\(_\text{RT}\): 4 three-phase SM\(_\text{RT}\) and 6 single-phase SM\(_\text{RT}\) (see Table 24). This scenario represents the network operational scenario in terms of telemetry (scenario 1).

A state estimation model was trained considering the telemetry scenario defined above and it was performing state estimations for a period of one week (672 time instants), according to what was described in deliverable D4.2 [1]. The performance of the LV SE was then assessed, which is presented and discussed in the section 3.3.9.3.1.

Afterwards, two other scenarios were defined to evaluate the LV SE performance. Scenario 2 is a more optimistic scenario. In addition to the SM\(_\text{RT}\) considered in scenario 1, another SM\(_\text{RT}\) per phase was selected in the feeders with less percentage of real-time telemetry (considering the number of customers connected to each one), making a total of 16 SM\(_\text{RT}\): meaning more 3 three-phase SM\(_\text{RT}\) and 3 single-phase SM\(_\text{RT}\) (see Table 25) in comparison with scenario 1. The selection process employed was the same as the one described before. Scenario 3 represents a particular case of scenario 1. The SM\(_\text{RT}\) considered were the same as in scenario 1, but this new scenario was intended to emulate the SM\(_\text{RT}\) failures, either in the measurement acquisition or in the data sending (e.g. communication problem), which can occur in real applications.

The same time horizon as before (3,393 samples for training purposes and 672 samples for the test period) was used in order to be possible to make comparisons between all scenarios.

In Table 25 are summarised the scenarios considered in the scope of this test.

### TABLE 25: ASSESSMENT SCENARIOS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>No. (\text{SM}_{\text{RT}})</th>
<th>No. of real-time measurements (m)</th>
<th>No. of variables to be estimated (n)</th>
<th>(m/n) (%)</th>
<th>Meter ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>18</td>
<td>63</td>
<td>28.6</td>
<td>SM001, SM011, SM012, SM017, SM027, SM036, SM040, SM043, SM044, SM053</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>30</td>
<td>51</td>
<td>58.8</td>
<td>SM001, SM002, SM004, SM007, SM011, SM012, SM017, SM025, SM027, SM035, SM036, SM040, SM043, SM044, SM052, SM053</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>18</td>
<td>63</td>
<td>28.6</td>
<td>SM001, SM011, SM012, SM017, SM027, SM036, SM040, SM043, SM044, SM053</td>
</tr>
</tbody>
</table>
3.3.8.3 PERFORMED TESTS

In the present section, the LV SE performance is assessed for each one of the scenarios previously defined. The results depict the absolute error computed for the voltage magnitude in all customers’ premises not being monitored in real-time (in each scenario) for the test period of 672 time instants. The absolute error was calculated between the real values (gathered by the SM installed at customers’ premise) and the estimated values obtained with the LV SE developed.

### 3.3.8.3.1 SCENARIO 1

As stated before, this scenario represents the current network operating conditions, i.e., this is the real network field situation in terms of telemetry (19% of the total customers own a SM\(_{RT}\)).

![Figure 79: Voltage Magnitude Absolute Error for All Customers (Not Being Real-Time Monitored) in Scenario 1](image)

In Figure 79 it can be observed that the third quartile of the state estimation error obtained is at maximum 0.43 V for the customer with the SM032 (connected to phase B), which gives good indications regarding the estimation accuracy of the LV SE.

It is also possible to see that the maximum absolute error obtained was 1.98 V for the customer with the SM018 (connected to phase C). This value occurs only once and the next higher value is lower than 1.56 V. This result can be observed in Table 26, where the four worst absolute error values obtained for the SM018 are presented.

<table>
<thead>
<tr>
<th>Absolute error (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.98</td>
</tr>
<tr>
<td>1.55</td>
</tr>
<tr>
<td>1.36</td>
</tr>
<tr>
<td>1.29</td>
</tr>
</tbody>
</table>

Moreover, the number of occurrences higher than 1 V is short. In Figure 80, the Empirical Cumulative Distribution Function (ECDF) of the absolute error for the SM018 is depicted, giving a better perspective about the percentage of the absolute error that stays below a given value. From its analysis, in 97.6% of
the cases the absolute error is lower than 1 V, and in 86.6% of the time instants the absolute error is lower than 0.5 V.

![Figure 80: Empirical Cumulative Distribution Function of the Voltage Magnitude Absolute Error Obtained for the Customer with SM018 in Scenario 1](image)

Furthermore, extending the previous analysis to all customers for which state estimation was performed, it can be concluded that the voltage magnitude absolute error is lower than 1 V and 0.5 V in 99.5% and 90.5% of the time instants analysed, respectively. This can be attested observing Figure 81.

![Figure 81: Empirical Cumulative Distribution Function of the Voltage Magnitude Absolute Error Obtained for All Customers in Scenario 1](image)

Regarding the computational time performance of the LV SE, several Key Performance Indicators (KPIs) were computed (see deliverable D2.1 for more details):

- State estimation model training time: 0.044 seconds
- Real-time data processing time: 0.060 seconds
- State estimation running time: 0.345 seconds (the average time of performing state estimation for the 672 time instants)
- Total computational running time: 0.405 seconds

3.3.8.3.2 SCENARIO 2

In the present scenario, the redundancy of real-time measurements in each phase of the feeders with less percentage of real-time telemetry was considered: feeders with ID 1, 4, 6 and 8. The additional 6 SM\text{RT}
selected for this scenario (see Table 25) are represented without boxplot in Figure 82. In this optimistic scenario, 30% of the total customers were considered as owning a SMRT.

![Figure 82: Voltage magnitude absolute error for all customers (not being real-time monitored) in scenario 2](image)

Comparing the voltage magnitude absolute error obtained in scenarios 1 and 2 (Figure 79 and Figure 82, respectively), it can be noticed that, as expected, the estimation accuracy is improved when more real-time measurements are available. The third quartile of the state estimation error obtained in this scenario is at maximum 0.38 V for the phase A of the customer with the SM026 (three-phase customer).

Moreover, and similarly to what was done for the previous scenario, the voltage magnitude absolute error obtained in scenario 2 is lower than 1 V and 0.5 V in 99.9% and 95.6% of the time instants analysed, respectively. This can be concluded from Figure 83.

![Figure 83: Empirical cumulative distribution function of the voltage magnitude absolute error obtained for all customers in scenario 2](image)

In what concerns to the LV SE computational time performance:

- State estimation model training time: 0.039 seconds;
- Real-time data processing time: 0.070 seconds;
- State estimation running time: 0.324 seconds (the average time of performing state estimation for the 672 time instants);
- Total computational running time: 0.394 seconds.
3.3.8.3.3 SCENARIO 3

Scenario 3 was intended to evaluate the LV SE performance in the particular situation where SM<sub>RT</sub> failures, such as measurement acquisition or data sending failures (e.g. communication issues), occur. As described in the deliverable D2.1, when a given measurement that was previously available in real-time suddenly becomes no longer available due to some abnormal event that may have occurred, the LV SE algorithm can overcome this issue, either by turning these variables (which are no longer available) into variables to be estimated or through the integration of forecasted measurements from the Net Load and Generation Forecasting component.

In the present test, only the estimation of variables that became non-available was performed, since power measurements were not considered for the reason already stressed in section 3.3.8.2. As scenario 3 represents a particular case of scenario 1, the number of real-time measurements that became non-available was increased until 50% of the real-time measurements available in scenario 1 were reached (see Table 26). For the same reason, the same state estimation model as in scenario 1 was used.

It should be noted that failures only in three-phase SM<sub>RT</sub> were considered, since they represent the worst case in terms of missing data (missing 3 voltage measurements at once). The SM<sub>RT</sub> with failure are presented at the end of each graphical representation of Figure 84 to facilitate comparisons. The shown 17%, 33% and 50% of data failure represents the failure of 1, 2 and 3 three-phase SM<sub>RT</sub>, respectively.

![FIGURE 84: VOLTAGE MAGNITUDE ABSOLUTE ERROR FOR ALL CUSTOMERS (NOT BEING REAL-TIME MONITORED) WHEN SOME REAL-TIME MEASUREMENTS ARE NOT DELIVERED TO THE LV SE](image-url)
Comparing Figure 79 and Figure 84, the estimation accuracy decreases when the percentage of data failure increases. However, the accuracy decrease verified with 17% of data failure is not very pronounced. In Figure 84, it can also be observed that the third quartile of the estimation error obtained for this failure percentage is at maximum 0.54 V for the customer with the SM038 (connected to phase C), which highlights the LV SE accuracy. Even when 50% of data failure occurs, the LV SE has a satisfactory performance, mainly if it is considered that the LV SE did not have any real-time measurement from 3 out of the 6 network feeders (IDs 3, 6 and 8). In this case, the third quartile of the state estimation error obtained is at maximum 1.16 V for the customer with SM013, connected to phase C.

Figure 85 depicts the ECDF of the voltage magnitude absolute error obtained for all customers in scenario 3. Observing this figure, the absolute error is lower than 1 V in 97.8%, 91.2% and 78.1% of the time instants analysed, according to the percentage of data failure considered: 17%, 33% and 50%, respectively.

**FIGURE 85: EMPRICAL CUMULATIVE DISTRIBUTION FUNCTION OF THE VOLTAGE MAGNITUDE ABSOLUTE ERROR OBTAINED FOR ALL CUSTOMERS IN SCENARIO 3**

In terms of computational time, the LV SE performance during this test was like the obtained in scenario 1. Table 27 presents the state estimation running time and the total computational running time, which are slightly different from the obtained in scenario 1. It should be recalled that a new training procedure did not have to be performed, since the same state estimation model as in scenario 1 was used.

**TABLE 27: COMPUTATIONAL TIME PERFORMANCE OF THE LV SE IN SCENARIO 3**

<table>
<thead>
<tr>
<th>Percentage of data failure (%)</th>
<th>State estimation running time (seconds)</th>
<th>Total computational running time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>0.343</td>
<td>0.403</td>
</tr>
<tr>
<td>33</td>
<td>0.340</td>
<td>0.400</td>
</tr>
<tr>
<td>50</td>
<td>0.361</td>
<td>0.421</td>
</tr>
</tbody>
</table>

3.3.8.4 EVALUATION OF RESULTS

The results shown in the previous section demonstrate the good performance of the LV SE tool regarding the estimation of voltage magnitude values. This feature is preserved even when some real-time measurements suddenly become no longer available. Although the overall accuracy decreases as function
of the increase in the percentage of data failure, the LV SE managed to estimate voltage magnitudes with enough accuracy, namely when a real-time data failure of 17% occurred. As expected, the addition of real-time measurements leads to a general improvement of the state estimation accuracy. However, in a real-world application, the trade-off between a better accuracy and an increased cost should be carefully analysed.

The good performance of the LV SE on effectively and accurately estimating voltage magnitude values can also be attested observing Figure 86 and Figure 87, which present the Mean Absolute Error (MAE) KPI and the Mean Absolute Percentage Error (MAPE) KPI, respectively, both computed for each time instant (of each scenario). These KPIs (described in deliverable D2.1), as well as the MAE considering the entire test period (Table 28), are in accordance with what was stated in the previous paragraph.

![Figure 86: Mean Absolute Error Obtained in Each Scenario](image1)

![Figure 87: Mean Absolute Percentage Error Obtained in Each Scenario](image2)

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3 - 17% Data Failure</th>
<th>Scenario 3 - 33% Data Failure</th>
<th>Scenario 3 - 50% Data Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAE (V)</td>
<td>0.23</td>
<td>0.18</td>
<td>0.30</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Regarding the computational time performance of the LV SE, it was evident the short computational time required for both training and state estimation procedures. In fact, the LV SE took less than half a second to perform state estimation for the network considered in the scope of the present test, which makes it suitable for real-time applications.
3.3.9 INTEGRATION AND PROCESSING OF METER EVENTS OR/AND OTHER SOURCES (E.G. TELECOMMUNICATION DATA) IN THE OUTAGE MANAGEMENT SYSTEM (OMS)

3.3.9.1 TEST OBJECTIVES

This test intends to demonstrate how the correlation between data from external entities such as the Telecommunication Operators and the meter events can be transformed into actionable insights for the DSO.

3.3.9.2 TEST BED AND CONFIGURATION

The UGC receives data from Telecommunication Operators with the purpose of correlating it with the Alarms/Events from the Smart Meters and DTCs, not only to add additional information about ongoing outages, allowing to complement the extent of the fault, but also to anticipate possible outages in the LV network that have not been spotted yet. More information can be found in section 3.3.10 of the deliverable D4.2 [1].

The systems involved in this test were UGC, Outage Management System, Sinapse and InovGrid Infrastructure.

UGC receives Sinapse events in the following cases:

- If six or more customers’ set-top boxes or internet routers in the same area with the same postcode are not communicating;
- If a TelCo operator antenna or repeater is not communicating.

For the test period, considered from 1-03-2017 to 31-07-2017, it has only register events for the set-top boxes and internet routers. These events were only related to TelCo failures and not correlation with OMS occurrences.

3.3.9.3 PERFORMED TESTS AND COLLECTED DATA

The following table describes the several tests performed to validate how the correlation between the data from the smart grid infrastructure and the TelCos can be useful to the grid operation and help to detect the outage extent.

<table>
<thead>
<tr>
<th>TABLE 29: INTEGRATION OF DATA FROM THE TELCOS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test Scenario</strong></td>
</tr>
<tr>
<td><strong>Objective</strong></td>
</tr>
</tbody>
</table>
DSO (the dispatch operators are alerted to it).

- For each SINAPSE event received in UGC, the following test procedure was applied:
  - UGC notifies the operator with a Sinapse alarm, when 6 or more set-top-boxes are off in the same street.
  - The dispatch operator checks in the OMS for possible ongoing outage or trouble calls in that location. If there is an ongoing outage, the Dispatch Operator reanalyses the possible outage extent, and sends that info to field teams.
In case, there are no ongoing outages or trouble calls registered in the OMS for that area, the dispatch operator sends an instant voltage and current requests for the smart meters and DTCs of the SINAPSE alarm’s nearby area to confirm if there is a problem in the LV network or in the Telecommunication Network.

In the test conducted, it was possible to conclude that the Sinapse alarms were not related with real LV network outages.

### 3.3.9.4 EVALUATION OF RESULTS

The integration of information automatically collected from external entities on UGC such as alarms from the Telecommunication Operator improves the approach on the treatment outages. The inclusion of data from external entities is important mainly for the following reasons:

1. It allows to enrich the information about the ongoing LV network outage
2. It enables the dispatch centre to reduce the time to receive the outage, compared to the current procedures where the only trigger the DSO has, to know that there is a problem in the LV network is through a customer call, thus reducing the outages’ restaturation time.

### 3.3.10 ALGORITHM TO DETERMINE CONNECTIVITY OF SM TO THE GRID (IDENTIFICATION OF PHASE AND LINE TO WHICH EACH SM IS CONNECTED TO)

#### 3.3.10.1 TEST OBJECTIVES

The objective of this solution is to detect and map the phase and the feeder of the secondary substation where the smart meters are connected to. A complete phase and feeder mapping of smart meters at LV network level (and therefore end customer’s delivery point) is key to improve the asset management, network planning and to enable a better monitoring of both energy unbalances, losses and quality of supply.

The architecture of this solution is presented in the figure below and is based on complementary hardware and software components with the following breakdown:
Hardware:

1. Electrical sensors to monitor each LV feeder and the power transformer;
2. Bridge to gather data from all feeders and to send it to a central application;
3. Smart meters with the ability to trigger events related to current variations. For this purpose, new firmware versions were developed and integrated in the DTCs (with this new specific feature);
4. DTC to collect data from all the smart meters of the SS and to send its data to a central application.

Software (at central system level):

5. Dedicated File Transfer Protocol (FTP) server to receive data from the field devices;
6. Application, with a specific algorithm, to process and correlate all the data sent by the smart meters and devices at SS.

The idea behind this solution is the ability to correlate the variation of some electrical measurements at the secondary substation with the current variation in each one of the smart meters installed in the corresponding LV network. On one hand, the solution provides detailed electrical measurements of the secondary substation with discrimination per power transformer, each one of the LV feeder and phases. The main electrical measurements under monitoring are: Irms (A), Vrms (V), Power factor, Active and Reactive Power (+P, -P, +Q, -Q), Active and Reactive Energy consumption (+A, -A, +Ri, -Ri, +Rc, -Rc).

On the other hand, at the smart meters side, a specific event is triggered and recorded whenever there is a current variation over a pre-defined threshold, with default value of 0,2A.
3.3.10.2 TEST BED AND CONFIGURATION

The test and validation of this solution was planned in a two-step approach: i) laboratory testing and ii) subsequent field trial.

The purpose of the testing in a laboratory environment was to validate the concept and to fine tune the solution. To this end, a secondary substation with 4 different LV feeders and 90 smart meters connected overall was simulated.

![Laboratory Testing Setup](image1)

FIGURE 91: LABORATORY TESTING SETUP

The field trial is meant to replicate and scale up the laboratory tests in real case scenarios. In this case, 5 different secondary substations with multiple LV feeders each were selected.

<table>
<thead>
<tr>
<th>Secondary Substation ID (# Power Transformers)</th>
<th>LV feeders to equip</th>
</tr>
</thead>
<tbody>
<tr>
<td>8645 (1)</td>
<td>8</td>
</tr>
<tr>
<td>8645 (2)</td>
<td>6</td>
</tr>
<tr>
<td>8593 (1)</td>
<td>6+6</td>
</tr>
<tr>
<td>6321(1)</td>
<td>7</td>
</tr>
<tr>
<td>9734 (3)</td>
<td>7</td>
</tr>
</tbody>
</table>
3.3.10.3 PERFORMED TESTS AND COLLECTED DATA

At the laboratory environment previously described (1 SS, 4 LV feeders, 90 meters), real loads, such as pure resistive loads and energy efficient LED lamps, were connected to a subset of smart meters. These loads were afterwards randomly connected and disconnected to trigger the generation of current variations events on the meters.

On daily basis, a large amount and diversity of data from the current sensors installed in all 4 LV feeders and the smart meters’ events were collected and sent to the FTP server at the central system level. There is data with different granularity – 5 minute profiles, hourly and daily measurements and events. This data was afterwards used as inputs to the solutions’ algorithms – to detect phase and feeder of each smart meter.

Also on daily basis, there is a system report generated with the update of all smart meters already topologically mapped (LV feeder and phase). Thereafter, the content of this report is validated and checked against the real electrical topology to assess the accuracy and effectiveness of the solution under testing.

Examples of data collected and used as inputs to the algorithms:

![Figure 92: Daily Electrical Measurements Collected at LV Feeders](image-url)
WP4 – DEMONSTRATION IN REAL USER ENVIRONMENT: EDPD - PORTUGAL

D4.3 EVALUATION OF DEMONSTRATION RESULTS AND DATA COLLECTION

FIGURE 93: HOURLY ELECTRICAL MEASUREMENTS COLLECTED AT LV FEEDERS

FIGURE 94: 5' PROFILE COLLECTED AT LV FEEDERS
3.3.10.4 EVALUATION OF RESULTS

The results obtained so far are very promising, both regarding the positive identification rate and accuracy. The mechanism is proving to be reliable, as the accuracy of the automatic feeder and phase mapping is 100%, i.e. for all the smart meters already mapped by the solution, the identification of the LV feeder and phase were in accordance with the real electrical topology. As for the identification rate, the results are good and above 90%. This figure, however, strongly depend on the current variations measured by the devices and should increase in real case scenarios. At the laboratory environment, although these variations are being randomly triggered, due to setup limitations not all smart meters are connected to a real load – there is no current variation events triggered for some smart meters.

For the purpose of this feature, the more current variation events the better, not only in terms of identification rate but also regarding the lead time needed to find the proper match between smart meter and feeder + phase. During the tests, we observed that usually 1 or 2 days with meaningful events from each smart meter is enough to obtain a positive identification.

In conclusion, the existing results do validate the output of this automatic feeder mapping algorithm and therefore the added value to the impacted use cases, namely asset management, network planning, energy balancing and loss monitoring, quality of supply.
3.3.11 NETWORK MONITORING – SMART GRID INFRASTRUCTURE PERFORMANCE AND POWER QUALITY ASSESSMENT

To better complement the developments of the project, a set of dashboards has been developed. The indicators chosen to be implemented are related to the supervision of the Smart Grid infrastructure and the power & voltage monitoring.

3.3.11.1 TEST OBJECTIVES

The main objective of the indicators for the Smart Grid infrastructure supervision is the analysis of the infrastructure Sysgrid (SMs/DTCs) through the assessment of the readings associated with the equipment and the corresponding services.

The main objectives of the indicators for the voltage and power monitoring are:

- Evaluation of the conformity of the measured effective value of the voltage over the grid (SMs/DTCs) with respect to regulatory limits;
- Identification of the worst performing grid points for voltage values (over voltages and under voltages);
- Identification of the periods of the day for which the most unfavourable voltage values are observed\(^4\);
- Evaluation of the design and use of the MV/LV transformers by analysing the powers measured by the DTCs;
- Evaluation of performance of the LV grid through the analysis of the power measurements by the DTCs.

Different indicators may be evaluated, namely the power factor.

3.3.11.2 TEST BED AND CONFIGURATION

Figure 96 represents the architecture solution used for the data flow and preparation of the dashboards. The main source of information is UDM. This model is loaded in a specific SAS file system and will be available for exploration. Additionally, information available through external files will be loaded in an Oracle schema via SAS Enterprise Guide tool where the indicators are created and loaded in the UPGRID data model. The resulting tables from the data model are subsequently uploaded to a SAS LASR Server memory to be used as the basis for the development of the dashboards for both Smart Grid Infrastructure Supervision and Voltage & Power monitoring.

\(^4\) Different analysis is possible and can be selected by means of different filters (time horizon, measurement point type, measurement point distance to DSS, LV, grid size, customers' contracted power and DSSs' installed power)
In the CONTROL-M platform an automatic routine with an application layer is created:

- Point 1: SAS ETL;
- Point 2: Data upload to LASR;

And a layer corresponding to the interaction between the users and the application:

- Point 3: Access to in memory tables using SAS Visual Analytics;
- Point 4: Exploration of data model using SAS Enterprise Guide and parameterization of the input information.

The data used in the dashboards comes from UDM, while the identification of the equipment is available via an external file. The external file used for the smart grid infrastructure supervision can have a maximum of 15,000 SMs and 300 DTCs. The external file used for Voltage and Power Monitoring can have a maximum of 2,000 SMs and 300 DTCs.

The historic of the last 90 days of data on the equipment identified is presented.
The set of indicators under analysis are shown in Table 31 and Table 32.

**TABLE 31: LIST OF INDICATORS – SMART GRID INFRASTRUCTURE SUPERVISION**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMs installed</td>
<td>Number of installed SMs and installation location</td>
</tr>
<tr>
<td>SMs registered</td>
<td>Number of registered SMs and location</td>
</tr>
<tr>
<td>SMs not registered</td>
<td>Number of not registered SMs and location</td>
</tr>
<tr>
<td>DTC installed</td>
<td>Number of installed DTCs and installation location</td>
</tr>
<tr>
<td>SMs registered by DTC</td>
<td>Number of SMs registered in each DTC</td>
</tr>
<tr>
<td>SMs without data (readings)</td>
<td>SMs with no readings in a specified date range</td>
</tr>
<tr>
<td>Number of readings (SMs)</td>
<td>Number of readings in SMs in a specified date range</td>
</tr>
<tr>
<td>Number of readings per DTC</td>
<td>Daily number of readings in SMs associated to each DTC</td>
</tr>
<tr>
<td>Success of services execution</td>
<td>Number of services executed with success</td>
</tr>
</tbody>
</table>

**TABLE 32: LIST OF INDICATORS – POWER AND VOLTAGE MONITORING**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum deviation from reference value</td>
<td>Maximum voltage (V) deviation from a determined reference value for a specific time horizon</td>
</tr>
<tr>
<td>Minimum deviation from reference value</td>
<td>Minimum voltage (V) deviation from a determined reference value for a specific time horizon</td>
</tr>
<tr>
<td>Number of readings (SMs)</td>
<td>Number of readings in SMs in a specified date range</td>
</tr>
<tr>
<td>Maximum Power</td>
<td>Maximum power (kW) values in a selected period (A+)</td>
</tr>
<tr>
<td>Average Power</td>
<td>Average power values in a selected period (A+)</td>
</tr>
<tr>
<td>Maximum Power Vs Installed Power</td>
<td>Ratio between the maximum power and installed power</td>
</tr>
<tr>
<td>Average Power Vs Maximum Power</td>
<td>Ratio between the average power and maximum power</td>
</tr>
<tr>
<td>Average Power Vs Installed Power</td>
<td>Ratio between the average power and installed power</td>
</tr>
<tr>
<td>Cos(phi)</td>
<td>Power factor</td>
</tr>
<tr>
<td>Hours in (A-)</td>
<td>Number of hours with negative flux of power (A-)</td>
</tr>
</tbody>
</table>
3.3.11.3 PERFORMED TESTS AND COLLECTED DATA

Smart Grid Infrastructure Supervision - Sysgrid (SMs and DTCs)

SMs and DTCs Information

The dashboard is divided in two sections, one related to SMs information and the other to DTCs information. In the two sections the time horizon for the data available data is displayed.

It is possible to browse between different graphics according to the specified indicators for SMs and DTCs, for different time horizons and selecting different filters (Operational area, county, parish, model and state of the SMs). The regional map enables the drill down and one can also consult the details of the SMs and DTCs equipment.

![Smart Grid Infrastructure Supervision - Sysgrid (SMs and DTCs)](image)

FIGURE 97: VIEW OF SECTION FOR “SMART METERING INFORMATION”

The two sections of the dashboard have the same type of analysis for SMs and DTCs. Thus, it will be presented the graphics existing in the dashboards for section “SMs’ information” and the calculation formulas for the indicators for the SMs since the same calculation methods were used for the DTCs.

- SMs commissioning status
FIGURE 98: SM COMMISSIONING STATUS GRAPHIC

- Coordinate maps and detail table for SMs

This hidden window (clicking in the region map it enable to redirect to this window) has all the information for the SMs (DTCs) and allows the search for a specific serial number or installation code. One can also download this information as pdf file.

FIGURE 99: VIEW OF COORDINATE MAPS AND TABLE DETAIL FOR SMART METERING
Using the sliding window, it is possible to verify the number of equipment with no readings from the specified day in the slicer.

![Graph of the number of equipment with no readings](image)

**FIGURE 100: GRAPHIC OF THE NUMBER OF EQUIPMENT WITH NO READINGS**

- **Services executed (by date)**

This graph shows the total number of services executed and the ones executed with success for the last 90 days. It is possible to drill down the date and analyse a specific week.

The metric is valued with 1 if the service was successful and 0 if it did not succeed, according to the defined rules.

![Graph of service evaluation](image)

**FIGURE 101: GRAPHIC OF EVALUATION OF SERVICE EXECUTED**

- **Collected readings (by date)**

This graph shows the number of collected readings for the last 90 days. The metric is valued with the number of daily readings for each SM.

![Graph of collected readings](image)

**FIGURE 102: GRAPHIC OF EVALUATION OF COLLECTED READINGS**
➢ **Success of collected readings**

This graph represents the number of readings collected with success. The calculation of this parameter is given by the ratio between the total number of readings collected from the SMs by the number of SMs installed.

![Figure 103: Graphic of Evaluation of Success of Collected Readings](image)

➢ **SMs by Equipment brand**

Number of SMs installed, registered and not registered according to the existing brands.

![Figure 104: Graphic with Smart Metering by Equipment Brand](image)

➢ **SMs by Equipment model**

Number of SMs installed, registered and not registered according to the existing models.

![Figure 105: Graphic with Smart Metering by Equipment Model](image)
➢ **SMs by parish**

Number of SMs installed, registered and not registered distributed by parish.

![Graph showing SMs by parish](image)

**FIGURE 106: GRAPHIC WITH SMART METERING BY PARISH**

➢ **Collected readings by equipment model**

This graph gives the number of SMs installed with readings and the ones without readings for the different equipment models. It is possible to control the number of days for this analysis using the sliding window explained previously in this document.

![Graph showing collected readings by equipment model](image)

**FIGURE 107: GRAPHIC WITH COLLECTED READINGS BY EQUIPMENT MODEL**

➢ **Collected readings by equipment brand**

This graph gives the number of SMs installed with readings and the ones without readings for the different equipment brands. It is possible to control the number of days for this analysis using the sliding window explained previously in this document.

![Graph showing collected readings by equipment brand](image)

**FIGURE 108: GRAPHIC WITH COLLECTED READINGS BY EQUIPMENT BRAND**
Weekly total per indicator

This graph gives a general weekly overview of the SMs state for the three indicators.

![Graph showing weekly total per indicator](image)

FIGURE 109: GRAPHIC OF THE WEEKLY OVERVIEW OF SMS INSTALLED, SMS REGISTERED AND SMS NOT REGISTERED

Power & Voltage Monitoring

The dashboard is divided in three sections: two of them are associated with the voltage analysis of the SMs and DTCs (one for the daily analysis and the other for the weekly analysis) and the other section for the analysis of the power for DTCs (daily and weekly).

It is possible to browse between different graphics according to the specified indicators for voltage and power. Several filters can be chosen in the “Parâmetros” button, such as SMs and DTCs models, equipment state, distance from the SS (SMs), contracted power (SMs), transformer power (DTCs) and number of customers for low voltage grid.

For the voltage analysis sections, it can be introduced a specific serial number or DSS number as filters, while for power section it can be filtered by the equipment (DTC) number.

Voltage sections (SMs and DTCs)

The two sections of the dashboard have the same type of analysis. Therefore, it will be presented and explained the graphics existing in the dashboards for section “Tensão Diária” as well as the formulas for the calculation of the indicators.

---

5 Daily Voltage
Coordinates map for Voltages ($|\Delta 100|$)

The red bubbles in the map represent the worst case between the $|\Delta \text{Max}100|$ and $|\Delta \text{Min}100|$ for voltage values. The green bubbles represent the best cases.
Information table – Indicators

This table shows the results for the indicators related to the voltages selected. The colour scheme respects the following rules:

1. Green signal for the percentages until 6%, exclusive;
2. Yellow signal for the percentages between 6% and 10%, exclusive;
3. Red signal for the percentages from 10%, inclusive.

FIGURE 112: COORDINATES MAP FOR VOLTAGES

FIGURE 113: TABLE WITH INDICATORS FOR VOLTAGES
### TABLE 33: INDICATORS – POWER AND VOLTAGE MONITORING

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vmax_100</td>
<td>Maximum observed voltage 100%</td>
</tr>
<tr>
<td>Δmax_100</td>
<td>Maximum Reference Deviation 100%</td>
</tr>
<tr>
<td>Vmin_100</td>
<td>Minimum observed voltage 100%</td>
</tr>
<tr>
<td>Δmin_100</td>
<td>Minimum Reference Deviation 100%</td>
</tr>
<tr>
<td>Vmax_95</td>
<td>Maximum observed voltage 95%</td>
</tr>
<tr>
<td>Δmax_95</td>
<td>Maximum Reference Deviation 95%</td>
</tr>
<tr>
<td>Vmin_95</td>
<td>Minimum observed voltage 95%</td>
</tr>
<tr>
<td>Δmin_95</td>
<td>Minimum Reference Deviation</td>
</tr>
<tr>
<td>%Inválidos</td>
<td>Invalid data</td>
</tr>
<tr>
<td>%Considerados</td>
<td>Valid Data</td>
</tr>
<tr>
<td>%Falta</td>
<td>Missing Data</td>
</tr>
<tr>
<td>Quantidade</td>
<td>Quantity</td>
</tr>
<tr>
<td>Quantidade Esperada</td>
<td>Expected Quantity</td>
</tr>
</tbody>
</table>

The formula for the calculation of the Maximum Reference Deviation 100% is:

\[
\text{DESV}_\text{REF} \% = \frac{(\text{V}_{\text{max}} - \text{V}_{\text{ref}})}{\text{V}_{\text{ref}}} \]

where Vmax is the value of the maximum voltage observed in the analysed time period and Vref is a constant of value 230. Only valid voltage values should be considered for this indicator. The valid values considered are between 1% and 173%, [3V, 400V].

The table must show the indicators for percentile 100 (maximum of the analysed period) and Percentile 95 (maximum of the analysed period excluding the values within the highest 5% interval). In this case the PERCENTILE.EXC function in excel is being used.

- Details Table

This table shows the detailed information for all the valid voltages.
It is possible to select an equipment serial number and analyse its indicators and its location on the map. The histogram for voltages gives the number of times in which the SM had a specific voltage value.

**FIGURE 114: DETAIL OF VALID VOLTAGES**

- **Voltage Histogram**

**FIGURE 115: EXAMPLE OF AVAILABLE INFORMATION WHEN FILTERED FOR A SPECIFIC SERIAL NUMBER**
➢ Voltage Values measured in a time period

![Figure 116: Graphic of Voltage Measurements for a Time Period](image)

This graph represents the minimum, average and maximum voltages values for a specific SM serial number.

**Note:** A small time interval must be chosen for these analysis due to the large amount of data.

➢ Three-phase Voltage values (Only for one equipment)

![Figure 117: Graphic for Three-phase Voltage for One Equipment](image)

This graph is more appropriate for the analysis of Three-phase SMs. Only one equipment can be chosen at a time for the analysis.

**POWER SECTION (DTCs – Supervisor of SMs)**

This section aims to show the performance of DTCs in terms of power. As for the voltage sections, this dashboard also provides the use of filters and allows to choose a specific date interval. The coordinates map and the information tables relate to the filters and the slicer in the up-right corner of the dashboard.
The graphs at the bottom are connected to the slicer in the bottom left which allows for a weekly analysis of the indicators.

The graphs at the bottom are connected to the slicer in the bottom left which allows for a weekly analysis of the indicators.

Selected time period Power analysis

FIGURE 118: VIEW OF THE SECTION FOR POWER ANALYSIS

FIGURE 119: EXAMPLE OF AVAILABLE INFORMATION WHEN FILTERED FOR A SPECIFIC TIME INTERVAL
WP4 – DEMONSTRATION IN REAL USER ENVIRONMENT: EDPD - PORTUGAL

D4.3 EVALUATION OF DEMONSTRATION RESULTS AND DATA COLLECTION

➢ Summary table

### FIGURE 120: TABLE FOR THE INDICATORS DETAIL

#### TABLE 34: DEFINITION OF THE INDICATORS FOR POWER

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pmax/Pinst</td>
<td>Ratio between Maximum Power and Installed Power</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pavg/Pmax</td>
<td>Ratio between Average Power and Maximum Power</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pavg/Pinst</td>
<td>Ratio between Average Power and Installed Power</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cos(ϕ) Min</td>
<td>Power Factor</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Potência neg. (horas)</td>
<td>Hours in negative power (A-)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For the calculation of the indicators in the table above it was necessary to previously calculate the different power parameters considered. The metrics used are the following:

1. Note: (A+) – Positive energy in a 15-minute period Maximum Power
   *If A+ ≤ 1500 kVA,*
   \[
   P_{\text{máx}} (\text{kW}) = \max(A +) \times 4,
   \]
   where \(P_{\text{máx}}\) is the maximum power value observed in the chosen time interval.

2. Average Power
   *If A+ ≤ 1500 kVA,*
   \[
   P_{\text{avg}} (\text{kW}) = \text{avg}(A +) \times 4,
   \]
   where \(P_{\text{avg}}\) is the average power value observed in the chosen time interval.

3. Installed Power
   \[
   P_{\text{inst}} (\text{kW}) = \text{Transformer Power},
   \]
   which is given by the equipment file.
4. Cos(phi)

For each 15 minutes,

\[
\cos(\phi) = \frac{P}{\sqrt{P^2 + R^2}}
\]

where the minimum value for the power factor is given by

\[
\cos(\phi)_{DTC} = \min(\cos(\phi)).
\]

➢ Weekly Analysis

![Weekly Analysis Diagram]

FIGURE 121: DETAIL OF THE SECTION FOR POWER ANALYSIS SHOWING HOW TO SELECT A SPECIFIC WEEK PERIOD

- **Pmax/Pinst**
  
  Number of equipment within specific intervals of Pmax/Pinst.

![Pmax/Pinst Chart]

FIGURE 122: GRAPHIC OF PMAX/PINST

- **Pavg/Pmax**
  
  Number of equipment within specific intervals of Pavg/Pmax.

![Pavg/Pmax Chart]

FIGURE 123: GRAPHIC OF PAVG/PMAX
3.3.11.4 EVALUATION OF RESULTS

The dashboards reveal to be useful for the voltage and power analysis of the infrastructure, namely the evaluation of voltage and power results obtained for the infrastructure for a distinct period. The implemented dashboards have the capacity of displaying detailed voltage and power information tables supported by geographic maps and interactive graphics. Thus, the time expended for a single analysis of a certain equipment turned to be much less with the use of the dashboards compared to the analysis using raw data from source tables directly. For example, for each analysed equipment it is possible to evaluate the voltage deviation from the established reference value (230V) for the 100 and 95 percentiles which are in line with the NP EN 50160 standard. Simultaneously it is presented the location of that equipment geographically and the voltage histogram for the defined time horizon.

Similarly, this type of analysis is done for the equipment’s behavior concerning to power values allowing the user to get in a simple and intuitive way the rates of use of the transformers and therefore improve the management of these assets.

If the user wanted to do the same analysis without the dashboards it only could be acquired merging information from several systems and different source tables which would take more time and the need
for several access permissions. These facts evidence the applicability of the dashboards for monitoring analysis and the way they can improve the users daily work.

The dashboards present information of the Sysgrid Infrastructure in an integrated way. It is possible to analyse different indicators related to SMs and DTCs simultaneously with the support of geographic maps and interactive graphics (filters, such as the type or the state of the equipment). Furthermore, the possibility to select a specific time interval for the analysis is a benefit when compared to an analysis directly from the source tables.

One example of an analysis that these dashboards made conceivable is the association between the SMs and DTCs, since with a few clicks one can know how many registered SMs are associated to a DTC. The same analysis takes much longer using source tables due to the need of connecting different systems and working with raw data. Thus, the major advantage that these dashboards bring to the activity is the possibility of a quickly exploitation of several indicators at the same time using different filters and historical data giving a general overview of the results in an appealing way through graphics and maps.

The developed architecture solution has revealed to be very powerful as it renders up to date data for promptly creating indicators for the Smart Grid infrastructure and for the voltage and power monitoring.

The ability to quickly and easily assess the several indicators related to the current state of the Smart Grid infrastructure allows for an expedited control over its growth as well as a faster acknowledgement and response when problems occur. Being able to graphically and numerically evaluate the infrastructure based on equipment type (SM/DTC), location, brand, model and successful services or readings has become a powerful tool when addressing such problems.

The main objectives for the indicators and dashboards have been achieved resulting in useful tools for Smart Grid infrastructure performance and power quality assessment. Continued testing will perfect data management and new features may be added using the existing architecture for further improvements.

### 3.3.12 INNOVATIVE VIRTUAL HAN INTERFACE AND COMMUNICATION TECHNOLOGY OF SMART METERS (3G AND NB IOT)

This chapter describes the developments made on the project of alternative technologies for Smart Meter communication, namely 3G and Narrow Band – Internet of Things (NB-IoT). In parallel, and to broaden the alternatives for accessing consumption data, from the customer’s side, a virtual Home Area Network (HAN) interface was also developed.

#### 3.3.12.1 TEST OBJECTIVES

The smart meters of these two alternative communication technologies should work in the same way as the other smart meters installed, that is, they must follow the same functional requirements and the specifications that are currently homologated by the DSO.

The difference is only in the remote communication interface (Wide Area Network - WAN), which becomes NB-IoT or 3G, and in the last (3G) the Virtual HAN port has also been added.
In this sense, the functional test objectives were directed to validate that the use of these alternative communication technologies does not impact on the existing functionalities (energy measurement, power control, billing and daily data, Firmware (FW) upgrade, etc.).

In addition to the functional tests, end-to-end (integration) tests were performed between the multiple actors, namely:

- In the connection with the Advanced Metering Infrastructure (AMI)/DTC at the WAN interface;
- At the optical interface with Work Force Management (WFM) toll, that is used in the smart meter commissioning at the customer’s premises and to execute local commercial orders/parametrizations.

### 3.3.12.2 TEST BED AND CONFIGURATION

The functional tests were done to validate that NB-IoT and 3G Smart Meters functionalities were working according to the specifications. These functional tests were carried out by Labelec, using automated tools but also manual/human resources.

For the Virtual HAN communication validation at 3G smart meter, a new test procedure was developed. It is like the physical HAN but using the Modbus TCP/IP instead of Modbus Remote Terminal Unit (RTU). In this case, the link is not physical to the RS485 port of the Smart Meter, but over the WAN interface.

For the end-to-end tests between 3G Smart Meters and AMI/DTC, no different procedure had to be made because it is TCP/IP based (as is the already used GPRS equipment). In the case of NB-IoT Smart Meters, which chipset is natively UDP, the manufacturer/integrator JANZ has implemented a control layer on top to make it connection-oriented, that is, in TCP. So, in the DTC perspective, these NB-IoT Smart Meters are managed in the same way as GPRS are.

### 3.3.12.3 PERFORMED TESTS AND COLLECTED DATA

#### TABLE 35: NB-IOT AND 3G SMART METERS - FUNCTIONAL TESTS

<table>
<thead>
<tr>
<th>Test NO 1</th>
<th>Test Scenario</th>
<th>Objective</th>
<th>Actions</th>
</tr>
</thead>
</table>
|           | NB-IoT and 3G Smart Meters - Functional tests | Validate that all features provided in the smart meter’s specification are correctly implemented. | Run the test procedures for all functional blocks (for both SM):  
- Energy and Power Measurement  
- Power Control  
- Clock  
- Battery  
- Events  
- Alarms  
- Memory |
### TABLE 36: NB-IOT SMART METER – END-TO-END TESTS (AMI/DTC)

<table>
<thead>
<tr>
<th>Test NO 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test Scenario</strong></td>
</tr>
<tr>
<td><strong>Objective</strong></td>
</tr>
</tbody>
</table>
| **Actions** | • Execute ad-hoc remote services:  
  • Get values from the meter  
  • Set values to the meter  
  • Execute the required services (reports and orders)  
  • Execute load tests:  
    • Configure scheduled tasks at the DTC to collect data (billing data, load diagram) with and adequate periodicity  
    • Check the received data and success rate |
| **Results** | In these tests, some issues were found, that have to be corrected through the application FW change of the smart meter.  
In the final FW version, all tests were run successfully. |

### TABLE 37: NB-IOT SMART METER – END-TO-END TESTS (WFM)

| Test NO 3 |
**Test Scenario** | NB-IoT Smart Meter – End-to-end tests (WFM)
---|---
**Objective** | Validate that WFM tool can communicate successfully (by optical interface) with the NB-IoT Smart Meters
**Actions** | • Execute an installation order  
• Execute the required commercial orders
**Results** | All tests performed well.

**TABLE 38: 3G SMART METER – END-TO-END TESTS (AMI/DTC)**

<table>
<thead>
<tr>
<th>Test NO 4</th>
</tr>
</thead>
</table>
**Test Scenario** | 3G Smart Meter – End-to-end tests (AMI/DTC)
**Objective** | Validate that AMI/DTC can communicate successfully with 3G Smart Meters
**Actions** | • Execute ad-hoc remote services:  
  • Get values from the meter  
  • Set values to the meter  
  • Execute the required services (reports and orders)  
  • Execute load tests:  
    • Configure scheduled tasks at the DTC to collect data (billing data, load diagram) with and adequate periodicity  
    • Check the received data and success rate
**Results** | In these tests, some issues were found, that have to be corrected through an improvement in the FW of the smart meter.  
In the final FW version, all tests were run successfully.

**TABLE 39: 3G SMART METER – END-TO-END TESTS (WFM)**

<table>
<thead>
<tr>
<th>Test NO 5</th>
</tr>
</thead>
</table>
**Test Scenario** | 3G Smart Meter – End-to-end tests (WFM)
**Objective** | Validate that WFM tool can communicate successfully (by optical interface) with the 3G Smart Meters
**Actions** | • Execute an installation order  
• Execute the required commercial orders
**Results** | All tests ok.
### Table 40: 3G Smart Meter – End-to-end Tests (Virtual HAN)

<table>
<thead>
<tr>
<th>Test NO 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Scenario</td>
</tr>
<tr>
<td>Objective</td>
</tr>
<tr>
<td>Actions</td>
</tr>
<tr>
<td>Results</td>
</tr>
</tbody>
</table>

### 3.3.12.4 Evaluation of Results

After the functional and end-to-end tests were successfully completed, the equipment was approved with the tested and validated FW versions (core/metrological, application and communication).

In accordance with European legislation, the Smart Meters manufacturer had to ensure the EC Type Examination Certificate (MID certification) for these new versions. The DSO can only install it at customer’s premises after obtaining this certificate from the manufacturer.

Having completed both the end-to-end tests and the certification process, Smart Meters using these new technologies are now awaiting installation date. NB-IoT enabled Smart Meters will allow for an increase in the amount of data throughput, as well as in its reliability and quality. The virtual HAN technology offers a lean way for data accessibility on the customer’s side, without the need for a physical HAN connection. This results in a more efficient installation process with less hardware and thus, less failure points.

### 3.4 Network Planning and Asset Management

In the scope of UPGRID project, an advanced mobility solution to support field teams has been developed. This new tool includes the creation of new approaches for the operation in the field. Field crews will be able to visualize the actual network state and grid assets, while working in the field in outage management or when performing maintenance tasks, allowing them to be more prepared and informed for the interventions.

Furthermore, this mobility application intends to be the main channel for obtaining information such as equipment and assets damage as well as to introduce new ways of communication between the dispatch centre and field crews.
3.4.1 DEPLOY SOME MOBILE DEVICES (E.G. TABLET, SMART PHONE) FOR ACCESSING AND VISUALIZE REMOTELY INFORMATION FROM LV SYSTEM (E.G. GEOGRAPHICAL CONTEXT, ASSETS AND OUTAGE LOCATION) TO SUPPORT GRID CREWS

3.4.1.1 TEST OBJECTIVES

The aim of this test is to demonstrate how the functionalities of UPGRID Mobility solution can support the operation and improve the communication between the dispatch centres and the field crews.

The main features of this solution are:

- **Access to MV and LV Network Information**

This solution provides access to the MV and LV network in a geographic and schematic context, all this supported in a mobile device.

The solution has the geospatial information of the network represented over the google maps API, allowing the usage of standard google functionalities such as address search, “my location”, navigation tools or Google Street View. The network represented includes the following assets: Substation, Secondary Substation, LV cabinets, Smart Meters equipment such as DTC and EBs, Electric Vehicles Charging Points and Arquiled Street Lights.

In addition to this feature, the application has two visualisation modes schematic and geographic that can be displayed independently or at the same time, and network elements are linked between them, so, as we navigate to a network element in the schematic mode, the geospatial mode will follow and vice-versa. In both modes, basic network asset information can be consulted, as a specific element is selected, and the user can have access to installation’s internal scheme and street view window.

In the figure below, it is possible to visualize the LV network, the detail window of a LV cabinet and its internal scheme.
FIGURE 126: UPGRID MOBILITY REPRESENTATION OF LOW VOLTAGE CABINET AND ITS INTERNAL SCHEME
Below it is possible to observe some smart grid assets such as DTCs, SMs, Arquiled Street Lights and Electric Vehicles Charging Points represented over the satellite view.

![UpGrid Satellite View](image)

**FIGURE 127: UPGRID MOBILITY SMART METERS REPRESENTATION IN GEOGRAPHIC CONTEXT**

This mobility tool also allows to send a work order to a specific field team enhancing the communication between the crews and the dispatch centre. Through the UGC, the dispatch operator can send a work order to the mobile device; and in the field, the crew can visualize it in the Upgrid Mobility as well as navigate to the network asset associated to the order. The crew can also update the work order state allowing the dispatch centre to track the work order. In the figure below there is an example of a work order received in the Upgrid Mobility with the following information: team identification, asset ID and order state. Clicking on the work order the application automatically show the respectively asset in the geographic view.
Damage Assessment Module
This solution allows field teams to better record the location and severity of damages with a mobile device in the field, providing them the capacity to associate evidences to a network asset and send that information to the Back Office.

This module allows the crew to easily take photos with GPS location and timestamp information embedded and then to attach them to a form that contains additional information such as outage identification and damaged equipment and send it to the Dispatch Centre.

This information, a form and a photo, is then uploaded to the server, where it will be received in the Dispatch Centre through the UGC.

In the figure below, it is possible to visualize how a damage report can be done through the mobility application. By clicking on an asset or at any point of the map, it is possible to report a damage and the crew can fill in a form with the characterization of the damage and attach a photo.
The collaborative module of the Upgrid Mobility solution aims to reinforce the interaction between the Field Crews and Dispatch Centres. To allow a much more efficient response in the field interventions, this solution presents the following features:

- **Integration with Skype calls and Chat Conversations**
- **Online sketching**

The integration with the Skype allows the crew and dispatch operator to initiate a call or a chat conversation without having to leave the mobility application. Furthermore, to enhance the communication through this module, it is possible to insert notes or emphasize small details, like a specific damaged insulator of an isolator string or the damaged supports of an overhead line, in photo and in real time as well as share it through a call with the dispatch operator.

This complementary information is very useful in the identification of the problems and brings significant operational improvement to the process.

In Figure 130, it is possible to visualize the collaborative component in the two tools UGC (Dispatch Centre) and Upgrid Mobility (Field Crews).
FIGURE 130: UPGRID CONTROL SHARING SCREEN VIEW

FIGURE 131: UPGRID MOBILITY SHARING SCREEN VIEW
3.4.1.2 TEST BED AND CONFIGURATION

The tests conducted involved the following systems: UGC and Upgrid Mobility.

In order to validate the functionalities developed, the dispatch operator sends a field order to a tablet running the Upgrid Mobility and a test per sub-functionality will be validated.

The test will be performed over the three modules developed: Access to MV and LV network Information, Damage Assessment and Collaborative functionalities.

3.4.1.3 PERFORMED TESTS AND COLLECTED DATA

The following table describes the several tests performed to validate the functionalities of the Upgrid Mobility component.

**TABLE 41: ACCESS TO MV AND LV NETWORK INFORMATION**

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Test LV voltage Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Send work orders to field crews in a tablet running the Upgrid Mobility application, with the asset location. Provide access to LV and MV network in a tablet running the Upgrid Mobility application.</td>
<td></td>
</tr>
<tr>
<td>Objective</td>
<td>To provide easy and fast access to LV grid in field and to be able to provide additional and useful information such as geographic information aligned with the schematic all this supported in a mobile device.</td>
</tr>
<tr>
<td>Actions</td>
<td>• Operator will send a work order to the Upgrid Mobility application.</td>
</tr>
</tbody>
</table>

![FIGURE 132: ASSETS OVER GIS PLATFORM](image)
• The crew will receive the order and navigate to the network element

FIGURE 133: ISSUE LOCATION AND RESPECTIVE WARNING TO THE FIELD TEAM

• Visualize the geographic location and characterization of the following Low voltage assets DTC, EB, Secondary substation, Low voltage cabinets, street light illumination, Electric vehicles charging points Google street view integration
Consult the secondary substation and LV cabinet internal scheme.

Send the work order status to the dispatch centre.

Through this test, it was possible to conclude that this mobility tool can bring a significant increase in the operation efficiency allowing crews to visualize the actual network state and grid assets and consequently be more prepared and informed for the intervention in the field.
### TABLE 42: DAMAGE ASSESSMENT MODULE

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Collect information from the field regarding network asset damage, such as geographic location, photos and characterization and send this information directly to the UGC.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>This solution allows field teams to better record the location and severity of damages with a mobile device in the field, providing the field crews the capacity to associate evidences to a network asset and send that information to the Back Office.</td>
</tr>
</tbody>
</table>
| Actions       | • Report a damage on a network asset such as a Substation, Secondary substation, DTC, EB  
  o Select the asset or a point in the map  
  o Damage characterization and evidences report (photos) |

This module was successfully tested. It was possible to conclude that this new approach to report damage in the network from the field can help to increase the efficiency of the operation business process.

### TABLE 43: COLLABORATIVE MODULE

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Communication between Dispatch Centres and Teams through UGC and Upgrid Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Validate how the collaborative module developed in the UPGRID project can help to</td>
</tr>
</tbody>
</table>
improve and reinforce the communication between the field crews and Dispatch Centres.

<table>
<thead>
<tr>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Application integration with Skype to directly initiate calls and chats conversation between Dispatch Centres and Field Crews.</td>
</tr>
</tbody>
</table>

![UGC Snap Shot – Interaction with Field Team](image1)

**FIGURE 137: UGC SNAP SHOT – INTERACTION WITH FIELD TEAM**

| • The online sketching tool allows enhance the communication between the two entities by inserting notes or emphasizing small details like a specific damaged insulator of an isolator string or the damaged supports of an overhead line in photo in real time and share it through a call with the dispatch operator. |

![Live Cooperation with Images and Sketching using Upgrid Mobility](image2)

**FIGURE 138: LIVE COOPERATION WITH IMAGES AND SKETCHING USING UPGRID MOBILITY**

<table>
<thead>
<tr>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>This collaborative module allows to have an innovative approach in terms of communication and interaction between field crews and dispatch centres. This complementary information is very useful in the identification of the problems and brings significant operational improvement to the process.</td>
</tr>
</tbody>
</table>
3.4.1.4 EVALUATION OF RESULTS

The tests conducted allow to conclude that the mobility functionalities develop in the UPGRID project can enhance the operational efficiency in the field as this tool allows teams to have access to more technical informational about assets to support their operation. Furthermore, this tool improves the communications between Dispatch Centres and Field teams, it was the first time an online sketching functionality for communication were developed and tested in EDP Distribuição, which allows to guarantee a more reliable information channel between the two entities as well as have a better characterization of the field reality.

3.5 MARKET DESIGN

One of the main goals behind the developments done in the Portuguese demonstrator is the deployment and testing of new market concepts. A Web portal has been developed and was presented to the local township that will allow all the customers to have access to their consumption habits as well as a better knowledge of their consumption profile.

3.5.1 WEB PORTAL FOR INCREASING THE CONSUMER AWARENESS TO LEVERAGE THEIR PARTICIPATION IN ELECTRICITY MARKETS

3.5.1.1 TEST OBJECTIVES

The Portuguese demonstrator is keen in developing and testing new market concepts. As such, the Web portal was thought out and developed to give the local township access to their consumption data and thus instilling them with the necessary toolset to get a better grasp and understanding of their consumption profile, as described in section 2 of deliverable D4.2 [1].

3.5.1.2 TEST BED AND CONFIGURATION

The development of the UPGRID Web portal is divided in three main components:

- **Pipeline for data reception**: responsible for receiving the consumption data and the characterization data of the local township clients, from the EDP Distribuição systems, as described in section 3.5.1 of deliverable 4.2 [1].
- **Data storage and transformation**: responsible for keeping the consumption data and guaranteeing the data persistence, making it accessible for the visualization applications.
- **Access and Visualization**: the core application that allows the clients of the local township access and visualization of their consumption data as described above.

Each component can be described in more detail as follows.

**Pipeline for data reception**

This component is responsible for the following tasks:
- Monitoring the FTP server, created by EDP Distribuição to act as a data repository for the UPGRID project. This data repository receives daily the client’s data consumption.
- Transfer the most recent files (.csv), if there is new data to import.
- Sends the corresponding request to the persistence and forecast modules, for the data to be transformed and handled in an efficient format for quick access by the visualization application.

Given the technical simplicity of this component, its development was done with a simple combination of shell scripts and daily scheduling using cron (UNIX scheduling tool).

By using a system tool and avoiding the usage of more complex frameworks, the impact of the data reception process is minimized for the systems resources that are available. Now, the current solution can handle the daily importation in <2min (as a precaution this process is scheduled to occur at the early hours of the morning to avoid any impact in the user experience of navigating through the Web portal).

Considering the need to import a bigger volume of clients (10,000), the data importation process would take no longer than 20 minutes, this value proves to be acceptable for architecture that has no dedicated hardware and that is not distributed.

**Data storage and transformation**

This component is tasked with the following:

- Transforming the consumption data from a .csv format to a more efficient format.
- Consumption Forecast for each client for the following week (on a weekly basis).
- Storing the client’s characterization data (VAT, SDP (Service Delivery Point, equivalent to the Portuguese CPE (Código Ponto de Entrega)) in relational database (PostgresSQL).
- Storing the consumption data for each client in a time series database (OpenTSDB).

This component is divided in:

- Unplug forecasting module developed by Whitesmith and deployed on-premises considering EDP Distribuição data protection policies, restricting that sensitive information flows outside corporate systems. This module receives forecasting request on a weekly basis for the data pipeline. It reads the time series database with the historical data for each client and sends the results of the forecast to be written on the same database.
- A data persistence module, built with a shell script for transforming the imported .csv and integrated modules in the Ruby on Rails application (for data presentation) to validate the writing onto the databases and assuring its consistency at every moment.
- A relational database for time series – OpenTSDB – that has all the forecast and consumption data. This separate database was created since to typical relational databases (SQL-based) aren’t efficient in hosting time series data as they are very slow when queries for a certain timeframe are run. So, the choice was made for a robust Open-Source solution that is tried and tested with good results for performance and reliability: The OpenTSDB works on top of an instance of Apache HBase to create data persitency.
The storage solution for the time series data was made to guarantee future scalability of this component, as an Hbase system is, by its very nature, distributed, making it relatively easy to start new instances and turn the database into a distributed component.

On the other hand, the forecasting module ends up being the biggest bottleneck in terms of performance for the system. Each weekly forecast, per client, takes on average 5 seconds. So, for a batch of 10,000 clients it could take almost 13 hours to process. Taking this into account, and to avoid overloading the server, this task is distributed along the day, having minimal impact in terms of performance of the other core components. This will mean that each client will have distinct experiences, as some will only have their forecast available later. This limitation comes from using an on-premises solution for the forecast system that is limited to the hardware that it runs on. And as such the workload cannot be distributed on cloud instances, as would happen on an as-a-Service for unplug.

**Access and Visualization**

This component will allow each customer to:

- Register itself in the Upgrid Web portal, using a combination of their SDP and NIF.
- Once registered, access to visualize their consumption data, access to suggestions about their consumption profile and comparing their tariff to other ones available in the market.

**Web application**

The web app was built using a Ruby in Rails framework server side, following a standard MVC (Model-View-Controller) architecture, with a frontend being developed with a standard combination of HTML5 + CSS2 + Javascript (for the interactive components of the page). All the components were built from scratch, with the exception of the graphics that use as their base the NVD3.js library.

The OpenTSDB shows itself as a good chosen solution, as the page’s issue repeated requests for certain time frames of consumption data (3 to 4 requests per information page), and where a whole year of the client’s data can be viewed without any noticeable time lag in the data loading.

**Mobile application**

The mobile app was built using a React Native framework, making it possible to develop simultaneously a version for Android and iOS. The app is fed from an API that is made available by the server RoR, offering the clients a very similar experience to the one they would get in the web page, but optimized to mobile devices.

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6 RoR: Ruby on Rails. It's an open source platform for developing software (one example done by it: Airbnb).
FIGURE 139: ARCHITECTURE OVERVIEW
Hardware/System

Presently, the Upgrid Web portal runs on a system with the following characteristics:

- Virtual x86 architecture (Without dedicated HW)
- 8 GB RAM
- 100 GB HDD (non-dedicated)
- Linux OS (RHEL 7)
- Deploy and management of different components (PostgreSQL, OpenTSDB, Rails) using containers (Docker) as to ease deploys and interoperability.

3.5.1.3 PERFORMED TESTS AND COLLECTED DATA

With the established platforms and protocols the pipeline for data reception was evaluated in terms of performance for a ~1k customers. The platform performed well and within nominal parameters for this type of task. There was a task to evaluate if during the daily importation, the data was correctly imported to the platform and consistent with the original system.

![FIGURE 140: LOAD DIAGRAM FOR CUSTOMER PRESENTED IN THE WEB PORTAL](image_url)
With these validations in place, the Web portal was deemed ready to be put into production making it accessible to any client in the Parque das Nações township that had available load data in EDP’s infrastructure.

### 3.5.1.4 EVALUATION OF RESULTS

The Web portal was built to evaluate and assess the creation of a platform that brings benefit to the customers, increases their know-how and increases their awareness regarding their personal consumption data.

The created application behaves as expected, and resides within EDP’s infrastructure, and fulfils its role of taking the raw data of the load diagrams and converting it to an appealing platform for the customer to use.

As the landing page states: “Mudou apenas uma coisa na sua energia. Tudo,” which translates to “Only one thing in your energy has changed. Everything.”
The Web portal will be continually monitored and will allow the use of the generated knowhow to evolve and support other projects within EDP to bring value to the customer and to increase the services provided. The portal has been tested uploading and displaying more than 7,000 Client’s data.

### 3.5.2 CREATE MARKET HUB FOR RELATIONSHIP BETWEEN DSO AND SUPPLIERS

The MHP mediates all communications between the RPs and the DSOs. Thus, its assessment was relevant in the context of this project. The objective of the MHP assessment is twofold. On the one hand, validate that it performs as expected, and supports the expected loads. On the other hand, is to validate that the correctness of the operations, meaning that requests are correctly performed. These tests further extend the ones reported in deliverable D4.1. In this case, the tests were performed in the final deploy environment.

#### 3.5.2.1 TEST OBJECTIVES

With the performed tests, the objective was to assess the MHP performance in a real-world scenario, deployed in the DSO machines, as originally proposed.

1. Test that the application behaves as expected, once deployed in the final machines;
2. Test the communication between different components, namely regarding the web service invocation both from and to the RP and DSO.
3. Test if the MHP behaves as expected under real load.
4. Perform end-to-end integration tests, to ensure that the MHP will provide the expected features.
3.5.2.2 TEST BED AND CONFIGURATION

The tests were performed with four virtual machines, to host the MHP and the HASS\(^7\) (c.f. specification in deliverable D4.2 [1], and Figure 143). Each virtual machine had a single core processor at 2.0GHz, 2 GB of RAM, and 40 GB of disk.

The MHP is the component responsible for handling all the requests, and communication with the other machines. It performs also the respective requests to both the RP and the DSO. The HASS component was responsible for providing efficient and secure data storage.

The HASS was configured with all the four machines to ensure high availability. As for the MHP itself, it was deployed in one of the machines. The Glassfish application server was deployed over Java 7, in which the MHP was deployed. In the same machine, and for practical reasons, MySql was installed, mainly for registering logs. The virtual machines had the required ports open (among others 80 and 8080) to both invoke external web services, and accept web services invocations.

After the setup, the requests were performed to the MHP, as scheduled, and logged appropriately. CPU and disk usage were monitored resorting to iostat, while the network was monitored with ifconfig.

3.5.2.3 PERFORMED TESTS AND COLLECTED DATA

Next follows a description of the tests applied in the MHP. These tests were used to evaluate the behaviour and performance of the MHP during normal usage.

\(^7\) HASS: High Availability Storage System
TABLE 44: END TO END COMMUNICATION TEST

| Test Scenario | End-to-end communication: Requests were made from the DSO to the MHP, to verify that a connection exists between these two components. Similarly, requests from the MHP were made to the RP, with the same objective. Therefore, end to end (DSO to RP) communication can be tested. |
| Objective | The objective of this test was to assess whether the end-to-end (DSO-MHP-RP) communication was supported. |
| Actions | • Requests were performed by the DSO  
• The requests were identified in the MHP  
• It was checked that in the RP, the requests were received  
• The status of the requests was propagated back to the DSO, with the RP information. |
| Results | The results have shown that end-to-end communication was correctly supported. Indeed, requests performed by the DSO reached the RP, and RP responses reached DSO, as presented in Figure 144. |

![Diagram of request flow between DSO, MHP, and RP](image)

FIGURE 144: FLOW OF REQUESTS

TABLE 45: CORRECT REQUEST DATA RELAY TEST

| Test Scenario | Correct request relay: Requests should be propagated to the correct component. Thus, performing different tests and monitoring the data flow allows to validate this scenario. |
| Objective | The objective of this test was to assess the correctness on requests relay. This means that requests should be correctly delivered to the RP. |
| Actions | • Requests were made by the DSO  
• The ID of the requests was checked  
• It was verified in the RP that the requests arrived, and that it was the correct request, and that the client belong to that RP |
| Results | Results have shown that the requests not only had the correct information when
delivered to the RP, but also were delivered to the correct RP. It is worth noting that, although in the previous tests several RPs were considered, in this test only one RP exists.

### TABLE 46: MHP PERFORMANCE TEST

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Performance test: The MHP needs to respond to the requests in reasonable time, i.e., take, at least, less time to respond to a request, than the frequency of requests. This test allows to validate if such is scenario occurs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Check that the MHP executes the requests in a useful timeframe.</td>
</tr>
</tbody>
</table>
| Actions       | • Continuous monitoring was applied  
• Each 10 second, the CPU, disk and network were analysed  
• The results were compared with the stress tests |
| Results       | Results have shown that the MHP can support the applied load. Both CPU and Disk usage were low, with minimal peaks.                                                                     |

### 3.5.2.4 EVALUATION OF RESULTS

The MHP has performed as expected. It could successfully handle all the requests in real time. Not only was it able to process a request before another one was made, but also keep the CPU usage low. Indeed, and according to deliverable D4.1, such was somehow expected, since in previous stress tests, the MHP supported far bigger loads than the ones expected in real world scenarios.

**FIGURE 145: CPU USAGE, DISK USAGE AND PERFORMED REQUESTS, OVER TIME**

Figure 145 shows the CPU load during the performed tests. The blue line shows the evolution of the CPU usage, the grey line represents the disk usage, and the orange dots show the moment when the requests were made. Considering an average CPU load of 0,5% when idle, and a peak of 8,5%, it is possible to conclude that the MHP can successfully support the expected load. Also, disk usage had even lower peaks, with an average usage of 1,5%. Furthermore, it is worth noting that the machine which had
the MHP, had also one Hbase node. Thus, the MHP can successfully handle the performed requests in reasonable time, and supports the applied loads.

Figure 146 shows the network usage during the tests. It is possible to see that the load was considerable low on idle, with an average of 1Kb/s for the sent data, and 2Kb/s for the received data. A peak occurred when the requests were performed, with a maximum of 5Kb/s. This usage is considerably low, and in practice no network constraints occurred. It is worth noting, that apart from HBase network usage, a remote shell session (SSH) was kept open during all the tests, and that the different machines had other processes using network communication (as is the example of HBase). Thus, the network usage is considerably low and negligible, which proves the viability of the MHP to handle the requests.

All the specified use cases were successfully tested, proving the correctness of the requests performed to, and by, the MHP. In specific, tariffs broadcasts, emergency requests and flexibility requests were recurrently tested, and correctly supported.

Regarding the four specified scenarios, the results are as follows:

1. Test that the application behaves as expected, once deployed in the final machines:

The MHP could fulfil its role, meaning that it supported the specified use cases. Indeed, it had the same behaviour as the one in the development environment, and as specified. The same entry points (web services) were available, and no performance issues were found. Thus, it behaved as expected in the final tests.

2. Test the communication between different components, namely regarding the web service invocation both from and to the RP and DSO.

In the tests, the MHP could successfully receive web service invocations from the DSO. Also, it successfully invoked RP and DSO web services. These tests validated the success on the communication between the different actors. Thus, the communication from different components was correctly implemented.

3. Test if the MHP behaves as expected under real load.

Considering the presented results (and as previously analysed), the MHP performance fairly exceeded the requirements of the tests. Loads averages were relatively low, and are not expected to
create constraints in the platform usage. Thus, the MHP performance was validated under real workload, with satisfactory results.

4. Perform end-to-end integration tests, to ensure that the MHP will provide the expected features.

During the tests, the end-to-end requests were successfully performed. Requests were well executed by the DSO, delivered to the RP, and its status reported back. Indeed, all the requests required an end-to-end communication process, essential to the overall process. Thus, end-to-end tests validated the correctness of the MHP features.

In conclusion, the MHP overall results were very positive, since all the test cases were successfully performed. From all the concerns, two are worth mentioning, specifically the correctness of the requests, and the performance of the MHP. Through the performed tests, it was possible to conclude that the MHP can successfully tackle these concerns, by correctly relaying the requests in appropriate time.

The MH helps set and test an architecture for an open and accessible market for low voltage grid requirements. The two platforms developed within the Upgrid Project enable effective access of distributed flexible assets to respond to flexibility requests from the DSO. It was critical to test effectiveness and response time of these assets. The tests proved that to respond to grid needs there is a real technical possibility in using demand flexibility assets.

### 3.5.3 DYNAMIC / REAL TIME PRICING BASED ON DSO SERVICES AND INFRASTRUCTURE REQUIREMENTS (DSM SIMULATOR)

The dynamic pricing goal is to promote a higher level of demand response, as the Energy Efficiency Directive defends. The scope of this analysis was to use the data resulting from the AMI and develop a type of dynamic pricing that can optimize the management of the Distribution Network and reduce the need to invest in grid expansion. In this way, customers will pay lower network charges and there will be a more efficient use of RES.
FIGURE 147: DEMAND RESPONSE SCHEMES

As seen in the red boxes of Figure 147, there are two main ways to promote demand response by customers: to set network charges that change according to the level of congestion of the grid, and to directly control load used by customers.

The dynamic pricing simulator seeks to find an optimal pricing scheme that meets the needs of the network operator and, at the same time, allows for a reduction of the grid costs in the long term, which will be reflected in the customers’ bills.

3.5.3.1 TEST OBJECTIVES

This functionality’s goal is to analyse and propose a dynamic pricing scheme. This scheme will be based on the DSO’s needs, which will send price signals to customers in critical hours for the network. The scheme is focused on the behaviour of 1,021 LV customers from October 2016 to March 2017.

3.5.3.2 TEST BED AND CONFIGURATION

The test analyses the real-time data coming from the AMI every 15 minutes during a period of 6 months from 1,021 customers with contracted power up to 20.7 kVA. In this analysis, the focus was to find when the 100 hours of highest network use happen. These hours should be the target of a stronger price signal that encourages customers to shift load to adjacent hours.

From the data analysis, the hours of highest network use occurred in November, December and January. The period of the day when critical hours happened varied from 10AM to 9PM. However, more than
70% of maximum consumption hours took place between 6PM and 9PM. As such, the dynamic pricing had to be built on these main features:

1. Consumption is higher in winter months. Hence, the dynamic price should set higher prices for winter months;
2. Evening is the period of the day when maximum consumption usually takes place, so it would be best if peak prices happened in the evening.

Although it was clear in the analysis that winter months contain the most critical periods for network management, the critical hours of the day are more volatile. In fact, temperature was one of the main drivers of critical hours of consumption, and some of the coldest days had critical hours from 10PM to 9PM. The load diagram of a very cold winter day has a typical shape that you can see below.

![Typical Load Diagram on a Very Cold Winter Day](image)

**FIGURE 148: TYPICAL LOAD DIAGRAM ON A VERY COLD WINTER DAY**

### 3.5.3.3 PERFORMED TESTS AND COLLECTED DATA

The dynamic pricing scheme would need to be such that consumption levels allow for regulated revenue recovery. This is the only way financial and economic stability of regulated activities is assured, which is a fundamental principle of European regulatory frameworks.

For the Portuguese case, the total allowed revenues for the Distribution activity is approximately 1.100 M€ in a year. This revenue is recovered through Distribution charges which, in the case of LV customers, have a load term (€/kVA) and a volumetric term (€/kWh). Given that load is contracted by the customer and suffers few changes with time, the dynamic pricing was focused on the energy term. In terms of percentage of revenues recovered by each term, the fixed term recovers on average around 30%, while the variable term recovers the remaining 70%.

One of the important aspects that need to be estimated is the consumer elasticity, which will determine the impact of price signals on load shifting responses.

To build the dynamic scheme, a reference / average price level $k$ was set, and prices varied regarding this price $k$. In off-peak hours, the marginal cost of consumption on the grid is nearly zero (if we exclude the impact of technical losses), so it would be possible to give a discount on price $k$. This discount could go from 25% to 85%, depending on the scheme that was being tested. That is, in non-critical hours customers would pay as low as 0.15*$k$ €/kWh, with $k$ being the reference price. On the other hand, the need to increase the price in critical hours could lead to a price up to 5 times higher than the reference
level. Critical prices could therefore go from 1.5\*k to 5\*k €/kWh. The reference price should be the price that allows for revenue recovery under a simple static tariff (same price all day) scheme.

The strength of the price signal depends on a variety of factors, but the level of customer response to price changes in each hour of the day is the main driver of the discounts and higher prices established.

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Dynamic pricing tests with LV customers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective</strong></td>
<td>To analyse and propose a dynamic pricing scheme that promotes demand response and allow for lower load-related investment needs</td>
</tr>
</tbody>
</table>
| **Actions**   | • Use of the Advanced Metering Infrastructure  
                • Collect the consumption real time data for a period of 6 months  
                • Separate the customers according to the power they contracted  
                • Analyse periods where network flows are highest  
                • Design tariff option with different prices  
                • Analyse impact on demand-response level |
| **Results**   | Based on the analysis on the demonstration field, the best tariff option should charge higher prices in Winter months and reduce prices during the rest of the year. Evening hours were found to be the most critical hours within the day. Hence, new tariff schemes to be implemented should focus on sending price signals during Winter days, in the period of the evening. |

3.5.3.4 EVALUATION OF RESULTS

The results of the dynamic pricing analysis concluded the following:

- For LV customers, dynamic prices should focus on the consumption term;
- The dynamic scheme should have a reference price, and then change according to the congestion level of the network. The hours of lowest consumption can have a strong price discount, while critical periods should have higher prices. In this way, the investment and maintenance costs driven by demand will be lower, which allows for lower customer bills;
- Unlike direct load control, dynamic pricing always depends on the quality of consumer response, which brings higher risks to the DSO than a flexibility contract. However, dynamic pricing gives the customer more freedom to choose whether he should consume during critical periods. In the future, both dynamic pricing and flexibility contract offers should exist, and customers should be able to choose the option they find most attractive;
- The Portuguese regulatory framework does not allow the DSO to set tariffs. That is a role of the Portuguese Regulator. In a rollout environment, dynamic prices can have DSO contributions, and
the activation of critical days may be made by the DSO. However, the rules of these schemes, as well as their price levels, must be established by the Regulatory Authority. This study allows both the DSO and the Regulator to understand which are the best periods to recover the grid’s costs. By applying stronger price signals in the periods of highest network use, the DSO can, in the long run, decrease its network expansion investment needs.
4. CONCLUSIONS

The UPGRID Portuguese demonstrator has achieved significant outcomes in the five ETIP SNET roadmap clusters (as depicted in Figure 1) and enumerated here:

1. Smart Customers;
2. DER Integration
3. Network Operations
4. Network Planning
5. Market Design

The objectives associated with these five clusters were firstly set in WP1\(^8\), then enhanced in WP2\(^9\), implemented and validated in WP4\(^{10}\) (for the case of the Portuguese demonstrator) and assessed & disseminated in WP7\(^{11}\), 8\(^{12}\) and 9\(^{13}\).

Making an analysis to the implementation and validation of the developed tools and functionalities, which was the purpose of the presented document, the main highlights associated with each integrated solution, are presented below:

**Cluster 1 – Smart Customers:**

- First ever (in EDPD) end-to-end DSM operation integrating over 50 residential consumers;
- Incorporation of consumers’ flexibility in DSO operation through HEMS;
- Over 5,000 customer’s consumption information enabled with a web portal;

The involvement of the customers was from the beginning of the project a primary goal. The DSM framework created has enabled interaction and participation of residential consumers in grid management, using market based resources (managed by the MHP through the RP) in a neutral way. The Web portal enabled the DSO to provide the consumers with the necessary set of tools to manage and study their own consumption patterns and thus put in place the necessary actions to improve their behaviour in terms of energy efficiency. The next step will be to use the know-how acquired to feed-in on going internal projects in EDP Distribuição, that will provide the clients at a national level with access to a personalized webpage and app.

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\(^8\) WP1 - Scope and Boundaries of Project Demonstration
\(^9\) WP2 - Innovative Distribution Grid Use Cases and Functions
\(^10\) WP4 - Demonstration in real user environment: EDP - Portugal
\(^11\) WP7 - Market and business framework for rolling out of UPGRID innovative concepts
\(^12\) WP8 - Monitoring & Impact Assessment of Project Demonstration
\(^13\) WP9 - User Engagement, Societal Research and Dissemination of Project Results
Cluster 2 – Integration of DER and new uses:

- Pioneering integration of public lighting as a flexible distributed energy resources
- In depth evaluation of EV public charging stations consumption profiles
- Demonstration of LV connected DER in-grid operation

With the increasing penetration of DER in the grid, being able to integrate these resources is a key aspect to guarantee the reliability of the system. To enable the integration of DER, both the DSM
schemes and the control of public lighting have achieved the proposed objectives. The HEMS solution permitted to demonstrate in the field to control active loads at the customer premises, based on set points triggered by the DSO, as a measure to mitigate grid constraints. Furthermore, the integration of the Public lighting in the UGC enabled its use as a controllable energy resource and increased the its visibility and consequently the LV Grid visibility as well.

**Cluster 3 – Network operations:**

- Ground-breaking integrated LV grid management prototype “UPGRID Control”
- Disruptive NB-IoT communication technology implemented in smart meters
- Innovative automatic voltage control prototype deployed

Network operation is the backbone that guarantees the daily stability and security of supply in the distribution grid. With an increasing complexity and number of assets integrated in the smart grid, the amount of data and potential information extracted from it also suffers an enormous boost. This presents two challenges: i) ensuring the communication layer is performing well; ii) having systems and tools able to cope with all the information coming from the field and digest these data to obtain valuable information.

On the communications’ domain, the project has enlarged the set of available technologies available for smart meter communication (first NB-IoT developed) as well as developed monitoring tools to better assess the performance of the communication layer (M2M).

**FIGURE 150: CENTRALISED AND INTEGRATED NETWORK OPERATION – UPGRID CONTROL**

UPGRID Control is the integrated tool including interfaces with more than 5 previously stand-alone systems (DPLAN UPGRID, UPGRID Mobility – Work Force Management solution, TelCo failures detector
– Sinapse, In-line power regulator, Outage Management System, MHP); as well as corporate systems (AMI). This ecosystem empowers the dispatch operator to act based on information from several sources, thus increasing the visibility and ability to deal with grid issues.

**Cluster 4 – Network planning and asset management:**

- LV Power Flow prototype “DPLAN UPGRID” integrating forecasts and SM data
- Advanced mobility prototype to support field teams “UPGRID MOBILITY”
- Automatic feeder mapping prototype based on smart grid assets

![UPGRID Mobility Solution](image)

UPGRID Mobility has created new approaches for the operation in the field. With this tool, the field teams have enlarged their possibilities to interact with both the dispatch centre and the assets in the field (visualize the actual network state and grid assets), thus allowing them to be more efficient and informed in their interventions.

DPLAN UPGRID’s main highlight is the use of both forecasting and smart grid data (something never integrated before), which allows the assessment of possible grid constraints at the LV level.

**Cluster 5 – Market design:**

- Development and operation of a market hub platform connecting DSO and consumers through market agents;
- Implementation of a Retailers Platform to manage consumers HEMS;
- Integration of LV consumers’ consumption data in grid congestion analysis for dynamic tariff construction;
The results achieved in market design enhance the market facilitator role of the DSO. The Market HUB platform is a neutral market access platform that can be used in the future to operate the grid in an efficient manner. An example is that, for a planned maintenance, a better planning of operations can be made considering load reduction action (enabled by DSM schemes).

Considering the results achieved, some of the developments made in the systems under demonstration are going to be included in future specifications and implemented in EDPD corporate systems. This way, the improvements obtained at the confined demo area are scaled to bigger areas, thus enhancing its benefits in the entire network.
REFERENCES

UPGRID DOCUMENTS

[1] UPGRID Deliverable D4.2 - Guidelines for field testing

[2] UPGRID Deliverable D2.2 – Report on services provided by DSOs to the retail market