PROJECT SENSIBLE'S RESULTS FROM MV/LV COORDINATED ISLAND OPERATION IN A DISTRIBUTION GRID

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ABSTRACT

The Horizon 2020 Storage ENabled SustaInable energy for BuiLdings and communitiEs (SENSIBLE) focused in the integration of small-scale storage technologies in buildings and distribution networks. The demonstration site of the SENSIBLE project, includes a EDP Distribuição's MV storage system and the project's LV small-scale storage systems. One of the most interesting use cases of project SENSIBLE consists in the coordinated islanding operation MV and LV storage systems, using a centralized control approach. This system will be able to isolate from the main grid thus effectively working as a microgrid with MV and LV Storage, PV generation and residential/commercial loads. This paper presents an overview of the assets, technologies and control tools that will enable new grid support functions from small-scale storage, addressing the main results and conclusions obtained by the end of the project.

INTRODUCTION

SENSIBLE Project Overview

The ambitious 20-20-20 targets of the European Union (EU) have been fostering the development of several projects focusing on the development of solutions to comply with these goals. SENSIBLE – Storage ENabled SustaInable energy for BuiLdings and communitiEs [1] is a Horizon 2020[1] funded innovation action aiming at the integration of small-scale electro-chemical, electro-mechanical and thermal storage technologies, together with Distributed Renewable Energy Sources (DRES), into distribution grid, homes and buildings.

The benefits of storage integration will be demonstrated in three sites: Évora (Portugal), Nottingham (UK) and Nuremberg (Germany). The aim is to create value for distribution grid operation, market players and end-users. Moreover, flexibility-based business models were proposed through the connection of local storage capacity with the energy markets, at the individual and aggregated level. SENSIBLE is also conducting life cycle analyses and assessing the socio-economic impact of small-scale storage integrated in buildings and distribution grids.

The Portuguese demonstrator is in a rural area with 238 clients connected to Low Voltage (LV) grid, supplied without redundancy by two distribution grid secondary substations of 250 kVA. The main objective of this demonstrator is to test new grid strategies and applications for tackling the technical challenges resulting from the large-scale integration of micro/mini renewable generation, together with the new load power consumption profiles, resulting from the deployment of demand side management and self-consumption strategies.

In the Évora demo site, several storage units are connected in LV to two secondary substations and there is also one MV storage connected to another secondary substation from Evora University. All of these systems were designed and are being operated with the main focus on improving the technical operation and quality of service of both LV and MV networks, namely by providing: 1) losses minimization, 2) voltage regulation 3) backup power capacity to mitigate the effects of voltage sags and power outages. Figure 1, illustrates a very simplified grid architecture of the Évora demonstrator infrastructure.

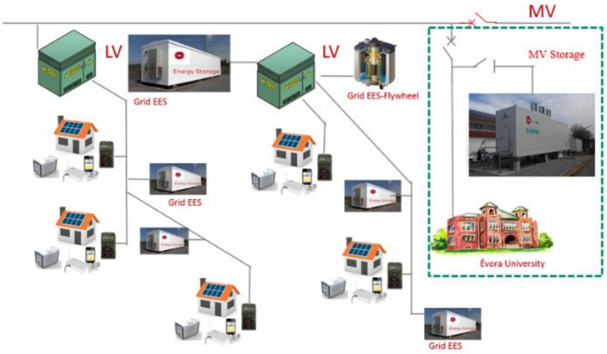

Figure 1 - SENSIBLE Infrastructure and EDP Distribuição's MV Storage.

As shown in Figure 1, the demonstrator includes MV and LV electrochemical storage, residential storage and PV. Smart meters are also installed in every consumer, as well as home automation systems in the households equipped with controllable loads.

The project objectives will be achieved through a variety of demonstration grid use cases, but this paper will mainly focus on the assets, tools results and main conclusions related with the MV – LV extended island operation, mostly linked with use case 11, **Microgrid Emergency Balance Tool.**

MV-LV EXTENDED ISLAND OPERATION

As previously stated, one of the most interesting use cases of the project is the coordinated islanding operation of the projects' LV storage systems and EDP Distribuição's MV storage system through a centralized control approach. This use case explores the possibilities arising from the optimized control of MV and LV distributed storage to face grid outages. This section will describe the main grid assets and control tools required, as well as their interactions [2].

Grid Assets

-Grid Energy Storage Systems:
- MV ESS0, with 480 kW/360kWh, at MV feeder.
- LV ESS1: with 50kW/50 kWh, at secondary substation.
- LV ESS2: with 30kW/22 kWh, at feeder level.
- LV ESS3: with 30kW/27 kWh, at feeder level.
- LV ESS4: with 10kW/22 kWh, at feeder level.

-245 smartmeters with GPRS communications
-2 specially built Distribution Transformer Controllers

Control and Monitoring Tools

LV and MV load forecast tools

A load forecast algorithm was created for the project, providing intraday and day ahead forecasts for both LV and MV use cases, using historical consumption data to estimate the model parameters over a training set period.

Parameter	Value
Number of consumers	245 at LV level + 53 at MV level
Update frequency	Every 24 hours in day-ahead Every hour in intraday
Forecast time horizon	24 hours in day-ahead 6 hours in intraday
Time resolution	15 min (both intraday and day-ahead)

Figure 3 - Load forecast specifications

The steps involved in the load forecasting are:

1) The tool collects the most recent weather forecasts (Numerical Weather Predictions for the region.
2) The tool collects the most recent load consumption measured data for Sensible consumers.
3) Day-ahead and intraday load forecasts are calculated from two inputs using a specific algorithm.

The data flow diagrams for load forecasting are shown in Figure 3 along with the tool architecture inside the EDP environment. The different modules and their operation are listed and described below:

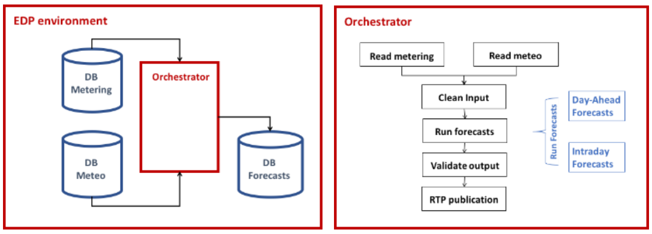

Figure 2 - Load forecasting, flow chart and modules

Whenever there is sufficient data for a specific household, the median consumption for that household for each hour of the week is computed on the training set. This means that the training set for one household contains at least one measure for every hour of the week. If this is not the case, missing hours are either interpolated by a linear regression, or taken from an average of the surrounding households. For every household, the 'median week' is obtained by concatenating the 168 (7×24) median hourly loads. This vector is stored and is used as a fall-back prediction when the advanced model has problems producing a forecast of adequate quality (i.e. missing input for a long period). The training set is then normalised by these median hourly loads for each household. The difference between a typical median day and the next day is performed using a quantile smoothing spline regression.

MV Network Islanded Monitoring and Balancing Tool

The main objective of the MV Network Islanded Monitoring and Balancing Tool is to manage the storage capacity of the MV storage, to ensure a secure islanding and maximize the time the network can operate in islanded mode. The tool runs in real-time both in interconnected and islanded mode to update the emergency operation plan according to the current network operation condition. Three distinct algorithms run for the distribution networks composing Évora Demonstrator, namely:

- End of MV feeder supplying Évora university premises and the two LV networks supplied by the two MV/LV substations

- LV network supplied by MV/LV substation not able to operate in islanded mode, considering that it's not equipped with a VSI storage device.
- LV network supplied by MV/LV substation able to operate in islanded mode.

The algorithms run together with the other DSO tools in to generate the emergency plan for every hour, in case a unplanned islanding occurs.

More specifically, the tool evaluates the technical feasibility of islanding the end of the MV feeder composed by two secondary substations and respective LV networks, and by MV consumer (Évora University). The main priority is to first ensure the supply of the MV consumer (Évora University) and if possible use the remaining capacity to supply LV networks. If there is not enough reserve to ensure the stability of the MV island, the algorithm authorizes only partial MV+LV grid or even just the MV consumer.
During islanded operation, MV ESS0 is operated as grid forming, while the remaining ESS operate as grid supporting units, namely ESS1, ESS2, ESS3 and ESS4.
The tool calculates the emergency plan based on the current state of the MG ESS, together with the aggregated forecasts from both LV networks MV/LV transformers and MV consumer (Évora University). Every 15 minutes, the tool will update the emergency plan, trying to generate an operational plan that guarantees the security of MV islanded operation for the predefined time horizon. When the real time MG measurements differ from forecasts, the MV Network Islanded Monitoring and Balancing Tool is going to correct the emergency plan.

DEMONSTRATION RESULTS

Technical results

The extended island demonstration activities had a simulation phase, to test the behaviour of the control tools followed by several real field tests involving the opening of the MV switchgear identified in Figure 1. The grid forming MV ESS0 is responsible for the transition to island operation, consequently, successful transition to island operation is limited by ESS1 power and to some extent, battery capacity and state of charge. The remaining LV systems are dispatched by the Islanded Monitoring and Balancing Tool and start contributing to load management a few minutes following grid disconnection. This section focuses on the results obtained in one of the field demonstration tests involving the project's area secondary substations and respective clients [3].

Before the islanding, the MG emergency balance tool defined the emergency plan for the next hour, based on the load forecast presented in Table 1 -Table 1.

Table 1 - MG forecasted power balance at MV feeder

Time	11:32-11:45	11:45-12:00	12:00-12:15	12:15-12:30	12:30-12:32
Active Power (kW)	197	193	199	208	213
Reactive Power (kvar)	112	110	138	128	125

Considering that the total load exceeds the maximum power of the ESS1, ESS2 and STG4 are dispatched at their technical limit to avoid significant voltage deviations (overvoltage) (Figure 4).

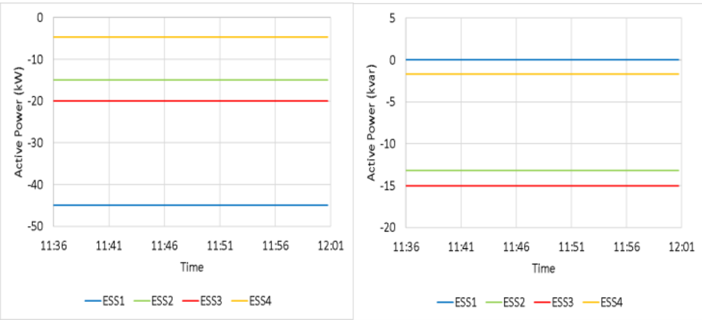

Figure 4 - MG tool active (left) and reactive (right) power dispatch

Figure 5 and Figure 6 shows the real measurements taken on the field during the MV islanding tests. On Figure 5 it is possible to analyse the voltage and frequency values ensured by the control of MV ESS0. Both voltage and frequency kept within the technical limits during all the demonstration period (±10% for voltage and ±1% for frequency)

Figure 5 - Voltage (above) and frequency (bellow) measurements on LV networks during MV islanding

Figure 6 provides the active power measurements on the coupling point of ESS0, and both LV networks. It is possible to verify that in the moment of the isolation, there is a small drop on power output of MV ESS0. This happens because the system passes from P/Q control to V/f control mode and assumes all the load that was being supplied by the MV network.

Two minutes after the isolation, the first setpoints calculated by the emergency balance tool reach the LV

ESS (1, 2, 3, and 4). Immediately it is possible to analyse that the LV network where ESS1, ESS2 and ESS4 are installed goes from consuming energy from the MV grid to start injecting energy.

On the LV network where ESS3 is located, it is possible to check a small decrease of load consumption on the coupling point (transformer) after the first setpoint due to the power output of ESS3. All the storage systems continue receiving power setpoints during almost 50 minutes when the DSO decides to perform the reconnection from the MV Microgrid to the MV main network.

Several similar test were performed using the same assets and control tools and despite some minor adjustments and modifications, the results were similar and overall system stability was demonstrated under the specified conditions.

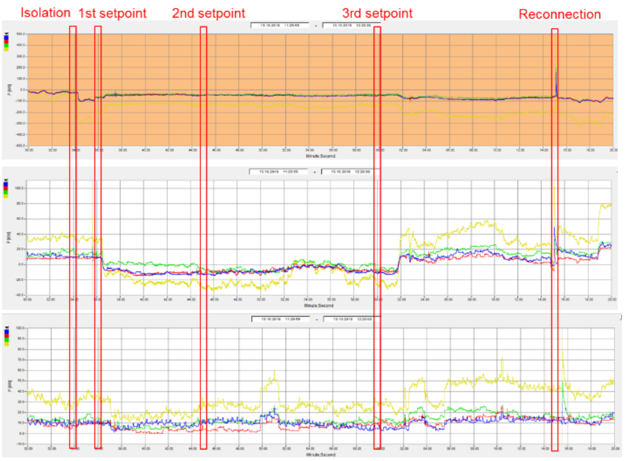

Figure 6 - Active power on ESS5 (top), LV Network 1 (middle) and LV Network 2 (bottom) during MV islanding

The results presented for both LV and MV emergency balance tools have shown that adequate coordination of distributed storage units and flexible resources can help improve the stability and security of the microgrid system operating in islanded mode, increasing the power and energy reserve capacity available. In the case of the Extended Islanding tests, it was shown that the coordinated control allows the LV ESS to provide support to the neighboring MV/LV substations, while maximizing the reserve of the VSI units.

Project KPI's – Energy Not Supplied (ENS)

As far as the continuity of service is concerned, one may analyse the grid constraints which occurred during the last few years and try to estimate the improvement in the quality of service if the SENSIBLE project solution had been already in place.

The improvement in the energy not supplied was analysed with this formula:

$$ENS = \frac{\boldsymbol{ENS_{Baseline}} - \boldsymbol{ENS_{SENSIBLE}}}{\boldsymbol{Total\ energy\ not\ supplied_{Base\ case}}}$$

Where:

- **ENS** – Energy not supplied (%)
- $\boldsymbol{ENS_{SENSIBLE}}$– Energy not supplied in SENSIBLE scenario (kWh);
- $\boldsymbol{ENS_{Baseline}}$– Energy not supplied in baseline case;

From the analyzed historical data during the last three years, between 2016 and 2018, there were 113 occurrences in this part of the MV grid, which disconnected the three secondary substations belonging to Évora's demo site. Most of these disturbances lasted less than 3 minutes, and in these cases, if the SENSIBLE solution was up and running, it would have been possible to supply the necessary energy, at the needed power, so that customers would not feel any disturbance.

If an average state of charge of 75% for all the storage units, which are involved in the Extended Island use case is considered, this means that approximately 361kWh would be available to mitigate each disturbance. Consequently, analyzing the historical data and estimating the energy not supplied in each occurrence it is possible to calculate the ENS index.

From the 113 occurrences, there were 9 which lasted longer and could represent a problem for the continuity of service, either way it would be possible to partially mitigate the events. For this Extended Island operation, it was estimated that only 1,1% of the necessary energy would not be supplied, which translates in an improve of 98,9%.

CONCLUSION

Sensible project and the specific focus of this paper, the Évora demonstrator of the project, clearly demonstrate the various technical possibilities and benefits arising from using distributed storage to support distribution grids. In fact, it is safe to say that these systems can help DSOs face some of the most difficult challenges, like quality of service in a context of increasing distributed energy resources or in a context of more frequent and severe extreme weather events.

However, these technical results were achieved by an experimental infrastructure, using tailor made control tools that are hard to adapt and customize to a different demonstrator site. Also, these tools are highly dependent on a steady stream of data, e.g. consumption data, that were achieved for this project through a purposed built smart grid infrastructure, but cannot easily be replicated or escalated to other parts of the grid. Furthermore, the integration of these control tools in existing Distribution Management Systems is extremely complex and typically faces resistance due to the high importance of these systems to daily grid operations.

The storage assets by themselves, and their grid integration and operation were also a challenge, due to a general lack of standards and guidelines. Although the project, due to its experimental nature did not face any significant regulatory constraints, the fact is that there still isn't a clear regulatory framework to guide the use of energy storage in the scope of the mentioned applications. And related with this topic, using conventional grid planning criteria and only existing regulatory incentives to decrease non-distributed energy or power losses, it is still not clear how to build the business case for the introduction of energy storage as another grid asset.

However, despite these limitations, energy storage will clearly have an important contribution for the upcoming energy transition, and that its applications are not restricted by voltage level, degree of grid integration or control possibilities.

ACKNOWLEDGEMENTS

This work is being carried out as a part of the SENSIBLE project (Storage ENabled SustaInable energy for BuiLdings and communitiEs - www.h2020-project-sensible.eu) that has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 645963.

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