INTEGRATION OF ENERGY STORAGE IN LV GRID NORMAL AND EMERGENCY OPERATION

Miguel MARQUES
EDP NEW R&D – Portugal
migueljorge.marques@edp.pt

Pedro MOUSINHO
EDP Distribuição – Portugal
pedro.mousinho@edp.pt

Andreia LEIRIA
EDP Labelec – Portugal
andreia.leiria@edp.pt

Ricardo BESSA
INESC TEC – Portugal
ricardo.j.bessa@inesctec.pt

Clara GOUVEIA
INESC TEC – Portugal
clara.s.gouveia@inesctec.pt

André MADUREIRA
INESC TEC - Portugal
andre.g.madureira@inesctec.pt

Carlos MOREIRA
INESC TEC – Portugal
cmoreira@inesctec.pt

Matthias GERLICH
Siemens AG – Germany
matthias.gerlich@siemens.com

Salvador RODRIGUEZ
GP Tech – Spain
srodriguez@greenpower.es

ABSTRACT

This paper presents the approach followed under project SENSIBLE to prove, in field-test scenarios, the benefits of integrating and coordinating small-scale storage devices to: (i) reduce the impact of Distributed Renewable Energy Sources in the Low Voltage grid and (ii) support the transition and the operation in islanding mode in the demonstration grid. The functional and ICT architecture developed for the Portuguese Demonstrator of Évora is presented, focusing in the use cases defined to test and validate the tools developed to enable the active management of the LV grid during both normal and islanded modes.

INTRODUCTION

The increasing penetration of Distributed Renewable Energy Sources (DRES) in distribution networks has changed considerably the way electric distribution systems are operated.

In the case of Low Voltage (LV) grids, the variability of these sources due to the behavior of the primary resource, either sun in case of photovoltaic (PV) microgeneration or wind in the case of small wind turbines, is becoming a challenge for operation as it affects significantly voltage profiles and branch flows [1].

In addition, a growing demand variability is expected as a result of demand response actions, together with new regulation that fosters PV self-consumption, poses additional challenges to the operation and management of the LV grid.

In this context, a coordinated use of all distributed energy resources is necessary where storage systems emerge as a promising solution to help coping with the variability of DRES.

Therefore, an intelligent integration and a coordinated use of small-scale energy storage devices combined with the flexibility provided by end customers can significantly contribute to improve the robustness, resilience and flexibility of the LV grid, a central goal for a Distribution System Operator (DSO). In this scenario, using storage devices to overcome the technical issues in the grid and enabling the creation of microgrids to strengthen the LV grid is the challenge addressed in this paper.

PROJECT SENSIBLE

Using different distributed energy resources technologies such as photovoltaic generation, energy storage (electrochemical, electromechanical and thermal), SENSIBLE (Storage ENabled SustaInable energy for BuiLdings and communitiEs) aims to integrate and manage microgeneration and small scale energy storage resources. This integration will manage to cope with challenges related to microgeneration and decentralized storage, creating value for both the DSO and the end customers (behind-the-meter applications). Project SENSIBLE will deploy three demonstrators – in Portugal, UK and Germany – where complementary applications will be implemented.

The Portuguese demonstrator will be deployed in Évora and focuses on the use of local and small-scale storage (downwards to the secondary substation) in the grid and also in houses, and the use of energy management tools, such as demand side management (DSM). This demonstrator will be focused on rural / semi-urban grids.

The UK demonstrator will be deployed in the Meadows (Nottingham), a social neighborhood with a high level of environmental commitment, in which focus is given on community application supporting DRES integration.

Germany's demonstrator will be installed in Nuremberg, inside THN (Nuremberg University) laboratories. It focuses on building energy management, combining thermal storage, electrochemical storage and also building's thermal inertia.

Lab validation will also play an important role in the project, as developed tools and the equipment to be integrated in the network and in the homes or buildings will first be tested in laboratorial environment.

The project started by defining requirements for the demonstration and adapt the ICT infrastructure to enable a set of proposed use cases, followed by a demonstration stage. The replication of the demonstrated functionalities is evaluated in a final stage.

In the framework of the demonstration stage, EDP will deploy in the Portuguese demonstrator of Évora, a number of grid-embedded electrochemical and electromechanical storage devices in secondary

substations and along LV feeders, owned and operated by the DSO. Residential storage units, PV panels and controllable loads will also be installed in each participating household and the flexibility granted by them will be managed by a Home Energy Management Systems (HEMS), which will be managed by the clients' retailers and that will be able to provide grid support services to the DSO.

Évora Demonstrator

The architecture of the Évora demonstrator was defined and detailed as to fulfill the requirements and enable the testing of a set of defined functionalities, which are outlined in the use cases. The components of the Évora architecture can be organized in four groups, according to the ownership/responsibility of each of the components: DSO Infrastructure/Tools, Independent Actors, Market Operators and Client/Retailer Infrastructure.

This architecture enables the demonstration of the key features of the demonstrator: storage used for MV and LV operation optimization, participation of independent actors (DER aggregators, services provider, etc.), integration of new markets (ancillary services) or Power Quality and Continuity of Service. In addition, this demonstrator will also target LV customer flexibility usage within the wholesale market and grid usage optimization regarding investment deferral.

The key features to be tested and demonstrated in the Évora demonstrator were organized in five different use cases.

One of the use cases is focused on the usage of the flexibility of LV customers, provided by home storage devices, PV microgeneration and flexible loads managed by a HEMS. This flexibility is tested to be used within the retail market and will also enable the optimization of grid usage aimed at deferring network reinforcements.

Another of the use cases focuses on the optimization of the MV distribution network operation using the available storage resources to overcome technical challenges to the DSO, such as minimization of technical losses and correction of voltage profiles.

The remaining three use cases are focused on testing and validating the contributions of storage and load flexibility to the LV grid. These use cases are hereinafter thoroughly detailed.

LV STORAGE OPTIMIZATION USE CASE

This use case focuses on the optimization of the operation of the storage devices located in the LV distribution network. The main objective is the management of the locally distributed storage devices in order to solve technical problems in the LV grid (namely related to voltage issues) and/or minimize technical losses.

The capacity and the flexibility provided by the

aforementioned grid storage devices (directly connected to the LV feeders and installed in the secondary substations) as well as by the small house devices managed by the HEMS will constitute the basis of the use case.

Figure 1 depicts the main components in the architecture that play significant roles in the LV use cases.
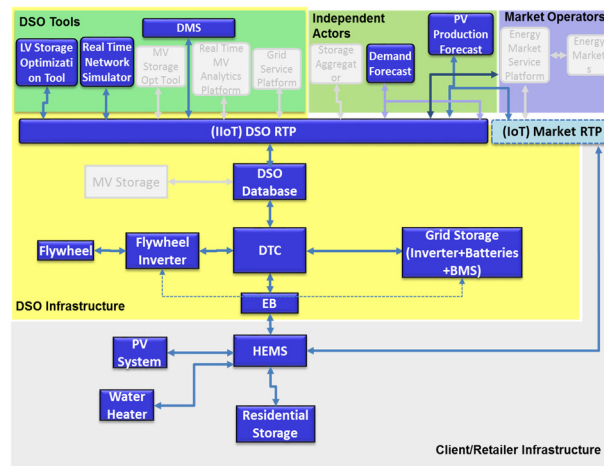

Figure 1 – LV Grid use cases key components
(highlighted in blue)

These components are either part of the DSO Infrastructure, the Client/Retailer Infrastructure or the group of independent actors that include forecasting tools.

The DSO-operated elements enable controlling directly its own storage devices that are connected to the LV distribution grid. Furthermore, on the Client/Retailer side, the HEMS allows for additional flexibility as it is able to calculate, based on current controllable load devices and residential storage devices' State of Charge and also on the availability to provide flexibility that the customer defines for a given time period, the flexibility bands that can be used by the DSO.

Using the Distribution Management System (DMS) the DSO will also be able to retrieve information on the current network topology, the state of operation which includes voltage profiles and load diagrams.

The Real Time Platform (RTP) plays a transversal role, acting as a middleware between the DSO smart grid Infrastructure and the LV optimization storage tool. Additionally, by accessing the forecasting information passed on by the forecasting tools, the DSO is able to retrieve information on the nodal active power (P) values expected for the time horizon that is being considered.

The **LV Storage Optimization Tool** plays a pivotal role in this use case. This tool, under development by INESC TEC, is based on a multi-period three-phase Optimal Power Flow (OPF) algorithm for optimizing the grid operation. It makes use not only of the storage connected

to the secondary substation, LV distribution feeders and buildings, but also demand-side management resources in domestic clients with small local storage capacity and HEMS installed.

The LV Storage Optimization Tool aims at optimizing the use of the storage devices and controllable loads defining an operating strategy for a pre-defined time horizon [2]. The algorithm will be developed to provide a plan for operation for the day-ahead taking as inputs forecasting data. The tool will then run in an intra-day operation every hour or whenever there are new forecast data and the conditions of the LV grid change considerably that reveal a problem that could not be anticipated in the day-ahead analysis. In this case, the algorithm will adjust the control actions while trying to minimize the deviation from the operating day-ahead plan.

The final output of the algorithm is the operating strategy of the distributed resources for the next hours/day. This output generates a set of control set-points for the storage and loads steady-state operation.

The main drivers for this approach are to minimize power losses, improve quality of service and ensure continuity of service, while respecting the technical constraints of the network and considering the future states of the LV grid.

Prior to the implementation of this use case, a numerical model of the Évora grid was used to perform a study to determine the most adequate location and sizing for the storage devices to be installed, with the objective of mitigating the undervoltages (bus voltage below 0,9 p.u.) and overvoltages (bus voltage above 1,1 p.u.) introduced in some buses with the fitting of water heaters and PV panels in households. The two most relevant cases occur for the two opposite situations:

- For the peak generation situation (noon in a hot summer day), a number of overvoltages are registered due to the presence of the PV panels;
- For the peak consumption situation (dinner time in a cold winter day) there are undervoltages in a number of buses, caused by the increase of load (fitting of water heaters).

Figure 2 shows, in the left, the merge of the grid operation statuses for these two scenarios, where a number of undervoltages and overvoltages are depicted (as described). The result of installing properly sized storage devices in key locations, both residential and grid connected, is depicted in the right of Figure 2. For this purpose, a trial-and-error approach was followed, and results show that using two grid storage systems – one of 100kVA installed in a key location along the LV feeder and a 30kVA system in the secondary substation – and 3kVA residential storage devices can bring the bus voltages to values within quality standards (0,9 p.u. – 1,1 p.u.).
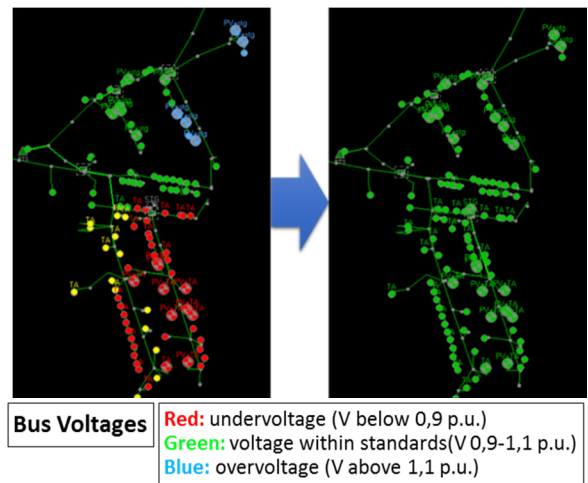

Bus Voltages | **Red:** undervoltage (V below 0,9 p.u.)
Green: voltage within standards(V 0,9-1,1 p.u.)
Blue: overvoltage (V above 1,1 p.u.)

Figure 2 – Effect of installing storage devices in Evora´s LV grid.

LV GRID ISLANDING OPERATION USE CASE

The implementation of a microgrid in a LV grid supplied by a secondary substation, disconnected from the main grid is, in fact, one of the key features to be tested in the scope of the Évora demonstrator.

The use case hereby presented focuses on both the transition to the islanding mode and the operation in the microgrid once the islanding mode is enabled. In fact, in the scope of project SENSIBLE, these two scenarios are described as two separate use cases but, for the purpose of this paper, these are treated as one use case only.

This LV grid islanding operation use case is dedicated to the operation of the LV network when disconnecting from the main grid (due to planned or unplanned events), using the grid-embedded storage units and managing the residential devices (via HEMS).

Sudden islanding of the LV distribution system may cause high unbalances between local load and power supply which must be immediately compensated by fast-response storage devices. To this purpose, in the secondary substation to be islanded, one flywheel and one battery energy storage (BESS) system will be installed which, in coordination, assure the system stability. The flywheel and the BESS grid forming inverters ensure frequency and voltage regulation through droop characteristics [3]. However, the flywheel system will only support frequency and voltage regulation during the first moments of the islanding, due to low energy capacity.

During islanding operation, the BESS will ensure the secure and stable operation of the system, supported by the other distributed resources connected downstream, namely the electrochemical storage installed along the LV feeders, and the PV systems as well as RESS in participant houses. The proper management of the operation of these devices ensures a secure islanding

operation, thus increasing the grid resilience [4].

A **Microgrid Emergency Balance Tool**, as depicted in Figure 1 (as a DSO Tool), is a software application that will also be developed by INESC TEC as the main element in this islanding use case. The goal of this tool is to manage the storage capacity, considering the flexibility of the resources in the LV distribution grid, provided by grid storage and the consumer resources participating in demand side management strategies.

The Microgrid Emergency Balance Tool comprises two modules: the pre-islanding balancing module and the emergency balance module.

The **pre-islanding balancing** algorithm runs during the interconnected mode, performing continuous monitoring of the LV grid and evaluating the LV grid state in order to estimate the severity of the disturbance and determine the storage energy capacity required to ensure the MG islanded operation during a pre-established period of time and also defining the most adequate control actions to the available resources in order to minimize the transient caused by the islanding procedure in case of a planned islanding.

The **emergency balance tool** is triggered after islanding and will monitor periodically the LV network operation in order to ensure that the total storage capacity is sufficient to ensure the frequency and voltage regulation of the islanded system. The tool will also monitor voltage in the LV network, ensuring that both frequency and voltage are maintained within admissible limits.

The MG Emergency Balance tool control horizon can be set to plan the control for the next 15 minutes or in a longer term (a few hours) based on load and micro-generation forecasting. As outputs, the tool will return a set of control signals to grid supporting storage and to customer energy management system in order to control flexible resources.

CONCLUSIONS AND FUTURE WORK

The first conclusions considered and presented in this paper are based on the main findings of the work developed during the first year of the SENSIBLE Project. As such, the ICT architecture presented and the use cases fit with the objective of the project, which is proving the benefits to the grid operation of seamlessly introducing small-scale storage in the LV grid. The use cases presented have thus been defined to enable the testing and validation of using storage devices to (i) optimize the LV operation and (ii) enabling the islanding and operating in islanded mode.

First results of the simulation work previous to the implementation of the use case on the optimization of the LV network (Figure 2) prove that the installation of storage in the LV grid can in fact help reducing the undervoltages and overvoltages introduced by the installation of PV panels and new controllable loads (e.g. water heaters) in the LV grid.

Future steps of the project will include, in the short term, the complete development of the software applications (including the key LV Storage Optimization Tool and the Microgrid Emergency Balance Tool). Subsequently, the installation, commissioning and testing work (both in laboratorial environment and on-site in Évora) will follow to validate the approach. Results of these tests will then be used to validate business models to enable a future real implementation.

REFERENCES

[1] A. Madureira, L. Seca and J. P. Lopes, 2012, "Coordinated voltage control in distribution systems under the smart grid concept", *Proceedings* CIRED 2012 *Workshop Integration of Renewables into the Distribution Grid*, IET, 1-4.

[2] A. Madureira, R.J. Bessa, J. Meirinhos, D. Fayzur, J. Filipe, A. Messias, D. Lopes and P. Matos, 2015 "The impact of solar power forecast errors on voltage control in smart distribution grids," *Proceedings of the 23rd International Conference on Electricity Distribution - CIRED 2015*, Lyon, France.

[3] J.A. Peças Lopes, C.L. Moreira, A.G. Madureira, "Defining control strategies for MicroGrids islanded operation", *IEEE Transactions on Power Systems*, vol.21, no.2, pp. 916- 924, May 2006.

[4] C. Gouveia, J. Moreira, C.L. Moreira, J.A. Peças Lopes, "Coordinating Storage and Demand Response for Microgrid Emergency Operation," *IEEE Transactions on Smart Grid*, vol.4, no.4, pp.1898-1908, Dec. 2013.