SMARTGRIDS ENABLING MICROGRIDS AND ISLANDING OPERATION: SENSIBLE AS A REAL DEMONSTRATION CASE STUDY

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ABSTRACT

This abstract summarizes the highlights of the work carried out in SENSIBLE, namely for the demonstration of Microgrid (MG) concept in a real distribution network SENSIBLE draws the path from a conventional grid to an advanced MG explored under a smartgrid paradigm, where thermal and electric energy storage play are one of the main actors. The implementation of an innovative distribution network management and control infrastructure based on the MG concept and taking advantage of the smart metering infrastructure enables the implementation of new energy services for consumers and new grid operation strategies, making possible the operation of a real MG where customers are key players providing flexibility in case of grid technical constraints.

INTRODUCTION

European Union (EU) 2020 targets have promoted the increase of renewable energy sources (RES) in electrical systems. This increase has been mainly located at distribution grid level (MV), which can induce technical constraints in conventional grids, since they were designed for a unidirectional power flow. Another important EU energy driver relates to high security of supply, concerning the critical importance of electrical energy in European society.

MG is a concept where a distribution grid (Medium or low voltage) can be operated independently from the main grid, including the availability of advanced capabilities like isolation from the main grid, local control features ensuring primary, secondary and tertiary control. Optimal Power Flow tools are also available enabling the optimal dispatch of distributed assets depending on targets which may vary from technical losses reduction, voltage profiles optimization, economic targets or other. This may change the grid operation paradigm since it can be used as a powerful concept and a new grid operation mechanism that allow the DSO to manage the distribution grid in safer, more reliable and smarter way. MG concept combining the availability of distributed assets (like storage), active clients (prosumers), smart grid infrastructure, distributed automation (DA), renewable energy sources (RES) as well as advanced control features (high-level power flow tools) MGs can be smartly enabled, as represented in figure 1.

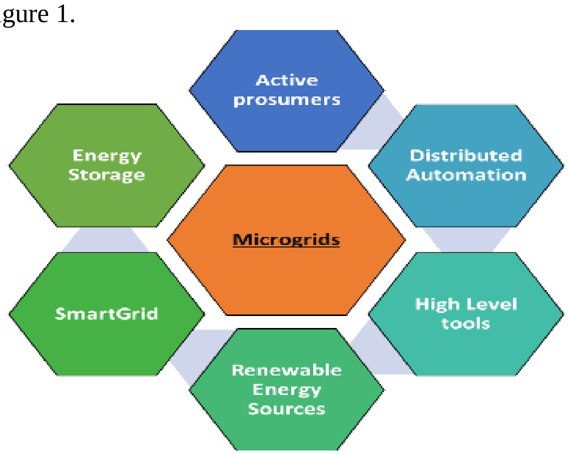


Figure 1 – MG enabling drivers

SENSIBLE[1] is an H2020 project, which scope is related to energy storage and energy management in three complementary domains: i) clients and communities; ii) distribution grid; iii) buildings. Portuguese demonstrator, in Évora-Valverde, led by EDP Labelec is focused in energy storage and energy management solutions enabling new tools for distribution grid operation and also in the development of new energy services for final customers, addressing then two of the mentioned domains.

CONCEPT DEVELOPMENT AND DEMONSTRATION

The presented concept is implemented in Valverde (southeast Portugal) which is fed in the end of a 15kV overhead line exposed to weather and therefore with some power quality issues. In Valverde, each one of 240 grid customers are equipped with smart meters (GPRS) and 25 households are equipped with µG, batteries and thermal storage, as well as a home energy management system (HEMS). Both Valverde secondary substations

1 H2020-LCE08-14, GA 645963

(SS) were upgraded with new automation equipment. Electrochemical and electrostatic storage was installed, being connected to one SS and along the LV feeders. Valverde demonstrator infrastructure is summarized in figure 2, where every MG enabling drivers where putted in practice.

Use cases summary and challenges addressed

Valverde use cases are shortly described below, as well as the addressed goals. Due to the wide content of the project, only uses cases with results integrated in the paper are explained.

- **UC 1 – Optimizing distribution network operation through energy storage management**
  - ➢ How to control storage operation in order to minimize technical losses and optimize voltage profiles in MV and LV networks.
- **UC 3 – Smooth islanding transition and main grid synchronization**
  - ➢ How the islanding operation be enabled in LV grids in a safe, reliable and smart way, making also possible a reliable synchronization when main grid is available, making use of batteries and double-layer capacitors (supercaps) properly coordinated?
- **UC 4 – Energy management in emergency operation**
  How could the management of energy storage and its coordination with other flexible resources help improve the resilience of the islanded system?
- **UC 5 – Residential flexibility management and DSM in market environment**
  - ➢ How can residential flexibility be valued in a competitive environment, bridging the gap between EU citizen and an integrated energy market where system services like deviations minimizations can be avoided if flexibility is aggregated?

ICT infrastructure

Figure 2 gives an overview on ICT architecture where several ICT domains are outlined, from: i) DSO high level tools (light grey); ii) independent actors (light green); iii) EDP Distribuição smart grid infrastructure 2(yellow); iv) Energy Service Provider (ESP) market tools which manage flexibility in energy markets (orange); v) Retailer infrastructure enabling residential flexibility management for several purposes(grey).

Valverde demonstrator outline

In figure 2 Évora demonstrator is outlined and progress will be explained below.

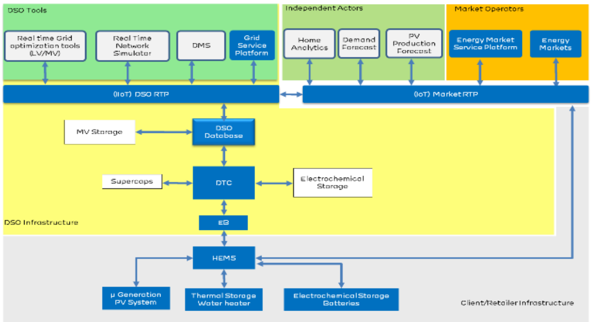


Figure 2 – Valverde ICT infrastructure layout

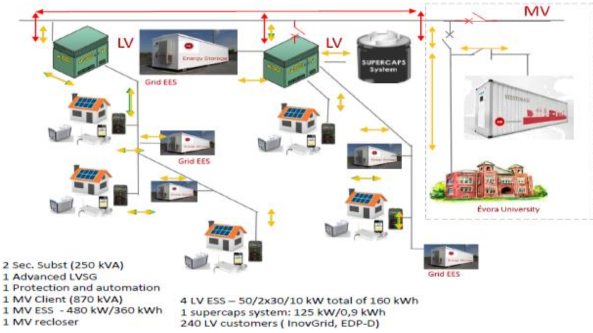


Figure 3 – Valverde demonstrator layout

DEVELOPMENTS AND PROGRESS

In order to enable islanding operation and energy storage management, several changes were done in a conventional LV distribution grid. The designed solution challenges the standard approaches at three different layers:

Operation, automation, protection

Primary and secondary control
Inverter droop control features ensure primary control. During islanded operation, the MG frequency and voltage regulation strategies will try to ensure continuous power balancing with minimum dependence of communication systems. Similarly to the conventional system, MG control structures typically follow an hierarchical arrangement comprising primary, secondary and tertiary control.
In the context of SENSIBLE, the Battery Energy Storage (BES) installed at the SS will be responsible for establishing voltage and frequency references, as well as ensure the system voltage and frequency regulation, through P-f and Q-V droop control.
Secondary control, after a disturbance, is done at local level, through a dedicated controller called islanding manager (IM), which guarantees power electronics coordination, secondary coordination.

High-level islanding monitoring and control tools

High level algorithms to be housed at the SCADA/DMS were included in order to help plan and operate in real-time the islanded MG. The tool developed in the context

2 inovGrid project, funded by FP7 program

of SENSIBLE project evaluates the MG operating state for the next hours, based on load and generation forecast and defines the most adequate control strategy for the MG distributed storage and flexible loads, that can increase the resilience and operation duration of the MG. The main objective is to coordinate the operation of the different resources in order to support the grid BES ensuring the voltage and frequency regulation of the system. Also a human machine interface is available to operate the MG by human hands when high level tools are not available.

Automation and local control

The Distribution Transformer Controller (DTC) operates: i) Smart meters, protection and storage devices; ii) transmits smart metering information to high level tools. The low voltage switchboard was upgraded with a fast circuit breaker, for synchronization and reconnection purposes. New protection devices, protecting not only LV network but also MV were installed.

Energy Storage Grid Assets

Several energy storage systems are considered in Valverde demonstrator, from Li-Ion batteries - energy response (50 kW, 2x30kW, 10 kW – 4 units) and supercaps-power response (125 kW – 1 unit)

Derived from the different characteristics of the storage technologies, compare to (Zakeri and Syri, 2015), one of the systems is referred to as energy storage: a lithium-ion battery systems and the other one as power storage: a double layer capacitor -based energy storage, as depicted in Figure 2. Depending on the level and type of integration, the power storage with its high power output for short duration can compensate the higher frequency load fluctuations in the grid, see (Aneke and Wang, 2016) ,and therefore reduce the stress ("C-Rates") for the batteries when relatively high currents are required for primary grid support. s

Residential infrastrucutre

The HEMS is able to provide DSM schemes to the DSO managing the clients' flexibility, which are equipped with PV (1,5 kWp), water heaters (2kW), and batteries (3kW, 3,3 kWh), smart plugs (up to 2kW). One residential battery prototype is also installed (10kW/20kWh).

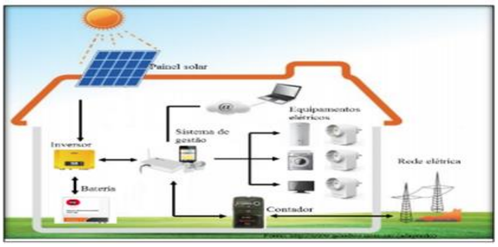


Figure 4 – Residential infrastructure

Nevertheless, customers are also able to value their flexibility in energy markets through a representative like a ESP which can represent a customers' portfolio leveraging synergies. An HMI interface was developed and provided to customers in order to enable them to manage their HEMS solution on their own.

RESULTS AND CONCLUSIONS

Valverde's demonstrator is now prepared and under operation, where results are being collected, after a laboratorial validation in INESC TEC and EDP Labelec SmartGrid Lab. Due to the existence of several use cases, only the most representative will be shared in this article. Figures 5 to 8 show the equipment already installed and running in Valverde, both at grid and residential side.

Figure 5 –V/f ESS Figure 6 – HEMS solution

Integration Supercaps – Battery Energy Storage

Power electronics integration as voltage sources present an implementation complexity not to be underestimated, especially for the realization of functional prototypes and systems that are meant to be integrated and manufactured and/or provided by many different parties. Without proper standardized interfaces, the amount of perspectives and misunderstandings are manifold and tend to appear unsolvable. As far as the design, planning and analysis of a system like this goes, it is a perfect application for a research project, the realization phase is not. SENSIBLE is understanding the complexity of integrating different sources of storage, provided by different manufacturers. Moreover the decision of having two ESS (batteries and supercaps) integrated as two voltage sources is really ambitious and complex. Integration on DC side through appropriate DC-DC converters is possibility to be considered. Figure 9 show a failed integration test due to lack of droop coordination.

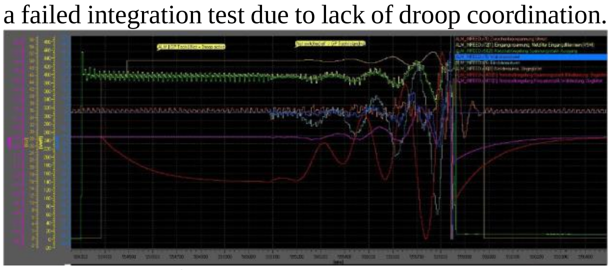


Figure 7 – Result of an issue when both Battery ESS and Supercaps were working in parallel, where lack of droop coordination led to overvoltage reaching 600 Vac.

Islanding results

Figure 10 represents a test performed where islanding operation is enabled through the local control features as well as synchronization algorithms enabling the safe transition to the main grid.

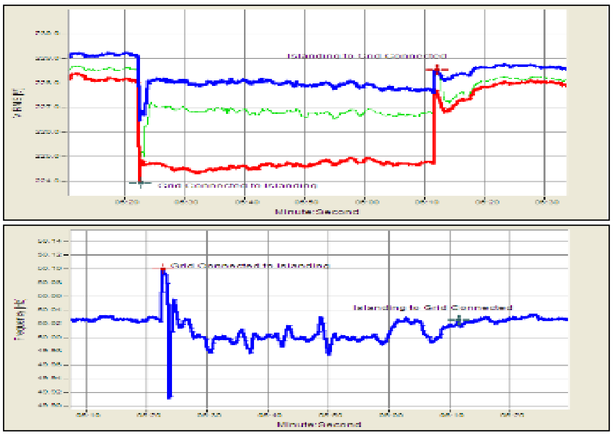


Figure 8 – Transition to islanding and synchronization (60 kW load), with voltage on the top and frequency on the bottom

Short circuit results

As explained in detail by Lopes Filipe [2] SENSIBLE developed a solution where power electronics were able to withstand a period under fault so that selectivity of protections can work, as showed in Figure 11. This ensures that the faults in the grid can be eliminated.

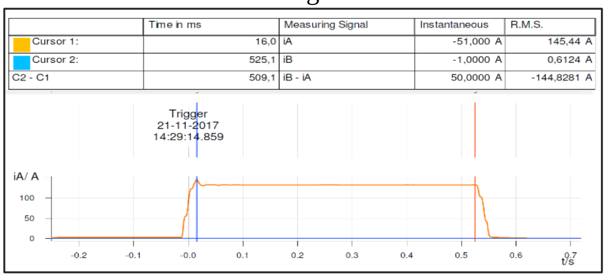


Figure 9 - Line-to-Ground impedance ($Z \sim 0.156\Omega$) fault, no load [2]

Tool performance

Figures 12 and 13 present the results where an under voltage constraint is detected and then the high level tools, through OPF technics makes use of flexibility provided by storage in order to solve it.

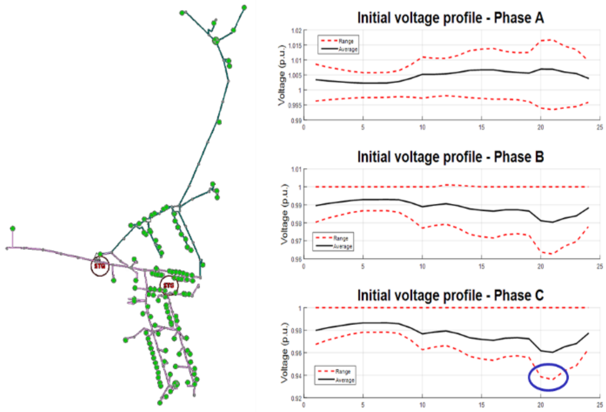


Figure 10 – Distribution grid and loads on the left and under voltage constrain detection by grid high level tools on right

Client energy management results

Figure 14 presents the results of individual management from Valverde's community and the integrated management by a ESP considering a market participation

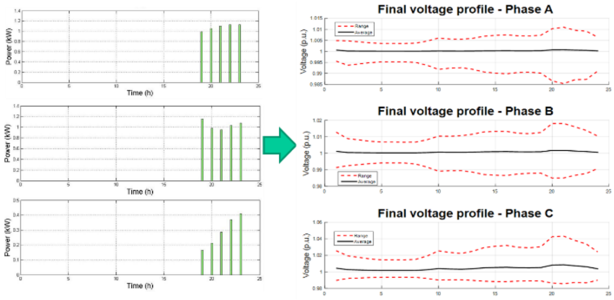
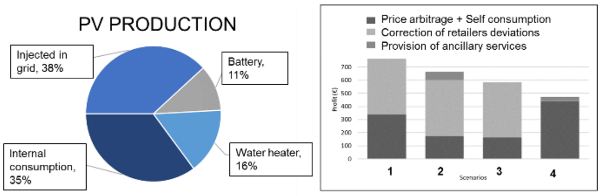


Figure 11 – By operating a storage device (left) the undervoltage constraint can be solved by the storage dispatch tools (right)

where other services, besides self-consumption are done like: correction of retailers' deviations on intraday or provision of ancillary services, these were studied in [3] by Castro et al.. Having more sources of revenue will diminish the payback time, although the possibility to provide them is very much dependent on regulation. On the left side of Figure 14, it can be seen that in this scenario, where only self-consumption is done, there is 30% of energy which is injected in the grid, for free.



Consumption	77 MWh
PV production	24,6 MWh
Savings	2.905€
CO2 emissions avoided	2, 5 tons
PV injected into grid	38%

	Tariff	Market Service
1	Time-of-use	Ret. Dev.
2	Index to spot market	Ret. Dev.+ anc.serv.
3	Index to spot market	Ret.dev.
4	Time-of-use	Ret. Dev + anc.serv.

Figure 12 – Results from Valverde demo site (left) – self consumption. Estimate on annual revenues when different services are provided (right).

Conclusions and next steps

SENSIBLE project is already in operation and some results are available as shared in this text. Energy storage represents a key asset to enable MG operation where clients are a key source of flexibility when flexibility is critically needed. Proper revenue streams must be identified so that clients may be rewarded by their flexibility when compared with energy markets references.

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[2] Lopes Filipe, Castanheira, Rocha, André, Almeida, Neves, Louro, Damásio, Gouveia, "H2020 SENSIBLE project – laboratory results for the short-circuit behaviour of the storage devices. under islanding conditions" *CIRED Workshop*, Lublijana, 2018.

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