InteGrid pilot in Portugal: Smart Grid based flexibility management tools for LV and MV predictive grid operation

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Abstract

This paper addresses the concept, scope and preliminary results of Portuguese demonstrator (PT demo) of the Horizon 2020 InteGrid project. The demo fully addresses EU policy drivers, namely demonstrating that environmental targets can be achieved through smart grids development with active participation of customers in grid operation and covers two goals: a) demonstrating the role of smart grids in scenarios with high renewable energy sources (RES) penetration; b) integration of the distribution system operator (DSO) role as market facilitator enabling disruptive business models to grid stakeholders including innovative energy services to the grid customers This paper demonstrates the technical feasibility and benefits of low voltage (LV) and medium voltage (MV) grid operation based on flexibility on the top of a smart grid infrastructure.

1. Introduction

During the last years, a large number of R&D and innovation projects have been implemented by DSOs throughout Europe with the aim to smarten the distribution grid and to enable the integration of a large share of RES. Moreover, policy makers have further refined the related market and regulatory framework in order to pave the way towards a new energy system taking into account the opportunities resulting from digitalization and consumer engagement in demand-side management projects. InteGrid's vision goes one step ahead by bridging the gap between citizens and technology/solution providers such as utilities, aggregators, manufacturers and all other agents providing energy services, hence expanding from DSOs distribution and access services to active market facilitation and system optimisation services while ensuring sustainability, security and quality of supply. The objectives of the InteGrid demonstrator in Portugal are mainly focused on using the distribution system as an enabler of flexibility-based products from LV and MV customers, with emphasis for flexibility integration with smart grid technologies designing predictive management strategies and integrate new business. In order to accomplish these objectives, the following use cases were demonstrated:

- Monitoring and predictive control of the LV network to estimate potential voltage violations, thus increasing grid observability and controllability
- Predictive control of the MV network enabled by combining load/RES forecasting and multi-period optimal power flow (MPOPF), integrated with a commercial Advanced Distribution Management System (ADMS) platform.
- A middle layer provided by the grid and market hub (gm-hub) is used for data management and flexibility exchange between the DSO and other stakeholders in LV and MV network.

PT demo obtained results are shown in an end-to-end demonstration covering all the process chains from data collection, to high level grid management tools where flexibility setpoints are sent both to LV and MV customers.

2. Concept and developments

In terms of controllability and observability, MV and LV operation scopes are different and three main aspects impose a different approach in grid operation: a) Most of MV grid is already remotely operated while LV is not. This means that, at MV level, the DSO may have its own flexibility by just changing grid topology, which is not possible in most of LV grids; b) The ratio between customer rated power capacity and grid capacity, where in MV one customer would have a significant higher impact when compared with a LV case; c) Communications in MV grid are much more reliable than in LV grids due to an economic and scale reason.

2.1. MV and LV forecasting tools

InteGrid Forecasting Service supports every tool envisioned for the operational planning of MV and LV distribution networks by ultimately providing access to daily active and reactive power forecasts for the network loads and RES, based on Numerical Weather Predictions (NWP) and the

DSO historical measurements data. This service is composed by: a) data management tools for NWP data acquisition, data cleaning, measurements data ingestion system; b) forecasting algorithms for MV and LV RES and load time series. The LV forecasting tool provides forecasts for power consumption and generation of LV consumers and consists in the application of a statistical model (conditional Kernel density estimation [1]) to generate point and probabilistic forecasts for the next 48 hours. NWP variables are used as input to improve the performance of the models and are leveraged using feature engineering techniques. Simpler models such as naïve forecast or linear regression are used if suboptimal conditions are verified, such as shortage of recent historical measurements data.

The MV forecasting tool provides active and reactive average power forecasts for HV/MV and MV/LV substations, large MV consumers and solar or wind farms. It relies on an ensemble of naïve, statistical and deep learning models to generate point and probabilistic forecasts for the next 48 hours. In order to improve the forecasting models accuracy, NWP are considered as exogenous variables.

2.2. InteGrid MV grid management tools

The exploitation of flexibility is a mean to enable a predictive management of the distribution grid. Two complementary tools were designed and implemented for the MV grid [2]: the MV Load Allocator (MVLA) and the Multi-Period Optimal Power Flow (MPOPF). The MVLA is intended to provide an estimation of the contribution of each load and distributed energy resource to the power flows in the network thus ensuring their coherence. It relies and combines different data sources to provide such an estimation. The MPOPF focus on managing the MV distribution grid for N-hours ahead by suggesting control-actions for the available flexible resources if any constraint violation is detected on the network. Therefore, the MPOPF works on the top of a network snapshot created by the forecasting services and the MVLA while tries to optimize the network operation. The main innovation associated to the MPOPF is the ability to solve a multi-period problem in a single execution. By doing so, the past, the present and the future can be interlinked through inter-temporal constraints (such as the ones related to storage). Thus, the MPOPF provides a global plan for the entire time horizon, which avoids situations where optimal decisions made for early periods would lead to limitations on decisions taken for later periods.

2.3. InteGrid LV grid management tools

For the LV level, a LV State Estimator (LVSE) [3] and a LV Control (LVC) tool [4] were developed. These tools recur to a huge amount of data produced by the AMI, along with multiple sources of flexibility, in order to perform the active management of active LV networks. This proposed framework acts in two stages: predictive (n-hours ahead) and corrective (near real-time).

In the predictive stage, the LVC tool recurs to forecasts for RES and load of the several consumers and prosumers connected to the LV network to analyze and define a set of control actions that intend to keep voltage magnitudes and branch currents within admissible limits defined by the operator. In the real-time stage, the LVC tool recurs to snapshots of the LV network every 15 minutes, produced by the LVSE algorithm, in order to analyze the network in real-time, and determine if any adjustments are required to the previously established control action. These snapshots are compared with the operation scenarios forecasted during the predictive stage and, if divergences are found, the LVC will correct the control plan in order to avoid any technical constraint violation. In order to perform the active management of the LV network, the LVC algorithm resorts on two main types of resources: DSO-owned resources, such as energy storage devices, and MV/LV transformers with on-load tap changing capabilities; and private consumers willing to participate in grid operation, via demand response schemes. The customers willing to participate in grid operation had a Home Energy Management System (HEMS) installed developed in the InteGrid project. The HEMS is simultaneously responsible for the optimization of the private consumer energy consumption and for acting as flexible resource for the DSO, sending flexibility upstream and receiving activation setpoints downstream through gm-hub.

2.4. VPP concept and developments

The access to MV customers' flexibility is enabled by means of a virtual power plant (VPP) that manages flexible DER and offers the flexibility to the DSO based on bilateral contracts or a market mechanism. The separation between the network domain and the grid domain is maintained by the implementation of the gm-hub, which acts as a message hub between all stakeholders. Two use cases are demonstrated: a) the provision of flexibility to the DSO to support operation of the distribution network; b) the provision of ancillary services from DER in MV networks to the TSO but respecting the restrictions of the MV network calculated by a traffic light system (TLS). Enabling access to other flexibility markets like the ancillary services of the TSO and dynamic assignment of DER to different markets is crucial for the economic feasibility of the VPP.

2.5. Advanced distribution management system

GE Digital deployed its ADMS and Forecasting products, enhanced with a set of functionalities to benefit from the interaction with MV and LV grid flexibility solutions.

The ADMS is designed to monitor, control and optimize the distribution network. It provides a network viewer, where the real time distribution networks for both the MV and LV is visualized in geospatial form, imported from EDP's GIS system. By interfacing the ADMS with the flexibility tools, it is demonstrated how such solutions can be deployed in the control operations of a typical DSO.

In the MV domain, the ADMS interfaces to SCADA system to obtain quasi-real time digital and analogue telemetered data for the MV network. The ADMS interacts with the Forecasting module to periodically retrieve Load and Generation forecasts. The ADMS further uses these forecasted values to run multiperiod power flow studies, based on the network topology. Results of each study are visualized against the network viewer, with potential violations in the network found by each study highlighted to the operator. The ADMS interacts with MPOPF, allowing a trigger of a multi-period optimization study in predictive and real time mode. The MPOPF study results are presented in tabular form to the ADMS user, who can choose to automatically create a planned schedule on the network including the recommended actions (flexible resource setpoints, as well as on-load tap-change voltage setpoints and capacitor bank connection status) from the MPOPF. In order for both ADMS and MPOPF to have the same view of the network, the ADMS exports periodically the real time topology along with its telemetry to the MPOPF using CIM format (IEC 61970 & IEC 61968). Following the recommended actions of the MPOPF, flexible resources may need to be activated by the operator. This activation is possible through the ADMS interfacing to the DSO tool of CyberGrid. Prior to the activation of the resources, the operator may run a power flow study in real time from the ADMS, simulating the effects of the recommended actions.

In LV domain, the ADMS interacts with INESC TEC's LV State Estimator tool. Both periodically and on demand, a LVSE study can be requested, with both the estimated values and the real-time measurements visualized on the network viewer. The process can trigger alarms alerting operators of operational constraints. A further visualization tool (Fig. 1) has been provided in the form of a heat map.

2.6. Grid and market bub

gm-hub (depicted in Fig. 2) is a key element in InteGrid project bridging the gap between smart grid technical requirements and digital market solutions, where the DSO manages flexibility requests and offers, from distribution grid stakeholders, according distribution technical needs under a regulated environment. It addresses multiple working streams and it can manage the flexibility offers and requests linking them to the distribution grid management tools, both at ML and LV. It is able to enable third party services and it is able to make available DSO provided services for the customers (like advice on contracted power or high consumption alarms) and it is able to enable aggregation business for market agents, like aggregators or retailers.

Fig. 1 Heatmap showing estimated voltages in Valverde

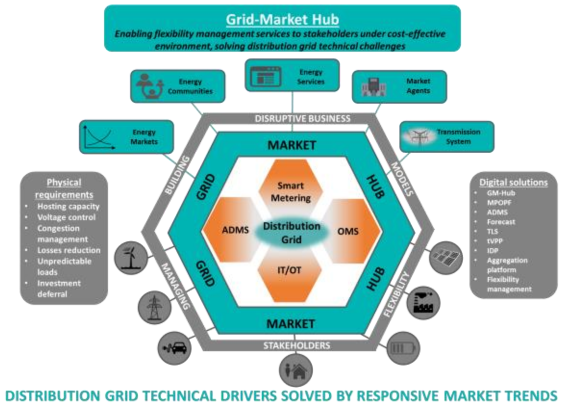

Fig. 2 Grid and market hub concept from InteGrid

3. PT demonstration results

The PT demo was developed in 4 geographies. In the Mafra district, a MV demo was setup and 20 industrial customers were installed with remote terminal units, from MV consumers to generators. Through VPP interface, MV customers are able to update their flexibility as well as to receive activation flexibility setpoints.

The LV demo was divided across three different locations: Caldas da Rainha, Alcochete and Valverde. In Caldas da Rainha, customer engagement technics were developed and in Alcochete and Valverde, smart grid operation functionalities combining DSO operated assets (e.g., energy storage) and flexibility provided by customers were developed. In LV demonstrator, up to 140 households were equipped it PV panels, batteries, smart water heaters and smart washing machines, and all integrated with an HEMS. LV customers are then able to update their flexibility according to their preferences (that can be configured using a smartphone App – see Fig. 3) and are able to receive the activation setpoints from the DSO (via gm-hub) to the HEMS.

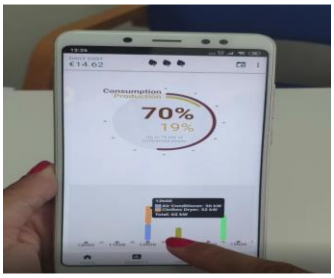

Fig. 3 InteGrid APP interface of the HEMS

The following figure depicts the deployment of InteGrid tools in the Portuguese demonstrator.

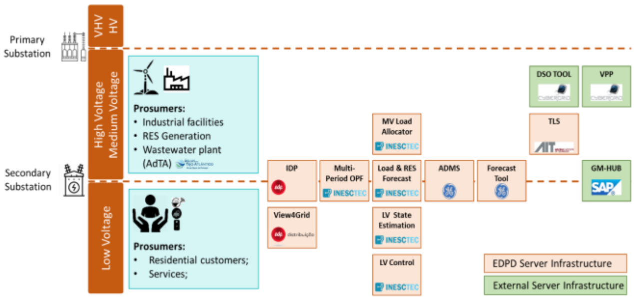

Fig. 4 Range of smart grid tools in the PT demo

In terms of InteGrid results, preliminary results are already available, based on real operation demonstration. In MV in a testing scenario where a MV line congestion was detected. For that and based on previous flexibility made available through the gm-hub to the DSO by industrial customers, and based on MV MPOPF tool, a flexibility activation was sent via DSO tool to the VVP platform, and from the VPP to the MV industrial consumers and wind power plants. The MPOPF tools proved to solve the constraints including a technical losses reduction of 4,53€ (for a specific interval in a single day) while the computation time to solve that solution was about 24s for a real distribution grid.

In the LV grid, a testing scenario where a voltage violation was detected in Valverde grid was considered. Based on flexibility previous made available from domestic consumers (parametrized in the App and defined in the HEMS) to the DSO through the gm-hub, the LVC tool resolved the voltage problem by sending active power flexibility activation setpoints to the HEMS, which automatically implemented control actions in behind-the-meter assets (e.g., smart appliances and storage). The voltage violations were reduced by 92% in terms of frequency and by 98% in terms of amplitude. From the available flexibility communicated by domestic consumers, around 29% was used to solve the voltage problems. Finally, it was possible to show that with InteGrid tools, the DSO operator was able to estimate all the voltage magnitude in real-time and using only a subset of meters (i.e., 10%) with real-time communication. The gm-hub displayed a 98% reply success rate, which showed that the platform is able to respond to the majority of requests.

In terms of installed residential appliances, a total of 410 equipment is installed and customer interaction with the HEMS/App has been increasing. Preliminary results also showed that energy consumption from the grid has decreased by 10.8% and peak load consumption was reduced by 3.6%.

Conclusions and next steps

The InteGrid Portuguese demo is now in operation and first results are available and shown in this paper. It was demonstrated that distribution grid operation can be optimized by using customers flexibility and this is valid for both LV and MV scopes, although the approaches are slightly different. In LV, the residential customers support the grid operation where an HEMS/APP system enables customer participation in grid management. In the MV, customer participation is done through a VPP platform. Nevertheless, in both cases the gm-hub is a key element to bridge the gap between distribution grid technical needs and flexibility from grid users. The project implemented standardized interfaces for the gm-hub, which enabled the participation of heterogenous flexible resources in grid management tasks. The Portuguese demo will continue the demonstration of additional functionalities, feeding the cost-benefit analysis and business model work so that robust conclusions can be delivered to the distribution grid stakeholders.

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4. References

[1] Reis, M., Garcia, A., Bessa, R. J.: 'A scalable load forecasting system for low voltage grids'. In IEEE Manchester PowerTech , pp. 1-6, 2017.

[2] Andrade, J., et al.: 'Functions to improve grid management tools'. InteGrid Project D2.2, 2018.

[3] Bessa, R.J., Sampaio, G., Pereira, J., Miranda, V.: 'Probabilistic Low Voltage State Estimation Using Analog-search Techniques'. *20th Power Systems Computation Conference (PSCC2018)*, Ireland, 2018.

[4] Simões, M., Costa, H. M., Madureira, A. G.: 'Predictive voltage control for LV distribution grids exploiting flexibility from domestic customers'. *MEDPOWER 2018 Conference*, Croatia, 2018.