LV NETWORK CONTROL ARCHITECTURE: H2020 INTEGRID CASE STUDY

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ABSTRACT

Within the scope of H2020 program, InteGrid aims to demonstrate intelligent grid technologies for renewables integration and interactive consumer participation, enabling interoperable market solutions and interconnected stakeholders, while addressing the challenges derived from this goal from a technological, market and regulatory and societal perspective.

The Portuguese demonstrator, which intends to innovatively boost the management of the distribution network using new DERs (including, here, consumers' flexibility) with already-implemented assets, in a predictive and integrated way, fostering the implementation of cost-effective, replicable and scalable solutions, will be the place where the herein described function will be demonstrated.

This paper presents the architecture of one of the above-mentioned solutions – the LV network control -, which, by merging both a predictive and real-time operational mode, will enable the DSO to exploit self and consumer-owned available flexibility resources in order to deploy a decision support tool to assist the active managing of the grid, avoiding technical problems.

INTRODUCTION

The way how electricity is being consumed and produced is extensively changing, as the role of different players in the energy sector is evolving, not only through innovative technology, but also through different energy use [1].

Envisioning to "bridge the gap between citizens, technology and other players of the energy system" [2], InteGrid aims to deliver new solutions that will, among other outcomes, enable the Distribution System Operator (DSO) to act as a market facilitator and data manager, through the development and implementation of tools that have the consumer in its core. This will facilitate the participation of consumers, via aggregators or new generation of retailers, to provide system services that contribute to a more efficient use of the electrical infrastructure.

One of these services, which are exploited through different tools in the project, is the **Low Voltage (LV) network control**. It will establish predictive and real-time operation strategies, in a real demonstration environment, making use of flexibilities (internal – DSO assets – and external, i.e., the one that stems from residential clients), to ensure that the LV distribution grid is operated within the technical voltage limits. This is achieved through the multi-temporal planning of control actions that anticipate potential problems in the grid and define the necessary control set-points to support the grid operation. This tool will be demonstrated in Valverde, a village that is part of the district of Évora, in Portugal. This grid functionality is provided by the Control Actions Management Module (CAMM), which is a decentralised control tool and thus it will be embedded in the Distribution Transformer Controller (DTC) that is responsible for management of secondary substations [3].

Aiming to reinforce the concept of interoperability at different levels, the Smart Grid Architecture Model (SGAM) [4] was followed. This three-dimensional model provides a framework that allows the representation of Smart Grid (SG) architectures, in a technological neutral way, through five different layers, as presented in Figure 1. The **business layer** characterizes the business context on the information exchange, addressing economic and regulatory topics, policies, market and business models; the **function** describes the functions and services and their interrelations; the **information** represents the information that is being exchanged between functions, services and components, including information objects and canonical data models; the **communication** covers communication protocols for the interoperable and standardised exchange of information between components and the **component** includes power system equipment, protection and remote-control devices, network infrastructure and any type of computers.

While the "Domains" are composed by the physical domains of the electrical supply chain, the "Zones" reflect the hierarchical levels of power system management.

The ultimate objective of SGAM is to represent in which zones interactions between domains take place, through different layers: the interaction between hardware components (**component layer**) has underlying protocols (**communication layer**) that define the way information is exchanged and the respective data models (**information layer**). Functions or services cover a set of components (**function layer**), under certain business objectives (**business layer**).

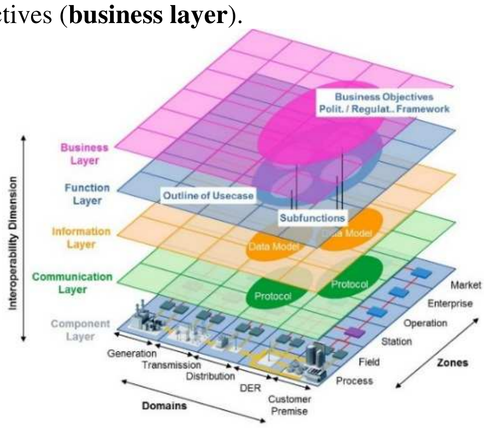

Figure 1 - Smart Grid Architecture Model framework [4]

TOOL ARCHITECTURE

The **LV network control** was mapped in the "Distribution" domain and in the intersection of the "Station" (that represents the aggregation level for field equipment) and "Operation" (which includes power system control operations) zones of the function layer, being symbiotically interrelated with a set of tools, as depicted in Figure 2.

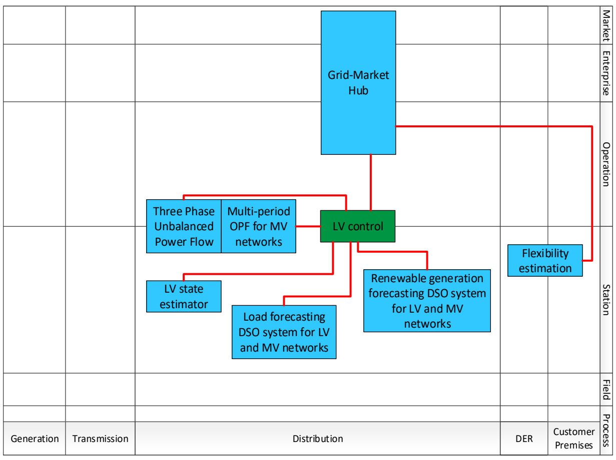

Figure 2 - LV network control SGAM mapping

The Grid and Market Hub (gm-hub) is a neutral data exchange platform that allows smart grid stakeholders to negotiate energy services. It is a key solution to allow LV grid planning and management, using existing flexibilities, to provide services in a standardised way between the market facilitator (a DSO role) and other stakeholders (e.g. retailers, aggregators and Energy Services Companies (ESCOs)). The major objective of this platform is to facilitate market access, allowing the emergence of an ecosystem of business models around it. The rationale that underpins the presented linkages, for each connection, is the following:

- **Multi-period Optimal Power Flow (OPF) for Medium Voltage (MV) networks**: the MV control can request to the CAMM, as a last resort action, changes to the active/reactive power operating points of the secondary substation;
- **Load and renewables generation DSO forecasting system for LV networks**: information about the future trajectory of net-load and Photovoltaic (PV) generation is transmitted, to be used in its predictive management strategy;
- **LV state estimator**: provides the CAMM with a snapshot close to real-time of the LV grid voltage magnitudes and probabilistic alarms for voltage violations;
- **Three phase-unbalanced power flow**: it is used in "simulation" mode to assess the technical impact of the control set-points defined by the CAMM, as well as to pre-validate the control set-points before its implementation;
- **Grid and Market Hub**: the CAMM uses information about the flexibility reported, via gm-hub, by the participating Home Energy Management System (HEMS), as a control variable that will be part of the planning and operation of the grid.

In case any potential violation occurs or is foreseen, a set of control actions are identified in order to overcome that situation. The proposed approach for the CAMM will rely on two different and complementary approaches:

1. In a first level, a predictive control will be sought, aiming at identifying potential violations for a pre-defined time horizon (e.g. 6-hours ahead) based on forecasting information. The required forecasting data (which takes into account meteorological data to define the behaviour of the LV clients, for some hours/day-ahead) includes net-load and solar PV forecast for each bus of the LV network. Whenever potential violations (node voltages or line loading) are identified, a set of control actions are determined, according to the existing flexibilities, to correct the violations and/or prepare, beforehand, certain resources to ensure the requested flexibility (i.e., storage devices);
2. In a second level, in real-time or close to real-time, the operation of the LV network is monitored. In case the current operating conditions do not differ much from the scenario used to produce the plan with control actions, the resulting set-points, which aim to mobilise a specific amount of flexibility, are sent to the DSO, though the gm-hub, to be validated before being sent to the field. In case the conditions are significantly different or should any unforeseen violation be detected, new control actions must be determined based on the most recent data available.

These control actions consist on a set of set-points, defined by the CAMM, for the available Distributed Energy Resources (DER), namely storage devices owned by the DSO and flexibility of domestic clients via their HEMS, but also secondary substation transformers with On-Load Tap Changers (OLTC) capability for the pre-defined time horizon, in order to mitigate the violation identified.

The voltage control tool being developed in InteGrid is, in fact, an evolution of the algorithm developed within the FP7 SuSTAINABLE project [5].

Flexibility services from domestic clients defined by a HEMS, according to the preferences set by each user, are facilitated through the gm-hub, which acts as a neutral access platform. These flexibilities may also be mobilised by the voltage control tool to solve possible problems that may arise. An innovative state estimation routine will be used in real-time, in order to assess the current operating condition of the LV network based only on measurements from a reduced set of meters. This will enable the validation of the control actions identified in the previous day. Figure 3 illustrates the general framework of the proposed approach for the control of the LV grid.

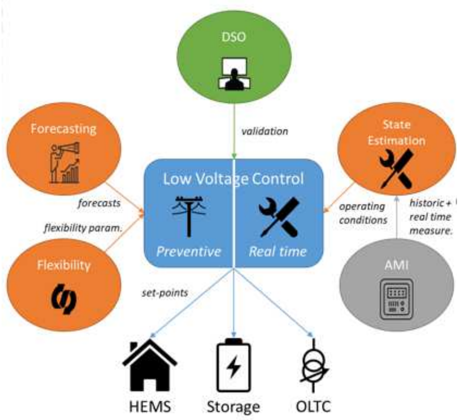

Figure 3 - LV control conceptual approach

Besides the forecasting and flexibility-related information, the control module also requires network measurements (voltage and active power), the topology of the targeted grid (connectivity, GPS coordinates) and the electrical characteristics of lines/cables (type of cable, section, length).

HEMS FEATURES

The HEMS is the platform that allows domestic consumers, as well as producers of energy, to actively respond to grid incentives that try to align the participation of households towards the overall efficient use of electric energy. This hardware and software system supports the implementation of energy optimization strategies, taking into account different types of loads, the potential existence of local PV, general configuration and preferences of devices and systems set by the end-user, considering one or more optimization goals [6]. Based on the characteristics of the local energy resources and the user preferences, the HEMS can define an energy use flexibility index that allows grid-related stakeholders to make use of it (even in indirect way) to exploit grid energy services, such as voltage control. This flexibility estimation, performed by the HEMS, takes into account the type of devices available within the household and the usage patterns associated to them. This means that device's energy models are embedded in the HEMS to allow a more accurate multi-temporal flexibility computation that is able to guarantee better activation results. This flexibility exchanged via the gm-hub does not include any information about the specific devices available inside the household. It reflects the probability, overall, that a household has to change its operating point.

The HEMS under development for the InteGrid project integrates several services that can be divided into:

- **User Interface**: allows end-users to insert preferences and configurations and get monitoring and status information of the HEMS and related devices and systems operation;
- **Energy Manager**: is responsible for collecting internal (devices and systems) and external information (incentives), analysing preferences and configurations to produce an optimal operation schedule of appliances and systems according to an optimization criterion for the next day. It may include existing microgeneration, which uses forecasting tools that can be used to allocate load to reduce grid imports. The energy manager includes energy models for different types of load, like shiftable and thermal appliances, thus providing a detailed characterization of the existing energy use flexibility in each household;
- **Security Manager**: ensures the secure data exchange among local devices and systems as well as with external systems. It detects abnormal data exchange patterns and ensures the necessary data privacy and protection;
- **Device Manager**: ensures monitoring and automation of existing energy resources in a domestic environment;
- **Integrated Services Manager**: is responsible for handling the events' requests associated to the HEMS operation and interactions among existing devices and systems. It handles alarms and provides notifications to the user every time actions are required. It runs the necessary forecasting algorithms and energy use detection schemes to support different energy optimization algorithms that provide flexibility activation to grid related stakeholders.

The HEMS is prepared to define an optimal schedule considering external inputs, based either on electricity prices and/or microgeneration maximization strategies, as a response to the DSO needs. These requests are intermediated by their market representative that publishes the necessary incentives for participation.

GRID PERSPECTIVE

Within the framework of an increasing penetration of DER connected to the DSO's grid, LV control also becomes an increasing challenge. As such, it is important for the DSO to take advantage of the available flexible resources, namely grid storage units and OLTC. The coordination of these devices is useful, since it allows avoiding technical violations that may occur in the grid, such as voltage violations or branch overload.

In order to assess the impact of these control actions, two indicators are used in the project: i) reduction in the energy curtailment of Renewable Energy Sources (RES) and Distributed Renewable Energy Sources (DRES) and ii) power quality and quality of supply, ensuring that the requirements set by EN 50160 standard are met.

INNOVATIVE ADVANTAGES

From the perspective of the grid control, the proposed approach has the following main innovations:

- Exploits forecast data in order to run a predictive management of the available flexible resources (including customer flexibility and DSO owned resources, such as storage devices and OLTC transformers) in the LV network;
- Uses pre-booked flexibility to manage voltage deviations;
- Utilizes an unbalanced three-phase power flow routine to assess the impacts of the proposed control actions;
- Re-evaluates the conditions of the LV grid in real-time using the most recent data available.

From the domestic user perspective, the proposed approach has also advantages, as follows:

- Ability to participate in energy services in a platform that interconnects household owners and market representatives to establish potential benefits for the grid and the consumer;
- Reports flexibility in a seamless way using HEMS that models the energy use according to the types of appliances, preferences and configurations set by end-users;
- Drives the demand to respond to grid requirements in ensuring a more efficient and safe operation, via flexibility integration;
- Ensures interoperability and privacy through the information exchange scheme that does not need to exchange private data.

EXPECTED RESULTS AND NEXT STEPS

The LV voltage control tool will be tested in the Valverde pilot, benefitting from the presence of DSO-owned resources (storage devices installed at the secondary substation and in the feeder) and several HEMS that will be installed for demonstration purposes.
The HEMS will be used in the pilot to show the differentiated participation of domestic consumers (some will also have micro-producers) of energy proving response to grid services, using a commercial representative (retailer or aggregator) service, to correct the grid operation.

CONCLUSIONS

The LV control module was, in a first stage, mapped in the function layer of the SGAM, as presented in Figure 2. This tool will receive inputs and communicate outputs through the gm-hub, while the HEMS will receive information from the LV state estimator, three-phase unbalanced power flow, multi-period OPF and forecasting modules.
The main innovations are the exploitation of forecast data; the use of pre-booked internal and/or external flexibility and a three-phase unbalanced power flow.
With the implementation of the described function, InteGrid intends to enable a new consumer-centric business model through which the DSO effectively operates the grid within pre-defined nodes' voltage limits.

ACKNOWLEDGEMENTS

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