LV SCADA – HOW TO EFFECTIVELY MANAGE LV NETWORKS WITH LIMITED TOPOLOGY AND ELECTRICAL CHARACTERISTICS DATA

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ABSTRACT

This paper describes the main developments of the LV SCADA project and addresses the technical challenges to be tackled when managing LV grids. This project entails the development of technological solutions that contribute for an effective Smart Grid implementation, creating flexible solutions allowing the anticipation of future trends, supporting the introduction of new technical, commercial and regulatory solutions to improve operation efficiency. This paper includes a description of the architecture, main functionalities and control capabilities associated to a new advanced LV SCADA that benefits from the AMI data available, allowing more precise network characterization without requiring widespread real-time information acquisition.

INTRODUCTION

Low Voltage (LV) grids consist of large dimension networks with several hundreds or thousands of buses where full knowledge of its state or detailed topology is often unavailable. However, in the last few years, several Distribution System Operators (DSO) have invested in Advanced Metering Infrastructures (AMI) that are able to collect information from LV customers through the installation of smart meters and Remote Terminal Units (RTU). This system is frequently based on a limited capacity communication sub-system, as the most common technologies are adequate for billing purposes but cannot guarantee real-time access to information.
Furthermore, the large-scale integration of renewable-based microgeneration at the LV level may bring technical problems to distribution systems since they may cause voltage violations (such as voltage rise [1, 2]). Also, this type of generation units, mostly connected through power electronic devices, has an effect on the power quality, fault currents and controlling solutions of the network [2, 3].
In addition, the concept of Distributed Energy Resources (DER) has emerged, including not only generation but also storage devices and Demand Side Management (DSM), in order to enhance system operation and allow further expansion of microgeneration. Therefore, the deployment of DER in distribution networks requires a change in network operation, shifting from a traditionally passive into a fully active approach. In this context, active network management can be regarded as a way to achieve cost-effective solutions following DER integration in distribution grids at both the planning and operation stages of the distribution system [4].
The development of a Low Voltage (LV) Supervisory Control and Data Acquisition (SCADA) system, developed in the LV SCADA project, has as main focus to extend monitoring and control to LV networks, considering that currently most of them have missing information to be characterized concerning topology and electrical properties. From the analysis of the current state-of-the art on the subject, there are two main particularities that may hinder an adequate monitoring and control of these networks: on one hand, the lack of information capable of providing adequate observability and, on the other hand, the increasing integration of DER, namely those with a variable nature, that can cause significant technical problems. These challenges cannot be satisfactorily mitigated with currently available solutions.

SYSTEM DESCRIPTION

The LV SCADA tackles the referred limitations taking benefit of all the new set of sensors that are being installed in LV networks: smart meters and advanced RTUs such as Distribution Transformer Controllers (DTC) that are installed at secondary substation level, constituting an Advanced Metering Infrastructure (AMI). This AMI is regarded as the source of information for elementary SCADA modules such as the Data Acquisition and Information Processing module which are transversal to all the system modules. This data feeds the innovative control functionalities that are being developed for the LV grid management.
The control and management architecture for the LV SCADA is summarized in Figure 1.
The new LV SCADA concept includes two new structures:

- The LV Data Concentrator which focuses only on the data acquisition aspects that will feed the new advanced functionalities to be developed working as a head-end system and interfacing with all LV assets, regardless of the communications technology used;
- The Low Voltage Control Centre (LV CC) / Advanced Distribution Management System (ADMS) which actually includes a set of advanced functionalities dedicated to the LV network management and optimization.

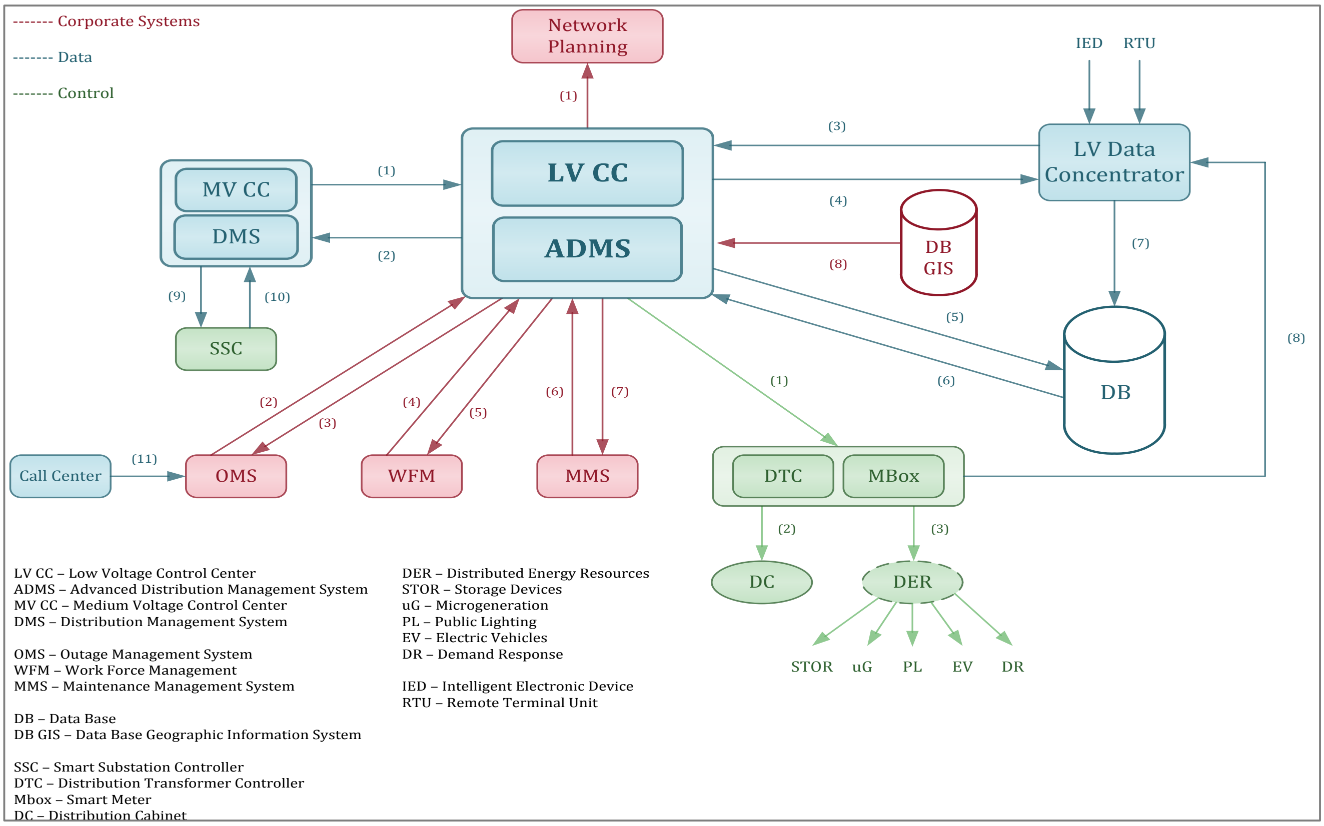

Figure 1 - Technical Reference Architecture.

In Figure 1 the main data and control flows between the several systems are identified, as well as the interaction with the main corporate systems that may exist.
The information flows (numbered in the figure) use the interfaces between the modules to send the available information and receive the control setpoints. The red lines connect the SCADA/ADMS to the Network Planning tools (interface (1)) and include information regarding cyclically repeated events that indicate the need to a problematic area which would require a revision or reinforcement of the network. Also, the interfaces (2-7) connect the ADMS to the Outage and Maintenance external systems providing information of outages, blackouts or alarms, together with their geographic location, that indicate a failure of a given customer or set of customers. This way, a coordination with field and maintenance crews can be assured for quicker response, minimizing unavailability time.
The blue lines relate to the Low Voltage Management System Data used for data collection The grid operational parameters are received from smart meters and sensors (8) on a real-time and non-real-time basis though the DTC and aggregated at the LV Data Concentrator. The ADMS will be fed (3) by this information (such as voltage, active and reactive power, alarms) and will manage alarms generated or inhibited according to the operational conditions (4). This head-end system also supervises and manage the communication network, regardless of the technology, and establishes a correlation between the state of communications and the grid. A historical database is also kept, serving the SCADA (5) and the LV Data Concentrator (7) as a source and being accessed by the ADMS functionalities (6) for algorithm training purposes. Moreover, there are interfaces to the control and management system for the HV and MV network (1, 2, 9 and 10) so that alarms resulting from outages at these levels will be correlated to the ones coming from LV.
The green lines represent the interfaces used for management of the DER (3) at the LV level which are monitored and used for dispatching setpoints for active management of these resources. The calculation and requests for the execution of the controls/setpoints are deriving from the functionalities described on the next chapter.

ADVANCED FUNCTIONALITIES

State Estimation

The State Estimator (SE) proposed for LV grids is a real-time functionality that is designed to provide a complete estimation of voltage magnitudes and, if required, the values for the injected active power in a given bus. The “core” of the algorithm is based on the concept of an autoencoder (AE) that, when properly trained [5, 6], can provide values for the state variables without the need to have information from all the nodes under analysis. The major benefits of the SE algorithm proposed when compared to the traditional state estimation techniques

(e.g., WLS algorithm) relies on the fact that, in order to achieve a state estimation solution, it is not required to have all the information about grid parameters (namely, branch technical characteristics) [7].
An effective state estimation through the use of AE requires inevitably a large historical database, which needs to contain data on the variables that are passed to the AE (missing signals and measurements recorded). This is crucial for a successful and effective training process since this is what enables the AE to learn the necessary patterns/correlations between the electrical variables of a given network. Therefore, the pre-processing of the input data to build the AE architecture is an indispensable function that needs to be performed before SE execution.
Besides the vital functionality of processing the historical data available, there are other functional blocks which have some differences when compared with traditional SE:
Topology Analysis – the application starts by analysing the topology of the network crossing this information with the actual measurements. The aim is to set the topology of the network, knowing which buses and network equipment belong to each feeder or at least belong to each MV/LV substation. Changes in topology usually imply either running a new training process or the selection of an appropriated AE specific for the new topology;
Observability Analysis – the application selects a set of data so that the network under analysis is observable. The concept of observability is related with the existence of at least historical data samples for one week regarding the variables to be estimated and few measured points collected in real time;
Training Process –the historical database provides the data for the training process that is based on a Resilient Back Propagation algorithm (using Minimum square error criterion). The output of this process is an AE object properly trained for a given topology of each MV/LV substation;
Running the SE – Using the already trained AE and real-time telemetered data available, a constrained search approach is applied for finding the missing signals. In this context, these signals are necessarily the state variable to be estimated – voltage magnitude values –and active power injections. Afterwards, an optimization process reconstructs the state variables through the minimization of the error between all the inputs and outputs of the AE. An Evolutionary Particle Swarm Optimization (EPSO) [8] was the optimization algorithm chosen for reconstructing the missing state variables.
The data stored in the historical database is of the utmost importance to the execution of the SE tool. Thus it is important to state that for each customer's meter, consumer and/or producer, the historical database is composed of at least measurements of the active power (kW) and voltage magnitude for 15 minute intervals. This database will be the basis of the training procedure of SE.

Distributed Energy Resources Management

This innovative control module was developed within the LV SCADA project. It consists of a management system for LV grids that enables controlling the available resources connected at the LV level in order to respect the regulatory technical constraints. In particular, for the specific case of LV grids, the main technical issue to be addressed is related to voltage profiles, that can be out of admissible limits due to the fact that the distribution network has the presence of several different DER [2]. The proposed control methodology is based on a set of rules that define the most suitable control actions for overcoming a specific technical violation that may occur, by sending specific set-points of active power to the different available resources. It was considered that the LV network has four main classes of controllable assets that can, if managed properly, assist in mitigating potential grid constraints: storage devices, MV/LV distribution transformers with On-Load-Tap-Changer (OLTC), microgeneration units and flexible loads. The proposed control methodology follows a merit order of control actions to the available resources, based on the objectives for the power system operation, namely maximizing the absorbed energy from microgeneration sources and minimizing operational costs (i.e., financial compensations, interruption of service, technical losses, etc.). Respecting these base rules, the first grid resources to be actuated in order to solve some potential technical constraint are those that are property of the DSO (namely, distribution transformer with OLTC and eventual storage devices) and only then the microgeneration units and controllable loads are considered.
This control process has the advantage of not being constrained by the availability of real-time smart meter measurements for all nodes, since the state estimation module does not require a complete grid characterization in order to be able to estimate its state (i.e., only needs some smart meters near real-time measurements in order to obtain a complete grid state estimation). Therefore, in this module, two distinct scenarios are considered regarding different levels of knowledge of the LV grid:

- Scenario a) – Considering that there is full knowledge of the grid topology, which leads to the possibility of running a power flow routine;
- Scenario b) – Without a detailed knowledge of the grid topology. A similar approach is applied using the state estimation module as a simulation tool.

In LV grids, it is common to have low levels or even erroneous characterization of the grid topology, hence the two control approaches proposed. The first methodology of control – Scenario a) – uses a "smart" power flow that iteratively tests different scenarios, following the merit order of the grid assets proposed, in order to find the best suited solution to tackle the technical problem.
The other approach – Scenario b) – is a methodology that uses the state estimation module as a simulation tool that tests the possible control actions following the guidelines for the merit order of equipment that is established. This is

used as a validation of the proposed actions before its execution.
This module will run cyclically using updated information from state estimation and, in case of violation of some technical constraints, will mobilize the most suitable resources to solve the problem. As soon as no more violations are detected, the module will try to remove eventual constraints from the controllable assets, such as microgeneration curtailment or shedding of flexible loads. The proposed approach is shown in Figure 2.

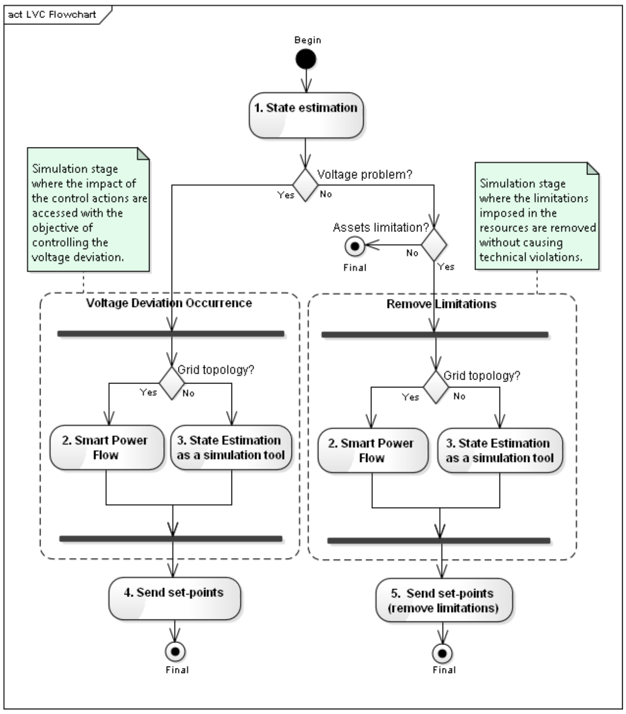

Figure 2 - High Level DER Management Activity Diagram.

Smart Alarm Management

The LV SCADA system must alert operators about abnormal conditions that affect the operation of the network. However, extensive information coming from smart meters and remote terminal units can trigger an overwhelming number of alarm events that will cause tremendous difficulties to operators.
Instead of generating an individual alarm for each measured voltage value that is out of admissible values, the LV SCADA system identifies the LV networks where voltage profile problems have been detected (either measured or estimated) and shows an aggregated voltage alarm for each of those networks. Alarm details such as deviation values (measured and estimated) and the equipment originating the operational violation can also be explored in the workstation. Note that, in general, an operator will not need to investigate these details to solve the voltage profile problem, since the DER Management module automatically performs this analysis and proposes actions for controllable resources.
Voltage limit violations may later disappear, due to the action of the DER Management module or simply because the consumption or production conditions have changed. In either case, the alarm is automatically removed from the list but the details are still kept on the system historical log in order to allow a post-analysis of the problem.
The Smart Alarm Management receives part of its inputs from the voltage profile control cycle that runs for each LV network. This cycle consists on acquiring real-time measured data for a few chosen equipment, estimating values for all network and proposing changes to some DER Note that the system may present the proposed actions for the operator to approve their execution (advisory mode) or automatically execute the computed actions without further human intervention (automatic mode).
During this cycle, the LV SCADA may detect communication problems when collecting data from a smart meter. If this problem persists, a procedure for communication attempts with neighboring smart meters is started. When using PLC as communication technology, if there is no response, the correlation with a problem on the electrical infrastructure is made, leading to the generation of a fault alarm. Multiple smart meter no-response events existing in the same area (thus caused by the same probable network fault) are gathered together into a single fault alarm.

PILOT DEMONSTRATION SITE

The functionalities that will be demonstrated within LV SCADA are contextualized on the concept of the InovGrid smart grid infrastructure deployed in Portugal. The objective is to have a real demonstrator that allows the validation of the different developed modules as well as the system performance and interaction with the operator.
A set of use cases has been identified by EDP Distribuição (the Portuguese DSO) in order to support the specification of the main requirements associated to the more advanced modules. These use cases are particularly useful to illustrate the actions and interactions between the user and the modules outcomes. To validate the functionalities described in this paper, a pilot demonstration will be deployed in São João da Madeira, a municipality in Portugal. This city is one of 7 new cities that will integrate the InovGrid project in order to test and validate advanced smart grid functionalities. Additional 100.000 smart meters will be deployed in these sites, using mainly PLC Prime communications between the smart meter and the DTC deployed in the MV/LV substation. This demonstrator covers about 250 customers, which will be aggregated at 2 MV/LV substations. These DTCs aggregate and compute data from customers and other existing sensors in secondary substation and LV feeders. This information will be sent to the LV SCADA system where operators are able to retrieve events and alarms, verify all the operational conditions of the network (measured and estimated) as well as to send controls to improve grid efficiency and reliability.
LV SCADA system also exchanges information with

different DSO corporative systems in order to leverage its intrinsic value and usefulness for a DSO business area, namely: Outage Management System (OMS), Work Force Management (WFM), Client Information System (CIS), Geographical Information System (GIS), SCADA and Distribution Management System (DMS) for HV and MV grid.

CONCLUSIONS

This paper presents the LV SCADA project that entails the development of an advanced system that contributes for an effective smart grid implementation, creating flexible solutions to allow the anticipation of future trends, supporting the introduction of new technical, commercial and regulatory solutions to improve network operation efficiency.

The fact that there are currently several smart grids initiatives worldwide raises the question of having an extended and automated network operation, including the LV grid.

This system, its advanced functionalities and scalable architecture projects the future of the electrical grid supervision and active management. The LV SCADA is capable of tackling the current and future control and management needs of distribution networks, supporting the DSO on the decision making process. The functionalities included leverage the potential of the system and enable the operator to tackle common problems when operating LV grids, such as the lack of characterization of the network, the almost non-existing observability, the management of operational and metering information in a single system and the ability to actively manage the system so that all regulatory limits are met and operational efficiency and reliability is increased. The ongoing pilot project validates the quantity and quality of the obtained results in real environment and under factual condition, electrically and communication wise.

In summary, the LV SCADA system developed, implements a new solution with functionalities that go beyond the state of the art, creating an added value solution capable to fit national and international markets.

Acknowledgments

This work has been partially funded by national funding from QREN through the "SCADA BT - Desenvolvimento de um sistema de comando e controlo adequado às Smart Grids em baixa tensão" project, grant 2012/24661 conceded by IAPMEI.

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