BEYOND AMI: LV NETWORK SUPERVISION OVER EXISTING AMI DEPLOYMENTS

Laura MARRON
ZIV – Spain
laura.marron@cgglobal.com

Aitor ARZUAGA
ZIV – Spain
aitor.arzuaga@cgglobal.com

Txetxu ARZUAGA
ZIV – Spain
txetxu.arzuaga@cgglobal.com

Sergio SANTOS
ZIV – Spain
sergio.santos@cgglobal.com

ABSTRACT

Low Voltage (LV) network is the last unknown limit of the distribution grid, that is about to be monitored. There are 10 million Km of distribution lines in Europe being amongst them 60% LV lines. Currently there is an important lack of visibility of what is happening in those lines. Smartmeters deployed in the LV line offer information for grid operation in addition to billing information. In this context, advanced metering infrastructure (AMI) will be a main enabler of "LV network supervision". European distribution companies are leading several projects such as GRID4EU FP7 project with the aim of increasing their real time knowledge of LV grid. Several solutions are being developed based on the deployment of smart devices in different LV points. These supervision systems offer an enormous amount of information to be integrated and processed in the corporate information systems of the distribution companies. Therefore a redefinition of the operation structure and evolution of the information systems is needed.

LV network supervision solutions are a cost-effective alternative to increase the distribution grid capacity due to better control and monitoring of the LV grid. Smartgrids being deployed mean a significant change in how power distribution grids are designed and how they need to be operated. This paper goes one step beyond AMI, describing how to integrate LV network supervision over existing AMI deployments.

INTRODUCTION

Distribution companies continue the "Smartization" process of their power distribution grids started years ago with the introduction of electronics, telecommunications and information systems in the grid operation.

Smartgrid and Smartmetering deployed infrastructures were first a consequence of regulatory mandates, but once they are in operation, they can offer much higher value beyond their intended purpose. Bidirectional communication deployed up to the Smart meters offers accurate information of the elements scattered in the LV domain. Note that deployed meters in the LV line offer information for grid operation in addition to billing information [1] so these available measurements are useful in several supervision and control systems. This means that on top of advanced metering infrastructure (AMI), several other applications can be integrated.

Intelligence in LV network will bring several advantages and applications in terms of "LV network supervision" [2] [3]. "LV network supervision" concept comprises aspects such as LV feeder automation, commercial losses (fraud) detection, detection and correction of unbalances, faults detection in LV lines, and topology verification of the distributed elements regarding phase and line. This implies numerous benefits for the utility, covering different aspects. Existing operations (processes and others) are improved in the electric company due to the new technology integrated in the grid. Utilities will also be able to manage the lifecycle of their assets, integrating each point into the Smart grid, in order to implement asset management in LV. Note that there are 4 million distribution transformers in Europe (according to Eurelectric data). LV Smartgrids offer the required support for the correct integration of small scale renewable distributed generation sources [4]. Finally at a higher level, each country will have tools so the infrastructure investment is optimized.

These functionalities are being developed and validated in the scope of the European GRID4EU FP7 project, evolving the data management up to the secondary substation.

Therefore this paper will describe LV advanced network supervision solutions available today, based on AMI plus other technologies. It will introduce the advantages and applications derived from the addition of intelligence into the LV grid, focusing on functionalities requested and technical solutions adopted. The research and development done within GRID4EU FP7 project regarding these solutions will also be stated.

This analysis will lead to the amount of data produced by these systems, and therefore the need of corporative information systems to be adapted in order to manage the new information available. Finally the evolution expected and the main challenges (technical and non-technical) LV supervision solutions should deal with are described.

THE NEED FOR LV SUPERVISION

As stated in the introduction, LV grids are typically passive networks where real time information is not available. Issues that may arise are identified through end clients' complaints (call centres). Identifying the problem source by the location of received complaints.

Regulatory mandates evolution in Europe during the last years has been the starting point for LV grid operation. Within the most important aspects of this shift we can highlight:

- Increasing number of “micro” sources of distributed generation, connected to the LV grid.
- Massive deployment of Smartmeters, which combine precise measurement technologies with telecommunication in a cost effective solution due to scale economies.
- Increasing introduction of smart loads that could be controlled.
- Energy efficiency policies that are starting to be taken into account by consumers.

These aspects made main stakeholders work together towards the LV grid evolution, so that it can be operated according to the business needs of the different electricity distribution companies. In this context there is a need of LV distribution grid monitoring and supervision so demand management can be optimized. Upgrading the whole distribution network by adding new elements that meet the new requirements is not a cost-effective solution. Therefore updating the existing infrastructure seems the most suitable alternative.

In the next sections we will define the system architecture for LV distribution grid supervision. First it is important to identify which are the useful LV elements that need to be monitored. Thinking on how to do this monitoring, we would define the requirements for supervision elements within the system. Finally, a system architecture that is able to cover these functionalities is proposed.

LV ELEMENTS TO BE MONITORED

This section analyses the LV elements to be monitored. This proposal combines supervision both at the Secondary Substation and at intermediate LV grid points.

LV supervision at the Secondary Substation

Secondary Substations are the first elements to be monitored inside the LV grid. Both the secondary of the power transformer and the LV feeders can be supervised.

This list summarizes the supervision needs identified within a Secondary Substation:

- Instantaneous measurements of V, I, P, Q and power factor per phase.
- Register of the main electric parameters, creating the following profiles:
  - Energy profiles – hourly.
  - Profile with the medium values of current and voltage.
  - Profile with the maximum values of current and voltage.
- Quality of service measurements, such as THD, flicker or network harmonics.
- Detection of several network issues. For instance, overcurrent, overvoltage, fuse blown out detection. Even high impedance faults in Medium Voltage network can be detected based on measurements taken form the LV grid (secondary of the power transformer). Three phase system unbalances could also be detected.
- Phase and feeder identification for the different clients connected to the LV grid.

This information allows distribution companies to improve their LV network operation, enabling:

- Energy balances with the aim of identifying losses (both technical and non-technical).
- Load level control per phases and feeders, so load unbalances can be detected.
- Preventive supervision of the network. This way status information can be obtained before clients call making complaints.
- Asset management could be implemented integrating each point into the Smartgrid. Utilities could manage the lifecycle of their assets.

Supervision at intermediate LV grid points

In addition to monitoring inside the Secondary Substations, some European countries found the need of supervising also intermediate points within the LV grid. Note that new generation Smartmeters that are being deployed already monitor the LV grid until the boundary between the distribution operator and the end customer infrastructure. Supervision at other intermediate points is focused on controlling the voltage levels in LV lines with high penetration of Distributed Energy Resources (DER).

Sensors scattered over LV grid will allow voltage control operation. Sensors can send periodically through radio or powerline the voltage measurements taken at the installation point. The controller in the Secondary Substation collects the voltage measurements of the elements scattered in the LV domain. This information can be used in order to act upon the tap changer of the power transformer and therefore adjust the voltage level.

SYSTEM ARCHITECTURE

In this section the system architecture needed to cover the functionalities described above is analysed. Firstly one supervision architecture example developed for GRID4EU FP7 project is described. Then, the evolution needed at the corporate information systems of the distribution companies will be detailed.

GRID4EU supervision architecture example

This section describes the architecture example of a LV supervision system development and validated within GRID4EU FP7 project.

This control system is based on measurements from the Secondary Substation, note that other architectures could also integrate measurements of intermediate points in the LV network. Elements to be monitored inside the Secondary Substation are highlighted in Figure 1 below; the picture was taken from a real field setup during the project.

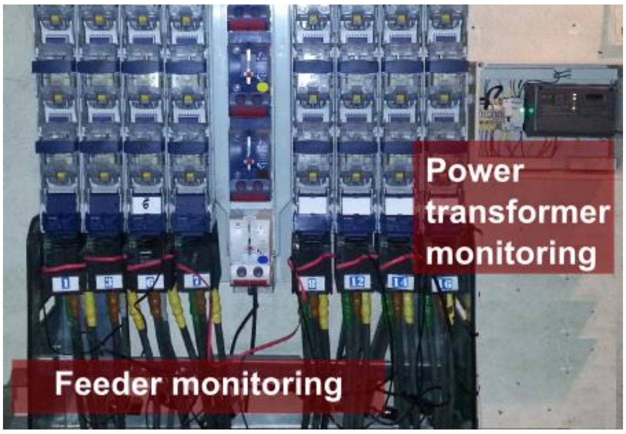

Figure 1 - LV elements to be monitored inside the Secondary Substation

We will focus on the solution to be installed at the Secondary Substation. It could be based on a modular device – evolution of the Smartmetering Data Concentrator or Remote Terminal Unit (RTU) - that manages the three phase LV feeder supervision elements through a fieldbus (RS485). The same device could integrate the supervision of the power transformer secondary. For GRID4EU FP7 project, LV feeder supervision elements were installed into a kit connected to the output of the three-pole basis of the LV panel, it contained three current sensors and a connector for transmitting signals (Voltage and currents) to the feeder supervisor. Note that due to the size of the LV grids, easy to install solutions are a must.

All the available information will be transmitted through IP communications to the centralized information systems of the distribution company. This LV supervision system example is based on cellular communications – GPRS – as these are the mainly adopted systems for distribution grids supervision solutions.

There is plenty of information to be sent with different types of events and measurements. Electronic equipment related to LV supervision is able to produce an enormous amount of data.

This has a direct impact on the corporate information systems, which need to be adapted so they can manage all this new information available. This evolution needed at the information systems level is an important requirement for LV supervision integration. Information systems architectures will be detailed in the following section, understanding some of the options available depending on the operation structure of each distribution company.

Evolution needed at the information systems

Different options for LV supervision integration

There are different information systems approaches regarding where to send the LV supervision information. There are mainly two approaches related to the operation structure of each distribution company:

1. Support LV supervision as an extension of the Smartmeters remote management systems.
   Distribution companies taking this option manage LV grid monitoring elements in a similar way they do with the deployed Smartmeters. Nevertheless some changes are needed at the existing system architecture.
   Data Concentrators that manage LV clients per Secondary Substation should be adapted to include the new network elements to be monitored. Also, new interfaces need to be defined to support LV supervision events and alarms. These events are for example, fuse blown out detection, or high impedance fault detection in Medium Voltage based on measurements taken form the LV grid.

2. Support LV network operation with an independent SCADA system.
   Other distribution companies associate LV network supervision with remote control elements. As a result, functionality evolution is done at the Remote Terminal Units (RTU) already available in Secondary Substations. These devices deployed for Medium Voltage supervision and control would be evolved to integrate measurements from the LV grid supervision points to be monitored.
   In this option, operation systems are kept separated from the existing information systems deployed for Smartmeters.

No matter the approach selected, information systems need to be adapted for this new LV grid operation. Systems should be able to manage real time measurements taken from different points of the LV network.

Proposal for the system evolution: Modular approach

In this section a modular approach for the information systems evolution needed is described. This approach ensures flexibility and scalability, making integration and future evolution easier.

This proposal is based on a "message oriented" system; see Figure 2 with the architecture example below. LV network has several information sources to be processed in parallel for different applications. Therefore different modules are defined, one independent module per functionality (quality of service, fraud, billing or network operation). These modules are subscribed only to the information types they need. Depending on the application and time conditions required the data processing could be deferred or in real time (event correlation), although typically a combination of both is needed. This proposal covers a scalable and modular architecture, based on messages exchange between modules.

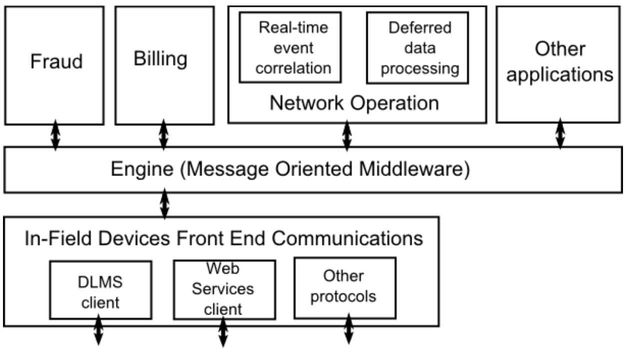

Figure 2 - Modular architecture for the information system

Specific modules can be added/removed when needed, adapting the system to the requirements of each distribution company. Integration between the different modules is also ensured, so those modules could even be developed and maintained by different companies.

As an example, different communication protocols can be supported for the in-field devices front end. Protocols for data exchange between the Head End System and the devices scattered in the field may be different depending on the application, for example each module can offer:

- Communication based on Web Services.
- Communication based on DLMS.
  Know-how of specific communications protocols and devices in the field is important to optimize the data readings. This is even more important for communications over LV grid, where data bandwidth is usually limited. Certain modules, such as DLMS client, could be developed and integrated by specific companies with knowledge of these protocols and devices.

Along the same line, advanced LV supervision functionality analysed in this paper could be integrated as an independent module as shown in Figure 3.

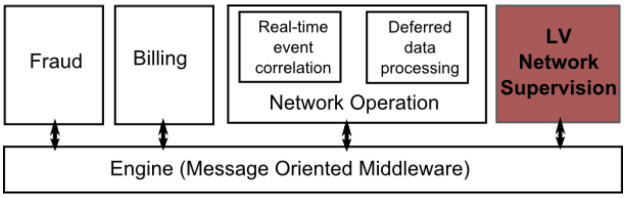

Figure 3 - LV network supervision module integration

MAIN CHALLENGES FOR GRID INFORMATION SYSTEMS

Massive adoption of these systems will depend on multiple factors.

Firstly, regulator’s task should be highlighted. It has a direct influence on the economic justification of these systems. There are two main factors that would support the supervision systems deployment. The activation of “micro” sources of distributed generation. Quality of service and distribution grid operation practises improvements.

Furthermore, the adoption depends on the availability of solutions that combine technology, cost and integration in the existing LV grid. Technology is a key element. At this moment LV supervision systems can benefit from the progress made during the development and deployment of the existing Smartmeters. This makes the embracing of these systems much easier, as there is electronic equipment available that brings telecommunication systems, advanced signal processing, metering, control and information storage together, at a very competitive price. Additionally, it is important to keep on researching new protection algorithms optimized for low power generation systems being deployed along the LV grid. Adaptive algorithms are needed, so they can adjust to the different load and network generation levels and therefore improve the faults detection mechanisms.

Additionally, an essential aspect will be how the sensors are integrated in the LV panels. The availability of solutions that are easy to install in the existing Secondary Substations will ensure the viability of these LV supervision systems. Figure 4 shows a LV panel with the installation of sensors per feeder that these systems require.

Figure 4 LV supervision sensors installed in a LV panel

Finally, distribution grids systems evolution takes us to open interoperable standard based systems. European distribution companies are interested in LV grid supervision, so they can monitor different network points with the aim of predicting their status. The problem here is that only Smartmeters are standardized. This is an important challenge that will be detailed in the section below.

Standardization required for interoperability

Standardization frameworks for LV supervision elements are required in order to ensure interoperability. Note that standard based systems can end being proprietary if the data model is not well defined, therefore protocols need to cover not only syntactic but also semantic interoperability.

This is applicable to DLMS, where we should define a proper data model so it can really be open. In order to be interoperable, the following LV supervision elements should share the data model.

- Elements at the Secondary Substation (feeder supervision).
- Supervision elements at intermediate points of the LV grid.

Other elements such as photovoltaic inverters, sensors with communication integrated, smart breakers at the Secondary Substation. The integration of these elements in the existing infrastructure would enable an important evolution in network planning. The combination of the information taken from LV supervision and the interaction with a mesh network of smart elements in the grid would make automatized solutions at LV possible.

CONCLUSION

LV network supervision solutions are a cost-effective alternative to increase the distribution grid capacity due to better control and monitoring of the LV grid. Smartmeters being deployed in the LV line offer information for grid operation in addition to billing information. Therefore several other applications such as LV network supervision can be integrated on top of advanced metering infrastructure (AMI).

This evolution forces a redefinition of the operation structure and evolution of the information systems. It is important to highlight the importance of adapting the information systems to the enormous amount of data that can be obtained from LV distribution grids. Being able of combining this information with data coming from other sources (such as geographical information, meteorological predictions or distributed energy generation predictions) will provide the distribution companies the knowledge needed to successfully operate the network.

ACKNOWLEDGMENTS

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n°268206.

REFERENCES

[1] Santos, S. et al; 2012, “Smart meters enable synchrophasor applications in distribution grids”, *CIGRE Session 2012 Paris*, paper C6-110

[2] Marrón, L. et al; 2014, “LV Feeder identification: Prior requirement to operate LV grids with high penetration of DER and new loads”, *CIGRE Session 2014 Paris*, paper C6-107

[3] Llano, A. et al; 2013, “Low Voltage Feeder Identification for Smart Grids with Standard Narrowband PLC Smart Meters”, *IEEE International Symposium on Power Line Communications and Its Applications ISPLC 2013 Johannesburgo*

[4] Arzuaga, T. et al; 2013, “Powerline communications for connecting distributed energy”, *CIGRE Session 2014 Paris*, paper D2 -103