LOW VOLTAGE SUPERVISION SYSTEMS: TECHNOLOGY, APPLICATIONS, USE CASES AND DEPLOYMENT

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ABSTRACT

In this paper, the authors share the knowledge gained in the field of Low Voltage (LV) distribution network monitoring, with particular focus on the digitalization of Secondary Substations (SS). This digitalization is achieved through the LV feeder monitoring (LV advanced supervision), which directly generates important benefits/applications, such as alarm detection, intelligent topology analysis, demand response management, renewable integration, load balancing and Electric Vehicle (EV) management.

The paper presents the key learnings obtained from several pilots and one massive scale project with Iberdrola, which is being deployed at the moment. All the use cases, benefits, field experience, etc. are also detailed in the current paper.

INTRODUCTION

Until now, distribution network evolution has been mainly focused on two areas: Medium Voltage (MV) automation and smart metering. In contrast, the LV network has been ignored, when it represents the final connection to the customer and new coming needs are going to force its redesign. Combining this LV supervision of the SS with smart metering data collection, some of these new needs can be met: demand and generation imbalances, dynamic power grid overloading, increased grid instabilities, LV asset failure and feeder instabilities due to distributed energy resources and EV charging.

Only few utilities have defined plans related to LV network. IBERDROLA has been testing this solution -during the last five years and due to the experience acquired, has decided to push the standardization of all the necessary devices for this ambitious LV supervision.

It can be distinguished two types of LV supervision: basic and advanced supervision. Basic supervision consists of monitoring the incoming of the LV panel while advanced supervision also includes monitoring the outgoings of each LV feeder. Additional features such as real time monitoring, configurable alarms, report generation, data analytics… can also be obtained with LV advanced supervision. As the number of benefits acquired with the LV advanced supervision is higher than with the basic one, the paper will be focused on the most complete solution.

LV ADVANCED SUPERVISION INFRASTRUCTURE IN SECONDARY SUBSTATIONS

Secondary Substations are the interconnections between Medium Voltage (for example 20-10-5kV) and Low Voltage (for example 400-230-120V). There are different types of connections: overhead, outside, inside a building or underground, depending on the country. Low Voltage supervision systems consist of several devices installed in the Secondary Substation to monitor the status of the feeders individually. This technology includes three-phase current transformers integrated within the LV fuse switch, one electronic card per feeder and one main device for gathering the information from feeders.

This technological solution is formed by:

Analog measurement

It consists of three-phase current transformers (CT) and voltage taps (L1, L2 and L3) for recording LV fuse switch. The feeder supervisor (SAL) is integrated in the LV switch and is fully compatible with main manufacturers' standardized solutions. The voltage measurement is done downstream the fuse, which it is key for a success blown fuse detection. These voltage and current taps are designed for placing an electronic card, to monitor the status of the feeder.

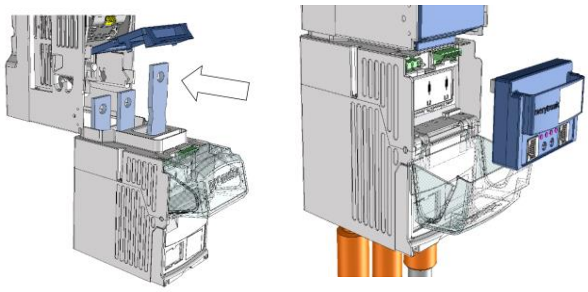

Figure 1. LV feeder supervisor (SAL) installation

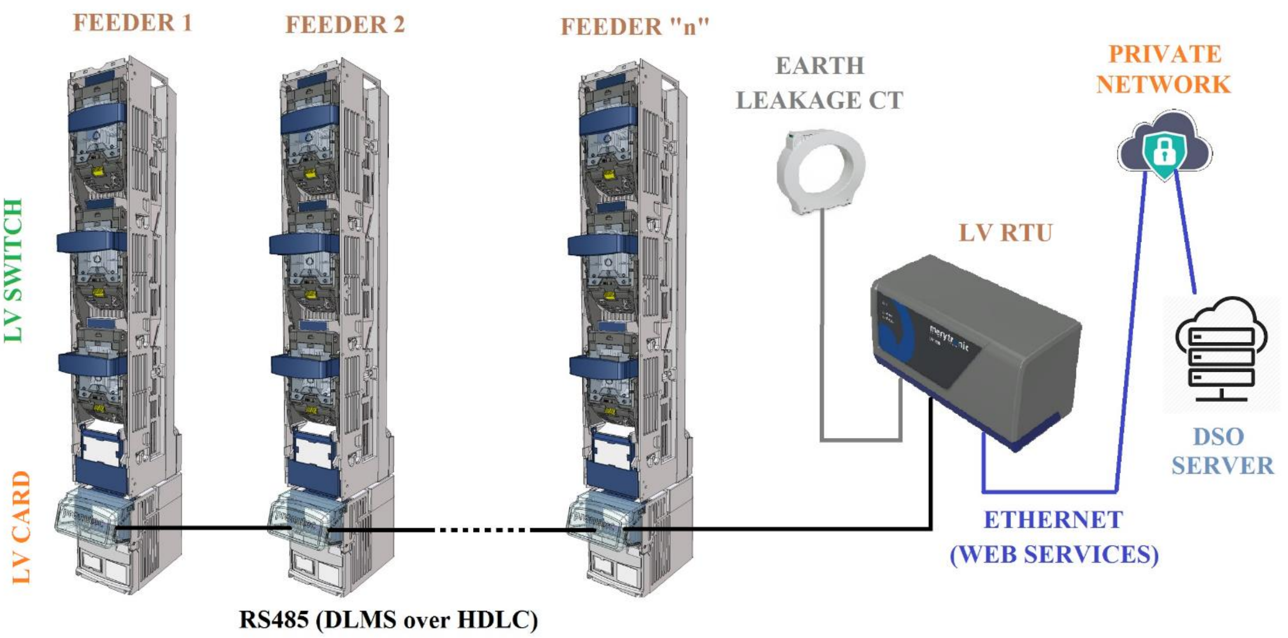

Figure 2. General schema for LV supervision technology

Digital measurement

The electronic card (LV Card) is connected and integrated in the LV fuse switch and is similar to a three-phase smart meter. It measures main electrical parameters, such as RMS voltage and current, active, reactive and apparent power/energy, power factor, etc. It has two connectors that allow implementing a communication bus between all the feeders with only one cable (daisy chain topology). The last (or first) feeder is connected directly to the LV RTU.

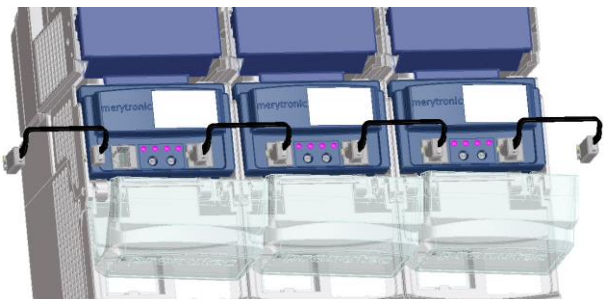

Figure 3. Daisy chain connection for several feeders

Data aggregation

The low voltage remote terminal unit (LV RTU) processes the information coming from all electronic cards and generates valuable reports for DSO (average values, maximum values…). It acts as master of the communication with them and it is ready for real-time communication with the remote control system of DSO, using web-services technology.

For communication between LV RTU and LV cards a serial bus (RS485) has been chosen, which has a high degree of immunity to noise. It also supports single master and multiple slaves due to balanced transmission line.

The chosen protocol is DLMS/COSEM over HDLC. DLMS/COSEM (IEC 62056, EN13757-1) is the global standard for smart energy metering, control and management. It specifies an object-oriented data model, an application layer protocol and media-specific communication profiles.

Standardization

All the technology necessary for LV supervision has been standardized by IBERDROLA, so different manufacturers can develop separate elements of the whole solution. With this high effort of standardization, interoperability between manufacturers is assured and it makes possible export the solution to other DSO and countries.

KEY BENEFITS FROM LV SUPERVISION

LV network is affected by regulatory actions promoting renewable generations, distributed storage, heat pumps and the growing diffusion of electric vehicles utilization. To face up these major challenges, LV advanced supervision technology has been deployed, so different operative departments from DSO will be directly benefited from that deployment.

Remote control system - Device management

The whole LV solution is remotely managed. This device management handles general configuration, alarm threshold configuration, status management and remote firmware updates. It includes real-time communication with the remote control system of the DSO.

Advanced Distribution Management System (ADMS)

Electric power distribution systems are designed to serve their customers with reliable and high-quality power. Continuous supervision of the status of each feeder enables an early detection of power outages and disturbances.

Real-time monitoring (alarms)

The proposed LV solution gives DSO the possibility of detecting several disturbances in the LV network, such as blown fuse detection, overcurrent, overvoltage, undervoltage... The system is fully configurable, so all alarm thresholds can be customized for each department needs.

Combining the outputs obtained from feeders and alarm activation/deactivation, the monitoring solution is able to give detailed information of the grid status. For example, the system is able to automatically classify the cause of the blown fuse as either due to an overload of the LV switch (typically, when too many customers are connected to the same phase and feeder) or due to a shortcircuit overcurrent (typically, when a fault in the LV network happens). Next figure shows a real case of use of detecting the origin of the blown fuse (rated 315 A):

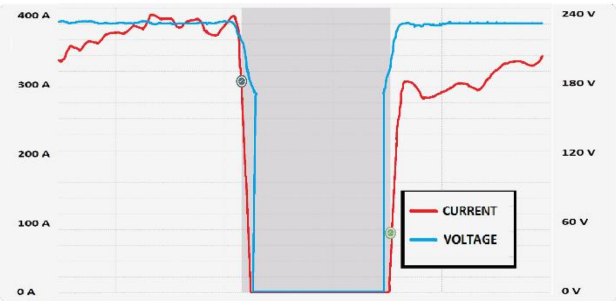

Figure 4. Current and voltage evolution of a blown fuse (caused by overload)

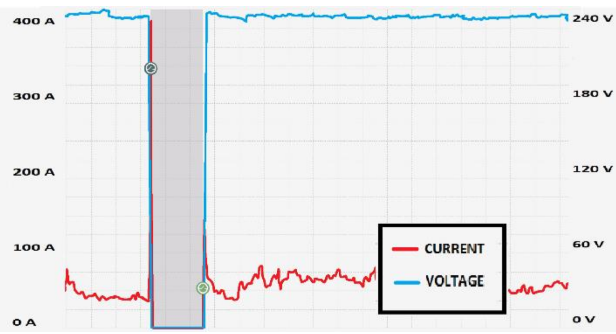

Figure 5. Current and voltage evolution of a blown fuse (caused by shortcircuit)

Status of the feeder (in service/out of service), blown fuse, overcurrent, earth leakage detection... is reported instantaneously to the operator, so the number (SAIFI) and duration (SAIDI) of power outages can be reduced.

Power Quality and oscillography

Power Quality measurements are performed per Secondary Substation to evaluate harmonics, dips, flicker, outages… These PQ measurements guarantee a high quality energy supply and reduce clients cost claims. The IEC 61000-4-30 standard, issued by the International Electrotechnical Commission defines for each type of parameter the measurement methods to obtain reliable, repeatable and comparable results. The standard distinguishes two classes of measurement performance (Class A and Class S). Class A devices are for contractual applications and resolving disputes between the utility and end customers. Class S devices are for statistical surveys and troubleshooting where uncertainty is not important [1]. In the proposed solution, the LV RTU performs the PQ calculations in the incoming voltage of the LV feeders. It is a Class S device and includes oscillography registers when an event is detected. This helps DSO technicians to understand and clarify the origin of an event.

Earth fault leakage current

Earth leakage current is the current flowing from the live parts of the installation to earth in the presence of an insulation fault. The main device also includes some auxiliary current inputs for measuring earth fault leakage current. This helps DSO technicians to detect technical loss in the LV network, especially high-impedance ones, which are those with fault current magnitude similar to load currents and do not trip fuse protections [2].

Network planning

Substation profiling and load balancing

Historically, it has been used the simultaneity factor in order to calculate the maximum power. With this factor and the contracted power, DSO are able to estimate the necessary cable sections, rated current of fuses and number of feeders per secondary substation. This estimation is not as accurate as desired, but this is now solved because of the smart meters and the hourly data of customer loads and feeders that they report.

With the new LV supervision solution, this approach can change completely. Historical data from LV feeders, combined with hourly information from meters and coupled with big data processing technologies, allows DSO to analyse and model in detail LV networks characteristics. With this information, the LV network forecast (demand and generation forecast) and availability can be improved, as well as a predictive and preventive maintenance. This improvement will help to design a more reliable, flexible and resilient smart LV grid (substations profiling) and can be valid for power losses estimation on LV grids.

Power losses are one of the most important indicators of the economic operations of DSO. Reduction of power loss is a complex problem, which requires qualified personnel. In order to reduce it, a proper load balance between phases and feeders is necessary. The LV supervision solution can generate the necessary data in order to simulate feeders' optimal reconfiguration.

Distributed energy resource (DER) management

In most regions -even in developed countries- the LV network infrastructure is aging. In addition, as renewable energies (solar, wind) gain importance, demands on the power grid are rising, with volatile and decentralized power supply threatening its stability. LV supervision solution can help to face up this problem. Combining data from LV feeders and smart meters, optimisation models of the LV network can be developed to find optimal configuration and operation of distributed energy technologies. These models can estimate the steady state voltage and thermal limits, which are important to DSO.

Demand response management

Combining the feeders and smart meters information, demand response management can be improved. Smart meters generate accurate information of consumer demand, which can be used by network operators to manage their network better. They can also enable the implementation of demand-response mechanisms to reduce consumption at peak times, thus avoiding unnecessary investments in additional capacity.

Transformer regulation management

The voltage regulation of the transformer is the method of controlling the output voltage supplied to the grid on the low-voltage side of the transformer. In any transformer, the secondary current produces voltage drop across the resistive and reactive components of the transformer's secondary side. On the other side, the primary current produces voltage drops across the resistive and reactive components of the transformer's primary side. For that reason, power factor is a determining factor in the LV voltage regulation. This means the voltage regulation of a transformer is a dynamic, load-dependent number. To get the best performance of the transformer, the voltage regulation should be as low as possible.

Power factor can be calculated with the energy estimation done by the LV supervision (per phase and feeder) and consequently the performance of the transformer can be improved.

Electric Vehicle charging

These new and flexible smart LV grids will also have a direct impact in EV charging process, and can pave the way for intelligent technologies as Smart Charging. EVs will be usually charged at night, but sometimes users might need charging batteries during the day in a very fast way due to unforeseen travels, emergencies or because the user forgot to plug the vehicle at night. In this situation the maximum energy supported by the charger and the car should be offered. However, maximum power to be used per customer is limited by a power contract in many countries. With the LV supervision solution, DSO can determine maximum power drain for each user depending on network availability; thus enabling fast charging services that reduce EV charging time.

Power storage management

LV network management with distributed energy storage will be in the mid-term the standard typology of LV networks. This storage may allow DSO to reserve part of storage capacity for relieving network congestion at peak times. The major difficulty in carrying out storage capacity reservations among diverse customers is its quantification. To overcome this difficulty, an algorithm of storage capacity reservation can be implemented, taking into account customer and feeder energy profiles.

Power Loss

Intelligent topology analysis (phase and feeder detection)

Measurement balance of energy supplied from the secondary substation to the final customers it is key to detect power system loss. Energy loss is detected by comparing the total energy sourced per phase and feeder with the aggregation of the energy read on the meters connected to them. In order to compute this calculation in a reliable way an error free feeder and phase mapping information is necessary. An algorithm has successfully been developed, tested on field and put into production showing 100% reliability on the link data. The algorithm guarantees the association between customers and feeder-phase is properly updated, even when there are topology changes on the network. This algorithm is independent of the communication model for smart meters (PLC, radio, cellular…).

In the context of distribution systems, total power loss is the difference between the power leaving a primary distribution substation and the power delivered to customers. Energy balance between hourly feeder profile and the aggregation of customer profiles determines the total loss per feeder in the LV network. According to consumption patterns of final customers, it is possible to distinguish between technical and non-technical losses.

Technical loss detection

Technical losses may occur naturally refer to power dissipation in electricity system components, such as transmission and distribution lines, transformers, and measurement systems. This is the portion of loss that occurs due to resistance in the distribution network. By estimating these technical losses, DSO can evaluate their operation technically and economically, as now it is possible to quantify its value on each LV feeder. Further actions can be taken based on this value, such as replacing cables with a higher power rating (lower resistance), upgrading transformers or offering rewards to customers for reducing power consumption during peak periods (demand management).

Technical loss due to failure of network asset isolations is overtaken by monitoring earth leak detection on SS earthing, and additionally by analysing feeder energy balance hourly profiles.

Non-technical loss: direct connection and tampered meter detection

Non-technical loss is caused by external actions to the power system and primarily consist of electricity theft (direct connection to LV distribution network), non-payment by customers and tampered meters.

Direct connections are identified by analysing those feeders where the energy balance shows a significant loss problem. The positive point is that the system is able to quantify the amount of kWh lost. However when it is caused by theft through direct connections to the grid (before the legal meter or without legal contract) it is still necessary to inspect the feeder by specialized technicians, which is usually a time-consuming work.

On the other hand, meter tampering directly links to a customer with a contract and a serial number, which facilitates detection work. Meter tampering shall be defined as bypassing the meter, or other electric alterations such as physically disorienting the meter, attaching objects to the meter to divert or bypass electric service or, insertion of objects into the meter. In several countries, this is a problem that DSO has to face up continuously, so after a deep field study, another algorithm has been developed to detect tampered meters. It has been tested in the field with great successful results.

Next figure shows a real case of tampered meter that was detected with the mentioned algorithm. The customer made a bypass in the phase and neutral connections, so part of the current was flowing through the smart meter and the rest through bypass cables.

Figure 6. Real case of tampered-meter detection

FUTURE APPLICATIONS

LV supervision technology has a great potential, so future applications could be included to increase that potential. Those applications are:

- New monitoring and control functionalities related to LV automation
- Monitoring and control of LV transformer load
- Detection and location of LV faults
- Remote control; reclosing depending on fault type
- Sensors:
  - Temperature
  - Fire
  - Humidity
  - Access control
  - Video
  - Noise
  - …

CONCLUSIONS

LV supervision systems consist of several devices installed in the secondary substation to monitor the status of feeders. This technology offers a wide range of advantages and benefits for DSO and final customers:

- Real-time monitoring (alarms)
- Power Quality and oscillography
- Earth fault leakage current
- SS profiling and load balancing
- Distributed energy resource management
- Demand response management
- Transformer regulation management
- Electric Vehicle charging – Smart Charging
- Power storage management
- Intelligent topology analysis (automatic meter and phase-feeder link detection)
- Technical loss detection
- Non-technical loss: direct connection and tampered meter detection

This technology can become an active part of the LV grid digitalization, which offers utilities the chance to redefine their business models by improving their internal operations and the services they deliver to end consumers.

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