ENEL GRID DIGITALIZATION THROUGH MULTIFUNCTIONAL CONTROL AND PROTECTION DEVICES

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ABSTRACT

This paper addresses the challenge of distribution grid digitalization starting from the HV/MV substation, by presenting the Enel Global Infrastructure and Networks strategy.

Enel Global Infrastructure and Networks (Enel GI&N) is a business division of Enel group, that is managing, through local distribution system operators (DSOs), more than 2.2 million kilometers of power lines in Argentina, Brazil, Chile, Colombia, Italy, Peru, Romania and Spain.

This strategy is based on the introduction of multifunctional control and protection devices, extended interoperability along the distribution grid (by using IEC 61850) and high-speed communication (by including the LTE).

This approach was tested in the Enel smart grid laboratories and it was validated in large scale implementations.

INTRODUCTION

Today's advanced digital protective relays and remote terminal units (RTUs) utilize high-speed communication to replace copper wires, moreover IEC 61850 series is giving a common framework for substation interoperability.

Several technology vendors may offer a full set of devices for the HV/MV substation, most of them have also system integration capabilities to provide turnkey solutions or manage the interoperability between multi-brand devices and subsystems.

In this scenario, traditional distribution system operator (DSO) digitalization is mainly based on two alternative approaches.

The first approach is the single-vendorship (and in several cases single-brand) for the entire substation, in order to include in the turnkey solution also the activities needed for interoperability (protocol configuration, protocol conversion etc.); in this case the procurement process is for the substation as a single unit and only different substations may be assigned to different vendors. The main benefit is the reliability of the final solution (that can be initially tested in the vendor premises), the main problems are:

- the substation designs may be strongly different and additional work may be needed for the substation-to-substation interoperability;
- the vendor is frequently the only partner for the future activities in the substation (improvements, maintenance etc.), with possible costs increment.

The second approach is the multi-vendorship inside each substation with system integrators for the interoperability; in this case, the procurement process is for the devices and a substation may have different vendors. The main benefit is the highest competition for each single device/activity, the main problems are:

- longer activation time for the substation, due to longer tests and integrations between the partners;
- low reusability of interoperability activities in one substation to the other, due to the possible different combination of vendors or devices.

For all the systems and devices involved in its business, Enel GI&N (as a large-scale corporation born by merge and acquisition of existing DSOs) is evaluating the possibility to converge towards a unique solution to be used worldwide by all Enel distribution companies, obtaining obvious savings in terms of maintenance and evolution costs [1].

Therefore, Enel GI&N selected a different approach for the grid digitalization based on:

- a set of technical specifications (by including IEC 61850 profiles);
- co-development and testing in the Enel smart grid laboratories;
- a set of protection, control and interoperability guidelines.

This strategy was initially developed and tested in the main Italian DSO E-distribuzione (Enel group) and was able to create a set of multi-vendor devices fully interoperable by design. By becoming a global strategy, it is continuously revised and improved with the contribution of all Enel DSOs.

This paper shows (also by reporting about real implementations) that Enel GI&N strategy has been able to combine the benefits by strongly reducing the problems of the above approaches. The paper also presents the Enel GI&N experiences of extended interoperability along the distribution grid by using IEC 61850, high-speed communication (by including the LTE) and innovative devices for the MV/LV substations.

The paper is organized such that the engineering of an IEC 61850 based protection system is presented at first. This is followed by the section describing the Enel multifunctional control and protection devices. Finally, field implementations will be introduced. Conclusions are presented in the final section.

ENGINEERING OF AN IEC 61850 BASED PROTECTION SYSTEM

As previously reported in [2], currently there is a gap in the way IEC 61850 based protection systems are specified and this creates problems in all the life-cycle steps, mainly from procurement to operation.

In the over mentioned traditional approaches, utilities focus on general overviews that show how a system is operating, if and where functions are allocated and, if distributed, how these functions are interconnected.
Therefore, the documents for procurement process are not containing all the details needed by other actors (system integrator, system providers, vendors etc.) to propose a standardized system.
These actors have a need for views regarding the design with a focus on specifics, for manufacturing, for testing and for solving component and system disturbances over a longer period of time; if crucial details are not provided by the utilities during the procurement process or after, the vendor normally present their own solutions. That prejudice the concept of DSO standardization and convergence, mainly because some of these solutions may be one vendor proprietary or very hard to implement by other vendors.

Enel GI&N issued (or is issuing) a set of global standards (for example Enel code GSTP103, GSTP104, GSTP113, GSTP114) that specify the communication profile for the devices used for protection and control purposes. These devices implement LNs, protocol stacks and communication services as defined in the IEC 61850 standard (with particular reference to IEC 61850-5, IEC 61850-7-3, IEC 61850-7-4, IEC 61850-90-1, IEC 61850-6, IEC 61850-8-1, IEC 61850-7-2) in order to support the features described in the IEC 61850-5.
Thanks of these standards, multi-vendor devices completely interchangeable and fully interoperable by design are already available.

Therefore, every substation device is able to communicate natively via LAN in the substation with:

- the RTU;
- one or more clients during the development or special/temporary operation stages;
- load shedding devices;
- MCPDs;
- RIOs (explained in the next section).

Every substation device may also communicate with other devices along the feeders, in particular with the RGDMs [3] installed on the same MV feeder in order to:

- participate in the logical selectivity for the feeder protection (by receiving the Blind signal);
- remotely disconnect the distributed generation (DG) and loads (by sending the TD signal).

MULTIFUNCTIONAL CONTROL AND PROTECTION DEVICES

Enel GI&N issued (or is issuing) a set of global standards (for example Enel code GSTP101, GSTP102, GSTP111, GSTP112) that standardize the functional, construction and testing requirements of the devices used for protection and control purposes in the HV/MV distribution substation. These devices accomplishes to the definition of protection equipment, by according to IEC 60255 series, and intelligent electronic device (IED), by according to IEC 61850 series.

The multifunctional control and protection devices (MCPDs) are platforms, consisting of an expandable set of boards inside the main enclosure and a set of different firmware (FW) to facilitate easy reconfiguration of the IED functions inside the substation. Its input/output (I/O) functions towards the field devices are readily scalable via remote modules connected to dedicated communication ports or via the local area network (LAN) in the substation. The MCPDs are compatible with the following grounding systems:

- insulated neutral;
- neutral earthed through an inductor with in parallel a resistor;
- neutral earthed through a resistor;
- neutral earthed through an inductor;
- neutral directly earthed.

The MCPD may use dedicated remote I/O module (RIO). MCPD and RIO mainly use the protocols from the IEC 61850 series to communicate with the RTU, the communication profiles are defined in other GSs (as described in the section before).

With reference to the cybersecurity, security by design is mandatory for any devices installed in the Enel GI&N premises.

Enel laboratory in Milan (Italy) is entrusted for multifunctional control and protection devices testing, however local implementations are followed by Enel laboratories in Spain and Brazil also.

For a better understanding, two MCPDs are introduced in this section:
- Multifunctional feeder protection (MFP);
- Multifunctional transformer protection (MTP).

Multifunctional feeder protection

The MFP is designed to control and protect the following HV/MV substation elements:
- MV feeders (1 kV < Vn < 36 kV);
- power factor correction devices;
- earthing transformers;
- section circuit-breakers (or busbar couplers);
- bus transfer couplers;
- HV feeders (Vn ≥ 36 kV);
- auxiliary services;
- capacitor banks.

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The MFP is one of the most famous devices for protection and control purposes in the HV/MV substations, several vendors are proposing solutions to the market.
More than 10 technical specifications were already available in the Enel DSOs, with dozens of qualified devices.

The convergent solution is proposed in a new set of global standards (Enel series GSTP10X) with the following main functions:
- phase overcurrent protection function;
- residual overcurrent current protection function;
- directional overcurrent protection function;
- negative sequence overcurrent protection function;
- unbalance protection function;
- directional earth overcurrent protection function (including arching ground);
- RLS function;
- directional earth overcurrent protection function for the detection of evolving faults;
- residual overvoltage protection function;
- emergency protection function;
- phase-to-phase overvoltage protection function;
- phase-to-phase undervoltage protection function;
- cold load pick up;
- switch-on to fault (SOFT);
- discrimination of inrush currents;
- directional active overpower protection function;
- discrimination of broken conductor;
- discrimination of breaker failure;
- synchro-check protection function;
- DC undervoltage protection function;
- frequency protection function;
- automatic reclosing function;
- disturbance recording;
- high impedance fault detection;
- measurement functions;
- self-diagnosis and control logics;
- remote access for maintenance;
- IEC 61850 interoperability profile as presented in the previous section;
- parallel redundancy interoperability.

This MFP is adopted in all the MV bay (1 kV < V_n < 36 kV) and in some HV feeders (radial, Vn ≥ 36 kV) bay, where differential and distance protections are not needed.

Multifunctional transformer protection

The MTP is designed to control and protect the HV/MV transformers, in particular:
- MV bays (up to 2);
- HV bay;
- on load tap changer (OLTC);
- transformer itself.

Also in this case, the MTP is one of the most famous devices for protection and control purposes in the HV/MV substations, several vendors are proposing solutions to the market.
Around 10 technical specifications were already available in the Enel DSOs, with dozens of qualified devices.

The convergent solution is proposed in a new set of global standards (Enel series GSTP11X) with the following main functions:
- phase overcurrent protection function;
- differential protection;
- zero sequence differential protection;
- negative sequence overcurrent protection function;
- OLTC overcurrent protection function;
- overvoltage protection function;
- zero sequence overvoltage protection function;
- undervoltage protection function;
- pole-discrepancy protection function;
- advanced voltage control functions;
- emergency protection function;
- synchro-check protection function;
- frequency protection function;
- automatic reclosing function;
- disturbance recording;
- measurement functions;
- self-diagnosis and control logics;
- remote access for maintenance;
- IEC 61850 interoperability profile as presented in the previous section;

– parallel redundancy interoperability.

FIELD IMPLEMENTATIONS

Most of the Enel DSOs are working in smart grid development from long time, addressing also digitalization strategies.
Therefore, Enel GI&N has a long experience in HV/MV substation digitalization; single-vendorship, single-brand, multi-vendorship with system integrators and several hybrid approaches were adopted worldwide by actual Enel DSOs, mainly before the merging.
In functional point of view, there are several good implementations in operation, in some cases as a result of national or international projects.
Nevertheless, in term of costs and simplification, the scenario is not uniform, only two examples:

– in E-distribuzione the local feeder protection has a cost < 1000 € and its interoperability inside the substation does not require any protocol conversion;
– in another Enel DSO the local feeder protection has a cost > 3000 € and its interoperability inside the substation requires additional devices for protocol conversion.

In order to describe some possible applications of over mentioned Enel GI&N digitalization strategy, two field implementations are presented:

– innovative voltage control system;
– smart fault selection.

Innovative voltage control system

Automatic voltage regulator (AVR) with OLTC are widely used to regulate the voltage of MV busbar of HV/MV transformers according to the variation of the loads; therefore, the control logic is fully local by using mainly voltage (on the busbar) and current (flowing on the transformer).
In order to have a better voltage management with high DG presence, E-distribuzione implemented an innovative voltage control system (VCS) able to act voltage regulation on three levels:

1. The first level is from central systems to HV/MV substation. The voltage to regulate at the MV busbar is calculated by the advanced distribution management system (ADMS) [4]. The MTP receive this information thanks to the interoperability with RTU and central systems, the MTP, again, control the OLTC.
2. The second level is at DG level (along the MV grid), performing the so-called local voltage regulation. In case of high/low voltage detection in the controlled point, the controller will start to modulate the reactive power. This regulation level uses also RGDM devices, that are also included in the over mentioned interoperability;
3. The third level is also at DG level (along the MV grid), performing the so-called centralized voltage control (CVC). This regulation is actuated if the local voltage regulation is not enough to solve the over/undervoltage problem. In this case the “nearest” controlled point will start to modulate reactive power. The VCS purpose is to perform the CVC on the MV grid acting on controllable nodes (CTNs). CTNs represent network nodes where the voltage is locally measured and it is possible to modulate the power flows (e.g. reactive power).

It is important to note that the described levels are independent and can be activated one by one or together; this is a big advantage in terms of modularity and retrofit because each level is performed by a set of devices.

The VCS has been entirely integrated in the E-distribuzione SCADA-ADMS in order to have a full solution ready to be deployed in the real field. In other word the VCS is not a simple experimentation but a new innovative infrastructure fully integrated within the remote control and automation system.

Further details about this implementation may be found in [5].

Smart fault selection

Enel GI&N has a long experience in network automation systems [6], the smart fault selection (SFS) is a new developed method.
The SFS is a self-healing technology performed by the devices installed in the grid, communicating through a high-speed communication network.
The devices, exchanging information each other like in a community, are able to self-decide which are the best disconnection point of the electrical network that has to be connected or disconnected.
It is important to mark that the smart fault selection doesn’t require any remote action by operator or system and operates in less than 1 second.

The smart fault selection base its operation on the exchange of goose messages (IEC 61850) between the protection devices; in this case, the MFPs and the RGDMs are involved.
This new technology is a step forward on the long automation experience of E-distribuzione. The classic automation systems are not disabled, but they operate in back up mode.

Further details about this implementation may be found in [7].

CONCLUSIONS

This paper presented the Enel GI&N approach for the HV/MV substations digitalization, that is based on the introduction of multifunctional control and protection devices, extended interoperability along the distribution grid (by using IEC 61850) and high-speed communication (by including the LTE).

Enel GI&N specified the functional, construction and testing requirements of the devices used for protection and control purposes in HV/MV distribution substation. These devices accomplishes to the definition of protection equipment, by according to IEC 60255 series, and intelligent electronic device (IED), by according to IEC 61850 series.

The interoperability trough IEC 61850 is specified in term of communication protocol and any other detail; therefore, every IED is able to communicate natively via LAN in the substation with another. This interoperability is also enlarged to the distribution grid, by using high-speed communication.

Grid modernization and digitalization projects are expected in next years in all Enel GI&N perimeters, by involving hundreds HV/MV substations.

The main expected benefit to respect the past digitalization strategies are:

- reduction of costs for the protection devices (in terms of procurement, maintenance and evolution costs) and no need of additional devices for protocol conversion;
- standardization and simplification of substation design;
- shorter substation activation time;
- functional enhancements.

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