TOWARDS A NEW GENERATION OF SECONDARY SUBSTATIONS ON FRENCH DISTRIBUTION NETWORKS TO ACCOMMODATE SMART GRIDS REQUIREMENTS

Christian GUILLAUME
EDF R&D – France
christian.guillaume@edf.fr

Michel CORDONNIER
ERDF – France
michel.cordonnier@erdf.fr

Fabienne MONTEL-RAGU
EDF R&D – France
fabienne.montel-ragu@edf.fr

Franck GAILLARD
EDF R&D – France
franck.gaillard@edf.fr

Malick MOUHAMAD
EDF R&D – France
malick.mouhamad@edf.fr

Florent LEMENAGER
EDF R&D – France
florent.lemenager@edf.fr

Mustapha HABJA
EDF R&D – France
mustapha.habja@edf.fr

ABSTRACT

Like most utilities, the French DSO ERDF has to prepare the evolution of its current networks to accommodate smart grid requirements.
In this context, ERDF is currently developing the future generation of secondary substations. The design of this new equipment represents a real technical and economic challenge as ERDF has in charge the operation of a large fleet of MV/LV substations. The new technical stage of smart secondary substations has to keep room for scalability in order to enable a progressive implementation on the French network for which the need of both existing and new built substations has to be covered.
To reach this target the development methodology chosen by ERDF consists first in launching a development market prior to a series market. The goal of this preliminary development market is to work with selected manufacturers in order to refine the envisaged requirements in order to come the closest as possible to industrial standard products and get a viable smart substation from technical and economic viewpoints. Regarding the components of this new substation, the studies currently carried out by ERDF with the support of EDF R&D focus in priority on the control command, the voltage and current sensors and the MV switchboard. Evolutions of the transformer and the LV panel will be studied in a second phase.
The aim of this paper is to provide a review of the ongoing developments of this new technical stage of MV/LV substations.

NEED FOR A SMART MV/LV SUBSTATION

Utilities have to face new challenges.

Distribution grids have to face important changes. In particular, the continuously increasing integration of renewable energy sources (RES) and distributed generation (DG) as well as the developments in the power demand (with situation of peak loads) and in new uses (such as Electric Vehicles) have significant impacts on the grid because of new constraints such as reverse power flows and voltage fluctuations.
In this evolving context it becomes necessary to promote new technical solutions to mitigate these effects. In practice, utilities have to introduce more intelligence in the components fitting their MV and LV distribution networks.

Smart secondary substations have become an essential brick of the Smart Grids.

Amongst the various equipments of distribution grids, secondary MV/LV substations are a key element as their strategic position and role (electric node located at the border between MV and LV distribution networks) can significantly improve the grid operation by means of new network services as for example better grid control including automation scenarios, information to estimate the operational state of the grid, monitoring of the main electric values (current, voltage, active and reactive powers), faster diagnostics, fault clearing with possible self-healing procedures.
In addition to the roll-out of smart meters, smart MV/LV substations have now become another essential brick of the Smart Grids.

DEVELOPMENT OF A NEW TECHNICAL STAGE OF MV/LV SUBSTATION

Like many utilities, the French DSO ERDF is currently developing a future generation of secondary substations.

The development must meet major requirements.

The development of the new technical stage has to be made while meeting several major requirements. For example, the design must rely on new industrial technologies available in the short term. The substation architectures to be adopted must be robust and sustainable so as to get a reliable, safe and easy to operate product with a good lifetime. Moreover, synergies must be found with the French smart metering solution called Linky in order to benefit from its infrastructure for network applications. From the economic viewpoint it is also necessary to design a new substation maintaining balance between investments, gains and operational costs.

Major issues have to be considered.

The development of a new technical stage involves different successive milestones: the elaboration of a technical specification, the phase of equipment qualification and the experimention of samples on real networks. All these steps are necessary to allow a possible large-scale roll-out of the equipment.

Before launching the first specification step, different important questions have to be answered.

What time horizon has to be considered?

The new technical stage of smart substations has to be correctly phased with the current series markets. Technical options have to be taken while considering a strongly evolving environment especially in the domain of telecommunications and information systems.

Which functions have to be included in the substation?

Many functions seem interesting technically speaking but there is a need for economic viability of the solutions to be deployed in terms of quantities, unit cost and gains.

What architecture for the substation?

The architecture of the future substation depends on many parameters. First, considerations of technical maturity have to be considered to define the product design. However, this one must also keep open enough to future evolutions in order to enable integration of future additional functions. It is also desirable to comply with international standards (such as IEC 61850 series) to enable interoperability between manufacturers knowing that this normative context is still incomplete, involving some difficulties to decide consolidated choices.

Otherwise, the cohabitation of equipments with different lifetimes and obsolescence cycles has to be ensured: lifetime of 40 years for power equipments versus 20 years for control command equipments and obsolescence cycles of less than 10 years for telecom solutions.

Compromises have to be made to define the good level of integration for control command and telecommunication devices into power equipments: a high integration level means reduction of purchase costs, facility of implementation, easier management of interfaces, while a low integration level promotes interoperability and facilitates retrofit interventions.

Regarding communication aspects, the choice of the appropriate media and protocols has to be considered in a perspective of scalability and must permit the integration in the telecommunication and information systems: to enable data exchanges, interfaces must be compatible with the Distribution Management System and the Information Systems used by ERDF.

Cyber security is also a growing issue and cyber security requirements also have to be taken into account in the design of the solution.

The development process will be gradual and target future-proof solutions.

ERDF has in charge the operation of a large fleet of MV/LV substations: around 750 000 units characterized by numerous kinds of architectures and components to meet the different network configurations and environmental constraints.

Given the volume of substations involved, the design of the new technical stage represents a real technical and economic challenge. The case of both new built substations and retrofit of existing ones must be covered. In these conditions and given the different major issues to be solved as mentioned above, it has been decided to develop the generation of the new smart secondary substations in a gradual and evolutionary manner.

In practice, a development market will be launched prior to a series market. The goal of this preliminary development market is to work with selected manufacturers in order to refine the envisaged requirements so as to come the closest as possible to industrial standard products and get a viable smart substation from technical and economic viewpoints. Regarding the components of this new substation, the studies currently carried out by ERDF with the support of EDF R&D are focused in priority on the control command, the voltage and current sensors and the MV switchboard. Evolutions of the transformer and the LV panel will be studied in a second phase.

The continuation of this paper presents these equipments (control command, sensors, MV switchboard) in the framework of the development market.

ARCHITECTURE OF THE SUBSTATION

Implementation of new built substations and retrofit of existing ones involve different needs.

There is a real diversity in the existing fleet of MV/LV substations. This situation is explained by successive generations of equipments coming from different manufacturers, deployment of substations in varied environmental constraints, leading to heterogeneous ageing states of equipments.

To cover the various configurations encountered in the French distribution networks, the design of the future substation must take into account two cases: implementation of new substations and retrofit of existing ones. The retrofit can be motivated by two possibilities:

- The obsolescence of equipment or its strengthening: the renewal of a part of the existing equipment provides the opportunity to enlarge the functional perimeter of the substation.
- There is a need for measurements: the addition of new functions inside the substation is imposed by the grid constraints.

The substation architecture depends on the choice made to incorporate its intelligence.

A new equipment called EMIS meaning "Equipment of the Modular type for Instrumentation an Supervision" gathers the substation intelligence. Enabling the control command of the whole substation, the EMIS includes the classical functions of a Remote Terminal Unit (RTU) and adds new functions to improve the network performance and meet new Smart Grids requirements.

The EMIS is designed for grid management and operation by allowing network monitoring and reconfiguration. Its design is modular and future-proof in order to permit the integration of future functions such as the circuit-breaker control for network automation with reclosing sequences or the control of voltage regulated distribution transformers.

The EMIS is composed of a "Supervision module" ensuring the necessary basic functions (central unit, telecommunications, power supply) and of different "Intelligent Electronic Devices" (IED) with dedicated functions such as management of MV and LV equipments or input/output connections. All these modules and IED are linked to one another through a Local Area Network (LAN). The EMIS device will be detailed in a further section of this paper.

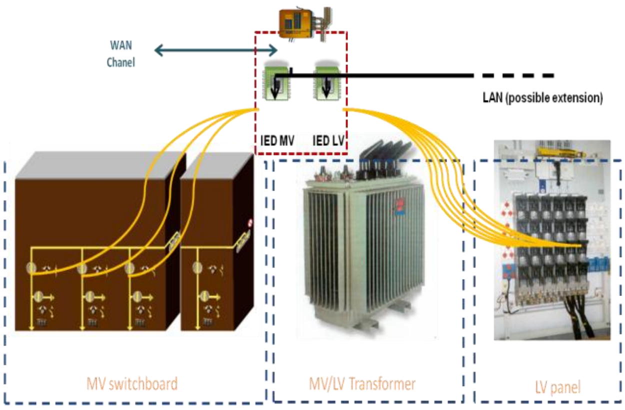
There are two possible options for the substation architecture.

To cover the two cases mentioned above (implementation of new substations and retrofit of existing ones) two architectures are conceivable based on the principle of complementary IED.

A centralized structure for retrofit without renewal of the power equipment

A unique enclosure incorporates the supervision module, the IED and the LAN.

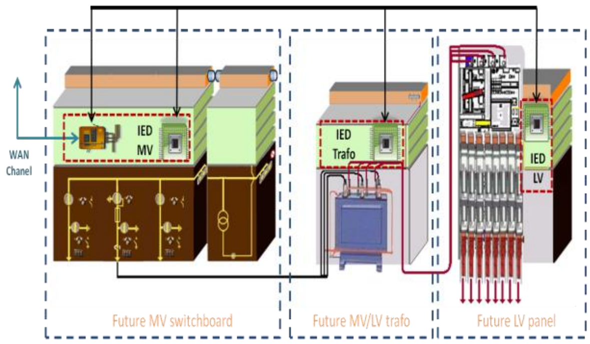
This case corresponds to the renewal of the current RTU in order to enable measurements. The investment is thus motivated by gains expected from measurement collection and processing. In this configuration the EMIS of the centralized type is implemented together with sensors on the different equipments to be instrumented.



A distributed structure for new substations and retrofit with renewal of the power equipment

The IED are outside the enclosure so as to be distributed the closest as possible to the power equipments in order to limit cabling with the sensors.

This case corresponds to new substations or retrofit of existing ones with renewal of the power equipments. The supervision module ensuring the communication interface with the Wide Area Network (WAN) is incorporated in the MV switchboard while dedicated IED are incorporated in their own power equipments: MV switchboard, MV/LV transformer and LV panel.



The above diagram represents the final target architecture based on distributed IED and on a standardized LAN.

At the present time, it has to be noted that the architecture studied in the coming development market is restricted to a scheme where the supervision module, the MV IED and an optional LV IED are incorporated in the MV switchboard. Moreover, the implementation of the LAN will be left to the manufacturer's choice in this first step but will then be specified according to standards.

All these evolutions will be studied with manufacturers selected in the framework of the development market.

FUNCTIONS OF THE SUBSTATION

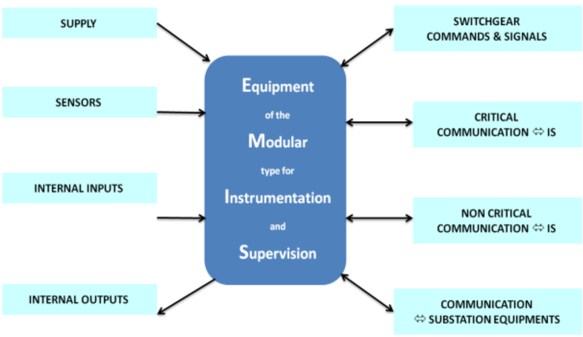
The functions envisaged for the smart secondary substations are listed in the following table (non exhaustive list).

Measurement of electric values
- MV voltage & currents - LV voltage & currents at the transformer level - LV currents on one LV network feeder - Calculation of MV and LV active & reactive powers - Fault detection due to a MV conductor cutting
Substation monitoring
- Temperature measurements (transformer & ambient temperatures) - Water level - LV voltage wave quality
Network automatisms and management support
- Switchgear remote control - Automatic permutation between supply sources - Decentralized automatisms

Support to maintenance and operation
- System tele-configuration & tele-administration (in the final technical stage) - Support to maintenance optimization like back-up supply batteries (in the final technical stage)
Upstream & downstream communication
- Communication with SCADA and IS - Communication between substations or with distant sensors (in the final technical stage)
Support to asset management
- Automated collection of information describing the different substation equipments (in the final technical stage)
Future-proofing of the system
- Evolutive communication interfaces - Tele-distribution of system upgrades
Integration of standards
- Compliance with industrial standards like IEC 61850 for example to enable equipment interoperability (in the final technical stage) - Standards and recommendations in cyber security (yet to be strengthened for the final technical stage)

EMIS AS CONTROL COMMAND DEVICE

As mentioned above, the EMIS is the control command equipment of the smart secondary substations. Its environment can be represented as follows.



The EMIS embeds a defined set of functions which contribute to the network reconfiguration (need for network operation) and monitoring (need for network control). These are divided into 5 main families: network, service, system, security and communication functions as described in the following table.

COMMUNICATION functions: critical WAN needs		
COMMUNICATION functions: non critical WAN needs		
NETWORK functions	**SERVICE** functions	**SYSTEM** functions
Automatisms Fault detection MV and LV measurements Equipment command orders Substation monitoring	Operation event registration Operator's interface Parameter setting Input / Output connections Measurement acquisition	Power supply System maintenance Synchronization System configuration
SECURITY functions		

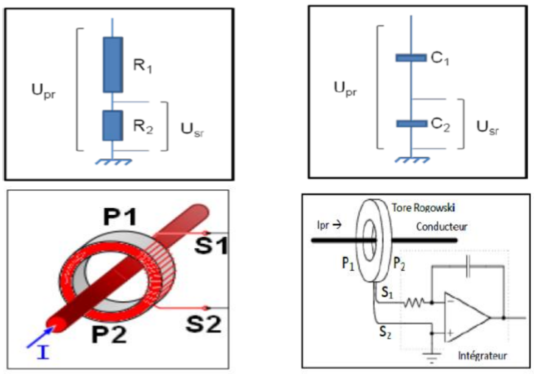
To cover the possible evolution of the needs in the future the EMIS design must be modular and evolutionary. It is the reason why the architecture is based on physical blocks gathering the different thematic functions. Based on this design the possible evolution is made available by adding new blocks without calling into question the other existing blocks in place.

At the time being the following physical blocks are envisaged but this can evolve depending on the upcoming discussions with manufacturers during the phase of development market.

- A basic block so-called "Supervision module" with central unit, communication and supply functions.
- Complementary dedicated IED: back-up supply, input/output connections, MV measurements, LV measurements, management of the current and future MV switchboards.

MV AND LV SENSORS (U & I)

To enable network monitoring and operation managed by the EMIS system, MV and LV sensors are required. Current measurements and fault detection will be ensured by current transformers of magnetic type or by Rogowski coils (precision fixed at 1%) while voltage values will be measured by capacitive or resistive dividers (precision fixed at 0.5%).



To confirm the choice of these different technologies and their compliance with the requested performance level, EDF R&D carried out investigations in its own laboratories. In addition to classical metrology, power and dielectric tests, several samples of sensors of each technology were tested on the Concept Grid (at EDF Lab Les Renardières) to evaluate their ease of implementation on a real network and to check their behavior under normal and disturbed service conditions.

Concept Grid is the latest EDF laboratory dedicated to tests of smart grid equipments, systems and functions. Its special design is halfway between laboratory tests and experiments in the field. The Concept Grid makes it possible to conduct, in complete safety, complex testing campaigns that would be impossible to perform on a real network.

MV SWITCHBOARD

The future MV switchboard obviously maintains all the advantages of the current Ring Main Unit (RMU):

- Compact and modular design enabling a possible evolution of the assembly configuration depending on the needs for network evolution (concept of extensible RMU by means of functional units which are themselves also extensible).
- Insensitivity to the environment: integral insulation meaning no electric field line in the ambient air and involving the benefice of water tightness.
- Easier operation thanks to dedicated cable terminations for conductor access.
- Operational safety through locking devices, sure position indicators and internal fault withstand.
- Various types of functional units to cover the needs for distribution and customer substations.
- Possible motorization of remote-controlled functional units.

Its design is future-proof so as to allow the integration of new functions intended to get a better network management and operation while ensuring the grid reconfiguration and supervision.

For reasons of cost and easier implementation, the future RMU will integrate the EMIS functions as well as the MV current and voltage sensors.

The distribution of the EMIS blocks into the MV switchboard will be under the responsibility of manufacturers who will be in a position to propose a high level of integration.

TELECOMMUNICATION

This new stage of smart secondary substations also implies new telecommunication solutions.

On the one hand, the monitoring of electrical values in the network as well as the will to set up remote management functionalities lead to new traffic and require more bandwidth, both of which could not be supported by the existing communication infrastructure of ERDF for distributed equipment.

On the other hand, operated telecoms tend to provide a lower service level in terms of availability in crisis situations.

ERDF thus set up a hybrid communication solution. The protocols for the communication channels are chosen in regards to what the media could support, with the aim to use international standards from the IEC 61850 series but taking into account their maturity and ensuring that the system reliability is preserved.

Therefore, the remote control of circuit breakers and switches is being addressed through a “critical” channel using reliable media (POTS or ERDF own radio network) and the legacy ERDF proprietary protocol to ensure unaltered service from the SCADA center.

A “non critical” channel using operated cellular networks (or other IP technologies) is set up to transfer new data such as the measurements of electric values or substation monitoring indicators. The data will be mapped from the IEC 61850 database to the IEC 60870-5-104 protocol according to the mapping defined in IEC 61850-80-1.

CYBER SECURITY

The set up of IP links, the connection with critical infrastructures and the international situation in terms of cyber protection demand that this new technical stage of distributed equipment implements strict cyber security requirements.

The requirements on the equipment concern not only the telecommunication channels but also the local hardening of interfaces and processes, the set up of indicators to detect possible intrusions, and the strengthening of authentication policies.

Furthermore, cyber security requirements are specified to secure the development environment at the manufacturers’ premises, in order to ensure that there has not been a breach during the conception phase.

PROSPECTS

Technical specifications of the future equipments (EMIS, sensors and MV switchboards) have been transmitted early 2015 to manufacturers in the framework of the development market.

This will lead to the successive phases of development and qualification of these new equipments before an experiment of some units on the ERDF networks.

At the same time, discussions with manufacturers will take place to prepare the final technical stage of smart secondary substations with all the targeted functions: interoperable and interchangeable EMIS blocks distributed as close as possible to the power equipments, a standardized LAN, sensors and power equipments upgraded with new additional functions to accommodate new Smart Grid requirements, remote management and maintenance of the equipment, etc.

The progressive development of the smart secondary substation wished by ERDF is planned during the next three years until end 2017, including all the successive phases: development, qualification and experiment phases of a first technical stage for the preliminary development market, together with the preparation of the targeted generation of the smart secondary substation which could be rolled-out from 2018.