Smart Substation For The French Power Grid

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Abstract

The paper describes a smart substation project launched two years ago, as part of the French government's plan "investments for the future". This project is named "Poste Intelligent" within RTE (Smart Substation, in English), and aims to test in real conditions the latest technological developments for both primary and secondary equipment using the second edition of the IEC 61850 standard and new information and communication technologies in a fully interoperable solution. For the first time in France, the substation is designed like an autonomous entity, with adaptive solutions using horizontal inter-substation communications, in addition to the traditional hierarchical concept of "substation to SCADA.

To manage complexity, a strong and well-designed automation system gives better and faster answers, and the automation system is based on a distributed design. Two demonstrators were selected in the principal French area in terms of penetration of wind energy with more than 600 MW installed power on the distribution system in a rural area that creates reversed energy flow from LV to EHV through the local HV system.

For the primary equipment, RTE implements optical CTs and low power VTs with a smaller footprint, and uses native fully digital breakers, disconnectors and power transformers. For secondary equipment, RTE implement its first process bus based on a full optical network including more than 20 breakers and at two voltage levels (220 and 90kV). At the same time, various new sensors installed on both primary and secondary equipment feed a full monitoring solution. A new HMI gives enhanced situational awareness for automatic real time optimization of the load capacities. The smart substation concept also addresses in the process bus and the station bus other needs such as meteorology, access control, video infra-red, virtual fence, monitoring sensors, water and electricity supply, thus creating a global native IEC 61850 solution.

The design of the smart substation system has a brand new approach to redundancy and reliability for overall optimisation and standardisation. In particular, the protection plans that were dependent on the voltage level are converging toward a single solution. "Poste Intelligent" is a utility's way of embracing the best digital substation technologies from a reputable vendor, tailored in a practical way to meet its needs.

1 Introduction

Digital substations imply a solution and architecture in which the substation's functionality is predominantly now achieved in the software. A digital substation is one in which the data related to the primary process is digitized immediately, at the point where it is measured. Thereafter, the exchange of that measured data between devices which may need to subscribe to it is via Ethernet, as opposed to the many kilometres of copper hardwiring which may exist in a conventional substation.

2 Drivers Towards Digital Substations

Increased reliability and availability, reduced maintenance cost

The extensive self-diagnosis capability of digital devices ensures maximised up-time of the substation. Any degradation in the performance of an asset is pinpointed in real-time. Inherent redundancy in the system may be employed to self-heal the operation, which permits troubleshooting without the need for any primary system outage.

Optimised operation of assets – situational awareness

The digital substation closely monitors all substation assets. Intelligent systems analyse the data and provide recommendations on maintenance and repair actions to conduct. The intelligence within digital substation schemes allows close monitoring of the load flow capacity of plant equipment, compared to its design ratings.

Safety

Digital substations eliminate dangerous cross-site CT circuits, and remove the explosion risk by using oil-free optical CTs

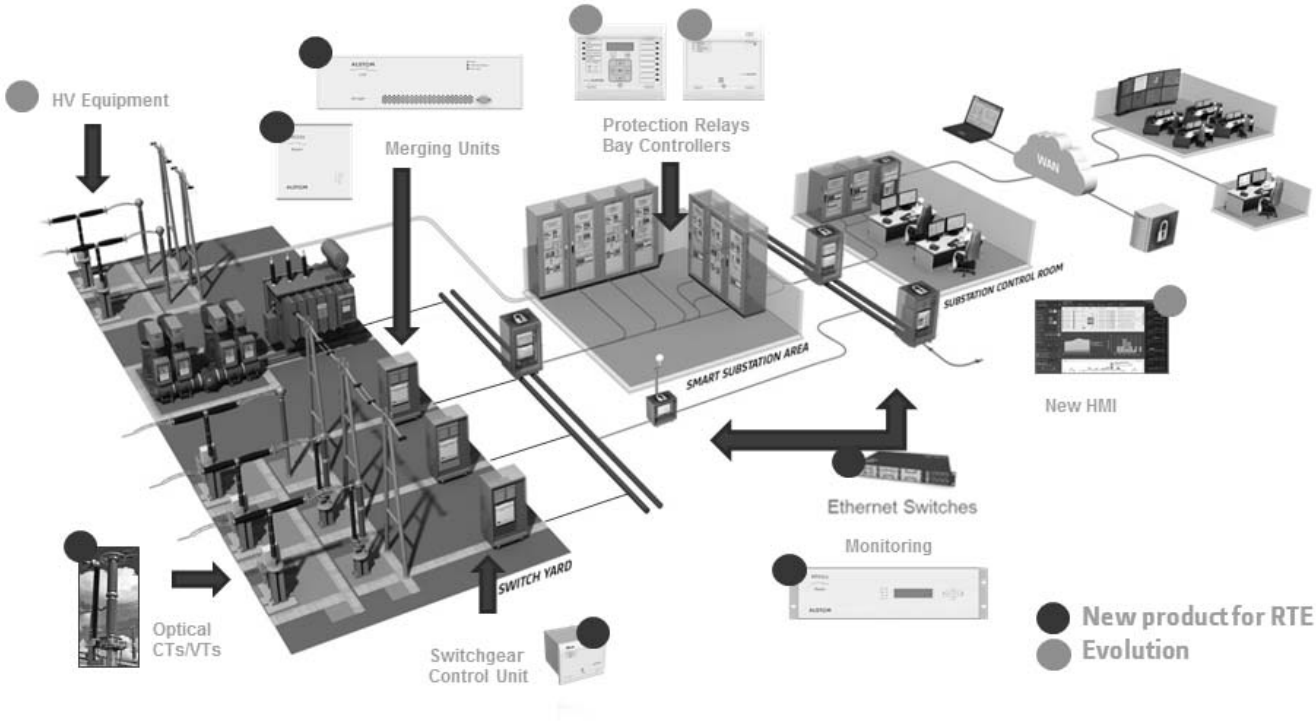

Figure 1: Architecture Levels In A Digital Substation

3 Generic Architecture

The process level in the switchyard

A digital substation is based on a communicating architecture, whereby real-time operational measurements are polled from the primary system. It is communicated to devices which must act on those measurements by means of a "process bus".

Control commands (switchgear operator commands, protection trips) also are routed to the primary devices via the process bus, in the opposite direction.

The protection and control level ("smart substation area")

Between the process bus and the station bus are devices historically identified as the "secondary equipment". These devices are IEDs (intelligent electronic devices), interacting with the field via the process bus, and with other peer devices in the bay, to other bays, and the digital control system via the station bus.

The station control area

The Digital Control System is the intelligence which binds together the digital substation. It is central to the flow, management and presentation of all components in the digital substation. Wide area control units (WACU) offer the possibility to exchange IEC 61850 GOOSE data between voltage levels within a substation and also between neighbouring substations.

4 Digital Instrument Transformers and Process Bus Devices

The root of many of the limitations of conventional instrument transformers is the reliance upon an iron core. Instead of an iron core, the translation from primary to secondary measurement may use optical, Rogowski or capacitive technology. Some examples of the principles are (taking those used on the Poste Intelligent project):

Small footprint optical sensors use the Faraday effect, whereby a fiber optic loop sensor carrying a polarized light beam encircles the power conductor. This light will experience an angular deflection due to the magnetic field that is generated by the primary current flow.

Low power voltage transformers implement a capacitive divider stack to produce the output voltage for digitization in the merging unit. The novel design does not have the traditional wound VT output stage of a traditional CCVT (capacitor-coupled voltage transformer).

Merging units perform all the data processing necessary to produce a precise output data stream of sampled values according to the IEC 61850-9-2LE standard.

In a fully-digital architecture, protection relays receive currents and voltages as IEC 61850-9-2 sampled values, and issue trip or alarm signals using IEC 61850-8-1 GOOSE. For retrofitting, or where the owner has a preference to retain traditional instrument transformers, analog merging units are available, digitizing the CT and VT outputs at any convenient kiosk out in the yard. Such kiosks may also embed the switchgear control unit (SCU), which in the RTE example shown below is not only used to actuate the switchgear in the yard and marshal its positional and status information, but also monitors the oil and SF6 gas health.

5 Generic Architecture

The Poste Intelligent (Smart Substation) project is a consortium project, led by RTE, to design, build and test implementations of real substations for the future. Two demonstrators were selected in the principal French area in terms of penetration of wind energy with more than 600 MW installed power on the distribution system in a rural area that creates reversed energy flow from LV to EHV through the local HV system.

The main objectives of the project are summarized below:

- Local state estimation – situational awareness of the grid's operating state
- Digital inter-substation communication – for wide-area control
- Incident management – faster recovery from electrical failures
- Environmental monitoring – e.g. to manage the ampacity of circuits as the wind cooling effect changes
- Asset management – optimized condition-based maintenance
- Interfacing TSO/DSO – a digital data bridge for voltage, demand and incident coordination
- Physical and cybersecurity – prevention of trespassing and cyber-intrusion
- Interoperability and interchangeability – for standards compliance and future-proofing
- Graphical user interface (GUI) – for intuitive remote control, including video surveillance

Note that the technologies are mature from a vendor point of view, hence the project seeks to ensure that they are tailored and adopted specific to RTE's needs.

6 System Architecture

The Poste Intelligent protection scheme is delivered fully redundant, with system A in the substation building and system B in a container in the yard. Each has internal control/relay panels reduced in size and number due to the small footprint of the process bus relays and bay computers. Both such IEDs are miniaturized, delivered in a small "8" footprint, typically half that of traditional equivalent devices.

The project aims to test mixed technologies, with optical, low power and conventional instrument transformers deployed within the architecture. For interoperability, the conventional CT/VT outputs are digitized by an analog merging unit, time-optimized for transmission-class protection duties (the analog merging unit is able to publish IEC 61850-9-2LE sampled values with less than ¼ ms of latency, and the SCU can process an incoming IEC 61850-8-1 trip and energize the circuit breaker trip coil contacts in less than 1ms).

In order to achieve a level of dependability (the ability to operate when required to do so) and speed which is equivalent to, or better than, a traditional substation scheme, the Ethernet architecture design is of paramount importance. All digital substation architectures can be set up as an IEC 62439 standards-compliant self-healing ring (HSR protocol) or dual-homing star (PRP protocol); both of which are "bumpless" redundant. This means that data is exchanged between devices via two diverse paths, and should one of these paths fail, data is instantly available hot from the other, with zero delay. Both HSR and PRP are used, as shown in the figures below, notably with a 1 Gigabit HSR ring within each bay.

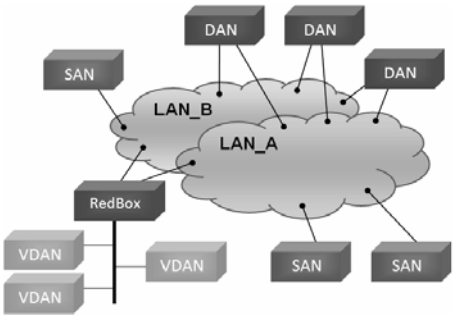

Figure 2: PRP Parallel Redundancy Protocol

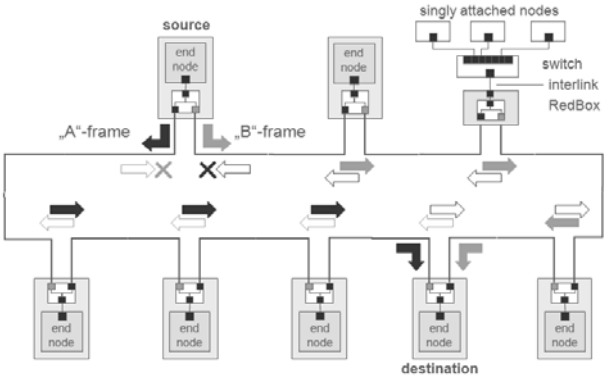

Figure 3: HSR Ring Protocol

For PRP, each intelligent device is typically a doubly-attached node (DAN), connected to LAN A and LAN B, to use a redundant network for common failure mode elimination. For HSR, the ring architecture allows digital messages to pass both in the clockwise and counter clockwise directions, for communication continuity in the event that a failure breaks the ring at one point. An interesting new redundant protection function architecture installs an extra IED (MPx), connected to the substation buses, which will be used to replace the functions inside another IED in the case of failure, as per the sequence below:

1. During the installation phase a spare standby device is installed in the substation that remains inactive, but can one day be reconfigured by the system to replace functions in one of several bays in the case of failure.
2. If a failure occurs (Bay 1), the system isolates this device by disabling its process bus and station bus interfaces. This can be achieved by turning off the attached network interfaces in the substation switches.
3. The configuration of the faulted device is retrieved and loaded into the standby redundant IED.
4. The device is placed into the mode defined by IEC 61850-7-4 Ed2 "Test Blocked". This allows for test signals to be injected into the network to prove that the configuration is correct. GOOSE signals issued by the device will be flagged as "test" so that subscribing SCUs know not to trip during this testing. In this way the protection can be tested remotely, all the way up to the switchgear control merging units without having to operate primary circuit breakers or by carrying out any secondary injection.
5. The standby IED is taken out of "Test-Blocked" mode and activated so that it now replaces the protection functions that were disabled from the initial device failure.

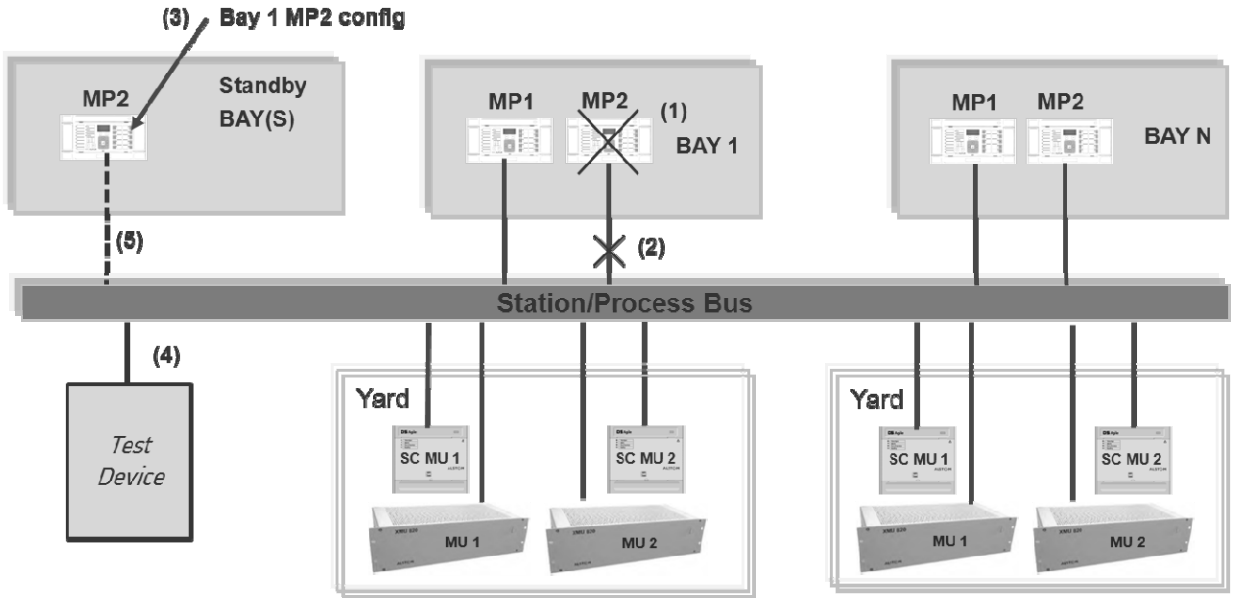

Figure 4: Hot Standby IED Activation Process for Reduced Downtimes

7 Situational Awareness

Poste Intelligent has paid attention to how data can be presented as simple “situational awareness” dashboards, such that operational staff can clearly see what is happening on the network, easing subsequent decision-making on actions to take. For example, weather based dynamic line and transformer rating software, offer a real time tool to adapt the load capacities to the prevailing wind and improve circuit ampacities. An example view from the DCS shows how weather sensing is used to permit renewable energy export to be automatically maximized as the wind speed increases, and the overhead line is cooled.

Figure 5: Digital Control System View Depicting integrated Weather Monitoring

Embedded condition-based maintenance monitors the health of primary plant components such as switchgear, evaluating the present status and any degradation trends, in order to schedule maintenance at the optimum instant. The DCS system views make use of augmented reality, whereby health and status indicators are annotated as an overlay onto real substation images.

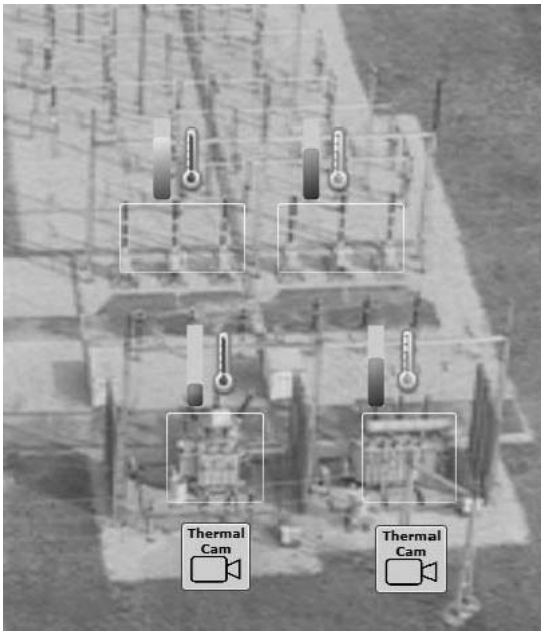

Figure 6: Example Situational Awareness View

8 Conclusions

Digital substation implementation allows the lifetime total cost of ownership of the substation to be reduced. The reduced size and weight of digital instrument transformers, and the protection and control panels provide attractive benefits, allowing placement in compact substations where space may be limited. The situational awareness features in the digital control system present real-time operational and maintenance data in the most intuitive manner. For maintenance teams, there will be fewer on site interventions and fewer emergency situations considering the full remote solution, and full redundancy and self-healing will be implemented on the secondary equipment. Poste Intelligent serves as a valuable vehicle to prove that the digital substation is now a practical and commercial reality.