Substation Automation System: IEC61850 future perspective

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1. Introduction

Electric Power Utilities are undergoing several changes driven by issues such as Regulatory Compliance, Network Reliability and Cost Improvement.

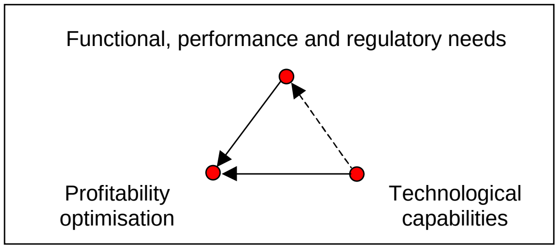

Figure : Inter-relations between key drivers for changes

The IEC 61850 standard “Communication networks and systems in substations” has been voted in 2004 after a 10 years development period. The associated technology has since then proved to be extremely successful with thousands of devices deployed in application areas ranging from simple distribution substations to more sophisticated industrial schemes combining several substations and generation sources, fast Loadshedding etc (contingency based Loadshedding/ power based Loadshedding) mainly for Oil & Gas and other industrial application.

The term IEC61850 currently encompasses 14 individuals standards and its further dependent on hundreds of other standards (notably IEEE 802.xx and associated RFC series) which are necessary to ensure open system architecture and individual devices interoperability.

IEC 61850 is first a toolbox enabling the development of products and systems through three key principles: **communication services** (including the well advertised fast peer-to-peer exchanges), **data modeling** (acting as a dictionary to provide non ambiguous names to all information) and **configuration language** (defining XML files to be exchanged between engineering tools). As such it unlocks some boundaries existing with previous protocols and offers opportunities for innovative automation schemes and application integration for instance.

IEC 61850 is also only a toolbox, meaning that it does not solve all the issues, especially when introducing new applications. In other words IEC 61850 is generating unprecedented expectations that goes far beyond what has been done with the previous communication technologies and some of them will need time to become fully industrial. Such requirements are essential to drive business plans and changes for the different actors (users, suppliers and integrators). They fundamentally reveal the need for roadmaps taking into account the evolution of different parameters: the standard itself, the base technologies, the engineering tools, the organizations, etc.

The aim of this paper is to contribute to such vision. It first analyses the lessons learned on Intelligent Electronic Devices (IEDs), Substation Automation Systems (SAS) and engineering tools to then highlight possible future directions.

2. IEDs (Protection Relays, Bay Control Unit, RTU, etc.)

2.1. IEDs experience

Current IEDs can be broadly classified into two technological families:

- IEDs existing with the previous generation of protocols and where an IEC 61850 interface has been added. The IEDs are able to communicate however their flexibility in term of data naming or version management is limited as well as their communication performance.
- IEDs that have been designed from the beginning to cope with IEC 61850. This is reflected both in term of software (for instance number of clients supported by a server or topological algorithms) and hardware (for instance Ethernet switch integration or redundant Ethernet ports).

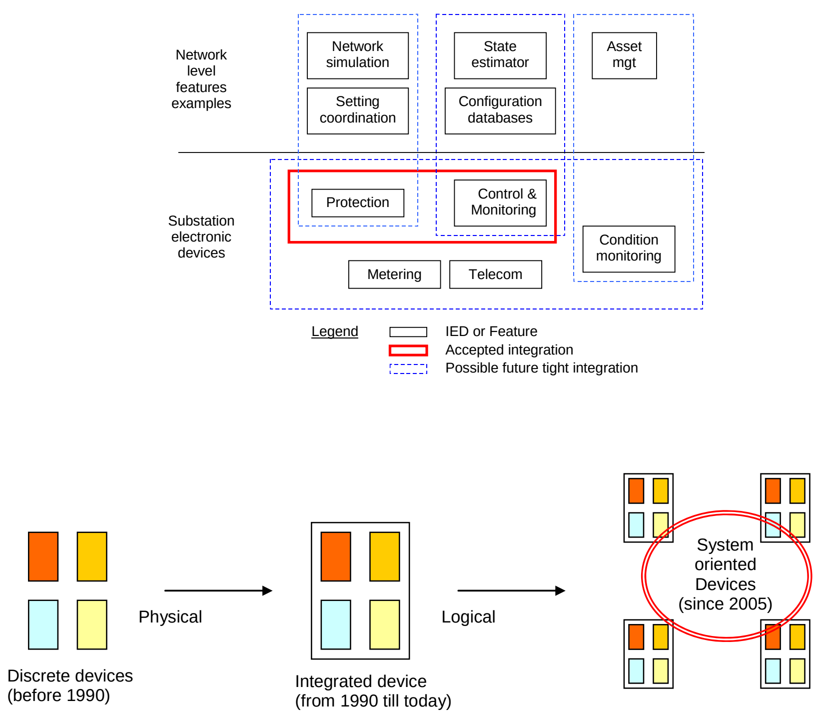

Figure 1: IED technical evolution over time (from discrete devices to system oriented ones)

The IEDs will continue to progress, adding processing capabilities and flexibility or evolving in the Ethernet interfaces (both in number and base technologies such as Wifi or Power over Ethernet).

IEC 61850 introduces two key changes:

- Direct communication between any two devices, whether these devices are or not located in the same substations. This is combining the so called Goose mechanism for local and fast peer-to-peer exchanges and the IP routable client-server transaction. The venue of Ethernet between substations and at the other end the cost effective process bus solution will clearly encourage such new exchanges.

- Semantic oriented data based on XML - Substation Configuration Language. This permits the automation of logical data links between applications thus making the transfer of a lot of data truly manageable. Again this can be extended outside of the substation through the coming compatibility with the CIM model (for control centre applications).

2.2. IEDs inter-operability

IEC 61850 defines conformance tests but not inter-operability ones. The root cause is that it does not standardize the functions (in order not to restrict the implementations) and cannot thus define functional tests needed for an end-to-end check.

In addition the manufacturers face several degrees of freedom when implementing the standard: interpretation of the standard itself, integration of optional items defined in the standard, integration of bug fixes (called Tissues), number of objects supported (for example number of Goose types possibly received), redundancy, etc.

This is however clearly an area where progress still need to be done in order to improve efficiency. Several directions are being followed to achieve this goal:

- Classification of inter-operability tests into different families in order to assess the associated complexity, see [2] and figure 2.

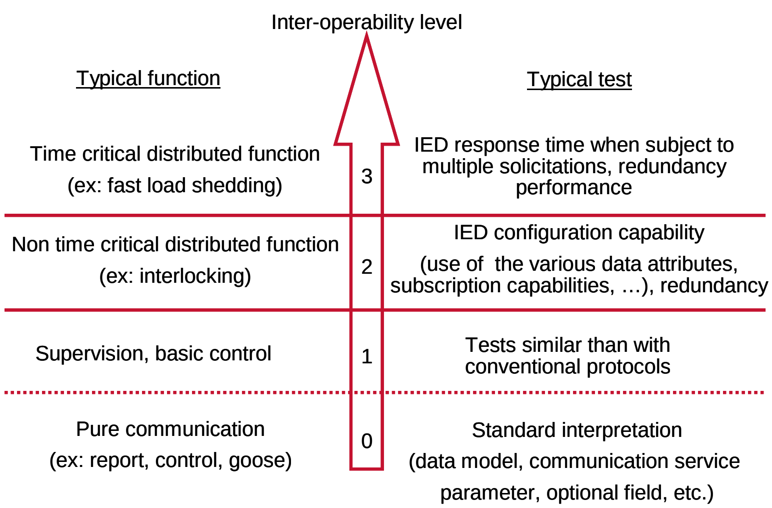

Figure 2: Inter-operability level classification proposal

- Definition of a methodology to define distributed functions and automatically generate test plan. This work is in progress within the CIGRE B5.32 working group. It relies on the capability to formally tests UML specifications.
- Definition of basic distributed functions. The purpose is to overcome the limitation of the IEC 61850 mentioned in the beginning of this section for a set of features common between most projects such as interlocking.

2.3. Process bus

The Process Bus or Sampled Values (SV), defined in IEC 61850-9-2.
Process bus, i.e. the communication of sample values for current and voltage between typically a sensor and a protection, is a very promising technology to reduce costs in substations.

In a substation control system is divided into three distinct levels:
- Substation Level
- Bay/Unit Level
- Process Level

Data gathering starts at the process level with Instrument Transformers (NCIT) whose outputs are immediately sampled, converted to digital representation, and formatted for subsequent transmission through the process bus LAN. The process bus is also used to control high voltage equipment such as breakers, breaker control units, disconnect switches, etc. Process level information is then communicated over the LAN to the protection and control devices that are located at the Bay/Unit Level. Fig. A.

Levels and logical interfaces per IEC 61850-5Process bus data exchange is denoted with Numbers 4 and 5 on Fig. A. Protective functions are to be performed at the Bay Level, while the overall substation-wide coordination, substation Human Machine Interface (HMI), and the SCADA system interfaces are performed at the Station Level [4]. Proposed approach promises to lower the installation cost by significantly reducing the amount of low voltage wiring and replacing it with logical connections established through the process bus LAN [5][6]. Potential savings are most easily visible in the case of an open-air high-voltage yard, which currently requires an extensive network of wiring trenches for bringing a multitude of instrument transformer signals and control wires to a substation control room[7][8].

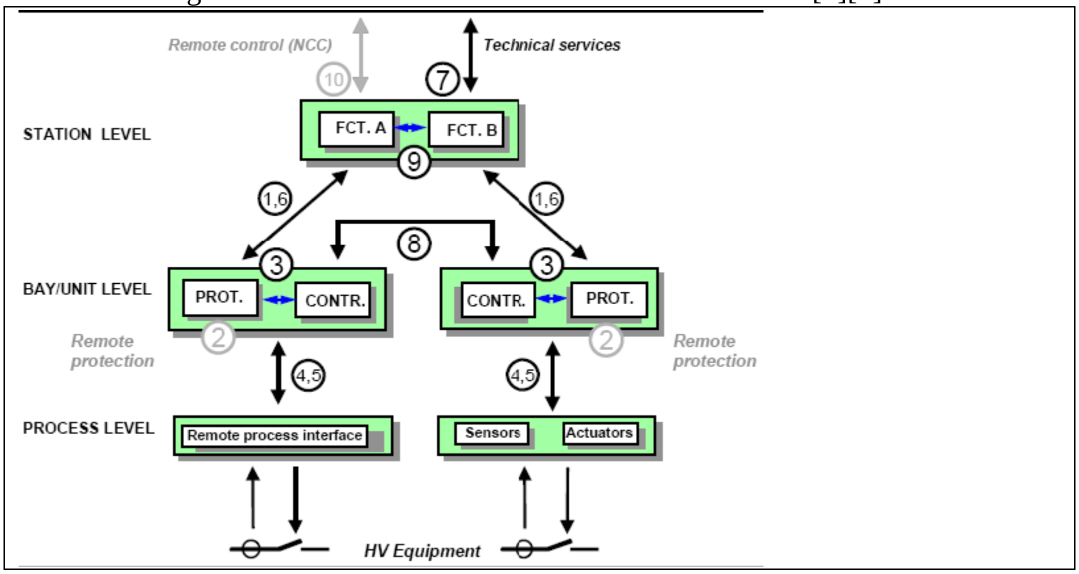

Fig A: Bus Architecture

This technology is still at a pilot stage. For instance: evolution of the merging units, busbar protection accepting process bus interface, integration of distributed synchro-check, also the commercial use of NCIT is still to develop.

3. System level

3.1. SAS experiences

IEC 61850 systems have been implemented in many countries, covering different application segments (transmission, distribution, industry), with different architectural complexities and depths of IEC 61850 implementation. Mix with IEC 61850 products from different suppliers is a reality. In India, AREVA T&D have already done projects involving IEDs integration of different vendors.

Here we consider the case where shift from conventional practice and with possible generalization. The common concept: standardization of the application. This comes on top of the communication standard, in order to reduce the total cost of ownership, to make the life easier for all actors and to reduce the project lead time. Both are "IEC 61850 quick hits", i.e. tangible benefits that can be achieved with immediate projects implementing the standard.

3.1.1. Standard Human Machine Interface (HMI)

HMI provide features such as single line diagram for substation information display and control, alarm screens and archiving. The look and feel varies from one supplier to another, both in term of visual representation and reaction after an operator interaction. The discrepancies are partly solved during the engineering of a typical substation automation system, for instance insuring that a circuit breaker has the same representation.

An alternate design consists on "imposing" a given HMI package to the integrator. This is somehow comparable to the existing practice that qualifies a restricted number of protection relays.

Such scheme has been implemented in Brazil using the SAGE software, common between substation and EMS levels (see figure 3). The HMI is a standard client (in the sense of client-server) developed by a local company, exchanging data from the various IEDs using the report and control services. The commonality with the EMS also enables the consistency of the graphical databases between levels.

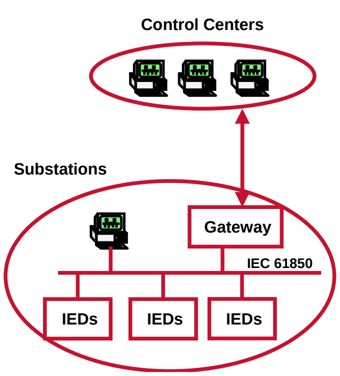

Figure 3: Standard HMI client

3.1.2. Progressive integration of IEC 61850

A “traditional” view among users is that IEC 61850 benefits only apply for new substations, or when the protection and control device are fully retrofitted.

The principle consists in standardizing the protection and control bay panels, i.e. I/O and automation schemes. This will be used when extending a substation, retrofitting the bay or building a new substation. The bay is still connected to the conventional RTU by traditional means and has an additional IEC 61850 interface. Standardizing the application is itself a priori independent from IEC 61850, however the migration toward a new technology is a good opportunity to re-think the existing schemes and reach a higher level of standardization.

The IEC 61850 interface can initially be used to remotely access to maintenance parameters (inside the substation or from the asset management centre). Ultimately it will enable to integrate the bay into a full SAS when all bays are ready.

An IEC 61850 gateway can be installed to convert the setting information from existing relays using different communication protocols from a private format to an IEC 61850 one. The benefit is to enable a common setting tool at asset management level thus simplifying the maintenance operations.

In industries also lot of integration and upgradation has happened in MV application. Areva T&D has successfully integrated the new load shedding system (on IEC61850) with existing Loadshedding system. A successful example of project implemented in Oil & Gas industry is shown below

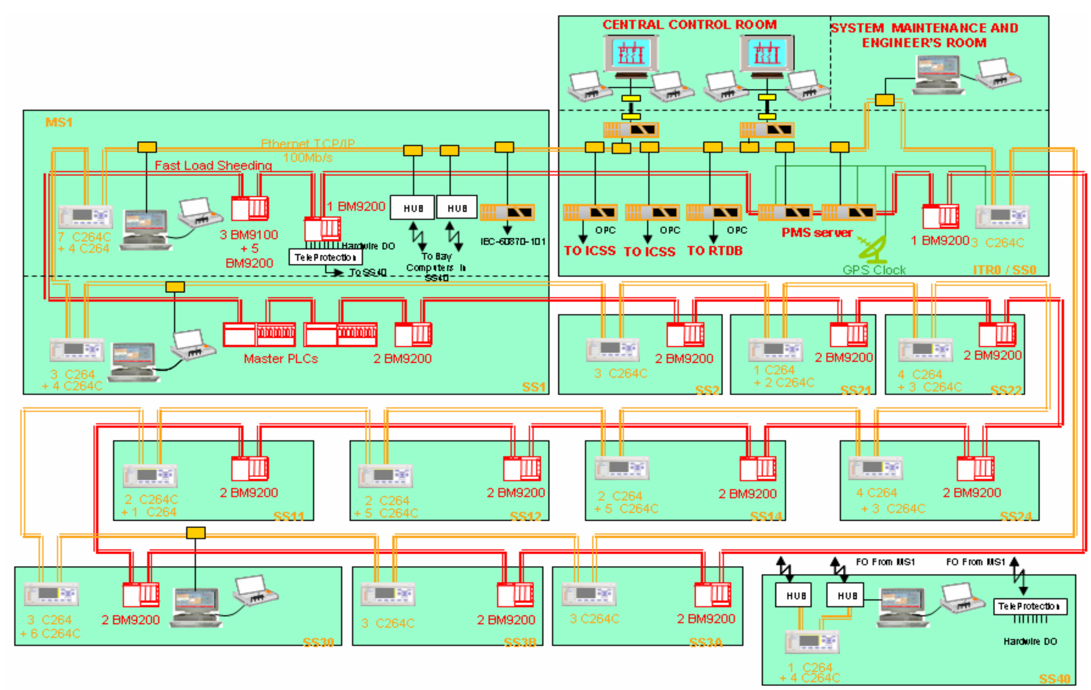

Fig B : Migration of legacy system to IEC61850

3.2. Lessons on system engineering

First IEC 61850 systems have been installed some years ago thus enabling a solid feed-back of this technology impact on the conventional engineering.

3.2.1. Design stage has become key

Clearly the system design is becoming a fundamental step (see also [4]). The freedom brought by the IEC 61850 toolbox – no theoretical limit to the exchanges between devices - must be counterbalanced by careful considerations in order to get a robust system capable to:

- Handle the performance in term of response time, for instance with new avalanche phenomena appearing on the communication side linked to the multiplication of peer-to-peer links and high speed network.
- Smoothly absorb the changes brought by the substation (i.e. a new feeder) or devices (i.e. a new software version), that is minimizing the re-engineering and unavailability associated to such events in an increasingly tightly meshed system.

3.2.2. System architecture

The physical architecture of the system (what you see) is becoming simple compared to the logical architecture (what flows between devices). The intimate understanding of the different devices and system database construction is needed to insure that for instance:

- the number of clients will be accepted by the severs,
- the Goose will be properly handled by the logic of the subscribing IED,
- the redundancy mechanism will be compatible with the functional performance,
- the addition of a new feeder will avoid the update of all the databases and that the associated tests on site will be easy,
- the regression tests to be done after a new device release are properly defined,
- etc.

This also illustrates some of the features expected by the “system oriented devices” discussed earlier in this paper: capability to deal with topology oriented algorithms that are more robust to change than basic binary equations, flexibility and predictable performance in the communication options in order to optimize the logical architecture, fine version management associated with the appropriate engineering tools.

3.3. Extensions outside of the substation

IEC 61850 has been initially developed for the communications within the substation. Systems have nevertheless being engineered to cope with multiple substations, in the process and railway industries for instance.

Additional parts of the standard and companion standard are at different stages of development to enforce this expansion, as illustrated on figure 4: naming of distributed generation assets (IEC 61850-7-4xx), communication between substations (IEC 61850-90-1) and with control centers (IEC 61850-90-2), cyber-security (IEC 62351).

Figure 4 also represents a new grouping arrangement, called “real time pool”: this is a set of substations and generation plants that communicate one with another in order to contribute to the grid stability. This is a generalization of the Special Protection Schemes – with richer data exchange content enabling better decisions.

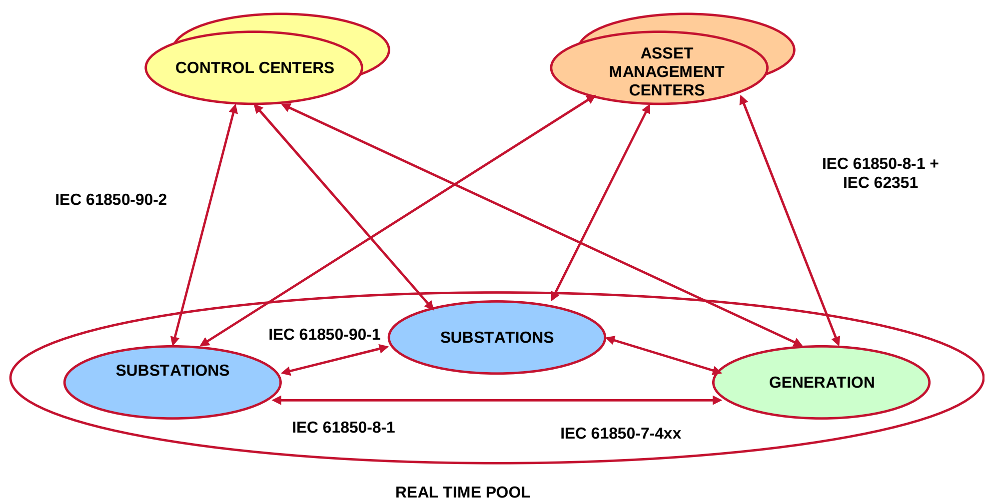

Figure 4: Expanding IEC 61850 applications

4. Engineering tools

The “Engineering tools” subject is probably the hottest topic in IEC 61850 discussions nowadays, with a specific focus on the configuration phase. The Substation Configuration Language defined in part 6 of the standard enables unprecedented capabilities to link engineering tools, suppliers’ products support the associated features, but the impression is still that this is not enough and that IEC 61850 systems are complex to engineer.

4.1. Is the configuration more complex?

The engineering complexity discussed here is the need to chain several engineering tools when using products from different suppliers (see figure 5 extracted from the standard):

- The system database is created by a system engineering tool using files provided by each IED engineering tool.
- The system database is then imported by each IED engineering tool to create the IED specific database and eventually download it to the IED.

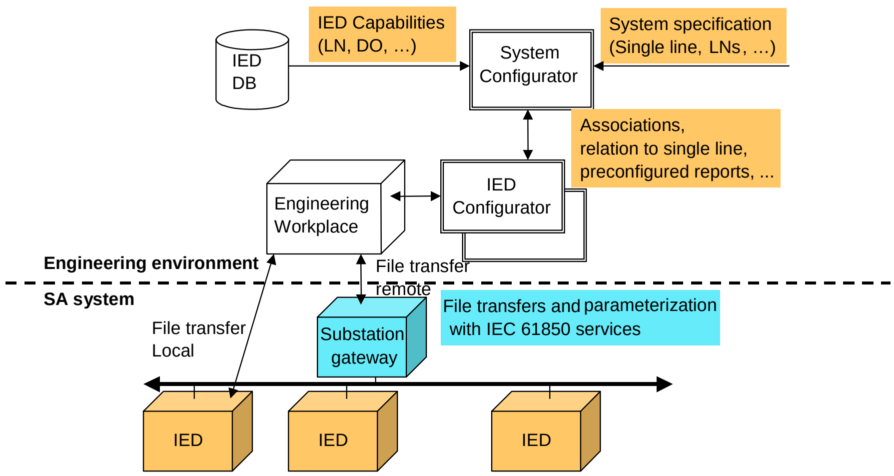

Figure 5 (extracted from IEC 61850-6): Engineering flow

A similar mechanism is also needed with other protocols but requires human interpretation to link the data references to each model – this is replaced by a formal and automatic XML file interpretation with IEC 61850. The engineering of an IEC 61850 is thus easier than a traditional system when comparing apple to apple, i.e. simply reproducing a master-slave system with IEC 61850 technology.

But an IEC 61850 system will express its full benefits when:

- Using more sophisticated data flows: multiple clients connected to a server instead of a single master to a slave, peer-to-peer, report conditions, etc.
- Attaching to the GOOSE message reception (i.e. the peer-to-peer message) some logic that has today to be programmed in the device specific language.

There is indeed an engineering cost for such benefits. In reaction to this added complexity the current expectation today is to have “a single engineering tool” for all system. This would handle not only the communication, but also the logic associated to the distributed functions, the graphical data shared between devices (alarms, single line diagrams), the link with the telecontrol centre usually done with a different protocol, etc.

4.2. When will the single engineering tool become available?

The current SCL semantic is today addressing the IEC 61850 communication and substation topology, not the device behavior (i.e. logic), nor the graphical display, nor the mapping to telecontrol protocol, nor the Ethernet infrastructure, etc. It is expected that this will be developed in the future version of the standard but there is not commitment yet.

In-between private extensions have to be done. Manufacturers (such as AREVA) have done it for their own products. This can also be developed for a given customer: the figure 6 illustrates the integration between the control centre database (containing the substation description, alarm messages, protection setting, telecontrol addresses) with the SAS database: the control centre engineering tool produces an XML file that is used to create a large part of the SAS database.

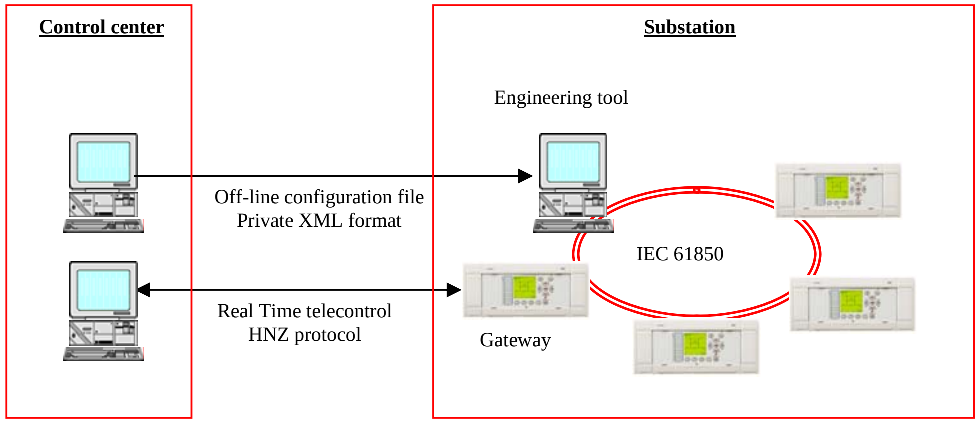

Figure 6: RTE example

4.3. Other engineering tools

There is currently a lot of focus on the configuration aspect. As highlighted in former sections further tools will become increasingly important: capability to estimate the performance prior to the real system and optimal test definition associated with the proper version management are two examples of this.

5. Overall roadmap

The roadmap definition for IEC 61850 investments starts with the clarification of the user's expectations – total cost of ownership optimization, smart grid, etc. As per any new technology, the instinctive move is to copy what used to be done with the former technology at first: the result is generally poor and some quick hits shall be quickly achieved in order to see real benefits. Long term investments will provide additional benefits. This is summarized in figure 7 (extracted from [4]).

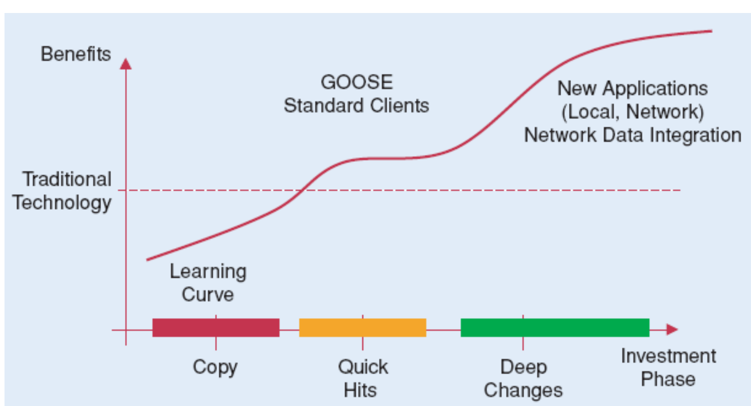

Figure 7: New technology adoption benefits vs. time

There is then the need to position the expectation with the available technology and associated costs. Figure 8 gives a series of current examples, partly discussed in the previous section: they are classified by maturity (vertical axis, from research to industrial) and technical category (horizontal axis, from concept to tangible product).

Technical Category		Concept → Tangible product			
Maturity Stage		IEC 61850 Standard	Base technology	Processes and tools	Application
Research ↓	Not yet there	Behavior configuration	PoE / Wifi	Performance modeling	Distributed synchro-check
	Preliminary stage	Bumpless redundancy	Cyber-security	Robust to change design	Grid automation
	Industrialization in progress	Edition 2	Process bus	Interoperability tests	Standard clients
Industrial	Mature phase	Edition 1	Station bus	Standard bays	Interlocking

Figure 8: Maturity matrix/Innovation pipe (examples)

6. Conclusion

IEC 61850 has generated a true business today. This paper has shown that in addition to the current practices a full innovation pipe is ready: this will progressively bring new benefits to the T&D industry at a pace that has never been experimented in the past thanks to the convergence of multiple domains. Common roadmaps between users and suppliers as well as in-depth training remain of course key for the success of this move.

<u>Bibliography</u>

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