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Introducing IEC61850 in Distribution Substations

Substation Automation Systems

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Portugal

1 Introduction

In the last decades, utility companies have been increasing the investment in Substation Automation Systems (SAS). The reason behind this is the intention to decrease the number of interruptions and its durations, with fast detections of faulty conditions, selective fault tripping and automatic restorations of power supply, improving the quality of the energy supplied to end users.
These SAS systems were until now, vendor proprietary, as there was no standard approach that could be followed. This leaded to closed systems, with narrow functional scope and with its own serial communication, where to integrate a third-party device or application, protocol converters had to be used.
From the need to overcome this limitation, a standard named IEC61850 has been studied and developed, over the last 10 years. This standard states a set of rules and definitions, in order to enable interoperability between Intelligent Electronic Devices (IED) from different types or manufacturers. Interoperability means that two or ore IEDs are capable of exchanging data and use it to perform their own functions in a coherent cooperation.
The Standard also allows a free allocation of functions, which permit that each vendor uses its own philosophy, for a specific function, but all the data that can be seen in the communication bus, regarding this function, look the same for all IEDs.
As a global standard for these processes, it also contains specifications about design, engineering, testing rules and others. But the current version is still open in some areas, like the fully redundant communication or the specifications for complex distributed functions inside a substation, like Breaker Failure Protection or Station Level Authority. These are some of the reasons why it demands a very good understanding of the standard itself, much before the engineering process starts in a new project.

2 User benefits

The first benefit from applying the IEC61850 to SA systems is clearly the installation of interoperability between IEDs of different brands. A global market needs global standards, where each device must have the ability to be integrated in any system with its own global principle of operation. Thinking global means cost reduction by equalizing competitors and their specific functions and by standardizing maintenance and operation procedures.

But if the interoperability is one of the most important aspects of the standard, the ability to maintain a certain level of freedom allowing the use of specific vendor functions, is also one of the major advantages, as it allows different philosophies from each supplier and still leaves a certain space for creativity.

It is also considered as a future-proof standard, because it takes in consideration the evolution of the technology in the coming years. It is based on the mainstream Ethernet communication and contains definitions for the communication to the process-bus, expecting that in the future the products will start supporting communication in the lowest level of the process.

The configuration language, *Substation Configuration Language* (SCL), is defined in the standard. The use of this language permits that different tools, from different vendors, can understand the information contained inside any IED. Enabling data exchange, it also avoids misunderstandings, and facilitates the integration between vendors. All the engineering is stored in these SCL files, which facilitates its reuse in the next projects. Also the project documentation is produced from these files, which makes it to be more standard between projects and vendors.

3 The first IEC 61850 project experiences in Portugal

a. The Projects

The first projects where it had to be implement the new standard were six, all included in the same supply package, namely, Cacém, Aeroporto, Glória, Serpa, Venda do Pinheiro and Parede substations. All these substations belong to the distribution grid, enabling 60/30kV, 60/15kV and 60/10kV conversions.
The six substations are of high importance for the grid, due to the fact that are installed in urban regions, but should be highlighted the importance of Aeroporto Substation, since it is the principal supply point to the Lisbon Airport.

b. Typical Single Line Diagram

The figure 1 shows a typical Single Line Diagram of the installed systems.

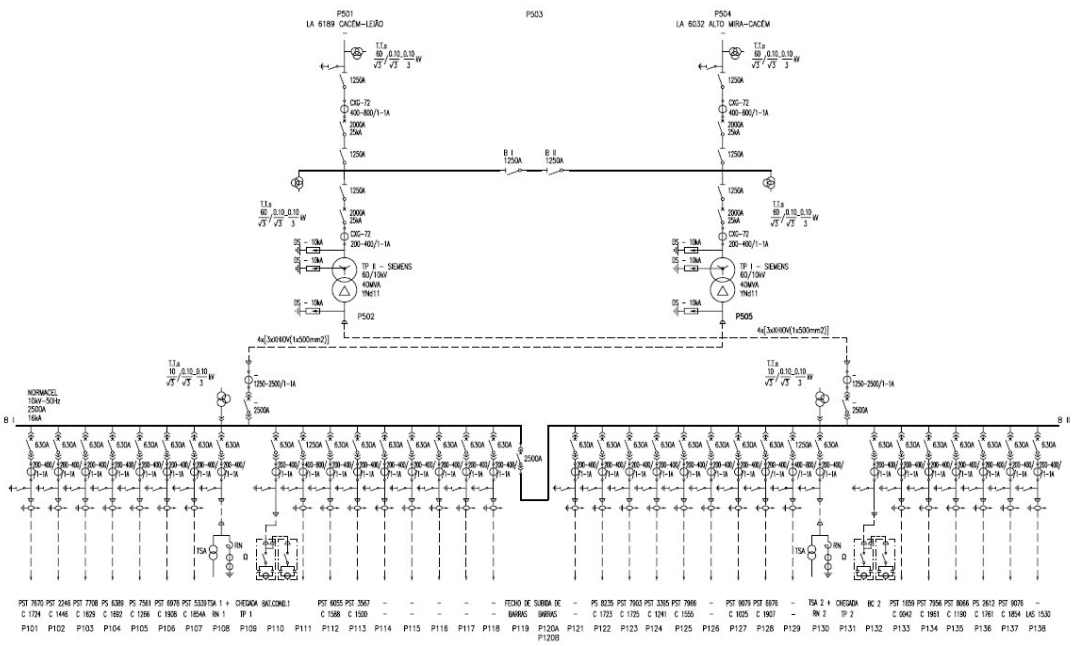

Figure 1 – Single Line Diagram of Cacém Substation

c. System Arquitecture

The system arquitecture designed to all the six substations is conceptually shown in figures 2.1 and 2.2 .

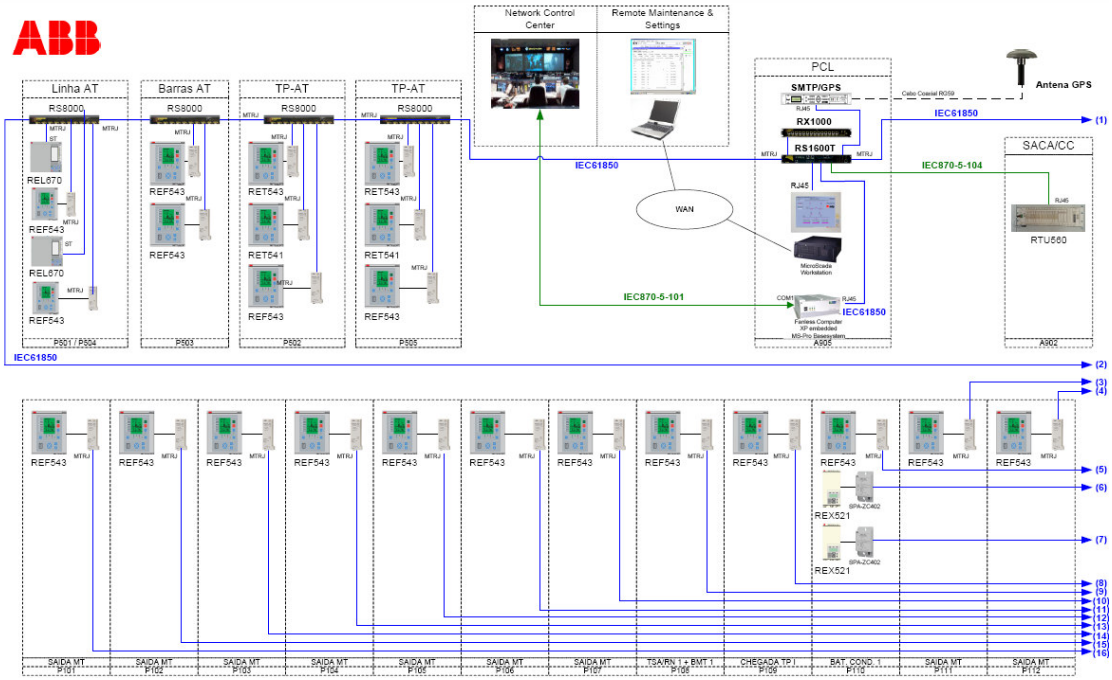

Figure 2.1 – System Arquitecture of Aeroporto Substation

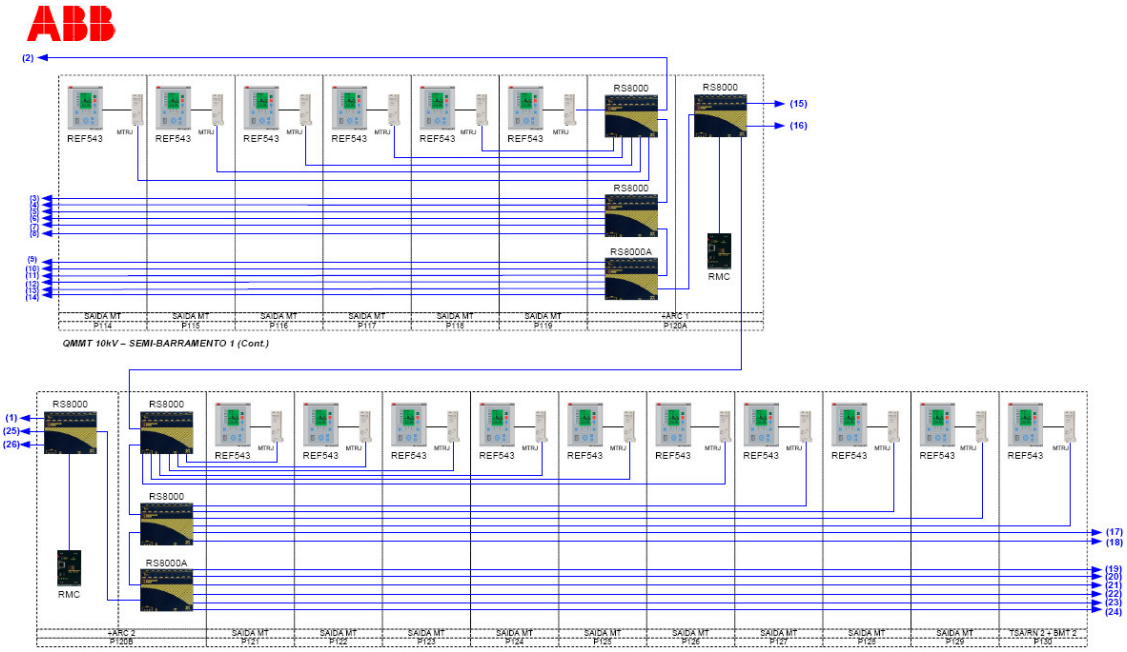

Figure 2.2 – System Arquitecture of Aeroporto Substation (cont.)

d. IED level

All IEDs installed are IEC 61850 compliant, and include horizontal communication (Goose) feature. Horizontal communication "Goose" was used for sending several data between IEDs. We can highlight Circuit Breaker Failure Protection (CBFP) trip signal from all outgoings to each corresponding incomer bay, earthling of neutral point to all feeders, Undervoltage and Underfrequency trips from both Incomers to all feeders, Trigger conditions for voltage and frequency restoration after a Load-Shedding, VTs truck positions, Parallel Operation of the Power Transformers, as important examples of information data exchanged with Goose. Roughly, 150 Binary indications are being sent using Goose messages.

e. Network level

The system uses a ring network topology, with full optical connections between all active elements. All switches are managed type, to enable the reprogramming of the network in case of failure.

f. Station level

The highest level in the substation consists of a computer without moving parts, running the SCADA application. This application provides all features needed to fully control and monitor the installation like Event and Alarm Lists, Single Line pictures, bay pictures, Commands to primary apparatus, measures from Voltage and Current transformers. It also implements global automatic functions like Voltage and Frequency Restoration and Time-based control function of capacitor banks.
The SCADA application is running on top of a Windows XP Embedded© operative system (OS). XP embedded© is an operative system from Microsoft©, that delivers the power of Windows XP© in a componentized form. This allows the built of smaller images that can be installed in Compact Flash memories, avoiding the use of Hard Disks. It contains special functions to protect Compact Flash memories against writes from the OS, because these types of memories have a limit to the number of times that can be written in.
Time Synchronisation was made using a GPS time server connected to the main switch.

g. Communication to Network Control Centre

The communication to the Network Control Centre was implemented using the standard protocol IEC 60870-5-101, trough a serial RS232 port of the SCADA computer. Roughly, 2000 indications were selected by customer, to be sent to the Dispatch Centre. All the primary equipment of the installation is controllable from the NCC, as well as Transformers tap changers, activation and deactivation of Automatic Functions and others.

h. Remote Maintenance

Several engineering tools are available for customer, in order to make its own Remote Maintenance operations. The connection from the remote engineering offices can be made by a dial-up modem or using the same Ethernet structure of the company, which is preferable due to the largest bandwidth. For this one, an Ethernet Router was provided, to connect the Local Network to the company's WAN network.
Remotely, maintenance teams can access each IED in the substation, checking for example event and error logs, change settings of Protection Functions, access switch's alarm lists or download a historic event list from a predefined day, from SCADA application. Basically, all active elements that are connected to the Local Network are remotely accessible for diagnosis and correction purposes, which is bringing a major advantage since it avoids time and cost consuming trips of maintenance teams to the installations.

4 The Customer

a. Introduction

The introduction of the standard in Portugal, started to be a demand from the customer, rather than a spontaneous proposal from the certified suppliers. The customer is the main Portuguese utility for electrical energy distribution.

There is a history background knowledge of the customer, due to many years of a close cooperation between engineering teams from both sides. This made it possible to standardize the SAS projects, based on previous existing system solutions.

A very detailed specification from the bottom engineering up to the Network Control Centre (NCC) communication was developed and discussed along the years, and a very stable engineering process workflow has been reached.

b. Customer expectation with the new standard

From all the benefits of migrating SA systems to the new standard, customer was focused in one in particular: standardize the system architecture from all suppliers, using same network topology for all, same physical network, same number of IEDs and same type of communication to NCC, among others. One can say that it was not the interoperability vision that leaded them to the migration decision.

The introduction of Ethernet for the complete communication structure inside the substation was also an important trigger for the migration.

c. Customer specification for IEC61850

Along with the decision to acquire systems with the new IEC61850, it was started by the customer, a process to create a standard specification for Substations. These specifications define among others, global automatic functions, particular functions per feeder, system architectures and events description. We can consider customer's attitude as medium involving in the detailed specification, not defining extensively the IE61850 details. This fact in addiction to the trusting attitude from the customer obtained from dozens of previous projects, revealed itself as an advantage, once it allowed engineering teams to fully control and orientate all the engineering workflow with the adequate timings and methods.

On the other hand, knowing in anticipation that customer would focus all attentions to the Factory Acceptance Tests (FAT) and Site Acceptance Tests (SAT), engineering teams were saved to be involved in dispersing discussions and meetings, regarding deep analysis of the new standard.

One of the keys for the success was the advantage taken from the experience of dozen of previous projects, with a different platform certainly, but with very good relation and interface with customer engineering teams. This marked an excellent starting point and was the compensation to the fact that it was not possible to find a pilot project where to first start applying the standard.

5 Impact of Introducing IEC 61850 in SA projects

a. Introduction

In a first approach, the feeling among the engineering teams about a totally new system brings a certain part of fear and a certain part of reluctance for abandoning a totally proved system, where the workflow was clearly controlled.

The most urgent issue regarding engineering teams when a project is gained and has to be delivered consists in training. All the programmers that will be involved have to be trained immediate and efficiently, otherwise a normal delivery time will not be enough for system development and error corrections.

At the same time, facilities have to be redesigned and prepared in order to receive the new IEDs. This usually means to make modifications in testing cabinets, arrange a good Ethernet network structure using compliant IEC61850 switches to all IEDs, new software tools to diagnose and repair Ethernet communications, and probably new servers, capable of running the new and more demanding engineering tools. These processes, to physically prepare the facilities where programmers will work, are very important, as it permits that after the training period, everything is ready to begin with the engineering tasks.

b. The engineering workflow

Engineering first started with the specification phase, getting all available documents from customer, and analyzing the latest previous projects. Then it was made a compilation of all functions, signal lists and other elements, from the previous projects that could be migrated and re-used in the new system.

The first obstacles come with the need of use new engineering tools, in a new engineering workflow and when people are not yet familiarized with the new interfaces, not expecting the first problems. When new tools are getting more familiar to engineering people, the first results start to appear, the first communicating feeders, the first Alarms and Events make the initial reluctance start to disappear, and starts arising the idea that a final working system is possible to reach.

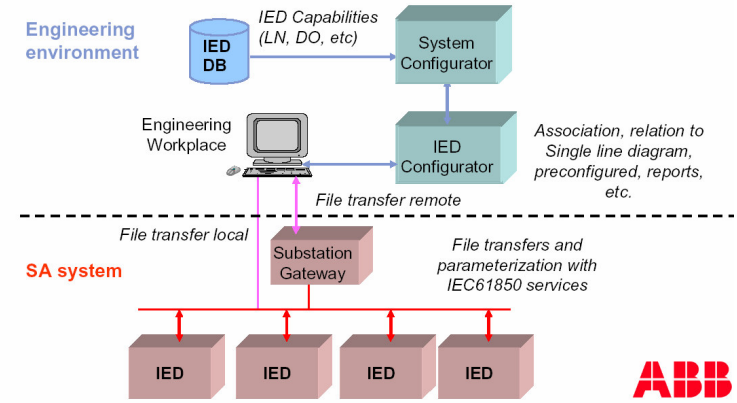

Figure 3 – SCL exchange the engineering process

But not considering the whole new environment for the engineering period, with modified facilities and new tools that have to be learned from zero, all the rest of the engineering workflow can be considered much the same as in a “normal” old project.

c. Vertical Communication

The local control of a substation requires a good Human Machine Interface (HMI) application. The HMI is directly dependant of a good acquisition of data like positions and measures directly from each IED, in order to have a coherent vision of the substation. This type of communication is purely vertical, using a client-server concept to implement the needed services: event and alarm reporting, commands to breakers and other devices in the substation and File Transfer.
The commands for primary equipment use the model of select-before-execute, to ensure safe and secure operation of this important equipment.
File transfer is used e.g. to upload a recorded file from a disturbance stored in one IED to a computer connected to the station bus, like the station computer.

The vertical communication is also responsible to bring up to the NCC gateways the data to be converted and sent to the NCC, as long as, in the inverse direction, to receive commands from the NCC and send them, in a secure way, to the correct IED.

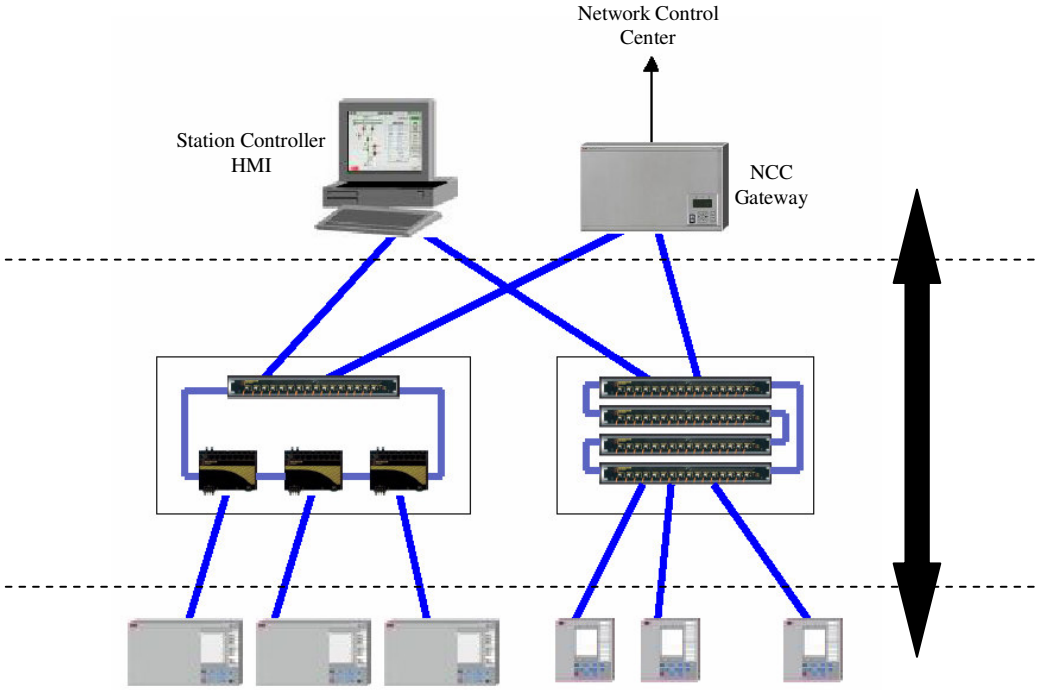

Figure 4 – Vertical communication

d. Horizontal Communication

With the horizontal communication capability, it is possible to exchange data from one IED directly to another. This feature is useful for example for station interlockings between different bays or for complex distributed functions that demands a coordinated action of different IEDs. In the IEC61850, horizontal communication is defined in terms of Generic Object Oriented Substation Event (GOOSE) mechanism.

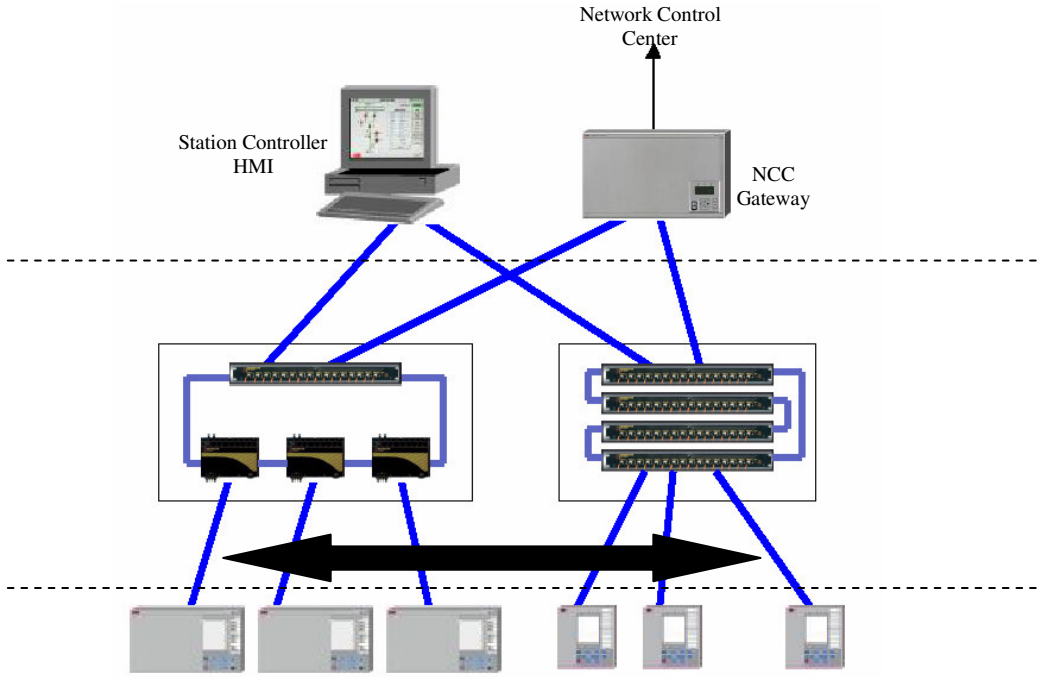

Figure 5 – Horizontal communication, Goose messages

Goose is based on multicast messages directly mapped to the Ethernet, where a message sent by one IED can be seen by several receivers. Due to the periodic send and to the fast repetition mechanism when a data value changes, these messages are considered truly reliable and this is why they could be used for critical data exchange between bays, like inter-trips, time-critical triggers or interlockings.

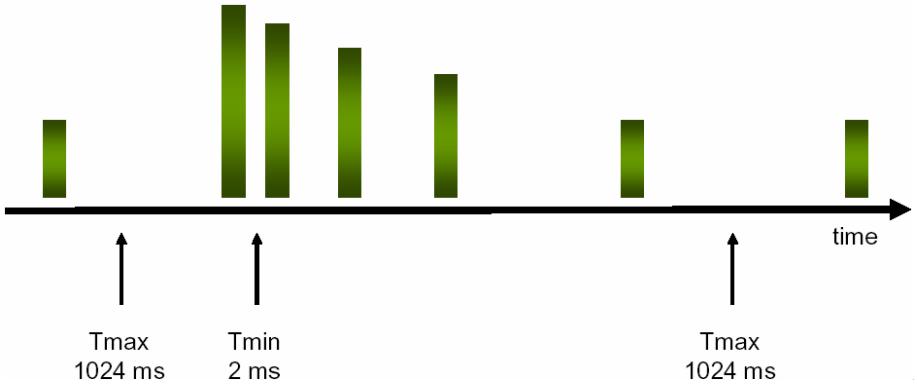

Figure 6 – Goose fast repetition mechanism

In the implemented systems, Goose messages were used for Circuit Breaker Failure Protection (CBFP), Automatic Voltage Restoration trigger, neutral reactance position to all feeders among several others, in an average of 150 multicast messages per system.

e. Time Synchronization

Time synchronization is now totally independent from the other services inside the system. It is possible to use different services for different synchronization accuracy classes, but currently is defined **SNTP** (Simple Network Time Protocol) that assures a 1 ms accuracy class.
Each IED connected will stay as a time client, fetching the time from a time server that can be a GPS clock or any other SNTP server running in a computer connected to the network. The 1ms accuracy is implemented via a mechanism of calculation and correction of the transmission delays between clients and server.

f. Verification and Testing

The Factory Acceptance Tests (FAT) with the customer's presence are of a crucial importance. FAT consists in a simulation, as close as possible, of the real conditions of the installation; to prove that the system fulfils what was contracted between supplier and customer. Usually a set of IEDs of each bay type is mounted in cubicles prepared to simulate the process, and then connected to the Ethernet bus and to station HMI, respecting what is the real system architecture. Typical tests are made for each bay, in order to check the correct operation of the IED, event report and HMI pictures, and in some cases also NCC communication can be simulated.
If global complex functions need to be tested, usually this requires that more IEDs of the same bay type have to be mounted in cubicles, to verify the correct behaviour of the system as a whole.
The FAT period is where it is still accepted that customer asks for small modifications to the initial specifications. All corrections to the system have to be made during or

immediately after ending this period, in order to have a system as close as possible to the final version, when leaving the verification room.
For the first IEC61850 projects it is also advised to make deep internal verifications, even before the FAT starts, without the presence of customer, in order to identify in advance as more problems as possible and their resolutions.

The Site Acceptance Tests (SAT) consists in a repetition of the FAT procedures, but now with the real process. The objective is to deliver a fully tested system to customer. No special differences were found comparing with the previous projects. Only should be taken in account the preparation of the physical conditions, before the commissioning team comes to substation, since there are new communication devices like managed switches that require software programming, a different communication structure and some more aspects that can delay the real start of the commissioning tests.

g. Documentation

Until now, the common practice shows that the final documentation is manually produced by the system engineers. From now on, the production of the final documentation of the system is much more facilitated by the common use of the Substation Configuration Language (SCL). It can be produced directly from the SCL files used for the engineering process. This brings an enormous advantage for customer, since all documentation received, will have a unique and standard format for all different systems independently of the supplier.

6 Conclusions

The introduction of the standard IEC 61850 to the SA systems is a positive measure.
The standard does not impose restrictive rules over many aspects – there is still a large functional freedom for each vendor to explore. But it normalizes a set of elements from design, engineering and verification, up to the system documentation.
It's a future-proof solution because it takes in consideration the progress of technology and is able to follow it.
Contains the interoperability advantage because it enables IEDs from different vendors to exchange information and use it to implement correctly their own functions.
Supports different philosophies of operation and free allocation of functions.

From the customer point of view, it brings independency of single suppliers, capability to mix devices, competitive performance and cost savings in engineering and maintenance.

The migration process must be very well designed. Trainings to the engineering teams must be consistently applied.

A good relation and understanding of the customer and its expectations are major factors to accomplish the migration task. If previous projects for the same client exist, they must be taken in consideration, as it already contains several important parts of the customer specification, which were previously tested and accepted.

7 References

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