Applying IEC 61850 to Substation Automation Systems

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Abstract— **Since more than a year, IEC 61850-based solutions are being supplied to the market. It is now time to collect and review first experiences as well as to derive improvements for the entire process chain on the customers' and manufacturers' sides.**

The paper highlights the features and impacts of the standard IEC 61850 'Communication Networks and Systems in Substations' on possible solutions for protection and substation automation as well as on project execution. The authors explain why utilities today should require that such systems are compliant to the standard.

Based on experiences in the implementation of IEC 61850, the authors are presenting a short but practical overview of how to implement the standard.

The paper indicates the challenges faced by customers as well as suppliers in applying IEC 61850 and suggests suitable approaches to take optimal advantage of the standard.

Index Terms—**Protection, Specification, Standard IEC 61850, Substation Automation.**

I. Introduction

IEC 61850 defines strict rules for realizing interoperability between functions as well as devices used for protection, monitoring, control and automation in substations, independent of the vendor. Interoperability means the capability of two or more intelligent electronic devices (IEDs) from one or several vendors to exchange information and to use it in performing their functions and for correct co-operation. This feature together with the possibility of free allocation of functions paves the way for a vast range of possible solutions for Protection and Substation Automation (SA) systems.

Being a comprehensive standard, IEC 61850 also covers design aspects, protocol requirements, testing guidelines, etc. In order to exploit its full benefits in any specific case, its application requires careful consideration of both customer requirements and available equipment.

Even if initiated only by few suppliers and users, there is an increasing number of commitments by suppliers to use and offer IEC 61850 in products and systems. Today, a lot of manufacturers are offering IEC 61850-compliant products, yet few also offer complete systems on the market.

Implementation of completely compliant systems may in a first approach involve more than the standard appears to suggest. Since many items defined in it still leave room in the actual implementation of applications, in products and tools, a system integrator not only requires expertise and a compliant portfolio, but should also avail of facilities to conduct extensive system tests. Such tests serve to prove full system performance and compliance to IEC 61850 including that of all products used therein.
To ensure continual improvement and optimal customer support also after system implementation, such a verification system shall be constantly maintained at the manufacturer's place. Besides attesting manufacturer-independent test institutes, UCA International Users Group also certifies manufacturers' testing institutes. Such verification facilities provide customers with a guarantee for state-of-the-art system know-how and implementation.

The paper highlights why utilities should require that protection and substation automation systems should be compliant to the standard. A very important aspect is how to specify IEC 61850-compliant systems for new installations as well as for extensions and refurbishment projects. The impacts of IEC 61850 on the entire project execution are analyzed and recommendations given for engineering, documentation issues, factory and site acceptance testing.

II. Brief Overview of the Standard IEC 61850

The general scope of the standard is designed to support the communication for all functions being performed in the substation [1]. In addition to its main goal, the interoperability between devices and tools as described above, IEC 61850 supports free functional allocation and any system philosophy. These can range from a distributed architecture (e.g. decentralized substation automation) to a centralized configuration (e.g. RTU-based). The standard separates the functionality, data model and communication services from the communication implementation. This makes it future-oriented, considering that developments in the communication technology are generally faster than those of functionality in the field of protection and substation automation.

III. Advantages for Users

A. Investment into the future

The system engineering done and documented with the help of the substation configuration description language (SCL) provided in the part 6 of the standard (IEC 61850-6) can be re-used later for system extensions or replacement of system components and even the complete system once it has reached the end of its lifetime [2]. Re-use of the SCL-files is also possible if the communication technology used becomes obsolete and a mapping of the data model and services to a new communication technology is defined in a part of IEC 61850 to be added in the future.

As IEC 61850 covers all communication needs within a substation, it also defines the communication to and from the process level, especially the transporting of samples (“process bus”). At the time being, most products available on the market cover the “station bus” only (all communication functions without the transfer of samples), but products supporting the process bus will be available soon. Therefore, choosing IEC 61850 as communication standard means for the user to also keep the options open for further optimization possibilities like usage of unconventional CTs and VTs.

B. Higher flexibility

The possibility of free allocation of functions as provided by IEC 61850, leaves the system architecture open for optimization to suit customers’ needs. Considerations in terms of architecture are driven by the users’ availability and performance requirements as well as by the functional capabilities of products used in a system solution. The IEC 61850 standard does not impose any restrictions on the architecture at all.

Further flexibility for the user is achieved by the defined interoperability, being the main goal of IEC 61850. Whereas interoperability also forms the basis for interchangeability, the latter is outside the scope of the standard. Therefore, a device ‘A’ can be replaced by a device ‘B’ from the same or another manufacturer only as long as device ‘B’ provides the same non-standardized functionality and also supports the same standardized data and services according to IEC 61850 as device ‘A’.

C. Higher integration

In comparison to previous standard protocols such as IEC 60870-5-103, the IEC 61850 standard defines much more data than only basic protection information. Thus it allows to completely integrate any IEC 61850-compliant 3rd party device into a SA system, whereby no difference between the various devices will be visible to the user at station level. By comprising not only the communication between the station and bay level, but also between the bay and process level, the standard is prepared to allow the next step of integration by introducing serially connected sensors and actuators. This leads to the further reduction in costs of cabling and an increase in the level of integration.

D. Common understanding

The function-related modeling of all data in a substation automation system is described in Part 7 of IEC 61850. This is complemented by a hierarchical plant designation scheme as in IEC 61346. Since the standard is globally accepted, it prevents differences between the ANSI and IEC worlds. By introducing this kind of global language or semantics for all data to be exchanged in substations, IEC 61850 helps users in improving the understanding of designs and reducing differences in interpretations between the parties involved in projects.

IV. Impacts on Specifications

The standard has an impact on all activities related to the field of protection and substation automation. How users in utilities and industry can specify protection and substation automation systems and how manufacturers can implement the standard in practice are main issues to be considered.

As described in [3], specifications for such systems should preferably be based on functionality rather than on specific devices.

The first specification step refers to the functionality, that is based on the single line diagram as well as control and protection functions needed (see Figure 1). All requested functionality is specified without reference to any possible implementation. This is the condition to be respected in order to allow the system integrator to elaborate an optimal solution, also taking into consideration other aspects such as the performance and constraints of the system, which are described below in more detail.

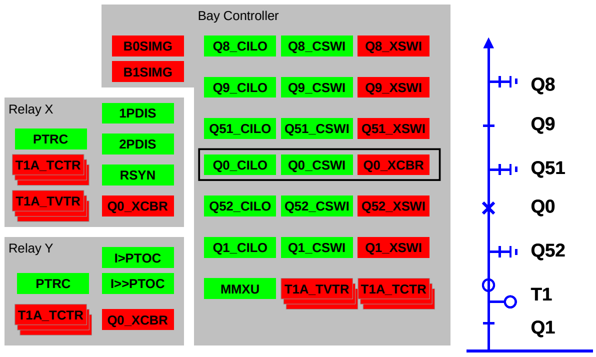

Figure 1 - Modeling example of one feeder

Specifying systems in accordance with the standard IEC 61850 means that the whole functionality is split into Logical Nodes (Figure 1) with their corresponding data, i.e. with the established common naming of the function-related signal names. If the specification does not already provide this, the system integrator has to do it. All persons involved in the project execution, i.e. in design, engineering, testing, FAT, commissioning, SAT, operation, etc., will once have to learn this common but simple language. From now on, it is advantageous for any user to achieve as much and as fast as possible compliance with the standard.

IEC 61850 indicates mandatory and optional data (see Figure 2). It is recommendable to check the "old" signal lists and to evaluate which signals are really needed, what purpose they have and which functions they belong to. This is especially important since they may be optional or extended data according to IEC 61850.

XCBR class				
Attribute Name	**Attr. Type**	**Explanation**	**T**	**M/O**
LNName		Shall be inherited from Logical-Node Class (see IEC 61850-7-2)		
Data				
Common Logical Node Information				
		LN shall inherit all Mandatory Data from Common Logical Node Class		M
Loc	SPS	Local operation (local means without substation automation communication, hardwired direct control)		M
EEHealth	INS	External equipment health		O
EEName	DPL	External equipment name plate		O
OpCnt	INS	Operation counter		M
Controls				
Pos	DPC	Switch position		M
BlkOpn	SPC	Block opening		M
BlkCls	SPC	Block closing		M
ChaMotEna	SPC	Charger motor enabled		O
Metered Values				
SumSwARs	BCR	Sum of Switched Amperes, resetable		O
Status Information				
CBOpCap	INS	Circuit breaker operating capability		M
POWCap	INS	Point On Wave switching capability		O
MaxOpCap	INS	Circuit breaker operating capability when fully charged		O

Data Name
Common Data Class
Description
Mandatory/Optional

Figure 2 - Data of the Logical Node for a circuit breaker

An important advantage of employing the standard configuration description language (SCL) is that the integrity of data is warranted through single data entries. The information contained, e.g. in a specification based on SCL, can directly be taken into the design and engineering tools of the system designer and integrator.

Since IEC 61850 does not define the quality of functions, each device manufacturer is free to determine the functions provided in a device, the algorithms and performance used as well as the setting information required by the appertaining tool. Users therefore still need to stipulate the quality of functions and their allocation to devices in the specification. In this particular respect, there is thus no change as compared to previous specifications for substation automation.

The standard defines certain response times for various data exchange scenarios, but not the complete system performance. Users are therefore recommended to outline the system performance in the specification by defining the minimum response times for transmission of commands and receipt of process data. Especially for bigger systems, acceptable transmission times during a defined avalanche condition should be included as well.

The design of a suitable system architecture is strongly influenced by the user's availability requirements. These should be specified either directly in figures or, perhaps more conveniently, by defining failure scenarios with accepted and non-accepted losses.

With the basic features of the specification mentioned so far, the system designer has a lot of freedom in respect of function allocation and communication. Several constraints may restrict this choice, however, with the main factors influencing the system design being:

- Geographical arrangement of the SA equipment, e.g. decentralized kiosks, centralised rooms for the whole secondary equipment; requirements for decentralised busbar protection scheme, in the station
- Existing or "homologated" devices to be used
- Inclusion of 3rd party equipment such as for Main 1 or Main 2 being of different manufacture
- Requirements defined by operation and maintenance philosophies or dedicated practices. Examples are the levels of functional integration allowed or disallowed: Main 1 and 2 placed in same or separate cubicles, auto-recloser integrated in the control terminal being acceptable or not, ditto for integration of control and bay protection functions in one single device per bay
- Indications as to the use of serial communication being intended or imposed for all possible levels:

process bus, between bays for signal exchange (e.g. for station interlocking), for signal exchange between devices inside a bay (e.g. between distance protection and recloser), for distributed functions such as synchrocheck or breaker failure protection.

For refurbishment projects, further important requirements need to be specified and considered like:

- Strategy for the refurbishment: in one step meaning interruption of service or step-by-step supporting migration with almost no service interruption
- Maximum acceptable interruption time for migration to the new system
- Adaptation resp. interfacing to parts of existing equipment, which are retained.

All these factors strongly influence the choice of the optimal solution. Figure 3 shows a typical solution for a transmission substation with completely independent station level devices for HMI resp. telecontrol and separate networks for the high and medium voltage IEDs.

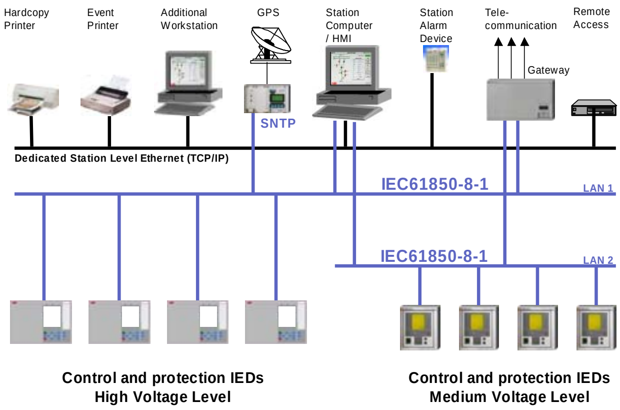

Figure 3 – Typical SA system configuration for a transmission substation

V. Impacts on System Implementation and Project Execution

Following the examination of the impacts of IEC 61850 on the specification, we analyze those on the project execution chain from design and engineering to commissioning and taking the system into operation.

A. *General system design*

Based on the specification, a solution concept needs to be elaborated. As mentioned above, the standard IEC 61850 allows free functional allocation. Owing to the split into functional nodes, the system designer is free to distribute the functions respecting any constraints as imposed by the specification. Especially distributed functions like busbar protection, breaker failure protection, station-wide interlocking and load shedding have to be designed very carefully in order to ensure seamless interoperability.

As already stated in CIGRE Colloquia and Symposia such as the Plenary Session in 2004, it is advantageous to place the functions as close as possible to the primary process. Considering all these requirements, only a system integrator with comprehensive experience will be able to elaborate such an optimized solution and to exploit all the benefits of IEC 61850 for the user.

B. *Engineering*

The “informal” specification information needs translating into a “formal” description using SCL by either the user/author or the system integrator. This formal description warrants high quality of work as well as integrity and consistency throughout the implementation process, i.e. from general system design to final commissioning, and facilitates corresponding checks in each step of the project execution.

Finally, the complete substation automation system is formally documented using SCL in line with IEC 61850. This ensures that all engineering work is “memorized” and allows reuse for adaptations, extensions and also refurbishment at any time.

C. *Compliance to IEC 61850*

The use of components, which are proven to be compliant with IEC 61850, is a prerequisite for proper project execution. The framework for such compliance testing is provided by part 10 of the standard and is being detailed by user organizations and test bodies. Each component has to be accompanied by a test certificate. The main compliance features are the data model in accordance with the implemented functions as well as the proper running of all needed and specified services. In addition, each compliant IED has to be supplied with a “formal” data sheet, the so-called ICD file being the SCL description of the device capabilities.

Practical experiences have shown that compliance tests according to IEC 61850-10 do not suffice from a system integrator’s point of view. The test cases described therein focus merely on a box approach and do not consider system-relevant items like station-wide functions or system performance.

Thus in addition to device certification, detailed type testing of the IED within a complete system environment is strongly recommended and shall be performed by the supplier/system integrator.

D. Factory Acceptance Testing (FAT)

The FAT serves to prove that the complete system meets the properties specified in the supply contract prior to delivery. Missing parts such as switchgear, NCC, etc. need to be simulated. Therefore, IEC 61850 is tested implicitly on system level.

The FAT can be divided into two essential parts, i.e. testing of bay solutions (cubicles), and testing of the complete system based on typical or all bays connected to the station level. IEC 61850 simplifies the FAT since data consistency has already been verified by formal checks in the design phase and by testing against the SCL-based system configuration description file (SCD).

E. Site Acceptance Testing (SAT)

The SAT serves to prove that the complete system fulfils the properties specified in the supply contract prior to being put into service. Since usually all parts are available on site, no simulation is needed. The SAT may be split into two important steps, i.e. testing of the correct connection to the primary gear and correct data transfer to remote locations such as NCCs.

IEC 61850 simplifies the SAT since by assuring a correct connection of all external interfaces, the data consistency and the logical behavior of the functions cannot deviate from the known FAT state. Only the overall performance of some functions may be impacted by the connection to the external equipment. Again, the SCD-file can support the test procedure.

F. Operation

The operation via station HMI deals with the visual part as well as the operational rules and these have to perform as specified and like in systems with proprietary communication protocols. The standardized object-oriented data model and services simplify the design of the station HMI and support the equal appearance of all devices for the operator. Domain-specific features of IEC 61850 like the direct support of the select-before-operate mode improve inherent security. The use of the substation section in the SCD-file facilitates the design of any kind of sequences and station-wide automatics. The client-server relation between the station HMI and the operated and supervised devices allows adding multiple workplaces to the system wherever needed.

G. Maintenance

The object-oriented data model with its standardized services provides very easy access to all data in the system and prevents misunderstandings about their semantic meaning. The SCD-files provide a much clearer guideline for searching and fixing failures in the system than any printed description. They may be reused at any time for the engineering of adaptations, extensions and also future refurbishment as long as not only the IEDs but also the tools remain compliant with IEC 61850.

VI. User Considerations For The Introduction Of IEC 61850

As mentioned in [4], a reduction in project cycle times can be achieved through the simplification of processes on the users' and manufacturers' side.

Pre-defined solution concepts with a choice of functionality and hardware architectures designed for various availability requirements are offered by some manufacturers to support users with the efficient introduction of IEC 61850-based systems in their organizations.

Several additional benefits may be derived from the use of such type-tested, modular and scalable solutions like:

- obtaining optimal designs fulfilling all requirements in terms of functionality in less time
- efficiency improvements from tendering to commissioning
- highest degree of device integration and use of device capabilities
- optimal performance
- better support
- high functionality, value and quality
- interfaces solved (internally as well as to other systems)
- increased reliability and dependability.

Suppliers with scalable and modular solutions offer the additional advantage of using pre-tested functional packages that can be put together to build the optimal solution fulfilling the customers' requirements. As there are always some special requirements from customers' sides, this kind of solutions shall allow adding those requirements to the predefined packages. The customer does not need to think about the equipment inside the solution packages but can select the appropriate functions for each particular solution.

VII. Conclusion

The standard IEC 61850 provides not only a powerful methodology to reach interoperability, but also supports its practical application for Substation Automation Systems. The examples analyzed and the recommendations proposed can be used as guidance.

The specification has to follow certain rules in order to allow the system designer to fully exploit the benefits of IEC 61850 for the user. The use of manufacturers' pre-defined solutions based on IEC 61850 could help to improve both the implementation time and quality as well as satisfy all functional requirements of the customer.

Highly qualified system integrators have their own system verification facilities and are capable of performing extensive and systematic integration tests for any device used and the complete system. Experiences have shown that this is currently a must as the standard still leaves room for interpretation. Preferably, the system integrator's verification facilities are also certified by UCA International Users Group to minimize the risks on customer's side.

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IX. Biographies

Peter Rietmann was born in 1969 in Switzerland. He received the B. Sc. diploma in electrical engineering from the Zurich University of Applied Sciences in 1992. In the same year he joined ABB where he worked in different positions in the area of substation automation and protection. Currently he is working as Product Manager for Substation Automation with ABB Switzerland Ltd., Power Systems, Baden/Switzerland.

Petra Reinhardt is working as Marketing Communication Manager with ABB Switzerland Ltd., Power Systems, Baden/Switzerland after having gained several years experience in substation automation and protection in Switzerland and South Africa where she has been working as sales engineer and key account manager.