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 the actual 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 and minimize risks for projects. The paper indicates the challenges faced by customers as well as suppliers in applying IEC 61850 and suggest suitable approaches to take optimal advantage of the standard.**

I. INTRODUCTION

A. The features of IEC 61850

IEC 61850 refers to substation automation systems and defines the communication between intelligent electronic devices (IEDs) in substations as well as the related system requirements. The main goals of this standard are:

- Interoperability
- Free allocation of functions
- Long-term stability through the separation of applications from communication

Strict rules are defined in the standard 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.

Together with the possibility of free allocation of functions, this feature paves the way for a vast range of possible solutions for Protection and Substation Automation (SA) systems.

Through the separation of the relatively slowly growing substation-specific applications from the fast advancing communication technology by the Abstract Communication Services Interface (ACSI), the standard can easily be adapted to future developments whilst leaving existing databases and functions untouched. This warrants long-term stability of the standard as well as sustainability of users' investments.

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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.

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.

Today's IEC 61850-based solutions are mainly realized with station bus (Part 8-1 of the IEC 61850 standard) that provides the communication between bay level IEDs and also between bay and station level devices. The standard also defines the communication for the process bus (Part 9 of IEC61850) but yet only few products are available on the market and even fewer installations in service, meaning it is too early to present any field experiences with the process bus. Therefore, this paper is not considering part 9 of IEC 61850 at all.

B. Project life cycle

The IEC 61850 standard influences the entire project life cycle, from the point of specification up to the task of maintenance. Various parts of the standard must be considered during the project implementation with its two major parts, the phase of specification / evaluation and that of project execution. The following chapters provide more details concerning the specification and the execution phases as well as on operation and maintenance.

II. SPECIFICATIONS

The standard has an impact on all activities related to the field of protection control 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.

A. Specification of functionality

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 the 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.

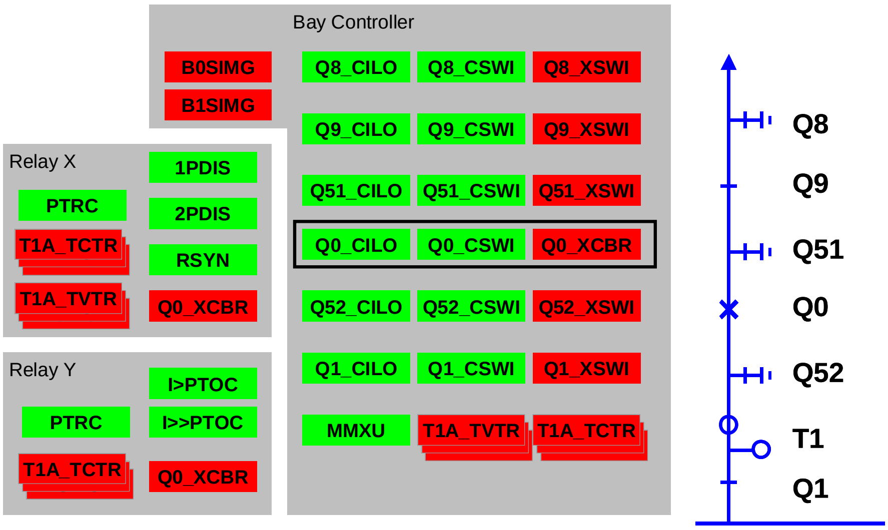

Figure 1: Modeling example of one feeder

Specifying systems in accordance with the standard IEC 61850 means that the whole functionality is split into Logical Nodes 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 Fig. 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 as 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.

B. Specifying the quality of functions

Since IEC 61850 does not define the quality of functions, each device manufacturer is free to determine the functions provided in an IED, 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.

C. Specification of distributed functions

The standard's support for interoperability between IEDs in different system architectures and the provision of communication services, such as GOOSE (Generic Object Oriented Substation Event), facilitate the realization of distributed functions.
Referring to [5], the table 1 below shows a list of typical distributed functions in substation automation (SA) systems, their allocation and the impact on interoperability, e.g. when mixing devices from different vendors. With respect to interoperability, three possible classifications are made:

- Non Critical – can be implemented with low risks
- Critical (vendor-specific) – can be implemented, locks into a vendor-specific concept
- Critical (gaps) – gaps in the standard

Distributed functions	**Allocation of function**			**Interoperability**		
	Station Level	**In one bay**	**More than one bay**	**Non critical**	**Critical (vendor-specific solutions)**	**Critical (gaps in the standard)**
Reverse blocking			X	X		C
Auto-reclosure		X		X		
Interlocking			X	X		
Double-command blocking			X		X	
Voltage selection			X		X	C
Breaker failure protection			X		X	C
Station level authority	X				X	C
Distributed synchrocheck			X		X	C

X = Simple switchyard topology or functional demands
C = Complex switchyard topology or functional demands

Table 1: Interoperability of distributed functions

These functions often need time-critical communication and are very sensitive regarding interoperability. Furthermore, the influence of various communication system architectures on their safety and availability needs careful consideration. Further aspects to be taken into account are described in the section on Compliance testing (chapter III, section C).

D. Specification of performance and availability

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 the 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.

E. Consideration of other factors

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, centralized rooms for the whole secondary equipment; requirements for decentralized 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.

III. PROJECT EXECUTION, SYSTEM OPERATION AND MAINTENANCE

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 of the system.

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. System integration

The integration of all components to a system fulfilling the specified behavior and performance falls within the responsibility of a system integrator. To ensure the success of a project, its role must be clearly defined in the specification and should be properly negotiated.

Especially when a project entails building a multi-vendor SA system according to IEC 61850, the responsibilities of the various parties respectively suppliers involved must be specified in detail, due to the technical as well as organizational complexity of engineering such a system. It shall be ensured that

- The parties have the right know-how at the right time
- The various parties in different locations interacting with each other are well coordinated and act as one global team to satisfy the customer requirements

Experiences gathered in the past two years have shown that in all project phases, system integrators are confronted with end users having certain expectations on the one hand, and (sub-)suppliers with different interpretations of the standard on the other. It is therefore essential to understand and apply the concepts which system engineering according to IEC 61850 offers. The new structural approach to communication system engineering includes the following:

- System level engineering with tools to specify the IEC 61850 data model of a SA system
- Engineering process being designed to support the IEC 61850 object model
- Assembly of the SA system from the basic objects defined by the IEC 61850 object model
- Application of a concept of reuse based on entities of the IEC 61850 object model
- Use of the IEC 61850 Substation Configuration description Language (SCL) as central data exchange format in all tools

C. Compliance testing

The use of components, which are proven to be compliant with IEC 61850, is a prerequisite for proper project execution. The degrees of freedom that the standard offers in combination with the varying levels of integration in IED application and communication software as well as configuration tools emphasize the necessity of thorough system testing. The framework for compliance testing is provided by part 10 of the IEC61850 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 are an indispensable starting point, but 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/distributed 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.

To minimize the risk for customer projects, such distributed functions should be specified and implemented in such a way that they are reusable for different customer philosophies and be verified once by system level tests. Such tests should especially focus on the following aspects:

- The application level modeling according to IEC 61850
- Adequate selection of communication services to warrant performance and safety
- Appropriate functioning of external components, especially Ethernet switches and radio clocks
- Integration into the system engineering by means of ICD / SCD files.

D. Engineering & Quality of SCL files

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.

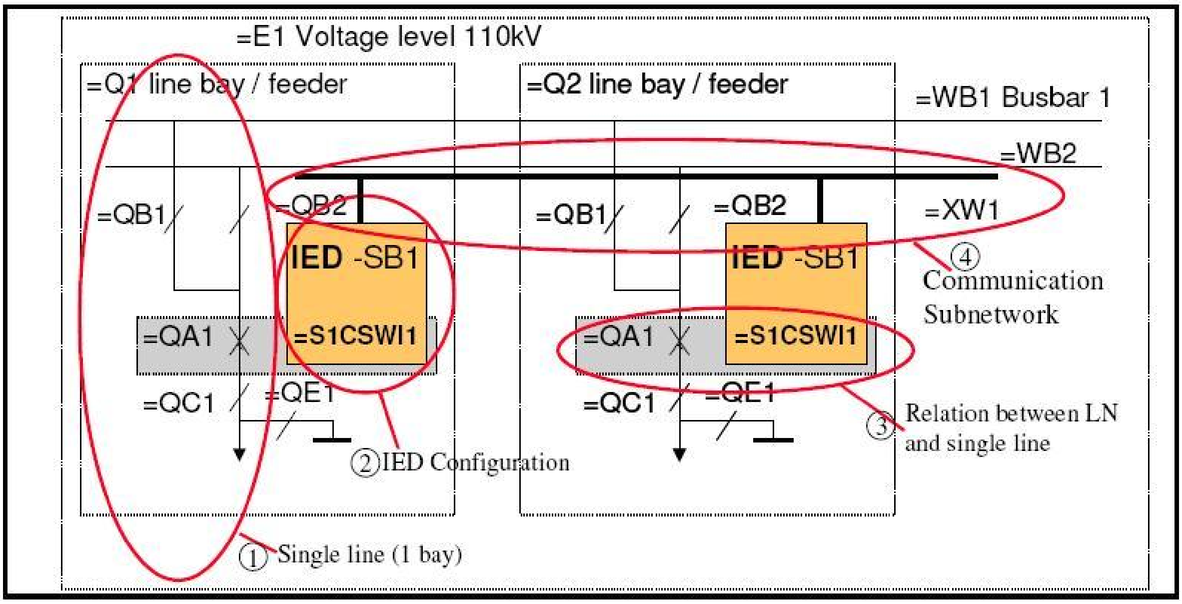

Figure 3: Content of a SCL file

The SCL described in part 6 of the IEC 61850 standard enables system integrators to describe a substation and its secondary system in a standardized way from a communication point of view. Having a system engineering tool that makes full usage of the standard and is capable of combining standard-conformant

SCL file inputs from different sources (suppliers) into a full-scope documentation of the engineered substation automation system should be seen as one of the core competences of a system integrator. It has been observed on the market that most suppliers currently tend to concentrate on the necessary part only, leaving out the possibilities (capabilities) the standard offers in the first step, and therefore giving away the main advantages from the beginning [6].

The additional information, i.e. beyond the normal functional distribution and data flow configuration, is located in the so-called substation section of the System Configuration Description (SCD) file, which documents the entire IEC 61850-related data in the system. Without this data, the configuration and dataflow within the system is anonymous, because it is not related to any primary equipment. Simply speaking, the dataflow is then configured on the level of legacy protocols, i.e. with data addresses 1….5000. A comprehensive comparison of such legacy protocols with IEC 61850 can be found in [7].

Of course, the documentation of this data in the SCD file is worthless, if the corresponding IED engineering tools cannot cope with them. Therefore, it is essential to assess the complete engineering chain and ensure that it is future-proof in terms of reusability of data. In general it can be stated, that the better the implementation of the concepts of IEC 61850 is done, the more advantages can be gained in the following steps of testing, commissioning and maintenance.

E. Factory and Site Acceptance Testing (FAT, SAT)

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).

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 network control centers (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 preceding steps show the quality of the supplier-independent, and therefore neutral, system documentation according to IEC 61850. This has a major impact on present and future maintenance cases as well as life cycle costs.

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 present 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. With the SCD files being the starting point for future extensions, not only the IEC 61850 standard itself, but also the engineering tools supporting it, must be backwards compatible.

IV. EXAMPLES OF EFFICIENT INTRODUCTION OF IEC61850

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.

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. An example for protection applications can be seen in Figure 4.

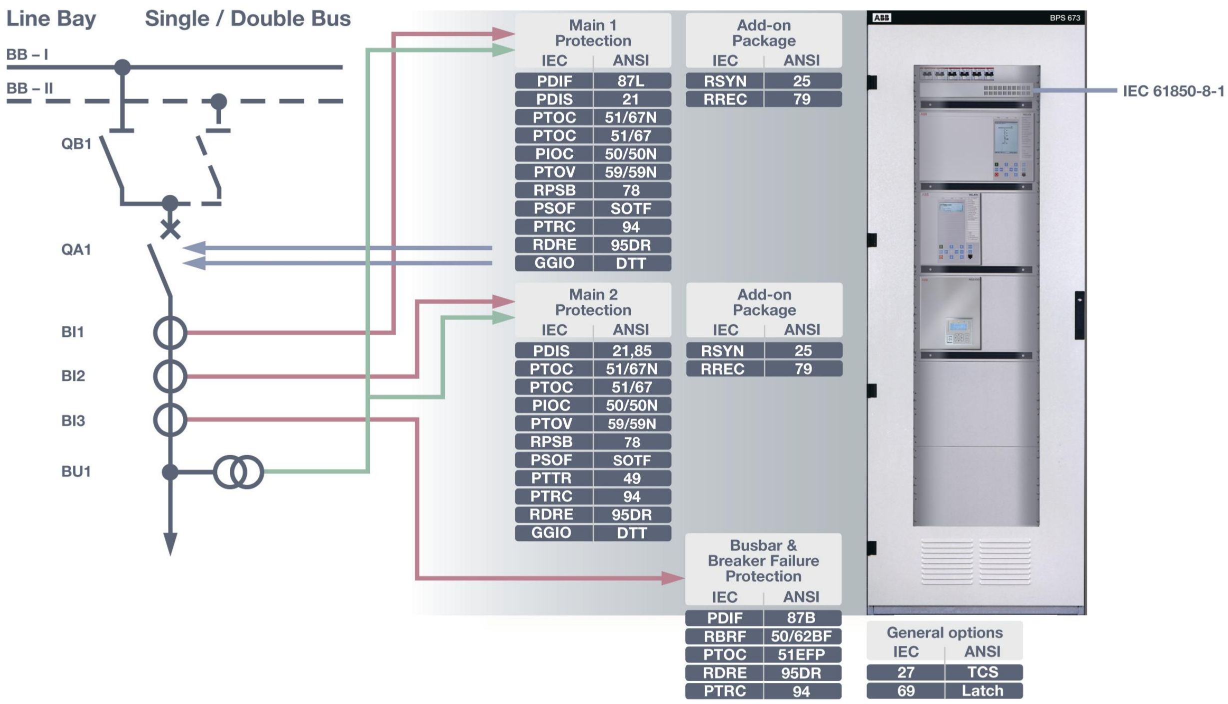

Figure 4: Example of a modular protection solution

V. CONCLUSION

The standard IEC 61850 not only provides 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 on 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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VII. Biographies

Peter Rietmann was born in Frauenfeld, Switzerland. He received the BSc. 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 Global Product Manager for Substation Automation with ABB Switzerland Ltd., Power Systems in Baden/Switzerland.

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