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Practical considerations in applying IEC 61850 for Protection and Substation Automation Systems

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Summary

The standard IEC 61850 'Communication Networks and Systems in Substations' defines guidelines for realising interoperability between functional nodes used for protection, monitoring, control and automation in substations. Interoperability and free allocation of functions open up a vast range of possible solutions. However, since IEC 61850 is an all-encompassing standard covering design aspects, protocol requirements, testing, etc., application of the same for any specific case requires careful consideration of customer requirements as well as available equipment.

First, the paper highlights the essential and basic aspects, which have guided the elaboration of the standard IEC 61850. The authors explain why utilities today should require that protection and substation automation systems should be compliant to the standard. Based on their experiences in the implementation of the standard, the authors are presenting a short but practical overview how to implement the standard.

The standard has an impact on all activities related to the field of protection and substation automation. A very important task is how to specify IEC 61850 compliant systems. The paper makes practical proposals about the different levels of possible implementations. This covers specifications aspects for new installations as well as for extensions of existing installations or refurbishment. Main aspects of Protection & Substation Automation Systems based on IEC 61850 that have already been realised are presented.

The impact of IEC 61850 during the whole project execution is analysed. Recommendations are given about engineering, documentation issues, FAT and SAT. Another aspect of the IEC 61850 is the impact on the equipment and on the automation system architecture. The authors indicate how the standard influences the structure of the connected devices and which types of system architecture can be chosen, based on reliability considerations and geographic implementation.

The authors indicate the challenges faced by utility customers as well as suppliers in applying IEC 61850 and suggest suitable approaches to take optimal advantage of the standard to better realise distributed functionality. Aspects that are not presently adequately covered by the standard and could be the subject of future improvements are addressed.

Keywords

Protection, Substation Automation, Standard IEC 61850

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Introduction

The standard IEC 61850 „Communication Networks and Systems in Substations“ is the first and only global standard that considers all the communication needs within a substation. It defines strict rules for realising interoperability between functions and devices used for protection, monitoring, control and automation in substations independent of the supplier. 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.

IEC 61850 is a comprehensive standard covering also design aspects, protocol requirements, testing guidelines, etc. To exploit the full benefits of IEC 61850 in any specific case, its application requires careful consideration of the customer requirements as well as of the available equipment.

Even if initiated only by few suppliers and users, the increasing number of commitments of suppliers to use and offer IEC 61850 in products and systems, has been demonstrated in the UCA International exhibition booth at the CIGRE Symposium 2004 in Paris. Today, a lot of manufacturers are offering IEC 61850-compliant products, yet few also offer complete systems on the market.

This paper highlights the essential and basic aspects, which have guided the elaboration of the standard IEC 61850. Why utilities today should require that protection and substation automation systems should be compliant to the standard is explained. A very important aspect is how to specify IEC 61850 compliant systems for new installations as well as for refurbishment projects. The impact of IEC 61850 on the entire project execution is analysed. Recommendations are given about engineering, documentation issues, testing and commissioning.

Trends in the field of substation automation systems

Before the introduction of microprocessor-based equipment and serial communication in substations, protection, control and monitoring were handled separately by different, dedicated pieces of equipment and resulted in the split of responsibilities between various departments inside the organisations of suppliers as well as of the utilities.

With the first deployment of serial communication in substations, the separation between protection, control and monitoring did at first not really change significantly. But very quickly users requested a common protocol inside the substation. The first approach in this respect has been made by the introduction of IEC 60870-5-103 as informative interface for protection devices. This protocol is not only restricted to information but also to some protection functions only. In addition, it led to a high temptation to use the private part of the protocol, which was intended for the purposes of ensuring backward compatibility only, for supplier-specific extensions instead.

The development in communication and microprocessor technologies, i.e. with the introduction of the serial communication on the one side, and with the facility to provide numerical multifunctional equipment on the other, has led to a change in the approach to substation automation solutions. In order to optimise a system and to reduce costs, the integration of more and more functions into less and less devices is needed and has become an ongoing trend. Different functions such as protection, control or monitoring can be combined in one common device e.g. in a bay unit covering all the functionality needed at bay level. Consequently, the specifications of such systems including all applications have to be changed fundamentally. Today, the entire functionality provided for protection, control and monitoring of a substation is not handled separately anymore, but typically contained in one common and consistent system. This trend is illustrated in Figure 1 showing the developments of Substation Automation over time.

This also raises the need for more information exchange between all specialists involved in substation automation and protection and therefore increases the pressure for a common communication protocol. All these needs and trends were merged into the new standard IEC 61850 „Communication Networks and Systems in Substations“.

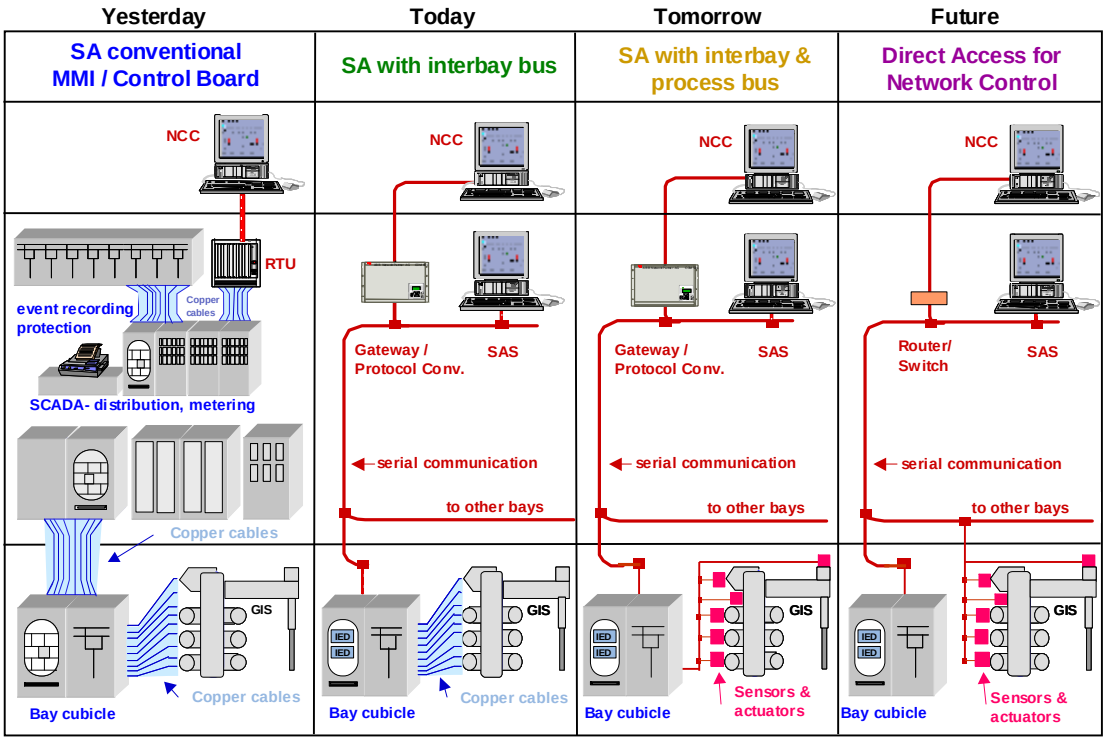

Figure 1 Developments of Substation Automation over time

Advantages for the users

- Investment for the future

To introduce IEC 61850-based solutions means for the user an investment into a future- proof system. E.g. 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 when the system will be extended, when only certain system components have to be replaced after several years of operation, and even when the complete system has to be replaced after reaching the end of its lifetime [1]. Re-use of the SCL-files is also possible in case the actual communication technology used becomes obsolete and a new mapping of the data model and services to a new communication technology is defined in a new part of IEC 61850 added in the future.

As the new standard 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 come out very soon. Therefore, choosing IEC 61850 as communication standard means for the user to also keep the doors open for further optimization possibilities like usage of unconventional CTs and VTs.

In the future, IEC 61850 may even become the standard for communication beyond the substation, e.g. between the substation and the remote control centres (telecontrol). A task force of IEC TC57 came to the conclusion that IEC 61850 is capable of covering all the needs for telecontrol.

- Higher flexibility

By facilitating the free allocation of functions, IEC 61850 leaves the system architecture open for optimization according to customers needs. Architectural considerations are driven by the availability and performance requirements of the user as well as the functional capabilities of the products used to build a system solution. There are no restrictions imposed by the IEC 61850 standard concerning the architecture.

Flexibility for the user is also given by the interoperability defined, being the main goal of IEC 61850. Whereas interoperability also forms the basis for interchangeability, the latter falls outside the scope of the standard. This means that 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 supports the

same standardized data and services according to IEC 61850 as device A.

- Higher integration

Compared to previous standard protocols like IEC 60870-5-103, the IEC 61850 standard defines much more data than only basic protection information. The standard allows the complete integration of any IEC 61850-compliant 3rd party device into a SA system. The user will not see any difference between the different devices 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 of costs of cabling and increase in the level of integration.

- Common naming for common understanding

Part 7 of the standard (IEC 61850-7-x) describes the function-related modelling of all data in a substation automation system. This is complemented by a hierarchical plant designation scheme as in IEC 61346. Since the standard is accepted worldwide, no difference between the ANSI and IEC worlds will appear. By introducing this kind of global language or semantics for all data to be exchanged in substations, IEC 61850 will help the users to improve the understanding of designs and to reduce misinterpretations between different parties involved in projects.

Summary 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 [2]. Its' main goal, the interoperability between devices and tools, has been described in section 1 of this paper. Moreover, the standard supports the free allocation of functions and accepts any system philosophy. These range from a distributed architecture (e.g. decentralised substation automation) to a centralised configuration (e.g. RTU-based). The standard separates the functionality including data model and communication services from the communication implementation. This makes it future-oriented, taking into consideration that the development in the communication technology is moving quicker than the development of the functionality in the field of protection and substation automation.

The data model of the standard is an object–oriented one, grouping the data into the smallest possible sets referring to the smallest possible functions to be implemented independently. These smallest possible data groups or functions are named Logical Nodes. The Logical Nodes and all data and attributes contained therein are named according to a standardised semantic, which is mandatory.

Each IEC 61850-compliant IED can be configured using its dedicated tool. However, all these IED tools have to be compliant with IEC 61850 regarding the standardised data model and data access (services). This allows the system integrator to obtain consistent and understandable data from all devices independent of the supplier for building up the complete system.

Impact of IEC 61850 on specifications

The standard has an impact on all activities related to the field of protection and substation automation, but the main issues are how to implement the standard in practice, which is to be done by the suppliers, and how to specify protection and substation automation systems, which is to be done by the users like utilities.

As already mentioned above, some changes in the technologies used for Substation Automation have been very important like the use of serial communication and of multifunctional equipment. This means that the specification should preferably be based on functionality rather than on specific devices [3].

The first step of a specification refers to functionality, which is based on the single line diagram and the control and protection functions needed (see Figure 2). 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.

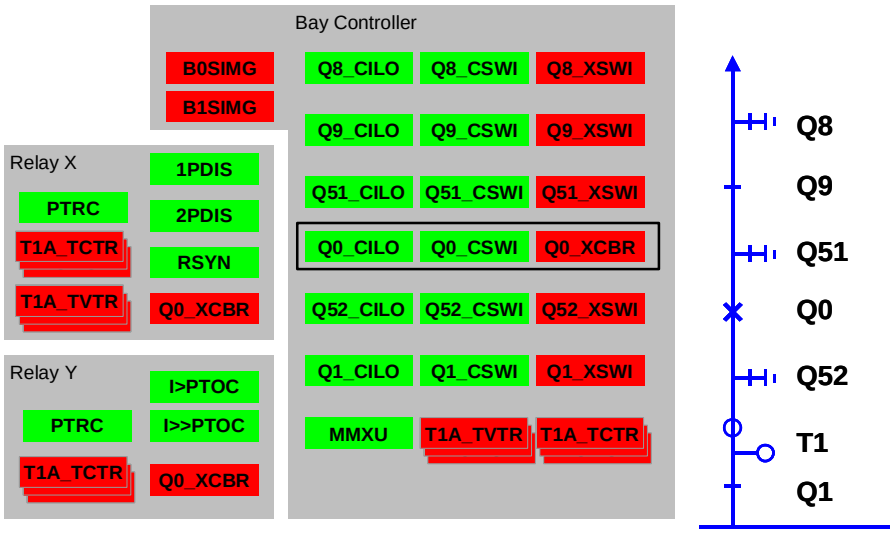

Figure 2 - Modelling example of one feeder

Specifying according to the standard IEC 61850 means that the entire functionality is split into Logical Nodes (Figure 2) with their corresponding data, i.e. with the established common naming of the function-related signal names. If this is not done in the specification already, the system integrator has to do it. Anyway, the people anywhere in charge of the project execution (design, engineering, testing, FAT, commissioning, SAT, operation, etc.) will once have to learn this common but simple language. It is an advantage to, from now on, achieve as much and as quick as possible compliance with the standard.

The standard indicates mandatory and optional data (see Figure 3).

It is recommended to check the "old" lists of all signals and evaluate which ones 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.

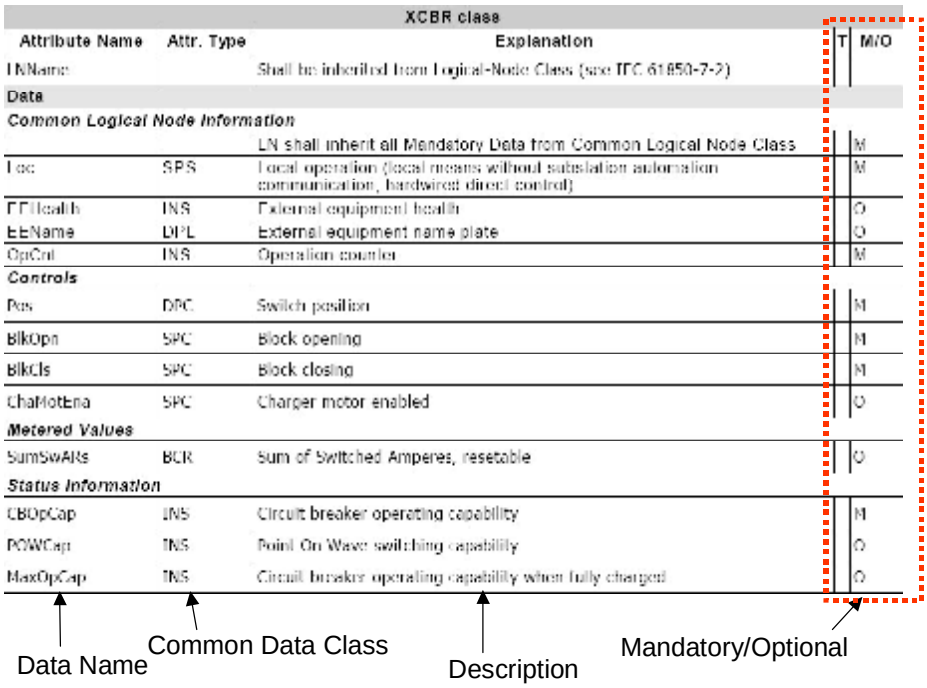

Figure 3 - Data of the Logical Node for a Circuit Breaker

The use of the standard configuration description language (SCL) has an important advantage: the integrity of data is warranted by using one single data entry. For example, if the specification is already using SCL, the system designer and integrator can take this information directly into its design and engineering tool. As the standard is not defining the quality of the functions, e.g. each manufacturer of protection devices still decides by itself which functions can be provided in

one device, on the algorithms and performance used and the setting information required by the corresponding tool. Thus, if these parts are important to a user, he or she still needs to add them into the specification by defining the quality of the functions and their allocation to devices. These parts of a specification do in fact not incur any changes as compared to a previous specification for substation automation meaning that those items are independent of the standard.

Even considering that IEC 61850 also defines certain response times for various data exchange scenarios, it does not consider the complete system performance. It is therefore recommended to outline the system performance in the specification by defining at least the minimal response times for sending commands and receiving process data. For big systems it also makes sense to describe the acceptable transmission times during a defined avalanche condition.

To set up an appropriate system architecture, also the requested availability should be specified. But in many cases it is more convenient to define failure scenarios with accepted and non-accepted losses instead of figures for availability providing the same information for system design.

With the basic features of the specification mentioned up to now, the system designer has a lot of freedom in respect of function allocation and communication. But in many cases several constraints may restrict this choice.
The main aspects influencing the system design are:
- The geographical arrangement of the SA equipment in the substation (e.g. decentralised kiosk, centralised rooms for the whole secondary technique; requirements for decentralised busbar protection scheme)
- Already existing devices or “homologated” devices to be used
- Requirements to use third party equipment (e.g. main 1 and main 2 from different manufacturers)
- Requirements from operation or maintenance philosophies or dedicated practices (e.g. the level of functional integration not allowed or requested: main 1 / main 2 in separate cubicles, recloser in the controller accepted or not, integration of control and bay protection functions in one single device per bay)
- Indications from the user if he already intends or imposes the use of serial communication at all possible levels: at process bus level, for exchange of signals between bays (e.g. for station interlocking), for exchange of signals between devices inside a bay (e.g. between distance protection and recloser), for some distributed functions such as synchrocheck or breaker failure protection.

In case of refurbishment, additional important requirements have to be specified and considered like
- Necessary adaptation resp. interfaces to the parts of the existing equipment, which will not immediately be replaced
- Maximum acceptable interruption time to migrate to the new system
- Strategy for the refurbishment: One step refurbishment meaning interruption of service or step-by-step migration supporting refurbishment without interruption of service.

All these constraints will strongly influence the choice of the right and optimised solution. Figure 4 shows a typical solution for a transmission substation. The functions of HMI and telecontrol are allocated to two completely independent devices at the station level.

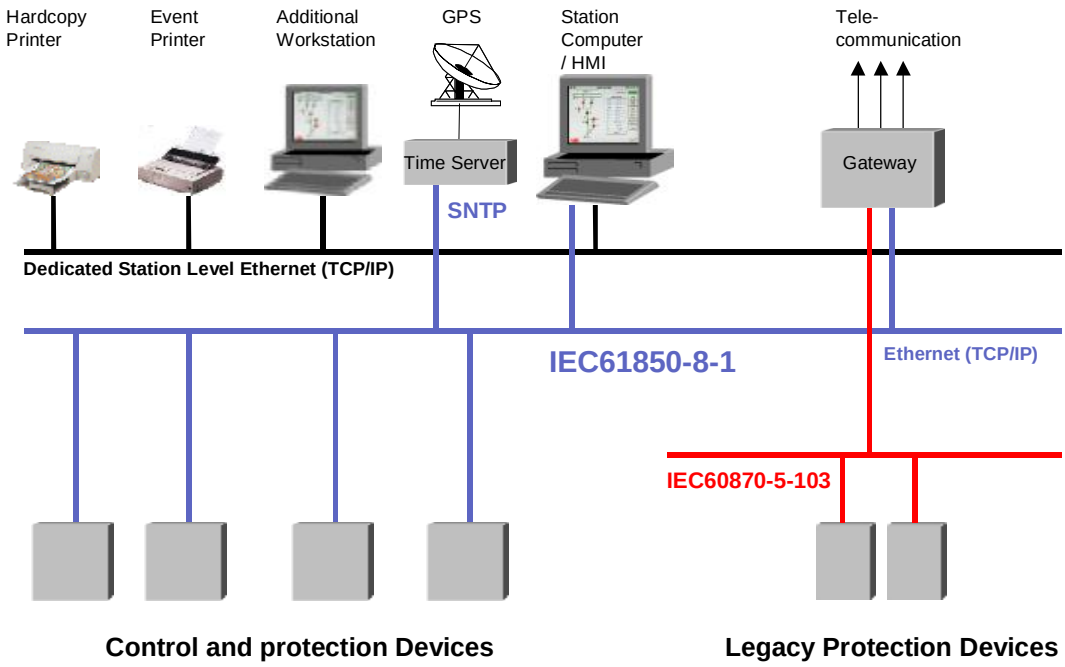

Figure 4 - Typical SA system configuration for a transmission substation

Impacts on system implementation and project execution

After having examined the impact on the specification, we have to look at the complete project execution chain, i.e. from the design and engineering phase until the system is finally put into operation.

- General system design

Based on the specification a solution concept has to be elaborated. The standard IEC 61850 allows the free allocation of functions. Due to the split into functional nodes, the system designer is free to distribute the functions, but has to respect the mentioned constraints as imposed by the specification. To ensure seamless interoperability, especially the distributed functions like breaker failure protection, busbar protection, station-wide interlocking, and load shedding have to be designed very carefully.
As already mentioned during CIGRE colloquia and Symposia (e.g. Plenary Session 2004), it is an advantage to place the functions as near as possible to the primary process. Regarding all the requirements, only a system integrator with comprehensive experience will be able to elaborate such an optimised solution exploiting all benefits of IEC 61850.

- Engineering

The “informal” information from the specification has to be translated into the “formal” description using SCL. This work may be done by the author of the specification or has to be done latest by the system integrator. The formal description warrants a high quality of work, ensures integrity and consistency during the entire implementation process, from the general system design to the final commissioning, facilitating the corresponding checks in each step of the project execution.

Finally, the whole substation automation system is formally documented in SCL according to IEC 61850. Therefore, the engineering work done remains “memorised” and can be reused at any time for adaptations, extensions and also refurbishment.

- Compliance with IEC 61850

A prerequisite for reasonable project execution is the use of components, which are proven to be compliant with IEC 61850. The framework for the compliance test is given in part 10 of the standard (IEC 61850-10) and is now being detailed by user organisations and test bodies. A test certificate has to be supplied. The main compliance features are the data model according to the implemented functions and the proper running of the needed and specified services. It shall also be mentioned that each compliant IED has to be supplied with a “formal” data sheet being the SCL description of its capabilities (ICD file).

- FAT

The factory acceptance test has to prove that the complete system fulfils the properties specified in the

contract between the supplier and the user before it leaves the factory. Missing parts like the switchgear or the NCC have to be simulated. Therefore, IEC 61850 is tested implicitly on system level.

The FAT may be split into two important steps, i.e. the test of bay solutions (cubicles), and the test of complete systems, generally based on typical or all bays connected to the station level. IEC 61850 simplifies the FAT since data consistency tests have already been done by formal checks in the design phase and by testing against the SCL-based system configuration description file (SCD).

- SAT

The site acceptance test has to prove that the complete system fulfils the properties specified in the contract between the supplier and the user before it goes into operation. On site, all parts are normally available and no parts have to be simulated anymore. The SAT may be split into two important parts, i.e. into the tests of the
correct connection to the primary equipment
correct data transfer to remote places outside the station like the NCC

IEC 61850 simplifies the SAT since by assuring a correct connection of all external interfaces, the data consistency and the logical behaviour 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.

- Operation

The operation via station HMI deals with the visual part and the operational rules. Therefore, these have to perform as specified and like in systems with proprietary communication protocols. The standardised object-oriented data model with its standardized services simplifies the design of the station HMI and supports the equal appearance of all devices - independent from the supplier - for the operator. Domain-specific features of IEC 61850 like the direct support of the select-before-operate mode are improving the inherent security. The use of the substation section in the SCD-file facilitates the design of any kind of sequences and station-wide automatics, if requested in the specification. Having a client-server relation instead of a master-slave one between the station HMI and the operated and supervised devices allows extending the system with multiple workplaces located wherever needed.

- Maintenance

The object-oriented data model with its standardised services provides very easy access to all data in the system and prevents misunderstandings about their semantic meaning. The SCD-files are a much clearer guideline for searching and fixing failures in the system than any printed description. It 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 stay compliant with IEC 61850.

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 specification has to follow some simple rules in order to allow the system designer to fully exploit the benefits of IEC 61850 for the user. The standard is not only issued, but also ready to use. The examples analysed and the recommendations proposed can be used as guidance. It should be mentioned that first installations are already in operation.

Applications of the standard outside the substation, such as for telecontrol and teleprotection, are under consideration. Additional application areas like wind power, hydropower and distributed energy resources are following the same approach for communication as well. Therefore, it is a very promising challenge for experts in utilities, for people in manufacturing companies and for consultants to learn and use IEC 61850-compliant solutions.

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