

The Impact of the coming Standard IEC61850 on the Life-cycle of Open Communication Systems in Substations

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Abstract – Open communication systems that provide interoperability between all devices in substations independent from the manufacturer are a basic requirement today. Such systems have to be based on an international communication standard supporting the application domain specific requirements. Specific is the very long life cycle of substations, which claims for long validity of the communication standard despite fast changes in computing and communication technologies. Maintenance and upgrade force a lot of changes in the secondary technology over this long life-cycle and may contribute very heavily to the life cycle costs because of the need of engineering and testing for any change. The standard IEC61850 provides long validity by the split of application and communication, and life cycle long support by the introduction of a standardised substation configuration language (SCL). The result is a reasonable reduction of cost for the secondary system over this life cycle.

1 Status today

1.1 Investments in primary and secondary equipment

The costs of a substation can be split in two main parts, primary and secondary equipment. Primary equipment is the switchgear with associated sensor and actuators. Secondary equipment is the protection and control equipment on bay level as well as on station level. The engineering and testing covers all parts of the station equipment; primary as well as secondary equipment.

Breakdown of investments split on primary and secondary parts (relative costs)

Voltage level	Primary equipment	Secondary Equipment
High	80 %	20 %
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.	.	.
Medium	50 %	50%

1.2 Cost of engineering and testing

A closer analysis of the initial investments in the primary parts shows two things, firstly that the initial cost of engineering and test of the primary equipment is a small compared to the initial HW cost, secondly that the primary part remains comparatively stable over the lifetime of the substation.

The secondary part shows a different picture. Initial investments made in the secondary part can be split as below. The split is fairly independent of the voltage level.

Item	Relative cost
Hardware	40%
Engineering & test	60%

This would not be too bad if the initially installed equipment will not be changed over the lifetime of a station. Since this is never the case, we have to look at the frequency of updating and replacement of the secondary equipment in a substation, to see the impact of changes on the costs.

1.3 Changes

The primary equipment as a whole needs changing once every 30 – 60 years. This means that it is normally not exchanged, but may be extended during the life time of the station. In cases where it is extended, the extensions are mostly known and can be planned and engineered already at the beginning. The primary equipment is not further addressed in this paper.

Upgrade or replacement of secondary equipment may be split in bay and station level equipment. On the bay level the protection/control equipment is changed either as result of maintenance replacement or upgrade of performance. In case of upgrade it is clear that the engineering and test efforts need to be redone, probably completely. The benefit here is that the work can be planned and optimised. However, the need to replace a unit due to malfunction may well come earlier than a planned upgrade.

When replacing a unit, the replacement is either an equal unit kept as a spare or, as in most cases, a newly ordered unit from a manufacturer. If an identical spare part is kept, the engineering can probably be reused completely, and testing can be limited. In the case where a replacement unit is ordered, the new unit is probably a backward compatible unit of a newer design i.e. it is not an equal unit. New equipment even if backward compatible incorporates new features that may be beneficial to use. In this case the engineering as well as the testing need to be redone just as in the case of an upgrade.

The product lifetime today is largely decided by the need to redesign the protection/control hardware due to no longer available electronic components. The delivery life time of electronic components used today in digital designs is approximately between 2 - 5 years. For commercial components like PCs it may even be below a year. If redesign of hardware is necessary due to one specific component, it will not be limited to replacing this component. It will take full advantage of advances made in all required components and technology since the last design. This results in a far more powerful design with new features and backward compatibility on functional level.

The frequency of replacement because of failures can be estimated roughly. When we assume a MTTF of 100 years for a protection/control unit and 25 installed units in a station, we have a first replacement due after four years operation on the average. After four years there is a replacement unit available by the manufacturer. But for reasons described above the unit is most likely of newer design and therefore belonging to the category "backward compatible" and "not equal units". This replacement of units can not be planned, and even when keeping some stock of spare units the need to order a new backward compatible unit will arise. It will only happen a bit later and with a consequently larger gap in available new functionality compared to the previously installed unit.

On the station level the station computer mostly has operating systems with a delivery life time of 1 – 2 year. PC manufacturers with new product releases once every eight to twelve weeks are not uncommon. This does not mean that the station HMI is replaced at this pace but whenever it is replaced, it will always be based on a new hardware (PC) version and probably also a new SW (operating system) version. Replacement may lead to adaptation of engineering data and certainly to testing of the substation automation system. The engineering data in the station computer has in most cases a system wide impact and will drive the need for testing. Note that for commercial station level and communication components the MTTF is far below the value of bay level equipment, typically in the order of 5 – 10 years.

To summarise the impact of changes, nearly all initial efforts in engineering and testing need to be redone. The only exception to the rule is when equal spare units are used, but then their buying and storing cost have to be added to the life cycle cost of the station.

1.4 Impact of communication

A further breakdown of the engineering and test costs for secondary equipment will show that an ever increasing part is spent in the communication or communication related parts. Communication is today omnipresent in the substation. Almost any change of any equipment will, due to the communication, directly or indirectly generate a need to engineer and test also other parts. Fast technological advances in communications itself contribute to the rate of changes as well as requiring engineering to be re done from the beginning. Therefore, the largest part of engineering and test costs is driven in an increasing pace by the use of communication.

Summarising the status today, the changing, engineering and testing of secondary equipment are responsible for a considerable part of the life cycle costs. This part might even grow with distributed equipment and usage of (investment cost optimised) commercial devices.

2 The role of communication in life cycle costs

2.1 Device selection

All secondary devices in substations are selected with their functionality as main criteria. Surely, also cost is a decisive factor today. Especially for protection, a long formal acceptance process may be involved. Another strong focus is also on capability of databases, convenience of HMIs and engineering tools, and performance of gateways to higher level systems.

2.2 The constitution of a system by communication

A lot of secondary devices in a substation may perform their dedicated tasks with nearly no communication, like most protection devices have done in the past. Other devices like controllers are part of an overall network control scheme and, therefore, strongly dependent on a communication network. But also protection devices are today required to have serial communication interfaces to get

- fast failure recovery with help of self-supervision (maintenance on request, remote maintenance)
- the complete history of internal and external events (post-mortem analysis, system improvement)
- measured values and disturbance records (usage for operation and maintenance)
- access to the operative parameters for changes (needed for operation and adaptation)

All devices with its applications interconnected by the communication system constitute the *Substation Automation System (SA)* including a lot of distributed or centralised databases.

2.3 With communication to distributed intelligence

The trend towards more communication-based functionality is continuing. Therefore, SA functionality will not be possible without a communication network within the substation. Distributed intelligence in form of new sensors and intelligent switchgear are example of drivers here. Communication is responsible for an increasing part of benefits, but also of total engineering and testing cost (see Fig.1).

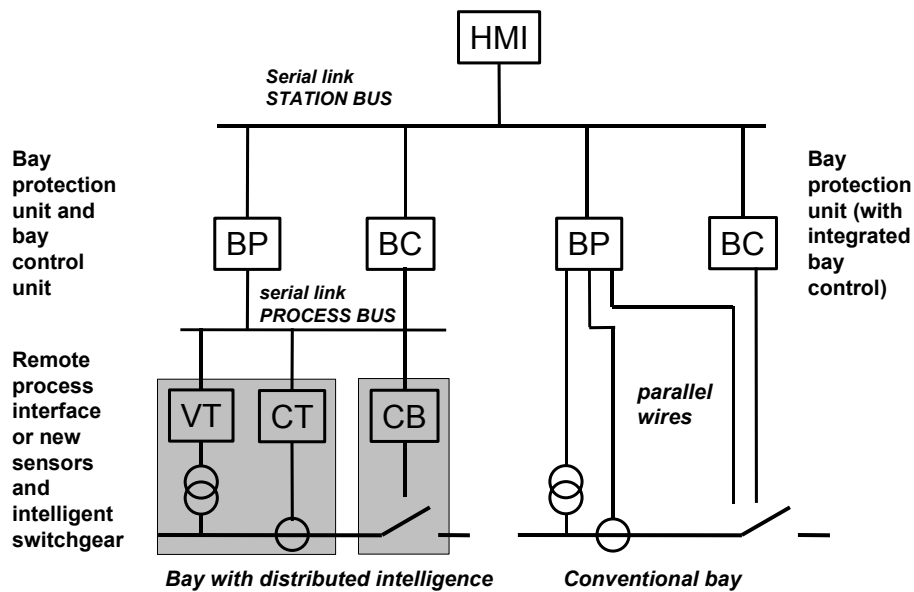


Fig.1 – Distributed intelligence driven by new sensors and intelligent switch gear (left) compared with a conventional bay (right). - Devices: Operators work place (HMI), bay protection (BP), bay control (BC), voltage transformer (VT), current transformer (CT), circuit breaker (CB), combined bay protection and control unit with integrated hardwired I/Os.

2.4 Engineering and testing of systems with communication

All devices in the system have to be properly connected with the communication system, i.e. they have to have at least a unique address. All data in the system have to be identified, properly named and addressed so that any sender may provide the proper telegrams and any receiver is able to open these telegrams and use its data. This relates also to internal and external databases where the communicated data have to be properly handled. The amount of data points depends on substation size and allocated functionality, but may reach more than 10'000 data points.

For the communication test first the connectivity of all devices to the communication system has to be assured, based on the addressing scheme. For mission critical systems like substation automation systems, an intensive point-to-point test for all data has to be performed to guarantee correct data exchange. All services like report generation, control operations, alarm handling, etc. must also be tested.

So far the static behaviour under non-exceptional conditions are covered. If once the data and connectivity engineering and test are done, the focus can be shifted to the dynamic behaviour and exception handling of the SA system. The communication must be able to handle the data throughput and avalanche conditions as applicable. This generates additional and individual requirements on engineering as well as testing. For the exception handling normally a standardised approach can be used on unit level, but applications may need to be individually addressed and can thus generate further requirements on engineering and testing.

2.5 The impact of changes in systems

As mentioned in chapter 1, changes of devices in systems happen not only in case that a faulted device has to be exchanged by an identical one, but also by a new one of the next generation or of higher functionality. Other changes may be triggered also by extensions and general upgrades.

Only in case of a 100% identical device exchange no engineering and only limited testing may be needed. Therefore, in nearly all cases at least parts of the data and communication engineering and a comprehensive testing have to be done again. If the new device has not the same communication protocol, converters have to be added and engineered.

Up to now, no change in the communication system has been assumed. Changing or updating the communication itself generates engineering and test work for most if not all connected units.

Remember that changes in the secondary system may occur several times in the lifecycle of the substation. For all these changes the same cost is generated as for the first installation. Not included are costs like the time for selection of components fitting into the system or for the training of maintenance people.

3 Goal

Adding up all figures for these changes and maintenance over the complete lifetime of the substation may result in considerable costs. The goal of any improvements shall be that the cost over the complete lifecycle of the substation is reasonably low and predictable. Since communication is the backbone of the system it plays a key role in cost handling.

4 Requirements for communication in substations

4.1 The need for a standard

The driving force of a standard is to reduce the cost per station. The basic feature of such a standard is the facility of an open communication system. This allows the open access to the global competitive market. There is also some hope for long term validity of investments made based on standards. We will see how this validity can be further assured.

4.2 The split of requirements for communication and application

Different technology life times are valid for the application and communication. The functions to be performed in substations are stable over a long time and programmed in a lot of databases and frozen in program code. The communication technology however is changing very rapidly. There is the wish to have always the most efficient communication systems and also the need to find available spare parts at any time. Rapid development also means rapid ageing and consequently out-phasing of components.

4.3 The engineering and testing problem

The long lifetime of the primary equipment compared with the secondary one generates the requirement for tools to update, extend, test and maintain the substation automation system and its crucial part, i.e. the communication system, also after a decade or longer time.

4.4 The request for a future proof standard

For the standard to help here, the standard needs itself also to be assured against ageing and replacement. It is of little use to address lifetime issues spanning half a century in a standard that will only live for a decade itself. It is then a logical consequence, that the standard first assesses its own lifetime validity and lifetime costs. The assurance of investments made when using a standard can only be achieved by assuring that the standard is the best available solution not only today but also tomorrow. It has to be able to survive a number of changes.

- Changes of its environment like technology,
- Changes of its user's preferences like customer uses RTU rather than decentralised SA,
- Changes caused by the manufacturers inventive ideas; there will be functions tomorrow which we did not think of today.

Only when this can be assured can we say that the standard has a potential to be the preferred solution not only today but also in the future. To apply the best individual solution,

open consulting and close partnership between providers and utilities stays as a value also for the future.

5 Promising approach of the standard IEC61850

5.1 Main features

Summarising the requirements for a communication network listed above, there is the

- need of a communication standard
- standard's ability to survive, which requires a certain flexibility in an evolving environment
- request to assure validity of engineering and test investments which at first glance would prohibit any flexibility at all

Looking at the main features of the new standard IEC61850 we will see how these features fulfil the above requirements.

- Free allocation of functions
- Extension rules to support new functionality
- Separation of communication from application issues in a well defined manner
- Description of the station from the application communication point of view.

No communication standard, or protocol, has explicitly addressed these issues before. The first three points above will assure a long lifetime of the standard. By having one standard only and a standard that itself addresses the issue of long term validity there is a considerable potential for cost reduction in the maintenance of a substation automation system.

The last point above addresses an entirely new issue. Not new as a requirement, but new in the sense that no communication standard or protocol description to date has ever addressed this before. It is the expensive issue of engineering and testing. Not only the engineering and testing of the station the first time, here the support is probably available by most customer and manufacturer today in order to support the in house engineering and testing. No, it is the support of the engineering and testing over the entire lifetime of the station. This issue is not necessarily well supported today and when it is supported it is based on proprietary solutions and devices.

5.2 Realisation approach

The realisation approach of IEC61850 is based on a common application model of substation automation functions. This model is based on small atomic function parts (not possible to divide and distribute any further), called Logical Nodes (LN). The logical nodes itself are standardised according to their function performed, and they contain standardised data objects (DO), on which the communication services are working. A function is then realised by a working together of logical nodes by data connections, which might be distributed to different devices, or which might run on the same device. Further standard rules are introduced to extend this standardised model with new logical nodes as well as new types of data objects. As the standard defines operational communication services only on the data objects, the LN/DO combination can also be seen as a wrapper to existing implementations, so that the resulting protocol can also be used for RTU's and gateways. A concrete, standardised protocol is then gained by mapping this abstract communication service interface (ACSI) with standardised semantics onto a real, existing and already standardised stack. The first fully standardised protocol in IEC61850 will be based on Ethernet, TCP/IP or ISO, and MMS.

This communication standard fulfils now the first three points in the list above – free allocation of function (function parts), extensibility to project specific or future application needs, and separation of application level (ACSI) from an underlying communication stack. But the function distribution introduces a new problem. For distributed functions each distributed part has to know, where the other parts are, and where and how it can get the input data it needs. If function parts are residing on different devices of different manufacturers, this introduces new compatibility problems at the engineering side. The standard IEC61850 addresses this in two ways.

- Each device can implement self-describing communication functions, which allow to query its configuration in a standardised way. This helps to check consistency of system configuration online, e.g. at commissioning time or when parts are replaced.
- The *Substation automation Configuration description Language* (SCL) allows describing in a standardised way the devices, their configuration and their functional and communication capabilities, a concrete communication structure of a SA system, and the allocation of devices to the substation primary equipment. This description can be exchanged between engineering tools of different manufacturers, thus facilitating a common approach to system engineering without the need of time consuming, error prone human conversion of engineering data.

5.3 Interoperability in space leads to interoperability over time

Luckily this approach to engineering and configuration data compatibility from engineering phase up to commissioning and maintenance, which has originally been thought to bridge differences between different manufacturers, also helps in maintaining system consistency over time. A newer device version of the same manufacturer, or even replacement of a device by a completely new HW generation (of any manufacturer), can be used to replace failed parts as long as the offered functions (logical nodes), data objects and communication services fit to the needs of the installed system described in its SCL. Also an extended system can be described in a new SCL file, and it can be checked against existing device descriptions, if it can be realised with the existing devices, respective it defines the requirements for any new devices.

6 Expected impact on life-cycle cost

Every substation and its automation system are an individual with a lot of local conditions and constraints. To get some feeling about the life-cycle costs as discussed in this paper an example is given in Fig.2 with the following assumptions:

As mentioned in section 1.2, the percentage of HW is 40% compared to the engineering and testing of 60%. This figure of 100% is used for step 1 (first installation). Further it is assumed that during the life time of the substation (40 – 60 years) the secondary equipment has to be replaced 3 times.

- With **no standard**, the full decay cost on the market is not effective. Therefore, a decay of 25% of the HW cost between two refurbishment steps (10-15 years) of the substation automation system is assumed. The engineering and testing cost per refurbishment are assumed to be the same as for the first installation. The integration up to step 4 results in 349 %.
- With a **standard** the full market can be used to realise a HW cost decay of 50% between two refurbishment steps. The engineering and testing cost per refurbishment are the same as for the first installation. The integration up to step 4 results in 315 %.
- With all the features of the **standard IEC61850**, especially with the use of SCL, a reduction of 75% for engineering and testing compared to the first installation is assumed. The integration up to step 4 results in 180%. The cost reduction over the life cycle of the substation compared with no standard is about a factor of 2.

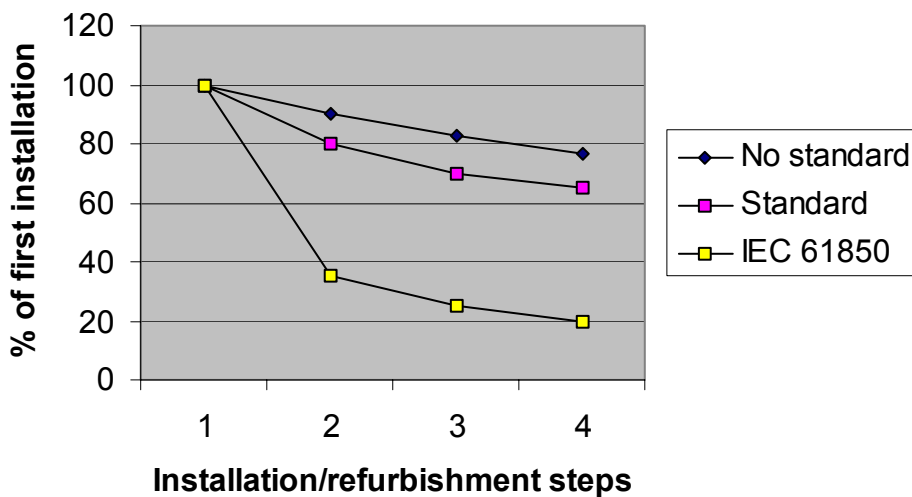


Fig.2 – The maintenance cost of secondary equipment over the life cycle of the substation

7 Conclusions

The communication standard IEC61850 addresses interoperability but also life cycle support as a well-recognised need.

Firstly, by the split of application and communication stack, in allowing for free allocation of functions, and by the standardised possibility to extend the supported functions, the standard will guarantee a long-term validity. This approach will then lead to less investment necessary in the communication part of the station as well as reduction of training cost of the personnel. Gone are the discussion of obsolete technologies on which a standard is based. Equally forgotten will the discussion be about what protocol supports better the RTU contra the fully distributed approach of SA. No more must we face the bottle neck created by a standard defining and supporting ten protection and control functions when two years later we need a standard supporting twenty five different protection and control functions. We can use one and the same standard and be assured that we are selecting the best communication solution for today's as well as tomorrows need.

Secondly, the engineering and testing cost largely determine the life cycle costs of the secondary equipment. The Substation Configuration Language (SCL) of IEC61850 is the tool to describe a substation and its secondary system from the communication point of view in a standardised way, i.e. it is possible to describe the complete substation functionality inclusive single line diagram in terms of SCL. The feature of combining device capabilities with communication configuration description and (at least functional) allocation to the substation primary equipment allows a lot of advanced possibilities above the goals considered by IEC61850.

The SCL is a standardised base for all, but especially communication oriented engineering work.

- Device specific engineering data, also in maintenance phase
- Test specification for manual as well as automatic testing
- Documentation of the communication in the substation
- Simulation of the communication

Advanced possibilities are

- Automatic testing,
- Object (aspect) based engineering and maintenance,
- Communication performance calculations
- Filling of NCC data bases and gateway engineering

These features allow also porting the substation and its secondary system configuration from an installed system to the units replacing it in any maintenance scenario. Therefore, the goal of minimising the secondary system maintenance over the substation life cycle time can be fully met.