Modeling interoperable protection and control devices for substation automation according to IEC 61850

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Summary
The standard IEC 61850 „Communication Networks and Systems in Substations" will provide interoperability for all functions in substations. To realize interoperable devices their data and functions have to be modeled according to IEC 61850. The approach and the data model of the standard is the key for understanding, but for physical packaging the device model has to be applied also. This is shown for a combined protection and control device. Example for protection is the distance protection as known from IEC 60870-5-103. It shows that the limitations of existing devices can be mastered, but that the full benefits can only be exploited with updated or new devices.
Keywords
Substation automation – communication – interoperability – IEC 61850 – modeling – design – protection – control – IED – IEC 60870-5-103

1 INTRODUCTION

Interoperability according to IEC 61850 means the capability of two or more intelligent electronic devices (IEDs) from one or several vendors to exchange information and to use it in the performance of their functions and for correct co-operation. Data transfer for utility networks is historically a one-way procedure with data flowing from a simple sender to a highly sophisticated receiver, which interprets the data. This is very often a human being that can read and understand the data with the help of his comprehensive background. An example is the master-slave communication commonly used in the past, e.g. for the information interface of protection devices according to IEC 60870-5-103. Interoperability is much more than simple data transfer, but provides for information exchange between two or more devices of similar intelligence. The receiver has to understand not only the structure (syntax) of the data, but also its meaning, i.e. the semantics in the context of the process and of his tasks.

2 THE MODELING APPROACH OF IEC 61850

All functions performed in substations have been split into the smallest entities, which communicate with each other. These entities or objects called Logical Nodes (LN) contain all function related data and their attributes to be communicated. The LNs have a standardized mnemonic name of four letters. Instances of these LNs may be implemented single or multiple in any IED. The data are accessed by defined services. Logical nodes for common applications are grouped into Logical Devices (LD), maybe one for control and another for protection. All these objects and services are the base of the function model. Since functions are implemented in devices, the function model has to be complemented by a physical device (PD) model, which describes the common properties of the device. The common device properties are described in the LN LPHD (Logical node for Physical Device). The Logical Nodes classes can be instantiated several times on the device, implementing its functionality. If not mentioned especially, we always mean instances if we talk about LNs in the context of modeling.
The data model including its services is mapped to a mainstream communication stack consisting of MMS, TCP/IP, and Ethernet; time critical messages directly to the link layer of the Ethernet. The system including the configuration is described by the Substation Configuration description Language (SCL) in XML.

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3 MODELING FUNCTIONS

3.1 Vertical function structures

Most functions have a vertical structure, e.g. they reside with their core functionality at bay level and communicate with both the station level (e.g. with the operators work place LN IHMI) and the process level (e.g. with the circuit breaker LN XCBR). If the data model of the circuit breaker (LN XCBR) resides in a breaker IED integrated in the switchgear or in an I/O card of the bay controller IED, depends on the existence of a serial link ("process bus") or parallel wires between the bay and process level.

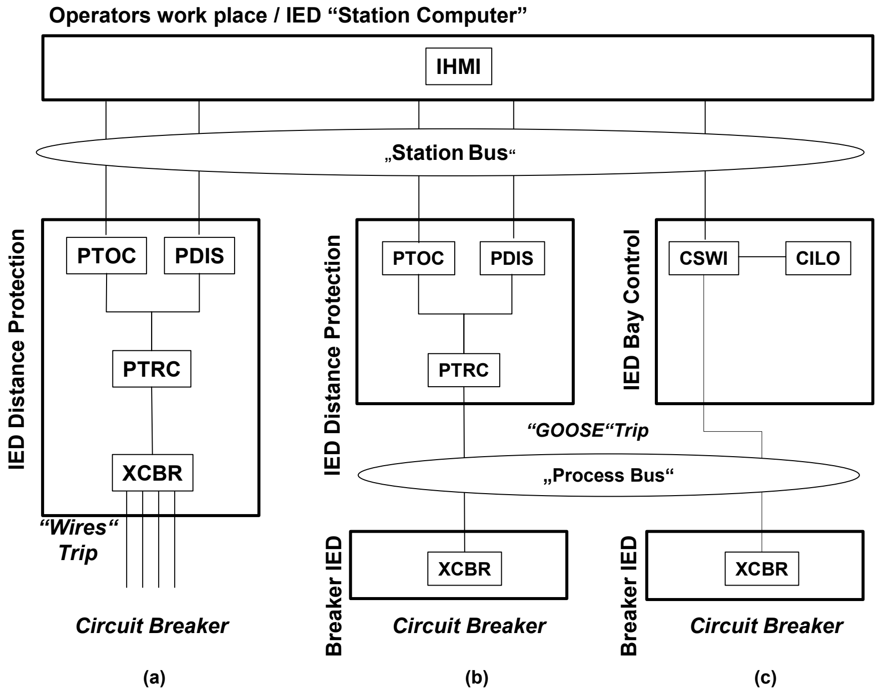

Figure 1 - Vertical function structure for protection (a,b) und control (c) with (b,c) and without (a) process bus

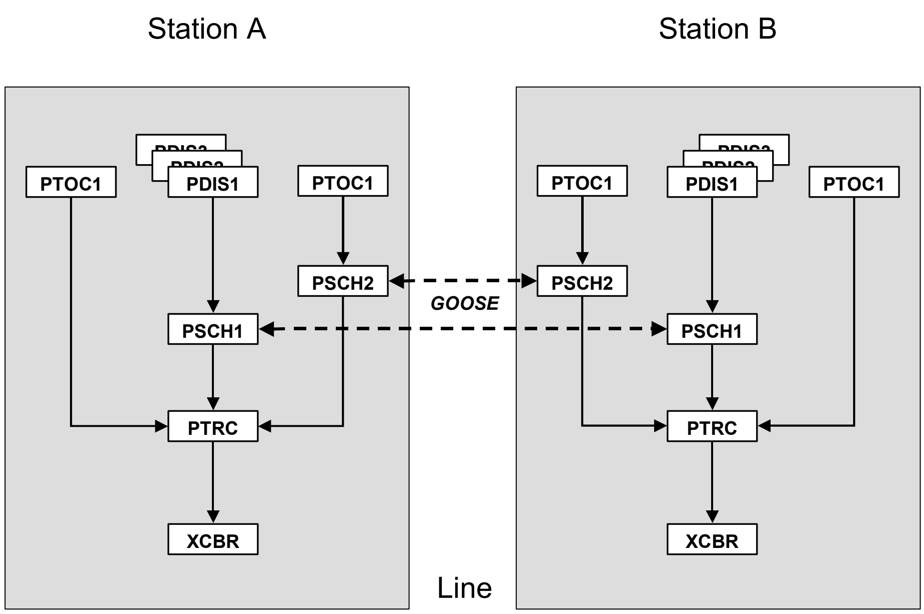

Figure 2 - Horizontal function structure for a line protection scheme with distance protection

3.2 *Horizontal function structure*

Some logical nodes exist in many instances in one level and communicate horizontally with each other. One example is the distance protection. Its LN class is called PDIS. The class definition contains three types of data, i.e. identification data like naming, status information data like “start” and “operate” (trip), and setting data. For modeling a device “Distance protection”, one instance of PDIS per zone shall be implemented, i.e. PDIS1 for zone 1, PDIS2 for zone 2, etc. The semantics of the different instances may be given in the description attribute of data NamPlt (Name Plate). The instances of PDIS may also communicate with instances on the other side of the line according to the protection scheme applied. Instances of PSCH co-ordinate the “start” (Str) and “operate” (Op) of PDIS instances and maybe auxiliary functions like time overcurrent protection (PTOC) according to this scheme. The result of the co-ordination is a trip via PTRC (trip conditioning) to the local circuit breaker (XCBR).

3.3 *Data dependencies*

The Logical Nodes (LN) define the data and the related server. To model the data flow, also inputs from other LNs can be described by the Substation Configuration description Language (SCL).

4 DESIGNING DEVICES

In this chapter we will discuss the design of a device, i.e. investigate how state of the art functions can be expressed respective mapped to the IEC 61850 functional and data model. We do not talk about mapping the IEC 61850 model of parts 7 to a protocol – this is already done in IEC61850 parts 8 and 9 in a standardized way. Further we restrict to modeling functions of a device. Functions within the system have been handled above.

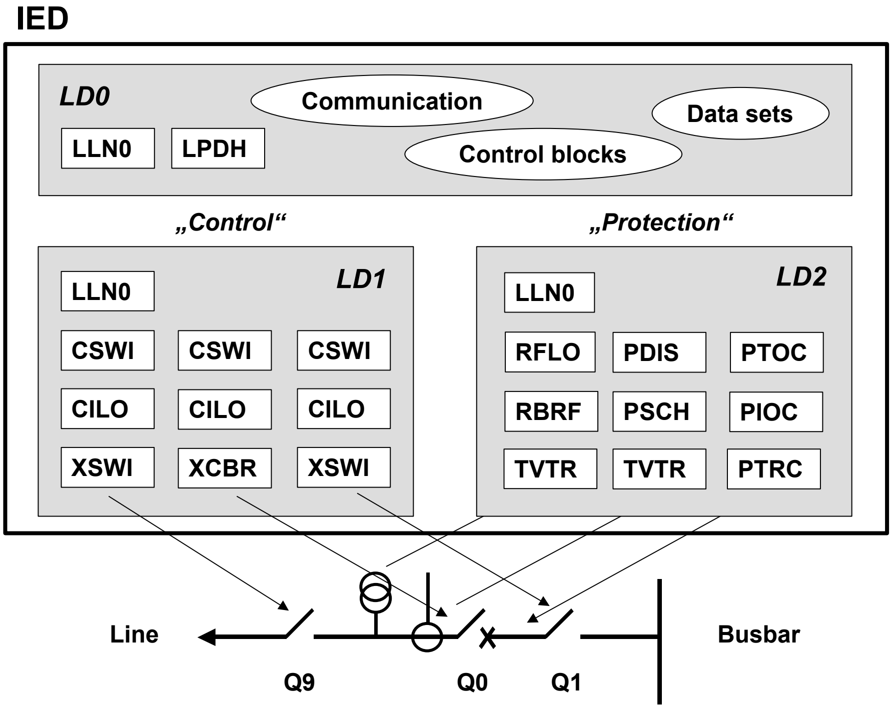

Figure 3 - Typical model of a combined device for protection and control

4.1 *Application of the device model*

Each IED is a physical device. IEC 61850 provides the logical node LPHD for modeling the physical device:

- Physical (Hardware) health
- Communication problems with statistical counters
- Power supply health with statistical counters

As all LNs must reside in some logical device (LD), this applies also for above LNs. If you have only one LD, then naturally they reside inside it, else they reside in the specially named logical device LD0, together with a LLN0, which contains common data for all LNs of a LD. In this second case it is recommended to reserve LD0 only for this purpose, and for definition of all communication related data sets and control blocks. This leaves the other LDs completely open for functional modeling, and you do not have to touch them at all for communication and system engineering at the IEC 61850 level (example see Figure 3).

4.2 Mapping existing functionality

If you have IEDs with an existing functionality and want to map this to IEC 61850, you have to cope with some problems when things do not match:

- Some general mandatory functionality like LD level Mode functionality does not exist
- Some mandatory data points do not exist
- Some mandatory data attributes do not exist
- Data or data attributes exist, but with other data type or other coding
- Services cannot be supported the way specified in IEC 61850

The provision of missing, but mandatory features can be provided at the following levels:

- IED internal program, firmware or application level
- IED communication driver for IEC61850

The selection between these possibilities depends on the generality of the problem in the IED, and on the amount of application configuration effort for a real project. If the conversion is restricted to a certain LN type, then it should be solved near the LN implementation. If it concerns a specific common data class (CDC), or is valid for data objects (DATA) like Mod, which occur in more than one LN, then it is better solved at IED driver level.

4.3 Example: Modeling an IEC 60870-5-103 device

The following illustrates some of the problems and possible solutions with a mapping of the IEC 60870-5-103 fault indications (information number IN) of the distance protection function to IEC61850.

IEC 60870-5-103		**IEC 61850-7-4, -7-3**			
IN	**Description**	**LN**	**DATA**	**Attribute**	**Comments to LN or DATA**
64	start/pick-up L1	PTRC	Str	phsA	Protection trip conditioning
65	start/pick-up L2	PTRC	Str	phsB	
66	start/pick-up L3	PTRC	Str	phsC	
67	Start N/ pick-up	PTRC	Str	neut	
68	general trip	PTRC	Op	general	
69	trip L1	PTRC	Op	phsA	
70	trip L2	PTRC	Op	PhsB	
71	trip L3	PTRC	Op	phsC	
72	trip I>> (back-up operation)	PIOC1	Op	general	Instant. Overcurrent
73	fault location X in ohms	RFLO	FDOhm	mag	Fault location
74	fault forward/line	PTRC	Str	dirGeneral	DATA no Boolean. Another value in the same attribute
75	fault reverse/busbar	PTRC	Str	dirGeneral	
76	teleprotection signal transmitted	PSCH	ProTx	stVal	Teleprotection scheme
77	teleprotection signal received	PSCH	ProRx	stVal	
78	zone 1	PDIS1	Op	general	Distance protection
79 - 83	zone2 - 6	PDIS2 – PDIS6	Op	general	One PDIS instance for each zone
84	general start/pick-up	PTRC	Str	general	Protection trip conditioning
85	breaker failure	RBRF	OpIn	general	Breaker failure
90	trip I>	PTOC2	Op	general	Time Overcurrent
91	trip I>>	PIOC3	Op	general	Instant. Overcurrent
92	trip IN>	PTOC4	Op	general	Time Overcurrent
93	trip IN>>	PIOC5	Op	general	Instant. Overcurrent

At the first glance this looks nice. All IEC60870-5-103 signals belonging to distance protection have been mapped (the missing information numbers IN 86 – 89 only belong to Transformer differential). One problem appears for IN 74 and 75: two different binary signals are mapped to one enumeration type signal. Further we see that a lot of LNs are used for all signals of the same distance protection function. The difference between the distance backup I>> (PIOC1) and other possible independent overcurrent functions (PTOC2, PIOC3) or earth fault functions (PTOC4, PIOC5) can no longer be seen by standardized identifications. However, is this necessary in this case? If yes, grouping by prefix (see later) offers a possible solution. On the other side, IEC 61850 LNs have a lot more mandatory data objects, which should be handled:

- The mandatory settings can be provided just as 'static' values to be readable via the IEC 61850 stack. The needed values can be provided via the IED SCL file.
- The mandatory general data objects Beh, Mod, Health, and NamPlt can be provided as read only values. An exception in our 103-example for Mod is the PSCH, for which beneath a status indication also a control command exists (both IN 17). Further the Protection *off* command and indication (IN 18) should be mapped to LLN0.Mod. Health can be mirrored from LPHD.PhyHealth, if nothing else is available, and be reduced to the states *ok* and *alarm*. An exception here again is the PSCH, where the IN 39 (teleprotection disturbed) can be mapped to PSCH.Health. Mod can be statically *On*, if not provided specially as described before. Beh then is calculated from Mod and Health as defined in 7-4. NamPlt is also statically provided.
- The mandatory PTOC Str and PDIS Str can be provided statically, values are then always *FALSE*. The mandatory RFLO FDkm can be calculated from FDOhm and some additional parameter.
- IEC 60870-5-103 has some more commands in control direction. From this e.g. the autoreclosure *on/off* together with the appropriate status indications (IN 16) should e.g. be mapped to the RREC.Mod data object.

Above examples illustrate most of the principle problems. The mapping of services is not relevant in this context, but only for a protocol stack mapping.

4.4 Packing of LNs

As we have already seen in the 103 example above, it is sometimes wanted to group LNs according to some common functionality, like the distance protection handled above, or all LNs handling the same primary device like the circuit breaker, or for common management like Protection on/off. For grouping of LNs within an IED the IEC 61850 provides the following mechanisms:

- Logical devices
- Logical node (LN) prefixes

4.5 Grouping with Logical Devices

The logical device allows via its logical node LLN0 common management functions for all contained LNs. This is especially

- the data object Mod, which allows to block or switch off all LNs of the logical device at once
- the data object Loc, which shows the local / remote state for all process controls within the LD.

Typically an IED contains beneath the LD0 for the physical device separate LDs for protection and control according to Figure 3, and very often, additionally for disturbance upload. If an IED controls switches as well as a transformer, then again this is typically separated into different LDs. Simple IEDs containing e.g. just protection might have only one LD, which then manages all contained LNs. As long as this grouping is function oriented, it is recommended to name the LDs (beneath the mandatory LD0) according to IEC 61346. If you make top down design of the SA functionality, then you might also group LNs according to LDs, if you want to have a common management function for them. These functional LDs are then later allocated to IEDs as needed and as available. After this process the LNs for the physical IEDs are added as needed.

4.6 Grouping with Logical Node Prefix

The prefix allows a functional grouping for engineering or naming purpose within a LD, without any common management functions. This corresponds to what has been called horizontal function structure above. Seen from the device modeling and engineering these might contain pre-engineered function parts within an IED fulfilling one common purpose. A typical grouping has already been mentioned above: all LNs for distance protection get a common prefix, e.g. 21 according to IEEE / ANSI notation, and the independent backup overcurrent function gets another (or no) prefix to separate it. The prefix can also be used to distinguish and denote different usages of the PTOC related function, e.g. first step or second step overcurrent, earth current protection etc. Related to the 103 example this could give the following groups:

Prefix (acc. IEEE/ANSI)	**Grouped LNs**
21_	PDIS1, PDIS2, PDIS3, PDIS4, PDIS5, PDIS6, PIOC1, PTRC, RFLO, PSCH, RBRF
51_	PTOC2, PIOC3
67N_	PTOC4, PIOC5

Table 1 prefixing for protection related LNs

Another typical grouping, which is more control related, is the following:

Prefix (acc. IEC 61346)	Grouped LNs
QA1 (circuit breaker)	CSWI1, CILO1, XCBR1
QB1 (busbar isolator BB1)	CSWI2, CILO2, XSWI2
QB2 (busbar isolator BB2)	CSWI3, CILO3, XSWI3
QE1 (earthing switch)	CSWI4, CILO4, XSWI4

Table 2 prefixing for control related LNs

4.7 Preconfiguration

IEC 61850 defines semantics on LN and data object level. However, the detailed functionality of a LN also depends on its binding to the process. A typical example here is the interlocking logic (LN CILO), which looks different for a bus bar disconnector than for an earthing switch or a line disconnector. One way to show a special CILO implementation according to the place of the switch in the single line diagram is to use prefixes, as shown in Table 2 above. Another, more general possibility is to model the appropriate part (e.g. bay) of the plant with links to the LNs in the Substation section of an SCL file for this IED: This SCL file then just contains the IED type description, with an empty IED name, as IED section, and the relevant part of the SCL Substation section.

4.8 Process interface

The process interface is modeled in IEC 61850 with T, X, Y and Z type logical nodes. These are typically found on process near IEDs, which are often called PISA (Process Interface for Sensors and Actuators), and are connected to protection and control functions via a process bus. If however a protection device is connected directly with cables to the process, then the question arises, if the modeling of the interfaces is necessary at all.
There are situations, where the necessity is clear: some interfacing LNs include some basic functionality like monitoring, supervision and command blocking. If the bay level device also provides this functionality, even if in some rudimentary form, then the modeling of the interface is necessary. A typical example is to use TVTR for VT fuse supervision. The rule should be that everything to be visible outside the IED shall be modeled as defined in the standard. This might also open up possibilities not so obvious.
An often-used feature is a local/remote switch per bay. This is typically modeled by an LLN0.Loc data object in the control logical device. If however additionally operation directly at the switchgear is possible, and for this also bay level (local) control shall be inhibited, the appropriate Mod or Loc data objects at a LD modeling the switchgear itself, i.e. just containing X and Y type LNs, can be used.

4.9 Setting groups

The standard allows the definition of setting groups and the switching between different setting group value sets. There is however at most one setting group per LD. So, if a device supports different setting groups, the LNs having data in the same setting group have to be put into the same logical device, and for each setting group there must exist a logical device. Especially it is not possible to have a part of LN data in one setting group, and another part of the same LN in another setting group.
In case that an IED has setting groups where the value set activation can be online changed, but value change of parameters within the set is not possible, then an IED can just contain a setting group control block, but identify no parameters as belonging to it. Naturally a setting group might contain changeable parameters as well as hidden parameters, i.e. parameters not visible in the data model. However, the hidden parameters can then not be changed in a standardized way. If a change is not wanted, but the actual value shall nevertheless be documented in a standardized way, this can be done via the SCL file. For parameters outside a setting group this can also be done by only providing read only access to them.

5 CONCLUSION

IEDs with existing functions can be modeled according to IEC 61850 with some restrictions, which should not apply for new IEDs. The free allocation, combination and connection of LNs allow to optimize the system architecture and to implement also new functionality. This supports in a standardized way e.g. combined devices for protection and control, which goes beyond IEC 60870-5-103. The IEC 61850 provides also extension rules, which allow also to introduce in a standardized way new LN classes and data for today unforeseen semantic (future proof). This was as already explored in the domain of wind-power plants (IEC 61400-25).