IEC 61850 interoperability from a client/integrator point of view

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Abstract

The primary object of this paper is to describe a number of functional and database design choices made by Hydro-Quebec in order to facilitate the acquisition and validation of Intelligent Electronic Device (IED) based on IEC 61850 standard. IEC 61850 is a standard that specifies "requirements and [provides] a framework to achieve **interoperability** between IED" in a substation. A short contextualization of the project is followed by a presentation of the concept of Logical Node (LN) which, because of the presence of optional fields, is problematic on some aspects.

The third section presents the main functional and database design choices made in the implementation of a configuration system prototype (SCALCID). The concept of LN SubClass is introduced as a mean to reduce the cognitive distance between the LN classes and LN Type. Hydro-Québec standard IEDs are organized on an n-level hierarchy where the first n-1 levels are "abstract" IEDs and the last one, "concrete" IEDs. The hierarchy is built by a standardization agent to allow an automated adaptable validation of the capabilities of the supplier's IED. The result of this validation is the main input by which to judge the qualities/capabilities of an IED from the standardization point of view.

The conclusion presents a suggestion to improve the IEC 61850 standard.

Key-words

IEC 61850, Interoperability, Substation, Substation Automation System.

1 Introduction

From 2003 to 2006, IEC introduced the IEC 61850 series of standards [1] for Substations Automation System (SAS) whose main objectives were "to specify requirements and to provide a framework to achieve **interoperability** between the IEDs [Intelligent Electronic Device] supplied from different suppliers". The standard is composed of 10 parts, but this paper is concerned only by part 7 (Basic communication structure for substation and feeder equipment) and by part 6 (Configuration description language for communication in electrical substations related to IEDs). Part 6 describes the requirements for the configuration and Part 7 presents the requirements for the real time exchanges.

In 1999, Hydro-Québec (HQ), a Canadian public utility, decided to begin the specification of a new SAS that should take over from ALCID, a LAN based control system developed in the eighties, based on proprietary application protocols. The change was motivated by the desire to have more than one supplier thereby possibly reducing the acquisition and maintenance costs.

In 2003, HQ chose the IEC 61850 standard because of its functional completeness and openness. The completeness allows the implementation of all the functions of the old system; the openness facilitates the adaptation to the idiosyncrasies of the old system. The fact that there was no need for any major functional change in the real time system mainly facilitated the acceptance of the transition toward the new SAS (ALCID II). But this acceptance was conditioned by a constraint on the parameterization: because of the complexity of the IEC 61850, the technical engineers did not need any knowledge of it [2]. This constraint can be satisfied:

1. "By programming", with a high risk to have a non adaptable SAS: that is to say the necessity of software engineering intervention for every significant change;
2. By a heavy intervention of the users in charge of the HQ standardization (standardization agents in the HQ terminology) to prepare the parameterization before the intervention of the technical engineers.

HQ chose the second option. Once the decision to adopt the IEC 61850 was taken, the main question on the agenda became "How to prepare a parameterization environment that facilitate the acquisition of the IED and assure that the IED are really interoperable and are compliant not only with the IEC 61850 but also with the HQ standards with the additional constraint that technical engineers don't need any knowledge of IEC 61850?"

This paper will present a partial response to this question based on the system currently available at HQ.

Section 2 describes the IEC 61850 concepts and problems that are essential in order to understand our approach to the SAS configuration.
Section 3 describes the present version of the HQ configuration system and the conclusion presents a suggestion to improve the standard.
Because this paper describes a system based on the current IEC 61850, it does not present any kind of formal model or meta-model of the IEC 6850 as in [2].

2 IEC 61850

Logical Node

The most important functional component defined in the IEC 61850 is the Logical Node (LN). A LN is "the smallest part of a function that exchanges data" [1], that is to say it is the smallest functional component of an IED (a physical node). 91 different classes of LN are currently defined by IEC but the standard allows the introduction of new classes as long as the class respects its syntactic rules. A LN, as a logical component, is a link to the substation equipments and, as a physical component, is a part of the IED Software. The LN class is structurally characterized by attributes (DATA) of a kind of CDC (Common Data Class) and is a part of a Logical Device (LD). CDCs are the standardized classes that define the structure of the DATA that are the constituent parts of LN classes.
A LD is a "virtual device that exists to enable aggregation of related logical nodes for communication purposes" [1]. The LD is contained on a Server as illustrated in the next figure.

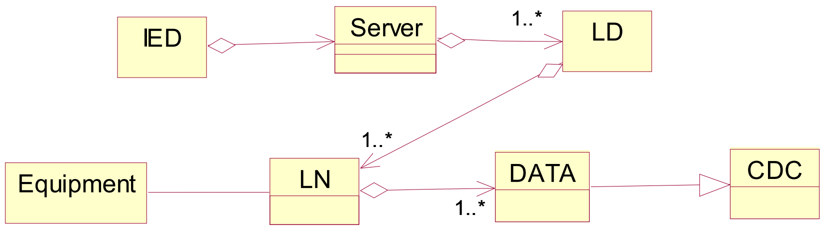

Figure 1 LN associations **s**implified UML diagram

A LN attribute is called *Data* in part 7 of IEC 61850 and *Data Object* (DO) in part 6.
To summarize: a function F_X is realized by the collaboration of $LN_1 \ldots LN_n$ that physically resides on $IED_1 \ldots IED_m$. At configuration time a LN can be moved from an IED to another, depending on the substation requirements and on the IED capabilities.

A server is seen by a client as a set of services allowing the reading of substation data or the receiving of asynchronous datasets. A service *GetDirectory* describes the structure of the elements offering the services that are available at server, LD, LN and DATA level.

Configuration

During the configuration, the IED capabilities description file is transferred from an IED database to a System Configurator where the capabilities are mapped to the substation specification. A System Configurator creates a file for each IED that is transferred to an IED configurator. The IED configurator then prepares and transfers a file containing the final version of the parameters to the IED: that is to say the parameters are transferred from the engineering environment to the SAS (the real time system).
Along with his "IED family", an IED supplier must deliver both an IED configurator and an IED capabilities database. An integrator must therefore deal with several different IED configurators that must exchange their IED capabilities/configurations with a common System Configurator.
The configuration files are XML files whose schema is defined in [1].

The problem with "classes"

The class diagram of Figure 1 represents a very simple and easy to understand model of the LN class associations but it does not represent the IEC 61850 standard correctly. Unfortunately, the "error" is not in our translation of the part 7 in UML but in the standard itself: LN and CDC are not "true" classes in accordance with UML (or programming languages) definition because both have some optional attributes (they are not instantiable).

Figure 2 presents as a concrete example the DO "PresAlm". PresAlm is defined as "Pressure alarm because of an abnormal condition (FALSE = Normal, TRUE = alert" [1]. PresAlm is shown in the figure as a component of two different LN classes for insulation medium supervision: SIML and SIMG. PresAlm as a SIML attribute is "Insulation liquid pressure alarm" and as SIMG attribute is "Isolation gas pressure alarm", that is to say the semantic of PreAlm is specialized because of the class membership. PresAlm is a kind of SPS (Single Point Status) that is a kind of CDC. The SPS has three mandatory attributes, two optional attributes and seven conditional optional attributes. Even if we consider only the two straight optional attributes, we can have four structurally different PresAlm (four different classes) for the "same" kind of object.

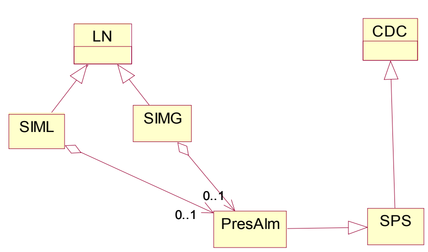

Figure 2 PresAlm

The next table shows two structurally different SIMG LN with different PresAlm. It is important to underline that the two SIMG are not instances but classes. Only PresAlm is detailed in the table.

Table 1 Two "kinds" of SIMG

SIMG_A DATA		**SIMG_B DATA**		
….		…		Mandatory attributes from LN
EEHealth				External equipment health
		EEName		External equipment name plate
InsBlk				Insulation gas not safe (block device operation)
		InsTr		Insulation gas dangerous (trip for device isolation)
InsAlm		InsAlm		Insulation gas critical (refill isolation medium)
PresAlm	stVal	PresAlm	stVal	Isolation gas pressure alarm
	q		q	
	t		t	
	d			
		Den		Isolation gas density

The "two kinds" of SIMG are not particularly similar and it is therefore very difficult for a software engineer to imagine that they constitute the same class. Because of this difficulty, part 6 introduces the concept of LN Type as an instantiable LN. But, are SIMG_A and SIMG_B LN Types? In other words, are they two instantiable LN? The answer is "Yes", if one supposes that the optional attributes of all SIMG DATA have been fixed. In the previous table only the detailed structure of PresAlm is shown: there are two "types" of PresAlm, the first one with a "d" attribute and the other without the "d". By analogy with LN Type one can speak about DATA Type. But since what is called DATA in part 7 is called DO in part 6 where the configuration language is defined, the type of the DATA is called DOType. In short, the previous table contains two different DOTypes for PresAlm and it contains two different LN Types for SIMG.[1]

We can imagine a situation where supplier A creates his own SIMG LN Type and names it SIMG_A, with its own DO PresAlm of DO type PresAlm_x. Supplier B, on the other hand, could create a LN Type SIMG_B with a DOType PresAlm_y. Theoretically, for the real time system, there is no interoperability problem because an IED client can query about the LN structure and so it can know what kind of SIMG generated the instance instantiated in the IED[2]. For example the service *GetLogicalNodeDirectory* (*NameofLNInstance*, *DATA*) will return the references to all the DATA available in the instance of the LN Type. But nothing prevents the two vendors from giving the same name to the two types (SIMG_C, for instance) or from giving two different names to the same type. This extreme "freedom" does not invalidate the interoperability but it generates many problems for the integrators when they want to verify detailed IED functionalities and be assured that the IED satisfies the SAS requirements. Problems can also arise when the client wants to know what the vendor is really selling to him.

3 SCALCID

In February 2006, HQ commissioned the *Institut Trempet* of *the Université du Québec à Montréal* to develop a prototype of a system configurator (SCALCID) for ALCID II. The main objectives of the

1 The attributes of DO can also have some options. A true instantiability therefore needs a Data Attribute Type (DAType as defined in part 6). To facilitate the reading and because the approach to DOType and to DAType is the same, this paper does not present DAType.

2 Theoretically, but not practically, at least if the client is a program that must react to the data and must not only display it for a human being.

prototype were the following:

1. Facilitation of the functional requirements elicitation, specification and validation; [3]
2. Design and implementation of a centralized database;
3. Storage of the IEC 61850 and HQ substation control standards data in the SCALCID database. This section describes the solution currently implemented.

Users Roles

Four roles have been introduced:

1. *Administrator*. This is a classical “database administrator” role with the addition of the enumeration management because of the great sensitivity of SCALCID to the enumeration changes. All the enumerations are not “frozen” into the software but easily modified in the database.
2. *IEC Agent.* This role allows the importation/exportation or update of the IEC 61850 data.
3. *HQ Standardization Agent*. This role allows the adaptation of the IEC 61850 standard to the HQ requirements. In particular, it allows the addition of new LN Classes and the creation of a link between the LN and the equipment.
4. *Technical engineer*. The technical engineer is responsible of the configuration of a SAS.

It is the HQ Standardization Agent who hides the IEC 61850 to the technical engineer to satisfy the constraint defined in section one of this paper. Even if the person-machine interface gives the user the choice to show LNs, technical engineers can do the SAS configuration without knowing the IEC “components”: LN, LD, etc.

Subclas

The passage from a LN Class to a LN Type presupposes an understanding of the concepts of DO Type and DA Type and their utilisation to concretize the LN Class. Our experience with substation domain experts leaves absolutely no doubt: this understanding is very time consuming and demanding and the passage from LN Class to LN Type is rarely very clear. Certainly on the one hand, this lack if clarity is due to a lack of pedagogical qualities in the standard, but on the other hand, it is also due to the cognitive distance between LN Class and LN Type.
In order to reduce this cognitive distance, we have introduced the concept of LN subclass. A LN subclass is created by deleting from the parent LN Class the DOs that HQ does not need and by adding the DOs that do not exist in the IEC 61850 standard but are needed by HQ [4]. The lack of optional DOs and the presence of all the DOs that characterize the LN facilitate the understanding of the LN function. Moreover, the cognitive step from the LN SubClass to the LN Type (the true concrete class in programming terms) is similar to that from LN Class to the LN SubClass. Because of this, once the first step in taken, the second one is therefore easily taken too.

HQ standard IED

The HQ standard IEDs are created by the HQ Standardization Agents from building blocks (LN, Services, etc.) previously created by him or by an IEC agent. The IEDs are organized on n[3] levels hierarchy:

- *Root.* (level 1) The root IED is an IED without LN instances. It is an abstract definition of the services, LN Classes and LN SubClasses available. LN Classes are not restrained to the ones defined in the IEC standard. Two roots are currently foreseen: one for the protection function and the other one for control and measures.
- *Abstract IED.* (level 2 to n-2*)*. All these levels are a specialization of their parent (level 2 is a specialization of root). New services, LN Classes and LN SubClasses can be defined but, as for root, there are no instances. Several abstract IEDs can be defined at every level.
- *Concrete IED.* (level n). At this level, services and classes cannot be changed but LD, LN Types and LN Types instances can be added. The LN type instances can be created one by one or via a

3 Currently only three levels are implemented even if the database is designed for a generic n level.

copy operation from the equipment. When the copy is from equipment the link with the process is also established.

IED Capabilities Validation

Before buying an IED, the XML IED capability description file of a vendor is imported and validated against a HQ standard IED. After a syntactic validation, a combination of three (3) different kinds of semantic validation can be chosen:

1. *Services and LN Classes*. The absence of services or LN is critical and can compel the rejection of the IED.
2. *LN Types*. A difficult validation because of the "freedom" of naming analyzed in the previous section. The absence of LN Types is less crucial than the absence of Classes, but the risk of rejection of the IED is very high. Whether Dos, DO Types or DA Types are missing will determine the level of difficulty brought about by the validation. Moreover, not all DOs, even if mandatory, have the same importance.
3. *LD and instances*. This validation concerns only HQ standard concrete IEDs. If an IED has all the LN Types but it has not all the instances, the vendor can most likely parameterize it. A new IED parameterization would possibly be easy to do if the HQ standard concrete IED is already linked to the equipment.

The result of the validation is the main input on which to judge the quality/capabilities of an IED from the HQ standardization point of view. After each kind of validation, a log file is generated to support the HQ decisions. It is important to underline that LN Subclasses cannot be validated because the vendors are not aware of the existence of this "concept".

Database

The next figure shows a simplified representation of database tables that support the IED capabilities validation.

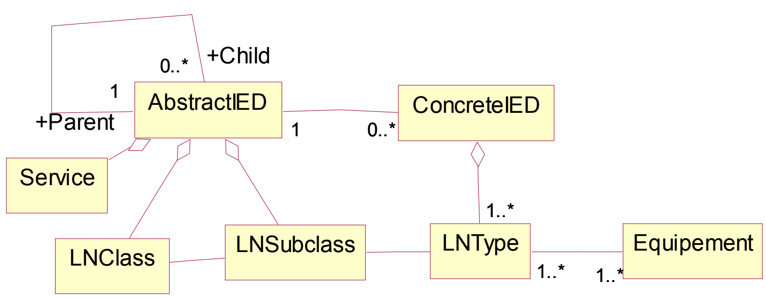

Figure 3 Validation Tables

Two columns of AbstractIED are especially interesting for our purpose:

- FOLLOWS_PARENT: True if the IED is consistent with its parent. This column allows the definition of a child that does not respect all the constraints imposed by the parent IED.
- CONSISTENCY: True if the IED is internally consistent.

Because the HQ Standardization Agent can practically do want s/he wants, the risk of having an inconsistent database is very high. To reduce the possibility of user errors, a *Cricality* attribute is associated to every database column. Criticality indicates the possible negative effect of change of a data on the database's integrity, and the Criticality value conditions the possibility and/or easiness of deleting data.

4 Conclusion

"The narrower the application domain is, the easier interoperability implementation becomes" is a truism in software engineering. The substation communication domain is narrow enough to allow an efficient and effective implementation of interoperability, but it is also large enough to require a sophisticated configuration. A common definition of the real time data's semantic exchanged between IEDs is therefore of little use without a configuration environment where technical engineers can efficiently manage a great number of parameters. SCALCID is such an environment

In this paper we have presented the HQ approach to solving the problems originated by the openness of the IEC 61850 standard which allows a construction of a SAS with modifiable building blocks. The task of reducing the number of possible objects and of hiding IEC 61850's complexity rests on the Standardization Agent's shoulders. However, in order to facilitate the Standardization Agent's learning of IEC 61850 types, we have introduced the concept of LN Subclass[4] and an application that allows her/him to build a standardized IED against which the vendor's IED is validated.

We believe that not only the SCALCID satisfies the HQ requirements, but also that it is easily adaptable to the requirements of any IEC 61850 client/integrator.

The implementation of SCALCID confronted us with a number of problems in the current IEC 61850 version in which the standard "openness" implies a rather overly complex configuration environment.

In order for the implementation of the interoperability to become more efficient, it would certainly be useful for the "optionnality" of DO to be handled real time and not at configuration time as is currently done with the concepts of LN Type. This implies that an LN Class must contain all the attributes provided by the standard but, when a client asks for the value of an attribute, if the LN (Instance) does not use this attribute, the IED responds "not implemented". This requirement requires a major change to the standard, but we believe that because at present there are so few IEC 61850 IEDs, the timing is right for implementing this much needed change.

Acronyms

CDC	Common Data Class.
DO	Data Object.
HQ	Hydro-Québec.
IED	Intelligent Electronic Device
LD	Logical Device.
LN	Logical Node.
SAS	Substation Automation System.
SPS	Single Point Status.

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[5] Trempet : http://www.trempet.uqam.ca/trempet/membres/Maffezzini/Telecommande/SCALCID

4 We are aware that the "subclass" is not a good term, but because of the particular use of "class" and "type" in the IEC 61850 standard, we have not found a more appropriate one.