A Case Study on the Impact of Interoperability on Substation Automation System (SAS) Engineering

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Abstract

In 1999, Hydro-Quebec launched a project for the modernization of its Transmission and Distribution Substation Automation System (SAS). One of the fundamental requirements of the new system was to increase interoperability between system components in order to reduce the cost of integrating such components. The requirement for conformity with the IEC 61850 standard makes it possible to support this interoperability but is it sufficient? The standard, written by manufacturers, has to be based on flexibility and openness. The payload for this flexibility appears not only in terms of the complexity of the standard and the structure of the IED but also in terms of amplified substation engineering activities. Initially, at Hydro-Québec, the adoption of this standard forces the system designer to standardize the first applications and to some extent "close" their implementation. The main issue deals with the IED parameters settings. The watchword is to hide the complexity of the standard from the project designer. Meanwhile, at Hydro-Québec, the gradual adoption of the standard will confirm that the system designer's role is more that of a system engineer, whereas the project designer will unquestionably have to assimilate the concepts of the standard.

Résumé

En 1999, HQ a lancé un projet de modernisation de son système de contrôle-commande (SCC) des postes de transport et de distribution. L'une des exigences fondamentales du nouveau système vise une interopérabilité accrue entre les composantes du système afin de diminuer les coûts d'intégration de telles composantes. L'exigence de conformité avec la norme CEI 61850 permet de soutenir cette interopérabilité mais est-ce suffisant ? Cette norme, conçue par les constructeurs de systèmes, se doit donc d'être flexible et ouverte. Ce besoin de flexibilité se paye non seulement en terme de complexité de la norme et de la structure des IED mais aussi en terme d'ingénierie des postes et d'organisation. Dans un premier temps, à Hydro-Québec, l'adoption de cette norme oblige le normalisateur à fixer les premières applications et en quelque sorte à « fermer » sa mise en œuvre. Au cœur de la question : le paramétrage des IED. Le mot d'ordre : cacher la complexité de la norme au configurateur. Et à moyen terme, l'adoption graduelle de la norme ne fera que confirmer le rôle du normalisateur comme s'apparentant à celui d'un ingénieur système alors que le configurateur devra indéniablement assimiler les concepts de la norme.

Keywords

Interoperability, IEC 61850, openness, control, Substation Automation System (SAS), standardization.

1. BACKGROUND

Hydro-Québec (HQ) is the state-owned utility responsible for the generation, transmission and distribution of electrical power in Québec. In 1999, HQ launched a project aimed at modernizing its Transmission and Distribution Substation Automation System (SAS) [1]. The current system consists of a distributed system on an Ethernet LAN with standardized layers 1-4 of the OSI model and an in-house application protocol. New functions are difficult to integrate. In 2002, starting with GOMSFE [2] as a basis, the project coordinators decided to rewrite the specifications of the new Substation Automation System (SAS) based on the IEC 61850 series of standards [3], which set interoperability requirements for IEDs (Intelligent Electronic Devices) in substations.

With respect to real time, no special constraints, aside from compliance with the standard, have been defined by HQ, while a major constraint was specified for substation engineering, namely that personnel in charge of SAS parameterization should have no knowledge of IEC 61850 to carry out their work. In this paper we will use the term “interoperable IEDs” to indicate IEDs that comply with IEC 61850, and the term “protocol” will refer to the exchange protocol between application processes rather than to the protocols from layers 1.7 of the OSI model which we consider to comply with the standard.

At HQ, the SAS engineering structure operates at two levels: the standardization level which sets fixed rules for all HQ substations, and the project level that tailors the system to the requirements of a specific substation. The HQ system designer and project designer are the personnel assigned to the two respective areas.

2. INTEROPERABILITY

Interoperability is defined in [4] as one of the six (6) subcharacteristics of functional capacity and comprises quality attributes in relation to the “*capability of the software product to interact with one or more specified systems*.” This definition, along with the measures of interoperability attributes defined in [5] and [6], may be of some use for assessing the quality of the product being developed, but is virtually of no use in system design. For interoperability, just like any other quality requirement, to be efficient and one of the elements that drives a project, it must take into account some of the characteristics of the domain. With respect to electrical transmission and distribution substation automation, to allow interoperable IEDs to be built, the IEC (International Electrotechnical Commission) created the standard [3]. In [3], interoperability is defined as being the “*ability of two or more IEDs from the same vendor, or from different vendors, to exchange information and use that information for correct execution of specified functions*.” Though still very general just like the first definition mentioned above, this definition, with the phrase “execution of specified functions,” adds information that may have or has a huge impact on the engineering of a given substation. IEDs are no longer considered as monolithic elements but as receptables for functions where interoperability comes into play. But the question is, what kind of function? Such a question is far from being trivial and its answer, by changing the level of interoperability, changes a project’s level of complexity. In fact, interoperability can be reduced to something quite simple (the function executed by an IED is “complete” and requires virtually no cooperation from other IEDs) or it can be made enormously complex (the function is in fact a subfunction which requires other subfunctions with their own respective subfunctions, and so on, to execute a significant task for the domain). The finer the granularity of the functions that can interoperate, the more the system will be flexible. For instance, a circuit breaker’s control function may be set up as several subfunctions that can be executed by more than one IED. IEC 61850 provides for circuit breaker control being handled by one, two or three IEDs, and the choice of the number of IEDs is left up to substation engineering, i.e. those in charge of the system architecture. This choice implies that the IEDs must be capable of adapting to the architectural requirements of the customers setting up the subfunctions (*logical nodes* (LN) in the terminology used in [3]) where deemed appropriate from a substation management standpoint.

This need for flexibility is obtained not only at the expense of the level of complexity of the standard and IED structure but also in terms of substation engineering and organizational structure. In this paper we are looking at engineering and structural problems.

Interoperability often appears as a requirement from customers who wish to use several suppliers so that they can benefit from lower purchasing, installation and maintenance costs for their systems. However, when manufacturers are the ones to indicate how interoperability should be implemented, the latter is defined to facilitate the manufacturing of IEDs. In the case of SASs, the manufacturers’ response has been to become involved en masse in the drafting of the IEC 61850 series of standards where a hierarchy of

classes is defined which implement a set of basic functions, i.e. the LNs. In other words, the standard not only defines a functional core that implements the main functions of a substation and SAS, but it also standardizes functional extension and modifications so that it does not hinder technological developments and adapts to each customer's specific requirements. Generic functions are standardized in an IED, thus making them less specific, with said functions requiring a relatively complex parameterization to operate. This approach, which is undoubtedly the most logical one from the standpoint of manufacturers at this stage of technological development, has impacts that are not always evident on structure and engineering at the customer's end. The customer needs to parameterize IEDs in order to adapt them to substation operating and SAS maintenance procedures, as well as parameterize the IEDs from different manufacturers so that they can cooperate in the execution of functions.
Efficient interoperability is therefore achieved by providing flexible and "open" machines that the customer then has to "close" and render operational through parameterization. IED parameterization is naturally not a new development associated with interoperability: customers have always been using parameters to adapt IEDs to substation characteristics. What IEC 61850 does in terms of interoperability is add more complex parameterization because of the specific features related to the sophistication of the logical framework architecture defined by the standard.

3 TASK SHARING

3.1 Introduction

Task sharing between the system designer, project designer, and IED manufacturers is heavily influenced by the constraint that states that the specific features of the standard [3] may at no time make the project designer's work more complicated. This constraint results from the traditional structure and efficiency of the engineering function at HQ, which takes into account the costs related to the training of personnel as well as the number of substations (transmission and distribution) involved. The idea then is to make transparent to the project designer the IED characteristics that pertain to the structure of the IEDs themselves so that the sole concern is the substation's functionalities as seen by SAS users. "Making transparent" means blocking some choices that the standard makes available by decreasing the openness intended by manufacturers. For instance, the standard, in the modeling of the equipment part (the part that concerns the process), presents a *substation* as made up of *bays* and, in the modeling of application process communications, it stipulates that the LNs in an IED be included in logical devices (LDs). The standard does not stipulate anything regarding the manner in which LDs are to be structured nor does it say anything about the bays. These two "omissions" have a different impact on knowledge for substation engineering. The bay-based structure flows fairly logically from the substation structure and does not require any specific knowledge other than in substation automation systems. The LD structure requires knowledge in communications and computer systems (e.g. performance, ease of access to data). In the HQ environment, it is natural for the project designer to create bays, but it is not logical that he would make decisions regarding the creation of LDs since the concept of LDs is directly linked to the way LNs are structured within IEDs, which is beyond the project designer's know-how.
Who, then, can create LDs, given that they are an essential part of IED parameterization?

1. *The manufacturer*. This solution is suitable for IEDs with set functionalities such as protection IEDs, but it is not feasible for IEDs with more general functions related to substation automation such as a bay controller involving several bays.
2. *The system designer.* The standardization of fixed functions from one substation to the next led HQ, at least for the first version of the system, to make an automatic association between the bay and LD. A 1-to-1 association was therefore implemented between Bay and LD [5] that allows LDs to be easily created using the parameterization support program.

However, though the choice made under point 2 to dissimulate the LD concept is fairly simple, it is much more difficult to dissimulate the LN concept which forms the basis for the standard. To demonstrate how substation engineering has been simplified by dissimulating the LNs, we will analyze the functional links between the IED LNs and the process.

3.2 Functional link between IED and process

The main parameterization work done by the project designer consists in "linking" the IED's generic functions to the process. In this respect, three possible approaches can be considered to define the SAS architecture:

1. Add a protocol "translator". The IEDs are connected on the LAN and communicate through a translator which converts the data from an IED into a format that the other IED can read and vice versa. This situation is widespread but is of no interest when interoperability is a central requirement. To talk of interoperability in such a case is to use the term incorrectly.
2. The IEDs are connected on the LAN and exchange information in order to correctly run their functions. No action is required on the project designer's part.[1] This is the ideal case which should be strived for but it is not realistic at the current level of technology and standards since not only would the semantics of the application have to be formally defined but the substation management methods (customer's rules) would have to be standardized outside of the company.
3. The IEDs are connected on the LAN and must be modified so that they can interoperate. Here we are dealing with open interoperable systems.

The remainder of the article will only consider the third case. The first case will not be considered since it is a solution that does not take into account the interoperability requirement within the actual IEDs. The second case will not be studied since it is of no practical interest (unless no more than one manufacturer is considered, which is contrary to the definition of interoperability in [3]). Neither will we consider an interoperability situation with no practical use for substation management even if it complies with the standard in every way; this is a situation where an IED responds to all messages that are not "read" only with a message that it cannot perform the task.
The remaining sections of this paper will thus consider the tasks that are added to the usual ones (those required to set up the current substation automation system) in order to make open IEDs interoperable.

3.3 Manufacturers' tasks

Parameterization may be delegated to manufacturers who are given substation specifications by customers. This is a turnkey approach but one that is not very compatible with open interoperability involving several manufacturers. HQ has decided to purchase the most open IEDs possible and to have the integration work (adaptation/parameterization) done in-house. The substation automation IEDs are therefore delivered as generic IEDs without any link to substation equipment.

3.4 System designer's tasks

The HQ system designer is a pivotal figure not only because he allows standardized SASs and IEDs to be created but also because, as the only person with knowledge of the standard, he is responsible for defining everything in the standard that is not directly related to the application process.
The system designer can be said to have two main tasks: the first consists in describing equipment and substations and associating them with the LNs, and the second involves all the operations required to ensure the standard is hidden from the project designer:

1) **Modeling.** Consists in describing the substation LNs while taking into account the IEC's requirements. Such modeling must allow rules and objects specific to HQ to be integrated [7]. In HQ's case, this work led to the drafting of a specification [8] which is the main input for the creation of the databases.
2) **Standardizing signal names.** Establish a naming convention for signals that is consistent with the standard while keeping the current system names so that the project designer does not see any changes in relation to the current system.
3) **System configurator.** Define the characteristics of a system configurator that allow IEDs from different manufacturers to be integrated.
4) **Type of parameterization**. Make a choice between what is set through off-line parameterization and what can be parameterized on line (the standard provides RT flexibility which must be limited if some IEDs are not to be made overly complex[2]).
5) **Standardize the IEDs.** Standardize some of the IEDs that follow the modeling in item 1 such that the parameterization is virtually reduced to copying the data of the standardized IED.

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[1] The updating of communication addresses is not being considered; though it can be a more significant task than anticipated, it is still always fairly simple in relation to application process interoperability.
[2] This flexibility, however, is highly useful and even necessary when a new generic client has to be added who wishes to receive information from the IEDs so that it can process them in a special way that is not necessarily related to the substation's basic functions.

6) **Standardizing typical bays.** Standardize certain bays (especially with respect to distribution) that would allow the eventual standardization of an entire substation (distribution station).

4.3 Project designer's tasks
In theory, the project designer's work should not change in terms of the current system's parameterization. To do so, the system configurator should allow a certain number of tasks to be automated. The project designer's tasks for a specific project are as follows:

1) **Implement the use of standardized bays and functions (LNs).**
2) **Implement the use of standardized IEDs.** LDs and LNs are allocated to standardized IEDs.
3) **Automatic configuration:** e.g. reports, datasets, logs.

4.4 Conclusion
The fact that manufacturers virtually play no part in parameterization and the project designer's role does not change, even if parameterization becomes much more complex, is only possible because the system designer's role has changed considerably. On the one hand, new activities have been added and on the other, the system designer's field of knowledge has shifted to communication and software engineering problems. However, without automation mechanisms, these new tasks would be too cumbersome and not very reliable. To facilitate the work of the system designer and consequently that of the project designer, we introduced a standardized objects database as a storage centre for the closing constraints that HQ requires from the IEDs.

5 STANDARDIZED OBJECTS DATABASE (SODB)
All of the data that describe the substation and IEDs are stored in a Configured Objects Database (CODB) under the project designer's jurisdiction. This database contains the data that describe a given substation and that are required to prepare the XML files to be loaded into the IED configurators to parameterize the IEDs. The contents of the CODB originate partly from the project data and partly from a Standardized Objects Database (SODB). The major functions of the SODB are as follows:

1) Set limits for the project designer's choices regarding:
   a. Equipment specifications;
   b. Communication features.
2) Store all enumerations of the standard to facilitate the work performed by system configurator applications.
3) Establish links between process data and the data standardized by IEC 61850.

We will show the importance of the SODB to substation engineering by considering an aspect of the third function.

For example, the following figure shows the conceptual model that links the SODB metaclasses for the different types of points.

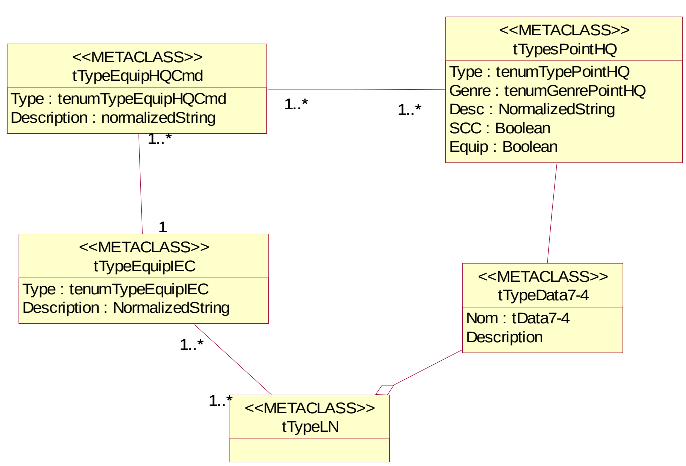


Figure 1: Relationship between the different types of points

tTypePointHQ defines the characteristics of the different "points" (digital inputs, analog inputs, and digital outputs) of the current system which are related to Hydro-Québec equipment seen from a control standpoint (*tTypeEquipHQCmd*). The types of controlled equipment are associated with the type of equipment in the IEC standard (*tTypeEquipIEC*). *tTypeEquipIEC* is linked to a type of LN (*tTypeLN*) that contains the data defined in the standard that are associated with the types of points in the current system.
This conceptual model was simplified when the SODB was created by setting up a table used to create a direct link between the types of points in the current system with the type of LN and types of points in the standard.

Table 1 – Association of HQ points with IEC points

Name	**Description**	**Source**
TypePoint	T-TypePointHQ.Type	T-TypePointHQ.Type
TypeData	T-TypeEquipHQCmd.Type	T-TypeDataCEI-7-4.Type
TypeLN	T-TypeLN.Type	T-TypeLN.Type

The above table allows the system configurator software to show the project designer the points from the old SAS and to automatically generate information on the new points from the standard's point of view [3].

6 Conclusion

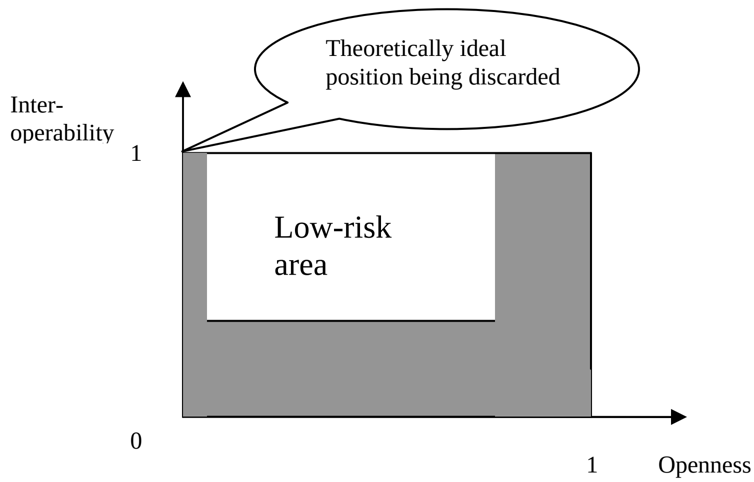
To conclude, we would like to present a certain number of questions, some with tentative answers, and propose the modeling of links between the openness of the IEDs and the interoperability that we would like to expand in the future.

What could be the impact of the proposed approach for distribution stations when applied to transmission substation automation, which is by nature more difficult to standardize?
Would system designers be capable of managing the SODB by themselves and update not only the contents but the structure as well? If not, then a pivotal role would have to be given to another type of player (e.g. software engineer), who would only be replacing the manufacturer, who has been needlessly "removed" from the project.
Is the constraint that requires that the project designer know nothing of the standard overly stringent? If so, then how will he be able to share management of the SODB? What part of the system designer's work will he be in charge of?
Currently at HQ, a database containing data from a facility is considered to be an engineering drawing and belongs to the facility operator. Is this still the case if an SODB is introduced?

None of the above questions have simple answers, but what appears to us to be feasible, at the current stage of interoperability standardization, is that the system designer acquire more in-depth knowledge in the area of databases and communication and that the project designer slowly begin to learn the concepts presented in IEC 61850. In this way, substation engineering, which currently seems to be outside of the control of project designers, could once again be their responsibility and the system designer's role could be more akin to that of a system engineer.
For substation engineering not to carry any unpleasant surprises (e.g. much higher than anticipated parameterization and application development costs), we suggest analyzing the interactions between the openness of the IEDs (in short, the quantity of possible adaptations) and their interoperability.

By following [5], the value of the interoperability attribute can be considered as a ratio of $Y= A / B$, where A represents the number of data formats that have been correctly exchanged with other IEDs and B is the total number of data formats exchanged. The ideal interoperability is therefore equivalent to 1. Openness is defined as a ratio of $X = C/B$, where C represents the number of adaptations to the data formats exchanged and B is the total number of data formats exchanged. The ideal openness is therefore equivalent to 0. Openness as defined here is proportional to the cost of parameterization.

The following figure shows the high-risk areas in grey. When interoperability is below a certain level, regardless of the openness, the system is inadequate. The same applies when openness is above a certain level, since parameterization costs become too high. We also considered to be inadequate an area with considerable openness (X tends to 0), even though the situation where interoperability is equal to 1 and openness is equal to 0 is ideal. It is considered as a high-risk area since the slightest change in requirements may considerably disrupt interoperability.



Lastly, we would like to add that the fact that a system is open and adaptable to users' changing requirements is not a positive feature in itself, as is too often stated. It is positive only if the cost of the adaptation work done by the client is lower than the price quoted by manufacturers to "close" the IEDs. But the tendency of clients to underestimate costs often prevents the right choice from being made. One way to decrease the possibility of having overly high IED closing costs is to make sure that the project designer has the required tools to automate part of the parameterization process. However, these tools, when they are very high-tech, account for a non-negligeable part of the IEDs' development cost.

7 References

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