Towards the Formal Integration of Two Upcoming Standards: IEC 61970 and IEC 61850

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Abstract— The constant demand for a better integration of utility applications and systems raises the question on the compatibility of standards that were, and still are being developed for the individual utility disciplines. This paper discusses the need for an integration of two particularly important emerging standards related to data interchange in substations (IEC 61850) and control centres (IEC 61970). The relatively independent development of these two standards motivated us to create a model that can show explicitly how concepts from one standard relate to those of the other. Further, by making these models *formal*, which in the case of IEC 61850 is *absent* in its current daft, we can show the benefits in checking internal model consistency and in automating the model mapping. Concretely, our UML models proved helpful in detecting inconsistencies in draft versions of the IEC 61850 and they served as a basis for the tool-based, bi-directional mapping of IEC 61850 to IEC 61970 data representations.

Index Terms— Common Information Model (CIM), IEC 61970, IEC 61850, Energy Management System (EMS), Substation Automation System (SAS), Substation Configuration Language (SCL), Resource Description Framework (RDF), Unified Modelling Language (UML), common model

I. INTRODUCTION

CONTROL systems in network control centres (EMS/DMS) and substations (SAS) are employed to monitor and control power system equipment. While these systems focus on the same physical objects, they differ primarily in the levels of detail of information provided, in performance requirements, and in their scopes of responsibility in process control.

Largely historically motivated, but also for the purpose of reliability and due to the importance of their functions, all these systems were generally developed as closed systems. Three main reasons contributed towards a change to open and standardised systems: (a) The proliferation of proprietary communication protocols, proprietary APIs (application programming interfaces), different data representations, etc., for all these systems and their constituent products, leads to repeated huge costs to ensure interoperability. This is especially true for a heterogeneous systems landscape, which is an inevitable fact in most today's utilities. (b) Utilities have recognized that the same data, and sometimes even the same

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functionality, are used in different applications and therefore should rather be reused than re-entered or, as far as functionality is concerned even reacquired or redeveloped. (c) New or refurbished applications need to be integrated into the suite of existing applications constantly and rapidly. Such reuse and integration efforts are immense and need agreed upon standards that cover the communications technology aspects as well as the application data semantics.

Two emerging standards are related to data interchange in substations (IEC 61850 [1]) and control centres (IEC 61970 [2]). Although they are still work in progress, some parts of them have already become de facto standards, and the system vendors provide first implementations of parts of the specifications: but more importantly, utilities require conformance to them in their current invitation for tenders. However, despite the similar application domain (electrical utility control systems) and the foreseeable future integration requirements of EMS/DMS with SAS applications the development of the two standards progressed unfortunately quite independently. Only recently has the IEC (the "mother" organisation of both standards) through its Technical Committee TC57 specified a reference architecture [3] for related standards for electrical utilities, among them also the two mentioned above.

It is the foreseeable interoperability or even integration of applications based on these two standards that challenged us to conceiving a mapping of their data models. Concretely speaking, it should be possible to extract and convert an IEC 61850-based representation of a substation configuration, represented in SCL (see III.B and IV.B) to an IEC 61970-based CIM/RDF representation (see IV.A). This extraction and conversion should be bi-directional and automated as highly as possible. Hence, the data mapping should not only be informal and targeted towards human processing, but also be based on machine-processable, formal models. We have chosen the UML (Unified Modelling Language [4]) as the model representation language, since it has become a *de facto* modelling standard in software engineering. For a brief introduction to UML, refer to [5] and [6]. For our purpose we have only made use of UML's static structure diagram (class diagram) and model management features (packages, etc.) with the standard, textual annotations defined in UML.

Fig.1 shows the context of this work. UML-based representations are an integral part of the IEC 61970 to consistently describe its data model (package CIM_10 in Fig. 1), but unfortunately not used in the IEC 61850. The latter does not use any formal modelling language but relies on

textual specifications only, which leaves model consistency checking up to humans. Consequently, we had to develop a UML model of the IEC 61850 first; i.e. we had to create consistent models of Parts 6, 7-2, 7-3, and 7-4 of the IEC 61850 (package IEC61850_Aug2002 in Fig. 1). Only then could we establish a model mapping (package CimTo61850_Mapping) based on the semantics of the data objects of the two standards. Besides enabling the model mapping, our UML model of Part 6 proved valuable in extending the existing SCL with type-based consistency checks. Hence, we call our version SCL+ .

CimTo61850_Mapping

CIM_10   IEC61850_Aug2002

automatic   manual
Schema   automatic coding of
generation   code   mapping
              generation rules
CIM RDF   automatic   SCL+
Schema   code   Schema
                                  generation
              Converter
              prototype
         validates   validates
Data   Data
Engineering   CIM   SCL+   Engineering
                 RDF   XML

CIM   SCL+
RDF   XML

CIM (IEC 61970)   IEC 61850
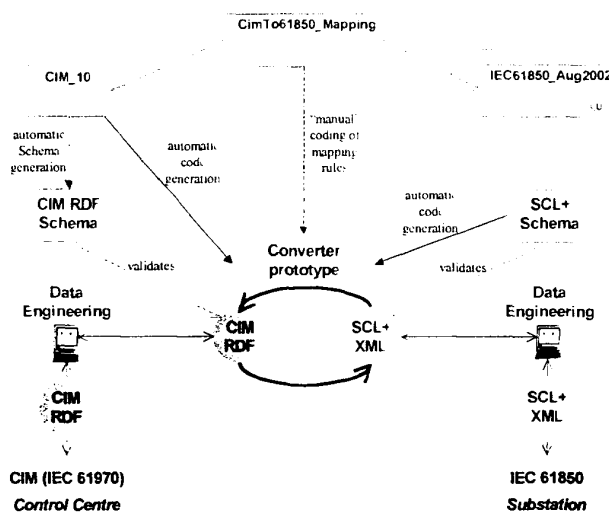Control Centre   Substation

Fig. 1: Tool-based conversion from IEC 61850-based SCL to IEC 61970-based CIM/RDF

The rest of the paper is structured as follows: Section II briefly compares the related IEC standards IEC 61850, 61970, and 61968. Section III then presents the data models of the IEC 61850 and the IEC 61970 as well as the basics of the model mapping. Section IV discusses the XML-based data descriptions of IEC 61970- and IEC 61850-based systems. These XML representations are meant to serve as standardized configuration descriptions in order to exchange configuration and static data in electronic form. They must of course be compliant with the data models and are simply another representation of UML model instances. Before concluding in Section V, a brief overview of a prototype converter is given.

II. RELEVANT IEC STANDARDS

The IEC WG57, Power System Control and Associated Communications, has issued and has been working on several standards, as described in [3]. However, three emerging standards deserve special attention, since they do not specify only the communications-related models, but contain also high-level data semantics for applications provided by the utility control and other IT systems (see Table I):

- *IEC 61850: Communications Networks and Systems in Substations* [1] primarily specifies abstract communication service interfaces (ACSI) and their mappings to concrete protocols. In addition, it defines an elaborate data model and a configuration data exchange format.

- *IEC 61970: Energy Management System Application Programming Interface (EMS-API)* [2] normalises a set of APIs for the manipulation of both real-time critical and near real-time EMS/SCADA data, as well as a data model and a configuration data exchange format.

- *IEC 61968: System Interfaces for Distribution Management* [7] extends the IEC 61970 model for both domain modelling and APIs. These APIs are meant for inter-application messaging at the enterprise level.

TABLE I
COMPARISON OF THE THREE STANDARDS

Comparison criterion	IEC 61850	IEC 61970	IEC 61968
Control system domain	SAS	EMS	DMS
IT system domain	Substation *intra*-apps	EMS *intra*-apps	Utility *inter*-apps
Data model	Yes	Yes (CIM)	Yes (extends CIM)
Serialisation format	Yes	Yes	Yes
Communications protocol	Yes	No	No
APIs	No	Yes	Yes

The comparisons in Table 1 show that all of them specify a data model, and provide a formal way for configuration data representation. Note that since the data model of IEC 61968 extends that of IEC 61970 (CIM, Common Information Model), it will not be discussed further — IEC 61968 has been included in the above comparisons only to put it in the context of the whole utility IT infrastructure. We will therefore limit our discussion to data models and configuration data exchange between CIM (for control centre systems) and IEC 61850 (for substation automation systems).

III. DATA MODELS AND MAPPINGS

The field data needs to be transmitted from substations to control centres, and the very first step in making the respective systems inter-operable, is the process of systems configuration. This is currently performed by communication protocol-dependent mapping of signal addresses (data points). We have started to develop a UML-based model, which enables a higher-level mapping of the related concepts, based on the data semantics (instead of addresses) defined in CIM and IEC 61850.

A. CIM (IEC 61970)

In order to support the exchange of power system models, utilities needed to agree on common definitions of power system entities and relationships. To support this, EPRI started developing a *Common Information Model* (CIM). This model has been submitted to IEC, and has been incorporated and further developed within the (draft) standard IEC 61970: Energy Management System Application Programming Interfaces (EMS-API) [2]. The objective of CIM is to support the integration of independently developed applications between vendor specific EMS systems, or between an EMS system and other systems that are concerned with different aspects of power system operations, such as generation or distribution management.

CIM specifies common semantics for power system resources (e.g., a substation, a switch, or a transformer), their attributes (e.g., ampRating for a breaker), and relationships (e.g., a transformer has two or more windings) using UML. The "master" model is maintained as a Rational Rose™ model file, which can be browsed online at [7]. The automatically generated model documentation makes normative Parts 301, 302, and 303 of the standard.

B. IEC 61850

Although the IEC 61850: Communication Networks and Systems in Substations [1] is basically a communication standard, great effort was invested in the domain analysis, which resulted in a quite elaborate data model. The main abstraction of this model is the *Logical Node* (LN), a number of which is defined in Part 7-4 of the standard. They serve to group related data objects, and are contained in IEDs (Intelligent Electronic Devices). An LN may thus represent one of the following: (1) a kind of atomic functional building block for substation automation functionality, such as a protection or a control function, or (2) a kind of proxy object for the primary equipment (e.g., an LN that groups data objects relevant for a circuit breaker or a tap changer). LNs are composed of data attributes, which are in turn composed of other data attributes, and so on for up to 5 levels; at the bottom end, there are primitive ASN.1 types, such as boolean or integer (defined in Part 7-2). The attribute names and types at each but the latest level, carry the semantics of the domain, and are defined in Part 7-3 of the standard.

Note that the data contained in an LN is not only typical operational data (e.g., measured value, or position status, with their quality and time tags), but can also be configuration data (e.g., the device nameplate, or its last configuration version). This implies that a device can describe itself.

For configuration purposes, the IEC 61850 defines the *Substation Configuration Language* (SCL) in its Part 6. SCL is an XML schema, with the elements and attributes reflecting the domain model. So, the self-description capability of IEDs can be made available in a standard, human- and machine-readable way, through an XML instance file. SCL allows one to also configure the communication-related attributes of an IED (e.g., supported ACSI services, server address), as well as the equipment and communication topology within the substation. The physical hierarchical structure of the substation is defined in SCL only, whereas the rest of the standard focuses on LNs (and their data), which model the functionality of the devices. SCL (together with the extension we have defined) is discussed in more depth in Section IV.B.

IEC 61850 specifies its data model by means of tables in a Word document (except for SCL, defined as an XML schema). Therefore, our first step towards the mapping of the two standards was to develop a UML model of the IEC 61850 itself (as far as data representation is concerned), including SCL [8]. Only then could we start to identify the concrete relationships between the two data models, which is examined in the next section.

The definition of the UML model for IEC 61850 allowed us to discover several inconsistencies in the standard's draft. They were all submitted to the IEC, and some have already been taken into account in the latest release of the draft.

C. Mappings between CIM and IEC 61850

Obviously, there is only a partial mapping between the two standards, as they are not used for the same purpose and scope. Notably, the level of information granularity is not the same: IEC 61850 goes considerably "deeper" into details of substations, whereas CIM has more aggregated information for several substations that is sufficient at control centre level. Besides the fact that the two models are quite different, this mapping between the two standards is made more difficult by differing terminologies.

A UML model of the mappings has been built [8], based on the CIM UML and the UML model of IEC 61850 we developed (see the previous section). Mappings are applicable to two sets of elements: (1) substation and equipment identification including hierarchical relationships, and (2) discrete status and analogue measurements, both including quality and timestamp attributes. Fig. 2 shows an extract of this model for some mappings of hierarchical relationships. The data classes are given in rectangles (attributes and operations are omitted in the figure). Several types of relations can be established between classes:

1. A generalisation (or "is-a") relationship is shown with an arrow towards the super-type. For instance, a Bay is an EquipmentContainer.

2. Association relationships capture the static relationships between entities. These generally relate to one object having an instance of another as an attribute or being related in the sense of owning (but not being composed of). An association is represented with a line connecting the two types. For instance, there is an association between Bay and BaySCL (which is a mapping association in this specific case).

3. Aggregation is the typical "whole/part" relationship. It is depicted as a line joining the two types, and with a white diamond (◊) on the "whole" part. On each side of the aggregation, cardinality constraints and role names can be provided. For instance, a Substation contains 0 to an undefined number of Bays (cardinality 0..n, role name

26

`Contains_Bays`), whereas a `Bay` is part of at most one `Substation(0..1, MemberOf_Substation)`.

4. Composition is exactly like an aggregation except that the lifetime of the "part" is controlled by the "whole". In other words. the "part" makes no sense without the "whole". This relationship is represented by a line with a black diamond (♦) on the "whole" part. Cardinality constraints are usually provided only on the "part" side because a "part" always belongs to one and only one "whole", by definition. For instance, a `DeviceSCL` belongs to exactly one `BaySCL` (which can contain any number of `DeviceSCL`).

Note that "pure" SCL objects have their name modified with an "SCL" suffix in order to avoid any confusion with other types from IEC 61850 Parts 7-2, 7-3, and 7-4.
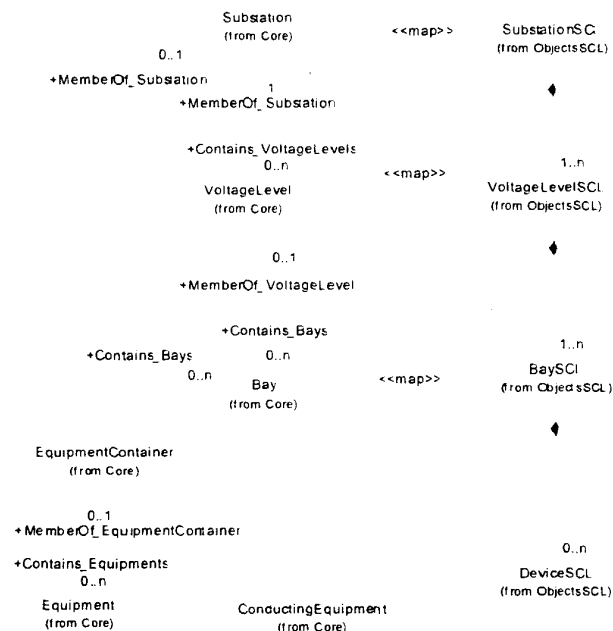

Fig. 2: An excerpt of the class mappings between CIM (IEC 61970–left, in white) and SCL+ (an extension of SCL defined in IEC 61850 Part 6–right, shaded). Mappings are identified with associations labelled with «map» .

As it can be seen in Fig. 2. some mappings of concepts seem quite straightforward. For instance, the CIM `Substation` corresponds to the SCL `SubstationSCL`. However, all mappings are not that trivial, for several reasons:

- Some concepts exist in one model without corresponding concept in the other model. For instance, `Battery` in IEC 61850 has no equivalent notion in CIM.
- Only a partial mapping exists: only parts or the description can be converted into the other format. The relevant attributes are to be translated, while the others are ignored.
- One element in one format corresponds to several different elements in the other format. For instance, `BaySCL` may correspond to `Bay` and/or

`BusbarSection` in CIM. Conversely, information from several elements may have to be combined to generate a single element in the other format.

- A mapping may be conditional, i.e., the conversion must obey some rules. For instance, the topological position of `Measurement` in CIM can be deduced from IEC 61850 `CurrentTransformer` or `VoltageTransformer` or both, depending on some attributes.

Even if the two models map quite well for some parts, the cardinality of the associations may not be the same for both standards. This introduces further difficulties, especially in the context of an automated converter of instance files. For instance, as it can be seen in Fig. 2, in SCL, a `BaySCL` must be part of a `VoltageLevelSCL`, which itself must be part of a `SubstationSCL`. For the corresponding notions in CIM, the organization can be quite different: a `Bay` may be part of a `VoltageLevel`, a `Substation`, both, or none. CIM does not constrain this. Thus, in CIM, there may be no bay at all, and equipments (such as breakers) can be contained directly by the `Substation`, at least according to the model. To the contrary, in SCL, all equipments must (indirectly) belong to a `BaySCL`. Therefore, any automated converter needs to pre-process the instance file before translation.

In contrast to the above described automatic pre-processing, there are some mappings that need a user interaction. One such a mapping is shown in Fig. 3. Despite the similar semantics of `CustomerMeter` in CIM and `BillingMeter` in IEC 61850, they do not have the same data attributes. However, with the user interaction, the mapping can be established (see comments in Fig. 3).
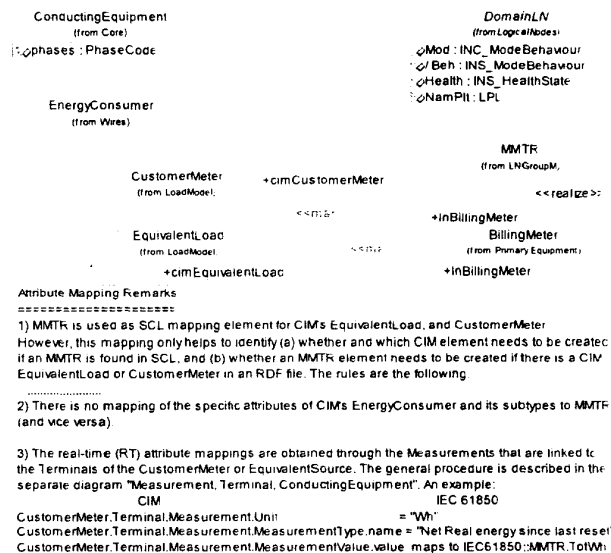

Fig. 3: An excerpt of the class and data attribute mappings between CIM (IEC 61970, in white) and IEC 61850 Part 7-4 (shaded). Class mappings are identified with associations labelled with «map» and data attribute mappings are detailed in the comment

IV. CONFIGURATION DATA DESCRIPTION

As far as the configuration data representation is concerned, both standards make use of the eXtensible Markup Language (XML) [9] as the language for describing data instances. In short, XML is a platform-independent language for interchanging data (originally designed for the Web), and is becoming the de facto standard as serialization format. An XML Schema allows one to define the data content and structure of an instance document, and thus to validate its structure.

However, the structure (i.e., the format) of the instance documents for each standard complies with different schemas.

A. IEC 61970: CIM/XML in RDF

CIM/XML, a language for expressing CIM models in XML, is defined in Part 501 of the standard [2]. CIM/XML is an application of the Resource Description Framework (RDF) standard [10].

RDF is a framework for describing and interchanging *metadata*, i.e., information about information. RDF was originally intended for representing metadata about Web resources, such as the title, author, and modification date of a Web page. RDF provides a common framework for expressing metadata so it can be exchanged between applications without loss of meaning. The goal of RDF is to elevate the status of documents from *machine-readable* to something we might call *machine-understandable*. RDF makes use of XML as a common syntax for the exchange and processing of metadata. RDF is based on the concept of *statements*, defined as a triple associating a subject, a predicate (or property), and an object. As a result, RDF instance files have a very simple structure (a directed graph), which is easily machine-processable, whereas XML schema allows for quite complex structures.

CIM/XML uses only a subset of the complete RDF/XML syntax, together with some extensions, as described in [11]. The CIM/XML schema is generated automatically from the UML model using the XPetal tool. Several successful interoperability tests have been conducted, using CIM/XML to exchange real-life, large-scale models (involving, in the case of one test, data describing over 2000 substations) between a variety of vendor products, and validating that these models would be correctly interpreted by typical utility applications (e.g., dispatcher power flow).

Noteworthy, an open source Java API called CIMvalidate allows one to validate a CIM instance file automatically.

B. IEC 61850: SCL (SCL+) as XML Schema

SCL is normalized in Part 6 of IEC 61850 [1] as an XML Schema. SCL describes the substation automation system configuration as well as the switchyard structure. It is designed to be mainly used by engineering tools as import/export format.

The SCL schema models only partially IEC 61850. For this main reason, we have defined our own schema, called SCL+, which extends SCL. The major differences between the two are summarized below:

- Extension of the XML Schema to incorporate the elements below the logical node concept (such as common data classes, data attributes), as defined in our UML model of 61850 (see Section III.B).
- The use of XML complex types instead of just complex elements for further reusability (sub-classing allowed, i.e., tailoring to specific needs can be done).
- Harmonization of attribute names.
- The original SCL (draft revision of September 2002) does not fully comply with the text description. SCL+ attempts to correct this.

Nonetheless, in its current state, SCL+ does only partially incorporate the data model described in IEC 61850 (Parts 7-2, 7-3, and 7-4). For instance, the logical node is defined as a complex type, with an LNClass attribute that defines its function. Moreover, a meta-model in SCL+ describes that a logical node is composed of a set of data objects. However, SCL+ does not contain yet any information about which data objects can be part of a given logical node.

C. Automated Converter Prototype

To test our UML model of mappings and see to what extent the conversion between the two data models can be done automatically, we have implemented a prototype conversion tool in Java, which encodes some of the UML mapping rules and is able to perform the conversion of configuration files from CIM/XML to SCL+ and vice versa. The following elements of a substation were considered for conversion, and only partially (CIM concepts): circuit breaker, disconnector, line, compensator, busbar section, substation, voltage level, bay, measurement, terminal, and connectivity node.

We had to address several additional problems due to the differing serialization formats, besides the mapping issues discussed in Section III.C. On one side, CIM specifies an RDF schema, which is generated from the UML model automatically with an open source software tool. On the other side, IEC 61850 defines SCL as an XML schema, which mirrors in an informal way the data model defined in the standard (but not in UML). Moreover, the SCL+ (and SCL) schema does not result in a structure for instance files as simple as the CIM/XML one. Elements are typically nested within each other, whereas CIM/XML provides a "flat" structure. As a consequence, even if both standards use an XML serialization format, the processing techniques of the instance files had to be significantly different.

The conversion process is preceded by a pre-processing phase in order to take into account differing cardinality constraints, as discussed in Section III.C. Moreover, due to the inverse role-name property in CIM/XML, a relation between two resources may be given in one way, the other, or both. In order to simplify the conversion process (as well as make it more efficient), we had to ensure that the relations between resources are given in both ways.

The prototype provides a proof of concept, and shows that it is possible to exchange the configuration data between substations and control centres in a standardised and automated way. The prototype was tested on the instance files used for CIM interoperability testing, and on SCL+ instance files that were generated by hand. User input is limited to the selection of the substation to convert when processing a CIM/XML instance file, while the opposite conversion (SCL+ → CIM/XML) is fully automatic.

Note that this holds true with the set of elements considered in the current prototype. However, for some other elements from the two models the automatic translation is impossible, because there are no simple rules to follow, and the user interaction is necessary (see Fig. 3 for an example).

V. CONCLUSION

In this paper we argued for a model-based mapping between the data models of the IEC 61970 and IEC 61850. It discussed our approach to such a mapping, which required a prior representation of the IEC 61850 data model in UML. Besides its need for the mapping, this allowed us to identify inconsistencies in the existing, informal IEC 61850 data model as well as to easily enhance the SCL with semantically meaningful type checking.

The paper further showed an example UML mapping based on our models and discussed its impact on the mapping of CIM/RDF to SCL files. It made explicit to what extent the conversion can be done automatically (i.e., directly derived from the UML model), and where user interaction is required.

The benefits of having such formally defined models are found, firstly, in the easy creation of programming relevant data classes for communications system developers. This was evidenced in the development of the prototype converter. Secondly, utilities can have well-specified and unambiguous definitions of their data, which avoids costly re-entering of data by tool-based semi-automatic conversions. This is of utmost importance for utility application integration and application extensions.

VI. ACKNOWLEDGMENT

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VIII. BIOGRAPHIES

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