Solving the Mismatches between the Electric System Ontologies

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ABSTRACT: *The heterogeneity between CIM and IEC 61850 ontologies is an important barrier for the semantic integration in the electric system domain. This paper proposes a new classification for the mismatches existing between such ontologies. This classification is based on the reasons that explain the existence of the mismatches rather than on their location in the ontologies. Moreover, solutions for all the types of mismatches identified are proposed. The interaction between these solutions will make it possible to solve all the heterogeneities without losing information and without modifying the original standards.*

KEY WORDS: *CIM, IEC 61850, Mismatches, Ontologies, Semantic Integration*

1. Introduction

The CIM (IEC 61968/61970) and the IEC 61850 are the two main standards that aim to achieve the semantic integration in the electric system domain. On the one hand, the CIM is focused on the remote energy management systems and, on the other hand, the IEC 61850 is focused on the local automation systems of the electric facilities.

An optimal management of the electric networks requires the interaction between remote energy management systems and local automation systems (EPRI, 2006). For that reason, the harmonization between CIM and IEC 61850 standards is a key issue for the development of future energy smart grids (NIST, 2010).

The problem is that such standards were developed by different working groups in the International Electrotechnical Comission Technical Committee 57 (IEC TC 57). This caused that the information models defined by the standards resulted heterogeneous, which means that there are incompatibilities or mismatches between them (Preiss *et al.,* 2006) (EPRI, 2006).

The alignment of heterogeneous ontologies is a major challenge for the Semantic Web development and also for the semantic integration in fields like Medicine and Biology. That is why the state-of-the-art includes many works (Euzenat *et al.* 2007), tools (Sirin *et al*., 2007) and languages (Horrocks *et al.*, 2004) which are intended to detect, classify and solve the mismatches that appear due to the heterogeneities between the ontologies.

The work presented in this paper takes advantage of the solutions proposed in those fields (mainly in the Semantic Web) and adapts them in order to achieve the semantic integration in the electric system domain by harmonizing the CIM and the IEC 61850 as automatically as possible and without modifying the original standards (Saxton *et al.,* 2003). The paper includes: a) a new classification for the mismatches between the standards, b) the proposed solutions to solve each type of mismatch, c) a description of the interaction between the proposed solutions in order to solve all the heterogeneities, and d) the conclusions reached.

2. New classification for the mismatches between CIM and IEC 61850

In (Preiss *et al.,* 2006) the ABB group led by T. Kostic made an exhaustive analysis of the incompatibilities between the standards. This analysis was based on an envisioned unified model, recently proposed by the EPRI in (EPRI, 2010), which would modify the original CIM and IEC 61850 information models in order to solve their heterogeneities. That is why the classification of the mismatches proposed in (Preiss *et al.,* 2006) focuses on where the incompatibilities occur in the original models, in order to detect the changes that had to be made on such models to design the unified one. Thus, (Preiss *et al.,* 2006) distinguishes three types of incompatibilities. Firstly, the *type (or class) level incompatibilities* occur at the class level in the models. An example of this type of incompatibilities is the one that stands for the fact that in CIM there is a class to represent the bus bar sections (*cim:BusbarSection*), whereas in IEC 61850 there is not. Secondly, the *relationship level incompatibilities* occur at relationship level. An example of a relationship level incompatibility is the one that exists because in CIM the class *cim:ConductingEquipment* is directly associated to the class *cim:Substation*, whereas in IEC 61850, the *scl:tCondutingEquipment* instances must be contained in a *scl:tBay* inside the substation. Finally, the *attribute level incompatibilities* occur at attribute level. An example of an attribute level incompatibility is explained in the following. The attribute *RSYN.DifHz* may not be included in an IEC 61850 device because it is optional in this standard. However, the equivalent CIM attribute, i.e. *cim:SynchrocheckRelay.maxFreqDiff*, could be mandatory in a CIM application.

The classification for the mismatches between CIM and IEC 61850 proposed in our work tries to find the solutions to those mismatches without modifying the original standards. In that way, this new classification is closer to the ones given in ontology mismatching works like (Euzenat, 2001), (Benerecetti *et al.*, 2001), and (Euzenat *et al.*, 2007) and is more focused on the reasons that explain the existence of the heterogeneities (Smart *et al.*, 2008) rather than on its localization in the models.

2.1. *Granularity Mismatches*

Granularity mismatches occur when two ontologies describe the same region of a domain from the same perspective but at different levels of detail (Euzenat *et al.*, 2007). The *TapChanger* mismatch is an example of this type of mismatches between CIM and IEC 61850. In CIM there are three different classes for representing tap changers: *cim:TapChanger*, *cim:PhaseTapChanger* and *cim:RatioTapChanger*, whereas in IEC 61850 there is only one, the *scl:tTapChanger*. Thus, in CIM the tap changers are represented in a higher level of detail than in IEC 61850 and, for that reason, in a translation from the second standard to the first one a decision has to be made in order to translate an *scl:tTapChanger* as one of the three CIM classes that can represent different types of that element.

2.2. *Perspective Mismatches*

Perspective mismatches occur when two ontologies describe the same region of a domain, at the same level of detail, but from a different perspective (Euzenat *et al.*, 2007). This type of mismatch appears between CIM and IEC 61850 when electric lines are represented. Thus, the CIM distinguishes two types of lines depending on the type of current, *cim:ACLineSegment* and *cim:DCLineSegment*, whereas the IEC 61850 differentiates two types of lines depending on its isolation, *LIN* (without isolation) and *GIL* (with gas isolation). In this type of mismatches there will be conflict situations during the translation in both directions.

2.3. *Coverage Mismatches*

Coverage mismatches occur when two ontologies describe different, possibly overlapping, regions of a domain at the same level of detail and from a unique perspective (Euzenat *et al.*, 2007). This type of mismatches in our case refers to the information that is included in one of the standards, but not in the other one. An example of this type of mismatches is the *BusbarSection* mismatch explained above. Due to this type of mismatches there are going to be losses of information during the translation from one standard to the other.

2.4. *Flexibility Mismatches*

Finally, flexibility mismatches occur when the ontologies are developed from standards that contain optional attributes and relationships. The conflict situations in this type of mismatches appear when an optional attribute or relationship is not included in the instance file of the source ontology and this attribute or relationship is required in the target ontology. These are the cases of the *RSYN.DifHz* and the *scl:tBay* mismatches explained above as the examples of *attribute level* and *relationship level* incompatibilities, respectively.

3. Proposed solutions to the mismatches

Once the mismatches between the CIM and the IEC 61850 standards are classified and the reasons that explain their existence are identified, the following section proposes solutions for each type of mismatch.

3.1. *Specific Domain Knowledge*

The only way to solve the conflict situations that appear due to the *granularity* and *perspective mismatches* is to employ specific domain knowledge in order to take the suitable decisions during the translation from one standard to the other (Figure 1). In some cases this specific knowledge can be found in the standards. This is the case of the *Disconnector* mismatch, which is a granularity mismatch that appears because in CIM there are three classes that represent different types of disconnectors: *cim:Disconnector,* *cim:LoadBreakSwitch* and *cim:GroundDisconnector,* whereas in IEC 61850 this elements can only be represented with the *scl:tConductingEquipment* class when its attribute *scl:type* takes the *DIS* value. In this mismatch the information about the type of disconnector that it is represented in the IEC 61850 configuration file (SCL file) can be obtained directly from this file if the *scl:tConductingEquipment* instance which is representing a disconnector is associated to a *XSWI* logical node. In that case the type of disconnector can be obtained from the *swTyp* attribute of the *XSWI* logical node. However, such association between the *scl:tConductingEquipment* and the *XSWI* logical node with the *swTyp* attribute is not always included in the SCL file. Moreover, the majority of the granularity and perspective mismatches cannot be solved employing only information contained in the standards. For that reason, additional domain knowledge is required.

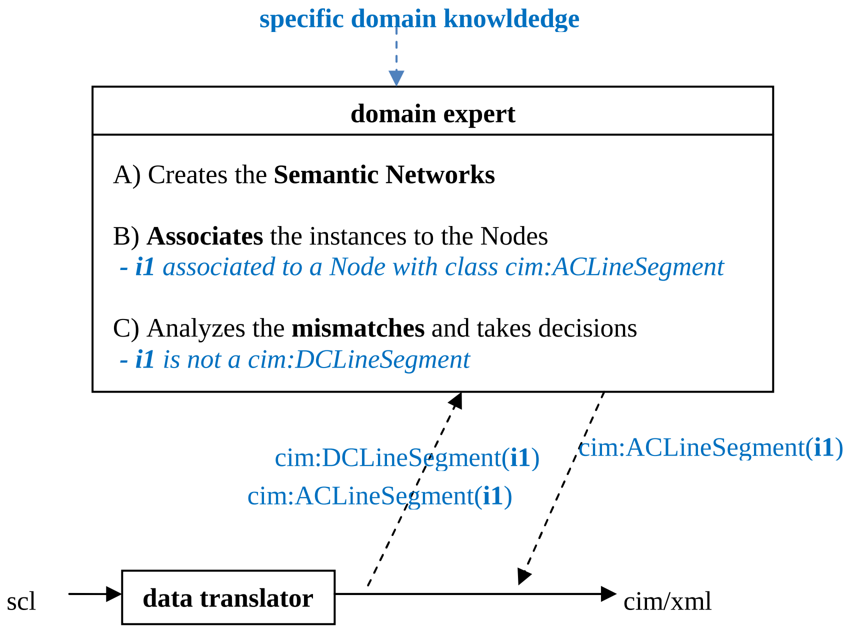

Figure 1. *The Domain Expert solves the Lines mismatch for the instance i1*

This subsection briefly describes the tool, called *Domain Expert*, and the methodology that makes it possible to automatically use additional knowledge about the electric system facilities in order to solve the granularity and perspective mismatches. The *Domain Expert* creates its knowledge base from two OWL[1] files containing information about how a specific type of facility (radial MV/LV substation, breaker and a half substation, electrified railway system DC substation, etc.) and its automation system should be represented in each standard. The knowledge base consists of two semantic networks (one for each standard) in which each node represents a type of element that have to appear, or at least, can appear in the output of the translation. Thus, when the data translator, for example, *ESODAT* (Santodomingo *et al.*, 2010), translates an instance file from one standard to the other, the *Domain Expert* analyzes the output of the translation and associates the

[1] Web Ontology Language: http://www.w3.org/TR/owl-guide/

instances of the file with their closer nodes in the corresponding semantic network. Such associations are based on the information about: a) the class to which the instances belong in the output of the translation and b) the relationships and attributes that have the instances in the output of the translation. From these associations the *Domain Expert* is able to solve the conflict situations that appear in the granularity and perspective mismatches. For example, if in the SCL input file there is an instance representing a line, in the output of the translation that instance will belong to two different classes, *cim:ACLineSegment* and *cim:DCLineSegment*. The *Domain Expert,* depending on the class of the semantic network node associated to the instance, will decide to which of the two CIM classes the instance belongs.

3.2. *Buffer*

In case that, once the instance file is translated from one standard to the other it is necessary to translate it back to the original standard, which is a common case in the interaction between CIM and IEC 61850 (EPRI, 2006), the lost information during the translation due to the *coverage mismatches* has to be retrieved.

The solution to this problem is based on a buffer which is able to detect the lost information by comparing the instances and values in the input and the output files of the translation. This lost information is loaded in an RDF/XML[2] file. During the translation to the opposite direction the buffer fulfils the output file of the translation with the information loaded in the RDF/XML file. In this process the buffer takes into account the possibility that an instance appearing in the RDF/XML file could have been removed in the target configuration tool. In this case the buffer will not add the information of the removed instance. For example, if the RDF/XML file contains a statement with the information about the *cim:Switch.normalOpen* attribute of a breaker and that breaker is removed in the SCL configuration tool, when the SCL file is translated back to the CIM the buffer will not add this statement.

In order to retrieve the lost information following the methodology explained above, the buffer has to retrieve previously the lost instance identifiers. The problem is that in CIM the instances are identified with the rdf:ID identifiers, whereas in SCL the instances are identified by the attributes defined in the SCL Schema. In that way, in the translation from CIM to IEC 61850 the rdf:ID identifiers are lost. When the files are translated back from IEC 61850 to CIM, in order to retrieve the lost information during the first translation, it is necessary to associate the instances included in the buffer to the instances described in the input SCL file. Such association is very complex if the instances employ different identifiers in the buffer and in the SCL file. In order to solve this problem, during the CIM to IEC 61850 translation, the data translator automatically generates in the output SCL file

[2] RDF/XML syntax: http://www.w3.org/TR/REC-rdf-syntax/

scl:tPrivate sections associated to each instance. These *scl:tPrivate* sections include the rdf:ID identifier of the corresponding instance and, following the IEC 61850 standard, will not be modified or removed in a SCL configuration tool. Thus, the process for recovering the rdf:ID identifiers could be easily done by the data translator at the beginning of the IEC 61850 to CIM translation.

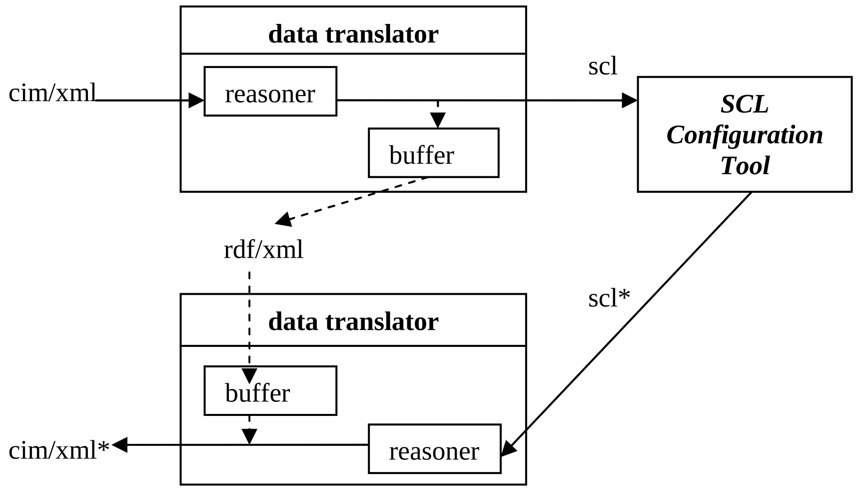

Figure 2. *The buffer included in the data translator solves the coverage mismatches by saving the no translated parts*

3.2. *Coordinated Profiles*

Flexibility mismatches appear due to the existence of optional attributes and relationships in the ontologies obtained from the standards. Such attributes and relationships are defined as optional in order to give the standards the flexibility required to be applied in different types of electric facilities. So the solution to this type of mismatches will be given by the creation of coordinated profiles that select the optional attributes and relationships that have to appear in the instance files of each standard to guarantee the interoperability for a specific type of facility. In that way, the cases in which a profile does not include optional attributes or relationships included in the other profile have to be avoided.

Currently, the profile elaboration is not automated at all and has to be carried out by specialists on the standards. In order to improve this process a tool, called *Profiler*, which processes the ontologies and alignments in order to guide the user in the coordinated profile elaboration, is being developed using Semantic Web resources. In the future, this tool will be able to generate the OWL files that are employed by the *Domain Expert* to solve the granularity and perspective mismatches following the methodology explained above, i.e. the profiles give the *Domain Expert* the specific domain knowledge required to solve the conflict situations. Such files are also employed by the data translator (*ESODAT*) to validate the instance files against the profiles.

4. Interaction between the solutions

This section shows how the different proposed solutions will interact in order to achieve the harmonization between the CIM and the IEC 61850 standards.

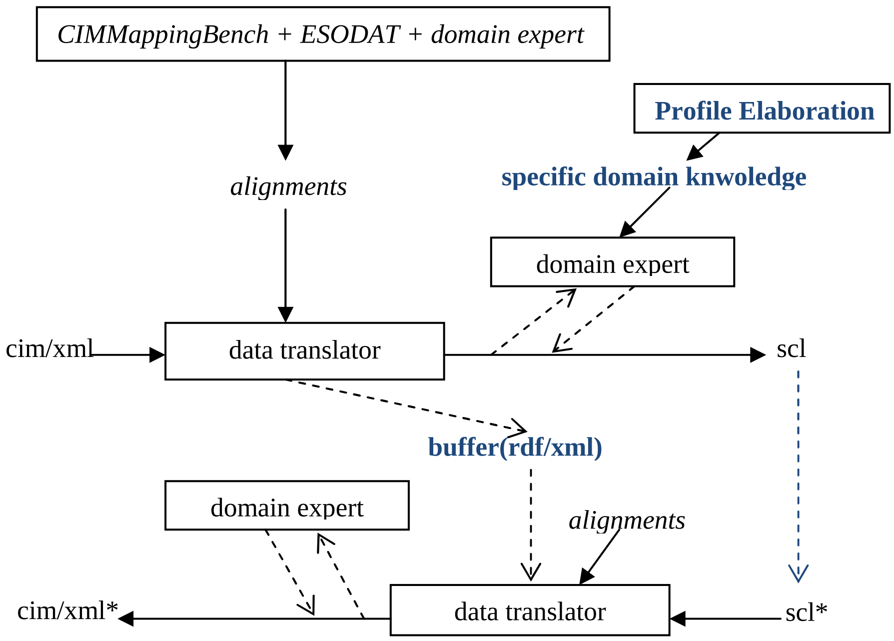

Figure 3. *Interaction between the solutions to achieve the harmonization*

The first step for the harmonization is to obtain the semantic correspondences (alignments) between the standards. In the state-of-the-art there are may ontology matching contributions that aim to automatically find the alignments between ontologies, such as: (Euzenat *et al.*, 2007), the SEALS Project[3] and the Ontology Matching Organization[4]. In the particular case of the electric system domain, the OFFIS institute of Oldenburg developed a methodology to align the ontologies created from the standards defined by the IEC TC57. This methodology, called COLIN (Uslar *et al.*, 2008) includes a tool (the *CIMMappingBench*) which semi-automatically obtains the alignments between the ontologies employing lexical-based, dictionary-based and string-based methods. Currently an interaction between the *CIMMappingBench, ESODAT* and the *Domain Expert* has been defined and will be implemented as part of a collaboration work between OFFIS and IIT. This interaction will improve the process of obtaining the alignments between the CIM and IEC 61850 ontologies and will consist on an iterative process in which the *Domain Expert* will check the validity of the translation obtained in *ESODAT* with the alignments found for a specific iteration. If the *Domain Expert* finds some mistakes in the output of the translation it will propose new alignments so that in the next iteration *ESODAT* obtains better results.

Once the alignments are obtained, they will be processed by the data translator (*ESODAT*) in order to translate instance files from one standard to the other. *ESODAT* contains a buffer that solves the coverage mismatches. Moreover this data translator is able to check if the instance files follow the definitions included in the coordinated profiles that solve the flexibility mismatches. During the translation the *Domain Expert*, which creates its knowledge base from specific knowledge defined in the coordinated profiles, analyzes the output of *ESODAT* and solves the granularity and perspective mismatches.

5. Conclusion

To achieve the harmonization between CIM and IEC 61850 standards it is necessary to solve the mismatches that appear due to its heterogeneity. Previous works (Preiss *et al.,* 2006) classify the mismatches attending to their localization in the ontologies: *class level, relationship level* and *attribute level* incompatibilities. Such classification seeks to detect the modifications that have to be made in the original standards in order to create a unified model (EPRI, 2010) for both standards without mismatches between them.

The work presented here gives a different approach that is closer to the ontology matching contributions mainly developed for the Semantic Web and proposes a new classification for the mismatches based on the reasons that explain their existence. Moreover, this work proposes solutions for all the types of mismatches that were identified and describes how these solutions should interact in order to harmonize the CIM and IEC 61850 standards.

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[3] SEALS Project: http://www.seals-project.eu
[4] Ontology Matching Organization: http://www.ontologymatching.org

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