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# Ontology matching system for future energy smart grids

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ABSTRACT

Future power systems (commonly referred to as Smart Grids) will be managed by numerous intelligent electronic devices. These devices will have to interoperate; that is, they will need to exchange data with each other in order to co-operate over complex control tasks. Interoperability will only be achieved when Smart Grid devices share common semantics on the data they exchange. Standardization bodies have created standard data models defining these common semantics, but a unified standard data model has not been created for all Smart Grids. Consequently, in order to achieve interoperability in this domain, it is mandatory to find semantic correspondences (alignments) between different standard data models. Creating equivalent ontologies from the standard data models facilitates this task, because ontologies provide powerful reasoning services that can be used for automating ontology aligning. The majority of ontology matchers proposed in the state of the art, however, are only able to find simple equivalences of terms, while most alignments in Smart Grids are complex correspondences involving more than two terms. This paper presents an innovative ontology matching system that finds complex correspondences by processing expert knowledge from external domain ontologies and by using novel matching methods. The tests carried out in this study were based on the main interoperability issue within Smart Grids: interactions between CIM and SCL data models. In such tests, the proposed system outperformed one of the best ontology matchers according to the Ontology Alignment Evaluation Initiative (OAEI).



## 1. Introduction

The term Smart Grid is nowadays synonymously used for future power systems (Mc Namara et al., 2013; Rayudu, 2010). The former centralized infrastructure with its unidirectional power flow from large power plants via the consumers, turns into a full-meshed topology including bidirectional power flows. This raises many challenges in terms of interoperability issues. Thus, numerous Smart Grid devices, possibly from different developers, need to exchange data with each other in order to co-operate over complex control tasks. The main standardization body in the electricity sector, the International Electrotechnical Commission (IEC), has created some standard data models defining semantics of the data that need to be exchanged within this domain. Unfortunately, a single standard data model has not been defined for all Smart Grids. It is worth noting that many contributions in the literature (Haslhofer and Klas, 2010; O'Leary, 1997) have concluded that, in practice, it is not always advisable (or even possible) to create a single standard data model that is valid for all the applications within a domain. Therefore, with the aim of achieving interoperability in Smart Grids, it is mandatory to align different data models.

Before aligning the models, these must be expressed in the same modeling language. In this work, data models have been converted into OWL (Web Ontology Language) ontologies (Bechhofer et al., 2004). Originally, ontologies were created in Artificial Intelligence (AI) to produce knowledge base components for intelligent systems (Gómez-Pérez et al., 2004). More recently, ontologies have started to be used in numerous engineering applications (Abanda et al., 2013; Blomqvist and Öhgren, 2008; Morbach et al., 2007; Wriggers et al., 2007). In this study, ontologies have been employed because they represent knowledge by defining logic theories, which enable machines to infer implicit knowledge by means of general reasoning services. These reasoning services are very useful for finding semantic correspondences (alignments) between two data models.

The process of aligning ontologies is known as ontology matching. Most ontology matchers are only able to find equivalences between ontology entities (Euzenat and Shvaiko, 2007). In Smart Grids, however, very few alignments can be expressed as simple equivalences (Santodomingo et al., 2012). For this reason, this paper presents a new ontology matching system that is able to obtain complex alignments between Smart Grid ontologies. This

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system processes deep domain knowledge from external ontologies (domain ontologies) and uses innovative matching methods.

The remainder of this paper is organized as follows. Section 2 provides a brief overview of the two main standard data models that promote interoperability in Smart Grids: CIM and SCL. Section 3 sets out the fundamentals aspects of Ontology Matching. Section 4 presents the proposed ontology matching system, which comprises a schema-based subsystem (Section 5) and an instance-based subsystem (Section 6). Section 7 is devoted to the tests performed in this study to evaluate the proposed system. Finally, Section 8 concludes the paper and provides an outlook on future work.

## 2. Interoperability in smart grids

This work addresses the main interoperability issue in Smart Grids: interactions between CIM-based and SCL-based systems. This section presents CIM and SCL data models and discusses their interactions.

### 2.1. Smart grid data models: CIM and SCL

The *Common Information Model* (*CIM*) is defined in the IEC 61970/61968/62325 standard series. It standardizes the semantics to achieve interoperability in a broad range of energy management functionalities, such as: network operations, asset management and electricity markets (Uslar et al., 2012). Hundreds of classes organized in packages are included in this data model. Among all the CIM packages, *Wires* and *Topology* packages contain several classes to represent electric power systems. For instance, `cim:Substation`, `cim:VoltageLevel`, and `cim:Breaker` are the CIM classes to represent substations, voltage levels, and circuit breakers, respectively. The CIM is currently maintained in UML. In this study, the equivalent CIM OWL ontology has been created by using the *Uml2Owl* conversion implemented in the open-source CIMTool.[1]

The *Substation Configuration Language* (*SCL*) is defined in the IEC 61850 standard series. It includes the concepts required for configuring the automation systems that locally control electric networks. The SCL defines terms to represent automation systems and electric facilities. For instance, scl:tSubstation and scl:tVoltageLevel are the SCL classes for representing substations and voltage levels, respectively. Meanwhile, circuit breakers are represented in SCL as `scl:tConductingEquipment` instances that take the value "*CBR*" in the attribute `scl:type`. The SCL is represented in the XML Schema Definition (XSD) language. The equivalent SCL OWL ontology has been created in this work with the *Xsd2Owl* conversion presented in (García and Gil, 2007).

### 2.2. Interactions between CIM and SCL

As detailed in (Falk and Saxton, 2010), during the planning and configuration of electric networks, engineers of the CIM-based management system must exchange files with engineers of the SCL-based automation system. The problem is that CIM and SCL were developed by different working groups with different requirements and goals. This resulted in the existence of mismatches hindering the interactions between CIM-based and SCL-based systems. In that way, simple equivalences of terms are not sufficient themselves for carrying out these interactions. For instance, CIM and SCL representations of circuit breakers must be aligned by a complex correspondence involving the class `cim:Breaker`, the class `scl:tConductingEquipment`, the attribute `scl:type` and the attribute value "*CBR*".

[1] CIMTool (from Langdale Consultants) is available at: http://wiki.cimtool.org/Download.html (accessed on January 2014).

## 3. Ontology matching

This section defines the concepts that will be used throughout the paper to describe the proposed ontology matching system. For that purpose, the terminology defined in (Euzenat and Shvaiko, 2007) is employed.

### 3.1. Ontology matching process

Ontology matchers are aimed at finding correspondences between entities (classes, properties, instances) of two ontologies $o1$ and $o2$. In this study, two types of property are considered: object properties (or relationships), which connect two classes or instances, and data properties (or attributes), which connect a class or instance to a data type (e.g., string, integer, etc.) or value.

Typically, ontology matching processes comprise two overall steps: *similarity computation* and *alignment extraction* (Fig. 1). In the first step, entities of $o1$ and $o2$ are compared. For each entity $e1$ of $o1$ and $e2$ of $o2$, a similarity measure $\sigma(e1,e2)$ is calculated. This measure is a function from a pair of entities to a real number expressing the similarity between them (Euzenat and Shvaiko, 2007). In order to work with similarity measures within the range [0–1], usually, similarities are normalized with the maximum $\sigma(e1,e2)$ that was calculated. The results obtained in a similarity computation are included in a similarity matrix $M$ containing all the similarity measures between entities of $o1$ and entities of $o2$. Several similarity computations are proposed in the state of the art. These can be categorized in

- *Element-based methods*, which analyze the entities of the ontologies in isolation (i.e., ignoring their relationships with other entities). In this work, different element-based methods included in the state of the art (such as the string-based comparison proposed in (Winkler, 1999)) were used (see Section 5).
- *Structure-based methods*, which take the structure of the ontologies (i.e., the relationships between entities) into account. Graph-based matching methods were identified as the most appropriate structure-based methods for the system proposed in this work (see Section 6.3.3). This is because graph-based methods are mature methods that obtain good results in the ontology alignment evaluations (Cruz et al., 2011). These methods represent

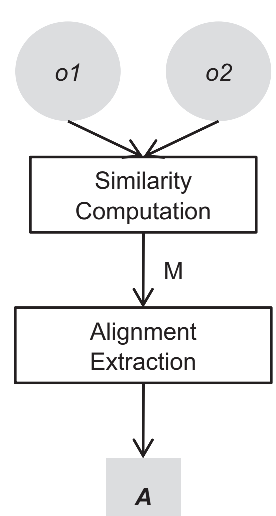


**Fig. 1.** Ontology matching process.