SSG: An Ontology-Based Information Model for Smart Grids

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Abstract. Nowadays, an electricity blackout can have a domino effect on the overall power system, causing extremely bad effects on the economical, ecological and operational countries perspectives. All this emphasizes the need for conceiving an upgraded vision of today's and tomorrow's power systems that have to be smart to meet the society expectations. Smart grids have been emerging as an appropriate solution for such needs. This work addresses two main related challenges encountered in the management of such power systems: (1) the semantic interoperability needed between their heterogeneous components in order to ensure seamless communication and integration, and (2) a means to consider their various objectives from economical, ecological, and operational perspectives, to mention some. In this paper, we propose a three-layered smart grid management framework, aiming at resolving these two issues. The backbone of the framework is *SSG*, a generic ontology-based model, detailed here. It aims at modeling the smart grid components, their features and properties, allowing the achievement of the smart grid objectives. Several evaluations have been conducted in order to validate our proposed framework and emphasize the *SSG* importance and utility in the energy domain. Obtained results are satisfactory and draw several promising perspectives.

Keywords: Information modeling · Ontology · Power system
Smart grid

1 Introduction

In the era of new technologies and with the growing need for reliable ecological energy supplies [8], current electrical grids have to be upgraded in order to be smarter, more flexible and able to operate, monitor and heal themselves autonomously. Here comes the *SG* as one of the main contributor in the power systems update. However, there are several challenges have to be solved before. One of the most important challenges is related to heterogeneity. In essence, *SGs* consists of a number of heterogeneous components (built and supplied by

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different companies, for different purposes, and using various protocols [16]). In addition, the heterogeneity of such power systems would arise further from the internal and external interactions of their components as well as with the external environment. All this underlines the need of an appropriate semantic interoperability ensuring a seamless information exchange between components within three layers as discussed in [14,15]: Field Layer, Knowledge Layer, and Management Layer. The three layers will be briefly described in what follows.

- **Field Layer (FL):** Via this layer, the data collector gathers all data exchanged between components via a low-level communication environment relying on standardized protocols (e.g., BACnet, Modbus, etc.). Once gathered, those data are stored in a low-level data repository and pushed up to the next layers.
- **Knowledge Layer (KL):** In order to resolve the interoperability issues and open up the possibility to model the new trends in today's energy systems (i.e., prosumers, electric vehicle, etc.), it is essential to capture and understand the semantics of exchanged data to ensure a seamless communication between the components within the power system. Through this layer, the semantic middleware insures the semantic translation of the collected data using our proposed ontology-based information model called *SSG*. Furthermore, the reasoner is responsible of processing information and using it to infer additional value thanks to many rules and constraints defined in this layer.
- **Management Layer (ML):** In this layer, a collaborative diagnostics, a self-optimization for disturbance, and a remote visualization for the users (via an integrated simulation and synthesis) are provided. Besides, the information extracted from the knowledge layer is processed in order to achieve the objectives of the power system. To do so, a battery of advanced management services (e.g., Demand side management, minimization of transmission losses, etc.) is designed.

In addition to the operational aspect related to the components operating, the *SG* needs to ensure several services each targeting a different objective. First, a *SG* aims at providing reliable and secured identification when incorporating heterogeneous components. In today's digital world, cyber-attacks [18,20], such as intentionally switching off the *SG* operators, could cause cascade damages on the grid. Hence, it is important to provide such an identification for the components helping in reducing the grid intrusions. Second, each component can play multiple roles, participating in the emergence of a new paradigm known as 'Prosumer' [12,21], referring to the components able to **PRO**duce power and con**SUME** energy at the same time. Hence, an *SG* can be seen as a multi-objective system that depends on a potential interaction among different stakeholders (i.e., energy sources, energy consumption loads, etc.), having each its objectives, which emphasizes the need of taking into account all the aspects involved in the achievement of the *SG* objectives. Third, the *SG* needs to cope with the mobility of the several components (e.g., electric vehicles, boats, etc.) during their lifetime. Fourth, an *SG* would become an important player in the electricity market relying on its components participation in the environment.

The goal of this study is to address the above issues and challenges by providing an appropriate information modeling for *SGs*. In other words, our goal is to propose a recommended data model for *SG* description, allowing to create an interoperable power system that enables the integration and the validation of the various new heterogeneous renewable distributed generation systems and various storage technologies.

In this paper, we present a dedicated framework for better management of *SG* driven by adapted tools and services. We also detail here our ontology-based *SG* model called *SSG*, capable of: (1) being compliant and aligned with existing information models, coping with the interoperability between all the layers, providing the reasoning capabilities and smart features needed, as well as (4) solving the multi-objective aspect of the *SG*.

The rest of this paper is organized as follows. Section 2 presents the state of the art of existing power systems information models. Section 3 presents our *SSG* ontology through its main concepts. Section 4 describes the evaluation methodology and results of the proposed framework and ontology. Section 5 concludes the paper.

2 Related Work

Several approaches have been provided in the literature addressing the problem of 'Power system information modeling'. They can be categorized into syntactic-based and semantic-based approaches. The syntactic-based models are intended to provide a standard way to represent the data of the system. The semantic-based models are ontology-based information models, aiming at providing a richer and complex knowledge representation about the entities and relations between them.

2.1 Syntactic Based Models

2.1.1 Common Information Model

The Common Information Model (CIM) [19] is a widely accepted electricity information model being part of the IEC 61970 standards. Its main objective is to develop a platform independent data model for enabling better grid interoperability. This model includes the exchange between market participants and market operators as well as communication between market operators. In the CIM model, the *PowerSystemResource* concept is composed of the *Equipment* concept that contains the components of a power system that are physical devices, electronic or mechanical. Two types of equipment exist: (1) *ConductingEquipment* and (2) *Powertransformer*. A *ConductingEquipment* concept, represents the parts of the power system that are designed to carry current. A *Powertransformer* is an electrical device, allowing a mutual coupling between electric circuits.

From the multi-objective perspective, the CIM model [19] does not fully describe all the operational properties of the distributed energy sources and the storage systems. In addition, it covers partially the ecological aspect (using the *EmissionType* parameter) and the economical aspect (using the *CostPerEnergyUnit* and *CostPerHour* parameters). The identification aspect is limited to only two parameters: *Id*, *Name*. However, the mobility and the multi-role aspects were totally absent in the model. From the interoperability perspective, the CIM model does not cover completely the field layer. In addition, since it is an UML based model, this impoverishes the semantic relations between the concepts, which limits its knowledge coverage. In addition, as mentioned before, since there is a lack in representing all the objective aspects of a power system, this also affects negatively the management layer.

2.1.2 MIRABEL FlexEnergy Data Model

The MIRABEL smart grid system [23] comes to hand over the flexibility in energy demand and supply. It incorporates the power profile concept which associates a consumption/production schedule for each branch.

In order to achieve such flexibility in energy demand and supply in the power grid, a data model has been developed in [23] consisting of five main classes: *branch*, *actor*, *energyprofile*, *constraint* and *flex-offer*. A *branch* is an energy consumer or producer that has a specific energy load over a certain time span (called *energyprofile*). An *actor* has minimum or maximum demands (called *constraints*) on their energy load, price and time. These constraints are issued (by an actor) toward the branches owned by the actor. The *flex-offer* class defines two types of demands: flexible demand and non-flexible demand. Flexible demand can often be shifted from the peak demand times to lower demand times, while non-flexible demand should be satisfied immediately.

From the multi-objective perspective, the model in [23] provides a high economical aspect representation and a slighter representation of the operational and identification aspects, since it is dedicated to conceive a flexible market power exchange. However, the ecological, mobility and multi-roles aspects are absent in it. From the interoperability perspective, the MIRABEL model does not cover completely the field layer. Similarly to the CIM model, Mirabel is an UML based model, which impoverishes its semantic expressiveness and the knowledge coverage. In addition, as mentioned before, since there is a lack in representing all the objective aspects, affecting negatively the management layer.

2.1.3 Facility Smart Grid Information Model

The Facility Smart Grid Information Model (FSGIM) [7] is developed with the aim of enabling energy consuming branches and control systems in the customer premises so to manage electrical loads and energy sources in response to communications with the smart grid. To achieve this, an object-oriented information model is defined to support a wide range of energy management applications and electrical service provider interactions. The proposed information model [7] provides a common basis to describe, manage, and communicate information on aggregate electrical energy consumption and forecasts.

From the multi-objective perspective, the FSGIM model covers almost all the components of a power system, except the storage devices (only the thermal storage systems are modeled). However, the model takes fully into account the economical and identification aspects. Concerning the ecological aspect, it is partially covered in the model (using *Emission* parameter). The multi-role aspect is completely absent in the model. From the interoperability perspective, the FSGIM model does not cover completely the field layer. In addition, since it is an object-oriented model, it has a limited means to express the semantic relations between the components and the reasoning capabilities of the system. All this causes a partial management layer coverage.

2.1.4 OASIS Energy Interoperation

OASIS Energy Interoperation [4] enables collaborative use of energy in a power network. It defines XML-based vocabularies for the interoperable and standard exchange of information related to energy prices and bids (demand and response), network reliability, emergency signals and the prediction of loads consumption. This information relies on the $WS - Calendar$ [5] and $EMIX$ (electricity market Information Exchange Specification) [3]. The first defines how to specify and communicate the duration and time of a schedule, while the later specifies the semantics in electricity markets.

From the multi-objective perspective, the OASIS model covers completely the economic aspect since it targets the electricity market information model. However, it neglects the remaining aspects. From the interoperability perspective, the OASIS model covers partially the three layers, since it does not cover completely all the components and operational parameters, without taking into account all the semantic relations between the components.

2.2 Semantic Approaches

2.2.1 Facility Ontology

The Facility Ontology[1] aims at conceiving a standard nomenclature for the power systems, by providing a representation of its components and their control parameters. Complying with the Suggested Upper Merged Ontology (SUMO), the proposed ontology aims to classify the power system in two main concepts: the *Physical* and the *Abstract* concepts. The *Physical* concept serves for describing the physical components of the power system (i.e., production unit, storage unit, consumption unit and conversion unit) with a set of related properties. Concerning the *Abstract* concept, two concepts are introduced: the *Management* concept, and the *Policy* concept. The *Management* concept consists of four sub concepts: (i) the *Energy_trading*, (ii) the *Lc_operation*, (iii) the *Mgcc_operation* and (iv) the *Operational_modes*. The *Lc_operation* and *Mgcc_operation* concepts contain all the information related to the load and central controllers. The *Energy_trading* concept represents the information related

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[1] https://github.com/usnistgov/facility.

to the power exchanged in the grid, such as the power prices, the minimum and the maximum power quantity. And finally, the *Policy* concept, refers to the information related to the constitution (*Design* concept), the operation (*Operation* class) and interface (*integration* concept) of the power system.

From the multi-objective perspective, the ontology shows a high efficiency in representing the operational aspect, by modeling all the components of the power system. Similarly to the operational aspect, the economical one was taken into account via the *Energy_trading* concept. The identification aspect was limited to the definition of the ID, $Mode$ and $Manufacturer$ parameters. However, the mobility, the ecological and the multi-role aspects were totally absent in the ontology. From the interoperability perspective, the Facility Ontology covers completely the field layer. However, it is poor in representing the semantic relations between the components (limited to the "hasSubClass" relations), which limits its knowledge coverage. In addition, as mentioned before, there is a lack in representing all the objective aspects of a power system which affects negatively the management layer.

2.2.2 Prosumer Ontology

In [9], the authors propose a classification of the power system components using several predefined scenarios. Based on the UK property classification, five power consumption patterns are identified, namely: (1) *commercial premises* consisting of the consumers having varying operating times, (2) *business related premises* consisting of the consumers having fixed operating times (e.g., office times), (3) *residential premises* consisting of the houses consumption, (4) $non-residential$ *premises* consisting of non-residential premises (e.g., hospitals, schools, etc.) having more critical power needs, and (5) *industrial premises* consisting of the factories consumption having uninterrupted power needs. Concerning the energy sources classification, two categories were also introduced in [9]: *renewable* and $non-renewable$ energy sources, while three energy storage systems categories were identified, according to the type, produced power and charge and discharge efficiency, namely: (1) *energy management*, (2) *power quality*, and (3) *bridging power*. In addition, the *component connectivity* focuses on enabling the exact connectivity relationships between the producers and the consumers. And finally, the *Service Contracts* comes to describe the information exchanged between the producers and the consumers in a competitive market. It contains the Start/End Date of the contract, the type of payment and the charges per units of power.

From the multi-objective perspective, the ontology in [9] shows a lack in the operational aspect, since it is limited to modeling the main components of a power system, without taking into account their operational parameters. When it comes to the economic aspect, it is partially taken into account by modeling the contracts between producers and the consumers. The ecological aspect is partially modeled by distinguishing the renewable and non-renewable energy sources. The remaining aspects are totally absent in this model [9]. From the interoperability perspective, the Prosumer ontology covers partially the field layer. This affects directly the knowledge layer modeling. Here again, the management layer can partially be addressed due to the lacks in the multi-objective aspect modeling.

2.2.3 Upper Ontology for Power Engineering Application

Based on the Common Information Model (CIM) [19], the authors in [2] propose an ontology that mainly aims at monitoring the health status of the power systems. In this model, the concept *Measurement* represents anything that can be measured, including data taken from sensors and historical data. In addition, anything that is extracted from raw data is represented as an *Interpreted Data*, and specifically as a *Summary Interpretation* or a *Detailed Interpretation*. Moreover, the components' operations in the system are represented via the *Agent Action*. This model supports the exchange of messages between agents, but not explicitly defined. Although adopted by several applications, the upper ontology usually needs to be enriched with additional concepts to cover all the required information.

From the multi-objective perspective, and since this model [2] is based on the CIM [19], this leads to inherit the same objective aspects coverage. Hence, the upper ontology covers partially the operational, identification, economical and ecological aspects, but doesn't take into account the mobility and multi-roles aspects. From the interoperability perspective, the upper ontology covers partially the field layer. In addition, it neglects the semantic relations between the components, which makes the knowledge layer incomplete. All this causes a lack in the management layer.

2.3 Summary

In this section, we present a comparison summary between the existing approaches, highlighting their strengths and drawbacks with respect to their ability to resolve the interoperability issue within a power system, and the integration of the necessary aspects allowing the achievement of related services. Three symbols for comparison will be used in whats follows: (1) '−' to express the low capabilities of an approach in covering a feature, (2) 'partial' when an approach has middle coverage capabilities, and (3) '+' to express the high coverage capabilities of an approach.

2.3.1 Interoperability Aspect

Table 1 shows the ability of the existing approaches to cope with the interoperability issue. In short, most of them cover the modeling of the field layer, which contains the physical components of the power systems. Concerning the Knowledge/Information layer, the semantic-based approaches show a better potential in the knowledge modeling, compared to the syntactic-based ones, represented by the classification and the categorizing of the power systems components, but lack in fully modeling the relationships between them. Table 1 also shows that existing approaches cannot provide an appropriate modeling of the management layer, since they are mostly limited to modeling the electricity market information.

Table 1. Comparison of existing power system information models with respect to the interoperability aspect

	Interoperability layers		
	Field layer	Knowledge/Information layer	Management layer
CIM [19]	Partial	Partial	Partial
FSGIM [7]	+	Partial	Partial
OASIS [4]	–	–	–
MIRABEL [23]	–	–	–
Prosumer [9]	Partial	Partial	Partial
Facility ontology (see footnote 1)	+	Partial	Partial
EFEFEFUpper ontology [2]	Partial	Partial	Partial

2.3.2 Multi-objective Aspect

Table 2 summarizes the main commonalities and differences between existing approaches with respect to the six categories of aspects used in the achievement of the Power Systems objectives. In short, few take properly into account the identification aspect. In contrast, the operational aspect is the core of most of the existing models, whose aim was to standardize the technical vocabulary in the power systems, except MIRABEL system which mainly focuses on the electricity market modeling. Clearly, as the comparison table shows, the economical aspect is highly modeled since most of the existing models aim at conceiving a market power exchange. Moreover, the ecological aspect is merely modeled through a small set of properties related to the gas emission of the components. However, two aspects are almost absent in the existing information models, namely: (1) the mobility aspect representing the shifts of the components in the system, and (2) the multi-roles aspect, representing the roles played by a component during its lifetime according to a certain context. To sum up, none of the existing approaches completely addresses the interoperability and the mutli-objective aspect of the power system. In the following section, we provide our *SG* Management System framework, aiming at resolving interoperability issues from the information perspective by integrating all the power system aspects related to its objectives.

Table 2. Comparing existing power system information models regarding the *SG* multi-aspect

	MG objective aspect					
	Identification	Operation	Mobility	Economy	Ecology	Multi-roles
CIM [19]	Partial	Partial	–	Partial	Partial	–
FCGIM [7]	+	Partial	Partial	Partial	+	Partial
OASIS [4]	–	–	–	+	–	–
MIRABEL [23]	Partial	Partial	–	+	–	–
Prosumer [9]	–	Partial	–	–	Partial	–
Facility ontology (see footnote 1)	Partial	+	–	+	–	–
Upper ontology [2]	Partial	Partial	–	Partial	Partial	–

3 *SSG* Ontology

As seen in our related work study, semantic-based models showed a higher expressive power in dealing with interoperability issues and to some extend with the multi-objective aspect of the *SGs*. Thus, this drove us to adopt a semantic-based approach called *SSG*, a generic ontology-based model, aiming at modeling the *SG* components, their parameters and additional properties allowing the achievement of its objectives.

3.1 Why "Ontologies are Appropriate" Means for Semantic Approaches?

Due to its importance [13] in information systems and artificial intelligence, an ontology-based *SG* information model would provide a shared knowledge conceptualization allowing an easier system interaction and manipulation, especially for non-computer scientists, while giving the grid reasoning capabilities and autonomy.

3.1.1 Ontology as a Shared Knowledge

Since an *SG* consists of a number of heterogeneous components, it is important to define a shared representation of the exchanged information. In addition, each component has a direct/indirect impact on the other components and on the overall grid.

3.1.2 Ontology as a Better Means for Information Retrieval

Since a power system is usually managed by non-computer-scientists, an ontology would help them interact and manipulate the system in an easier and more intuitive way. Besides, an ontology would provide a structure that is flexible, and that naturally organizes the information in multidimensional ways.

3.1.3 Ontology as a Reasoning Strategy

Due to the intermittent aspect [6] of the renewable energy sources and the exposure of the power system to predictable and non-predictable events (power system anomalies, storms, etc.), an ontology becomes essential since it can also represent beliefs, goals, hypotheses, and predictions. These latter will give the components the ability to act and react autonomously or collectively according to a certain event or goal.

3.2 *SSG* Overview

While conceiving an ontology, the main target is to settle a shared terminology describing the power system. Several steps were conducted while developing our ontology [22]. In the aim of being compliant with existing standards, the first step was to identify the well-known and most adopted standards in the power domain.

Two important standards have been identified: the CIM/IEC 61790 model, and the IEC 61850-7-420 related to the basic communication structure for distributed energy resources logical nodes. The second step consisted of grouping the concepts into categories in order to check the coverage of the ontology regarding the needed aspects. And finally, the refinement phase consisted of establishing the semantic relations between the defined concepts. Thus, to cope with the interoperability issues, the skeleton structure of the *SG* (called the **basic structure**) is mainly based on the CIM standard and the multi-objective aspect (called **extended structure**) is based on the IEC 61850 standard and completed with a set of additional properties.

3.3 Why CIM and IEC 61850

CIM is an open standard for representing power system components developed by the Electric Power Research Institute (EPRI) in North America. The standard was developed as part of the IEC TC57 WG13 on developing a Control Centre Application Programming Interface (CCAPI) to provide a common model for describing the components in power systems for use in a common Energy Management System (EMS) Application Programming Interface (API). Besides the fact that the CIM is a standardized data model, this format has been adopted by the major EMS vendors to allow the exchange of data between their applications, independent of their internal software architecture or operating Platform.

IEC 61850 is a standardized data model for representing distributed energy resources (DER), which comprise dispersed generation devices and dispersed storage devices, including reciprocating engines, fuel cells, microturbines, photovoltaics, combined heat and power, and energy storage. The IEC 61850 is now an International Standard, that addresses most of the issues that migration to the digital world entails, especially, standardization of data names, creation of a comprehensive set of services, implementation over standard protocols and hardware, and definition of a process bus. Multi-vendor interoperability has been demonstrated and compliance certification processes are being established.

All the aforementioned reasons mentioned above, lead us to adopt both standards in the aim of being compliant with international norms and protocols. Our ontology, called *SSG*, is a graph representing a collection of subject-relation-object triples, where:

- Nodes designate subjects, objects, or subject/object properties: (1) *SG* branches and components (e.g., EnergyStorageBranch, WindTurbine, etc.), and (2) Corresponding property values (e.g., panelWidth, totalCost, etc.)
- Edges connecting source/destination nodes, designate relations: (1) Relations between components (e.g., WindTurbine isA DistributedEnergySource, etc.), and (2) Property and value relations (e.g., windTurbine HasSpeed 50, solarPanel HasCost 7500, etc.)

The property values and edges in *SSG* are mainly classified into five categories: identification, mobility, operation, economic, and ecology. Details are provided in what follows.

3.4 *SSG* Basic Structure

To cope with the interoperability issues, our *SSG* basic structure is a semantic translation of the CIM extension proposed in [24]. Knowing that the CIM is not dedicated to cover specifically the *SG* components modeling, the authors in [24] proposed additional features (e.g., solar power, wind power, etc.). Here comes the importance of our ontology that represents in a simple and clean way, each branch structure which contains the set of the equipment that composes it. Figure 1 shows the 'Microgrid' concept, inheriting from the 'CIM:SubControlArea', which describes relative information of the power system operation and allows the creation of several connected power systems instances. Based on the branch concept defined in [24], four main branches are added here: (1) Distributed energy resource branch, (2) Energy storage branch, (3) Electrical load branch, and (4) Infrastructure Branch, where each has its own Branch Switch and Branch Controller. The Branch Switch is responsible of turning on/off the branch, and the Branch controller is the manager of the branch operations. All concepts borrowed from CIM have been prefixed with 'CIM:' in the following figures of the provided ontology.

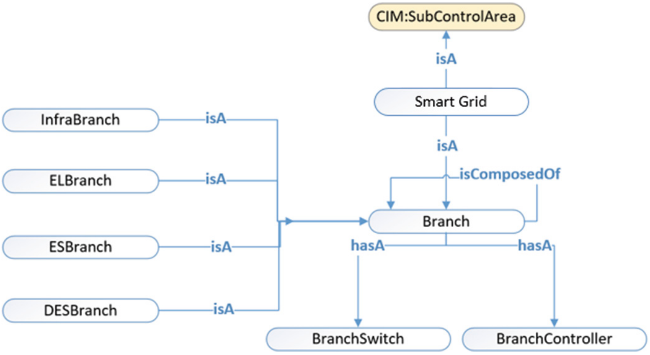


Fig. 1. Extract of the *SSG* skeleton structure

3.4.1 Distributed Energy Resource (DER) Branch

The distributed energy resource branch consists of renewable or non-renewable energy sources. Figure 2 shows the DER branch concept, consisting of a Solar Power Branch, Wind Power Branch, Combined Heat Power Branch and Fuel Power Branch.

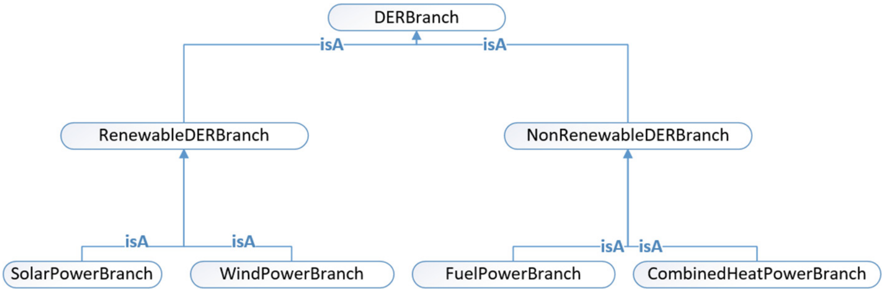


Fig. 2. Extract of the DER branch

Note that a branch is a combination of several equipment, when working together, they accomplish a specific function in the *SG* (e.g., a Solar Cell and a Converter are two main equipment constituting the Solar Power branch and allowing its functioning in the power system). In more details, a Solar Power branch (cf. Fig. 3) consists mainly of a Solar Cell and a converter. The Solar Cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. The converter is a branch for altering the nature of an electric current or signal, especially from AC to DC (Ac/Dc Converter) or vice versa (commonly called Inverter). This latter can be a Monophasic inverter or a Triphasic inverter.

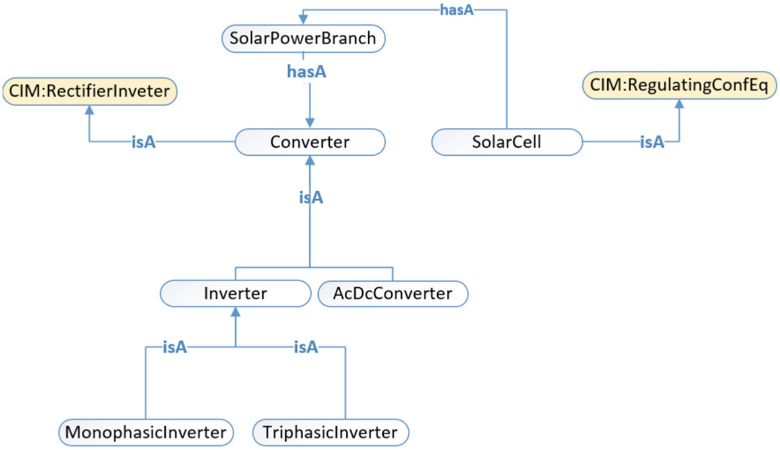


Fig. 3. Extract of the photovoltaic branch package

Figure 4 depicts the wind power branch. It includes mainly, the wind turbine and the converter. The wind turbine generates electricity from the kinectic power of the wind. The wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity. Similarly to the photovoltaic branch, the converter consists an essential component in the wind power structure.

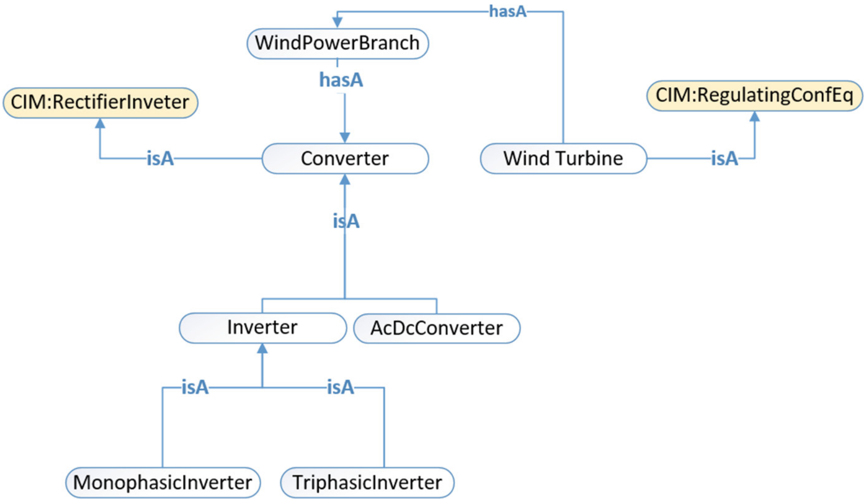


Fig. 4. Extract of the wind power branch

3.4.2 Energy Storage (ES) Branch

Recently, the energy storage systems start to have a great potential in radically transforming the global energy landscape, helping to solve key issues in the integration of renewable energy systems. Energy storage systems play an essential role in stabilizing the *SG*, improving the quality of power supply, and achieving power peak shaving. The energy storage branch consists mainly of the energy storage device (e.g., Pumped-Storage Hydroelectricity (PSH), batteries, etc.) and a converter (cf. Fig. 5).

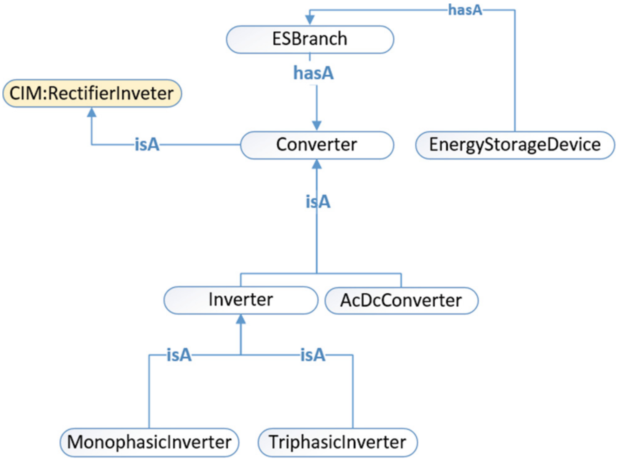


Fig. 5. Extract of the energy storage branch

3.4.3 Electrical Load (EL) Branch

An electrical Load is an electrical component or branch that consumes electric power. It is mainly consisting of the electrical appliance components (cf. Fig. 6).

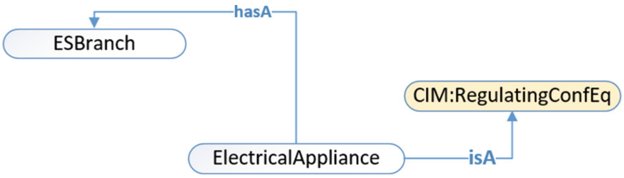


Fig. 6. Extract of the electrical load branch

3.5 *SSG* Extended Structure

To cope with the multi-objective aspect of an *SG*, *OntoMG* aims to model all the aspects/functionalities participating in the achievement of its objectives. Hence, six concepts are defined, each covering an objective aspect, namely: (1) identification, (2) economical, (3) operation, (4) mobility, (5) ecological and (6) multi-roles. Those concepts are the key for conceiving an *SG* able to reason and act autonomously.

3.5.1 Identification Concept

An *SG* consists of several heterogeneous branches, each having its own characteristics and operation modes during its lifetime. Thus, when joining an *SG*, each branch is associated, through an identification service, with an 'identity' consisting of a number of properties distinguishing it from the others and giving it the possibility to be automatically recognized. The identification concept consists of a number of properties (cf. Table 3): the serial number which is a unique value, the type, brand and model designating a certain provider.

Table 3. Identification concept

Name	*Description*	*Type*
Serial#	Unique identifier of a component within the system	String
Type	Type to which a component belongs	String
Brand	Feature that distinguishes one seller's component from those of others	String
Model	Style or design of a particular component	String

3.5.2 Economic Concept

Due to the importance of the *SG* from economic perspective, it is essential to consider related properties of its components. Those properties imply several features related to the *SG* participation in the electricity market. Table 4 shows the main properties of the economic aspect consisting of: the maintenance cost, the total cost, the start up cost, the stop cost, the installation cost, the equipment cost and the operating cost. Two additional properties are only assigned to the branches being able to sell their produced/stored power are the power price per KWh, the power price per hour, and the power cost.

Table 4. Economic concept

Name	*Description*	*Type*
EqCost	Equipment cost of a component	Number
MaintenanceCost	Maintenance cost of a component	Number
InstallCost	Installation cost of a component	Number
OpCost	Operating cost of a component	Number
TotalCost	Total cost of a component	Number
StrCost	Start up cost of a component	Number
StopCost	Stop cost of a component	Number
PwrKWhPrice	Power price vector per KWh	Number
PwrhPrice	Power price vector per hour	Number
PwrCost	Production power cost vector	Number
CptBill	Consumption bill vector	Number

3.5.3 Operation Concept

The operation concept encompasses the technical properties related to the components functioning during their lifetime in the power system. Since our model is based on the IEC 61850 in its extended structure, this eases the exchanges of the technical information between the *SG* components.

Tables 5, 6 and 7 show the list of the distributed energy source (DES), energy storage (ES) and electrical load (EL) operation properties, respectively.

Table 5. DER operation concept

$Name$	$Description$	$Type$
$IEC : VRtg$	Voltage level rating	Number
$IEC : ARtg$	Current rating under nominal voltage under nominal power factor	Number
$IEC : HzRtg$	Nominal frequency	Number
$IEC : TmpRtg$	Max temperature rating	Number
$IEC : VARtg$	Max volt-amps rating	Number
$IEC : WRtg$	Max watt rating	Number
$IEC : Vartg$	Max var rating	Number
$IEC : MaxWOut$	Max watt output - continuous	Number
$IEC : WRtg$	Rated Watts	Number
$IEC : MinWOut$	Min watt output - continuous	Number
$IEC : EffRtgPct$	Efficiency at rated capacity as percent	Number
$LaunchCount$	Number of time the components is launched during an interval of time	Number
$Penalty$	Waiting time penalty of launching the component	Number
$SInit$	Desired schedule of the component	Double
SOp	Operational schedule of the component	Double

Table 6. ES operation concept

$Name$	$Description$	$Type$
$IEC : AhrRtg$	Amp-hour capacity rating	Number
$IEC : BatVNom$	Nominal voltage of battery	Number
$IEC : BatSerCnt$	Number of cells in series	Number
$IEC : BatParCnt$	Number of cells in parallel	Number
$IEC : DisChaCnt$	Discharge curve	Number
$IEC : DisChaTim$	Discharge curve by time	Number
$IEC : DisChaRte$	Self discharge rate	Number
$IEC : EffRtgPct$	Efficiency at rated capacity as percent	Number
$IEC : SOCPct$	Battery level as percent	Number
$IEC : SOHPct$	Battery lifetime as percent	Number
$LaunchCount$	Number of time the components is launched during an interval of time	Number
$Penalty$	Waiting time penalty of launching the component	Number
$SInit$	Desired schedule of the component	Double
SOp	Operational schedule of the component	Double

Table 7. EL operation concept

Name	*Description*	*Type*
ActhAm	A.m active hours	Number
ActhPm	P.m active hours	Number
Cpt	Current consumption	Number
MaxCpt	Maximum consumption	Number
MinCpt	Minimum consumption	Number
MinStrTim	Minimum start time consumption	DateTimeStamp
MaxStrTim	Maximum start time consumption	DateTimeStamp
StrTim	Start time consumption	DateTimeStamp
MinStopTim	Minimum stop time consumption	DateTimeStamp
MaxStopTim	Maximum stop time consumption	DateTimeStamp
StopTim	Stop time consumption	DateTimeStamp
isPrimary	Designates a critical load	Boolean
isSecondary	Designates a non-critical load	Boolean
isShiftable	Designates a shiftable load	Boolean
LaunchCount	Number of time the components is launched during an interval of time	Number
Penalty	Waiting time penalty of launching the component	Number
SInit	Desired schedule of the component	Double
SOp	Operational schedule of the component	Double

3.5.4 Ecology Concept

Knowing the importance of the *SG* in the integration of green energy production, it becomes essential to take into account the components contribution in the environment. This participation is modeled through ecology concept (cf. Table 8) using several properties, such as the carbon emission ratio, the Ethylene emission ratio, and others gas emissions ratios, expressed in g/Kg. In addition, the pollution costs related to the toxic emissions are modeled using several properties: Carbon Emission Cost, Etyl Emission Cost.

Table 8. Ecology concept

Name	*Description*	*Type*
CarbEss	Carbon emission ratio	Number
EthylEss	Ethyl emission ratio	Number
HeatEss	Heat emission ratio	Number
CarbEssCost	Carbon emission Cost	Number
EthylEssCost	Ethyl emission Cost	Number
HeatEssCost	Heat emission Cost	Number

3.5.5 Mobility Concept

In order to model the components ability to move during their lifetime in the *SG*, a two-dimensional tracking is represented through two concepts: 'Time tracking' and 'Position tracking'. Each concept has a set of properties allowing a fine-grained tracking (cf. Tables 9 and 10).

Table 9. Time tracking concept

Name	*Description*	*Type*
DepTim	Departure Time of a mobile component	DateTimeStamp
ArvTim	Arrival Time of a mobile component	DateTimeStamp

Table 10. Location tracking concept

Name	*Description*	*Type*
Ctry	Country	String
Lat	Latitude	Double
Long	Longitude	Double
PosInMG	Position in the *SG*	String

3.5.6 Multi-roles Concept

Future *SG* are going through comprehensive changes, especially due to the integration of the Prosumers, where an entity can consume and produce simultaneously in a complete paradigm shift [12].

Fig. 7. Multi-role concept

Figure 7 shows the 'Role' concept defined to model the different roles that a component can play during their lifetime in the grid. Besides, three additional properties are defined (cf. Fig. 11): the 'RoleCondition', the 'RoleStartTime' and the 'Duration'.

3.6 Discussion

Our SSG ontology design and structure highlight its capabilities in resolving the interoperability issues from the three layers:

- Field Interoprability Layer: This is resolved thanks to the use of the CIM and IEC international standards allowing to be compliant with existing standards in the domain. In addition, new concepts are added aiming at covering new technologies and concepts such as electrical vehicle, etc.
- Knowledge/Information Layer: This is resolved thanks to the adoption of an ontology-based model, which allows the semantic modeling of the data.
- Management Layer: This is resolved thanks to the integration of several parameters allowing to cover the six services' categories of the *SGs*:

Table 11. Multi-roles concept

Name	*Description*	*Type*
RoleCondition	Required Condition to play a specific role	String
RoleStartTime	Start Time of a specific role	DateTimeStamp
Duration	Play duration of a specific role	Double

- *Identification Services:* the main identification services are the *Authentication* and the *Registration*. In the aim of establishing a secure access to the power system, an *Authentication* service is required. It verifies the identity of any component wishing to access the *SG*. The *Registration* service, is the process of registering the components in the power system using a set of parameters defined in the information/knowledge layer.
- *Operational Services:* the main operational services are: (1) the *Voltage and frequency regulation*, (2) the *Fault detection*, (3) the *Power loss minimization*, and (4) the *Peak power reduction*. The *Voltage and frequency regulation* consists of maintaining a balanced output of the voltage and frequency iof the grid, done despite the systems' disturbances and the load variations. The *Fault detection* consists of detecting power system errors as fast as possible, so that an appropriate action can be immediately taken before major problems can happen. The *Power loss minimization* consists of ensuring the power exchange between the components in a way to reduce the power transmission losses. The *Peak power reduction* consists of reducing the maximum power consumption (for instance, by applying prediction techniques of electrical consumption [11] and demand-side management techniques).
- *Economical Services:* they consist of managing the impact of the components on the electricity market. They play an essential role in delegating the cheapest component that should be launched or implemented to satisfy a certain need. For instance, one main economical service is the *electricity market management* which consists of establishing auction algorithms in order to find the optimal power prices and to maximize the net benefit of the components.
- *Ecological Services:* they consist of managing the participation of the components in the environment. The main ecological service is the *Green decisions management*. It consists of ensuring a cooperation in the power system by gathering the components that have mutual benefits, in order to make green decisions (e.g., putting up consumers having high power needs with the renewable energy sources in the aim of reducing the pollution ratio).
- *Mobility Services:* they are related to the components movements [17] in the power system. The main mobility service is the *Components location tracking*. It consists of determining and tracking the precise location of a component at any time. It is also used by the *Fault detection* service by

facilitating the detection of the location of any problem in order to fix it more rapidly.
- *Multi-roles Services:* they are related to the components which are able to execute many roles during their lifetime in the *SG*. The main multi-roles service is the *Role forcing* which forces a component to play a certain role (i.e., produce, consume or store power) when there is an essential need in the *SG*.

4 Experiments

We conducted several experiments in order to validate our proposed framework and emphasize the *SSG* importance and utility in the electricity domain. Before detailing the conducted tests, it is important to quickly describe the *SSG* design process. We developed *SSG* after exploring the current standards in power domain. In essence, we designed it iteratively by: (1) exploring and comparing the current standards in power domain, (2) presenting our observations and conclusions to several experts, (3) considering their feedback regarding their future needs and expectations. This iterative process has taken almost two years long in order to come up with a stable version. Hence, the feedback and knowledge of the experts have constantly been used to improve the ontology in every iteration.

4.1 Evaluation Criteria

It is worthy to note that there is no unique methodology for developing and evaluating ontologies. Developing ontology is usually an iterative process that can start with a rough first pass at the ontology and then revise and refine the evolving ontology. This process of iterative design will likely continue through the entire lifecycle of the ontology. In our study, we adopted two main quality criteria provided in [10] to evaluate *SSG*:

- **Comprehensibility:** it refers to how easily the language can be understood by technical actors (agents, engineers, etc.). Important aspects are the support of abstraction mechanisms (hiding details), uniform constructs, and a reasonable number of concepts.
- **Domain coverage:** it refers to the ability of the ontology to capture and cover the domain knowledge. It is related to the structure of the provided representation (concepts and relationships) and is the most important aspect of the ontology evaluation.

4.2 Evaluation Context

Although automatic or semi-automatic evaluation techniques are attracting more and more interests, manual evaluation or what is called 'human assessment evaluation' remains commonly adopted in the literature when addressing ontology evaluation [1]. Thus, we conducted manual evaluations to validate the core of *SSG*. We also deployed *SSG* into two projects. Before detailing the obtained results, we detail in what follows: (1) the ontology layers that has been evaluated, (2) corresponding evaluation metrics, and (3) the testers' profiles.

4.2.1 Ontology Layers

Three main ontology layers have been evaluated in our experiments:

- The *syntactic layer* includes respectively the ABox (concepts/classes) and the TBox (instances) of *SSG*
- The *semantic layer* encompasses the semantic relations between concepts (e.g., isA, hasPart, etc.), shaping the structure of the ontology
- The *context layer* includes the additional properties related to the *SG* needs, which are here reflected by its multi-objective aspects.

4.2.2 Evaluation Metrics

In order to correctly evaluate the ontology, three evaluation metrics have been used (the 3Cs requirements [25]):

- The *Correctness* aims at evaluating the clarity of the vocabulary and data of the syntactic layer of the ontology. It is used in our experiments to mainly measure the comprehensibility criteria,
- The *Consistency* targets the evaluation of the semantic layer of an ontology. It is also used to measure the comprehensibility,
- The *Completeness* targets the evaluation of the syntactic and context layers. It aims at evaluating the domain coverage criteria with the services that a *SG* must deal with.

4.2.3 Tests and Testers

Three tests were conducted, each targeting a specific evaluation metric: an ambiguity test, a quiz test, and a real use case scenario to evaluate the correctness, consistency and completeness, respectively. The first two tests were conducted by:

- 80 experts in electrical engineering (45 participants) and electronics (35 participants),
- 45 non-experts in electrical engineering and electronics (mainly computer scientists).

Note that our experts and non-experts are the assistant professors, associate professors, full professors and PhD students of the University of the Basque Country, Spain and the University of Pau and Pays de l'Adour - France.

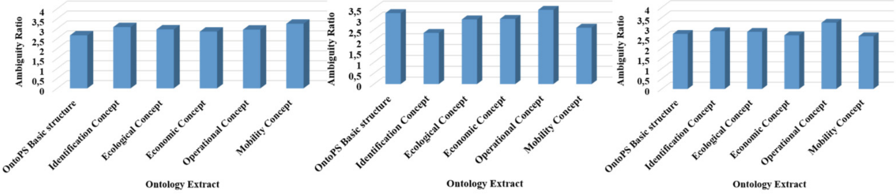
The choice of having computer scientists in our tests is related to the fact that we believe that future power systems will be multidisciplinary and would require some expertise in Information Technologies in order to understand how things are working together. In what follows, a detailed explanation of each evaluation is presented.

4.3 Comprehensibility Results

In what follows, we show the results obtained with the two metrics of Correctness and Consistency to measure the comprehensibility criteria.

4.3.1 Correctness

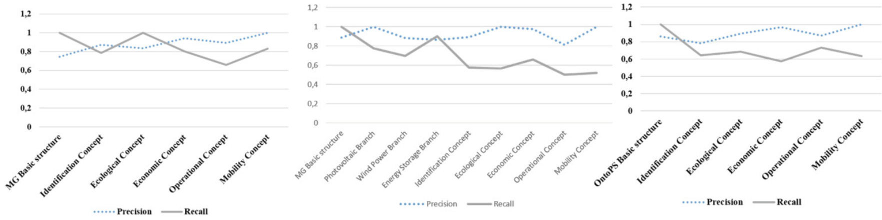
A first ‘semantic ambiguity test’ was done to evaluate the ontology correctness that targets the *syntactic* layer evaluation. A semantic ambiguity refers to the ambiguity of a word to be used in different contexts in order to express different meanings. In this test, the participants were asked to rate the ambiguity degree (if the word is clear/understandable or not) of a list of 60 items on a scale of 0 to 4 (4 expresses a very clear concept with no ambiguity, and 0 expresses a high ambiguity). Those items are categorized into two main categories: the low-level and the high-level items. The low-level items, target the technical data related to the power system structure and branches (i.e., the basic structure). However, the high-level items target the semantic data extracted related to the identification, ecological, economical, operational and mobility concepts (i.e., the extended structure). The obtained results are as follows:



a. Ambiguity Rate for the Computer Scientists (Non-Experts)

b. Ambiguity Rate for the Electrical Engineers

c. Ambiguity Rate for the Electronic Engineers



d. Precision and Recall of the Computer Scientists (Non-Experts)

e. Precision and Recall of the Electrical Engineers

f. Precision and Recall of the Electronic Engineers

Fig. 8. Experimental results

- For non experts: Figure 8a shows the results of the tests conducted by the 45 testers in computer science. The ambiguity rates vary from 2.66 (Basic structure) to 3.25 (Mobility concept), which can be considered as a very good result for non-experts in the electricity domain. A closer look to the rates led us to conclude that the hardest part was related to the evaluation of the low-level items, driving an ambiguity rate of 2.66. However, it was easier for them to understand the high-level items, resulting an ambiguity rate that varies from 2.85 (Economic concept) to 3.25 (Mobility concept). This is explained by the fact that the computer scientists are less familiar with the technical vocabulary related to the power systems (e.g., solar cell, flywheel, etc.), yet they are globally aware about the high-level concepts related to

the electricity market (e.g., Power Price, etc.), ecology (e.g., Gas Emission, etc.), identification (e.g., Serial Number, etc.), and mobility (e.g., Component Position, etc.).
- For electrical engineers: Figure 8b shows the results of the 45 testers in the electrical domain. The ambiguity rates vary from 2.35 (Identification concept) to 3.6 (Operational concept), which is very satisfactory. We observed that the easiest part for electrical experts, contrarily to non-experts, was to evaluate the ambiguity of the technical part, leading to an ambiguity rate of 3.6 (Operation concept). However, it was more difficult for them to understand the high-level items, resulting an ambiguity rate that varies between 2.35 (Identification concept) and 2.975 (Ecology concept).
- For electronic engineers: Figure 8c shows the results of the remaining 35 testers (most of them are students). The ambiguity rates vary between 2.58 (Mobility concept) and 3.25 (Operation concept). A closer look to the rates led us to conclude that the results were not converging, since the lowest ambiguity rate is 2.58 for the mobility concept which is related to the high-level terms, while the highest ambiguity rate is 3.25 for the technical terms. This will allow in the future to measure and compare the **Learning load** of an expert and a non-expert in order to master the proposed vocabulary.

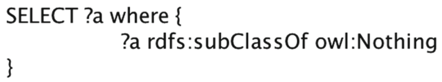
4.3.2 Consistency

A second test was conducted to evaluate the ontology consistency. In this test, the testers were kindly requested to choose the adequate relations between the concepts in a given ontology extract. Similarly to correctness, the list of 6 ontology extracts (each related to an ontology structure and concept) is categorized into two main categories: the low-level and the high-level extracts. The low-level one targets the technical data related to the *SSG* basic structure, while the high-level category targets the semantic data related to the identification, ecology, economic, operation and mobility concepts. For this evaluation, we adopted the precision and recall metrics commonly adopted in Information Retrieval since they meet our needs in evaluating whether the relations between the concepts are relevant or not. Please note that Precision (PR) computes the ratio of the number of correct answers w.r.t. the total number of answers (correct and false), while Recall (R) underlines the number of correctly identified answers w.r.t. the total number of correct answers, including those not answered by the user. The obtained results are as follows:

- For non experts: Figure 8d shows that the highest precision obtained by the computer scientists was reached when dealing with the mobility concept (of 1). This comes from the intuitiveness of the answers (which are the concepts in the ontology such as Country, Latitude and Longitude) that do not need an expertise in the power domain. However, the lowest precision (of 0.74) was reached when dealing with the basic structure. This comes from the specificity of the answers related to the different basic components that compose the 'SG'. On the other hand, Fig. 8d shows that the highest recall (of 1) is reached when dealing with the basic structure. This comes from the fact that since the testers are not experts in the power domain, they chose multiple answers, which increased sometimes the percentage of the correct answers. However, the lowest precision (of 0.658) was reached when dealing with the operation concept. This result confirms our expectation regarding *SSG*.

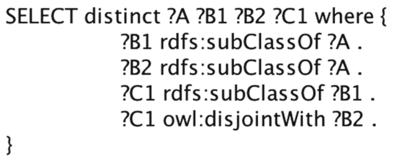
- For electrical engineers: Figure 8e shows that the highest precision (of 1) obtained by the electrical scientists was reached when dealing with the mobility concept (similarly to the computer scientists). However, the lowest precision (of 0.78) was reached when dealing with the identification concept. This comes from the fact that this concept is brand new for the testers who were assuming that some technical information (e.g., nominal active power, etc.) is enough to provide component identification. In addition, those details were modeled in the operation concept and were not linked to the identification one. After discussion with them, they understood the identification risks and agreed about the limitations of only considering the technical details. Figure 8e shows also the highest recall (1) reached when dealing with the basic structure. This comes from the fact that our testers are experts in the power domain, hence they all chose the correct answers without forgetting any correct one. However, the lowest precision (of 0.575) was reached when dealing with the economic aspect, because some answered by choosing operational aspect parameters, since they considered that they are also related to the economic aspect.
- For electronic engineers: Figure 8f shows that the highest precision (of 1) obtained by our testers is also reached when dealing with the mobility aspect branch. However, the lowest precision (0.81) was reached when dealing with the operational aspect. This comes from the fact that the electricians are not all familiar with the operational and technical concepts of a power system. Figure 8f shows that the highest recall (of 1) is reached when dealing with the basic structure. This comes from the fact that most of them were not aware of all the details in the 'SG' domain. Hence, they chose almost all the proposed answers to avoid forgetting any correct one. However, the lowest precision (of 0.5) was reached when dealing with the operational aspect. This comes from the numerous correct answers, since testers focused on what they considered the most pertinent ones.

In order to consolidate the validation of our ontology structure, an additional experiment was added. In [1], the authors define consistency as a criterion that verifies if the ontology includes or allows any contradictions and propose the following SPARQL queries that search for anti-patterns, a strong indicator of in-consistencies, in the ontology. The first query detects concepts with no parent (cf. Fig. 9), and the second detects abnormally disjointed concepts in the ontology (cf. Fig. 10): We executed both queries and found no inconsistencies in our SSG ontology structure. This denotes the soundness of the integration of newly added concepts with the CIM and IEC standards.



```
SELECT ?a where {
                ?a rdfs:subClassOf owl:Nothing
}
```

Fig. 9. Anti-pattern of subsuming nothing



```
SELECT distinct ?A ?B1 ?B2 ?C1 where {
                ?B1 rdfs:subClassOf ?A .
                ?B2 rdfs:subClassOf ?A .
                ?C1 rdfs:subClassOf ?B1 .
                ?C1 owl:disjointWith ?B2 .
}
```

Fig. 10. Anti-pattern of skewed partitions

4.3.3 Discussion

Those results show that our ontology provides promising results in term of correctness and consistency, reflecting the comprehensibility and the clarity of our ontology concepts and relations for the experts and non-experts.

4.4 Domain Coverage Results

The domain coverage criterion comes down to evaluate the context layer of *SSG*. This latter targets the ontology capability of modeling the properties allowing the power system to meet the end-users needs by executing corresponding services. Hence, in order to evaluate it, *SSG* has been deployed into two main projects: HIT2GAP and ISare as detailed below. *SSG* has been serialized into RDF/OWL and posted online[2].

4.4.1 Integrating *SSG* in HIT2GAP

The *HIT2GAP*[3] is an European joint collaboration research project (EU/H2020 Grant Agreement No: 680708) for developing a next generation building control tool for optimizing energy usage. The main objective of this project is to propose a new paradigm of an energy management platform for smart buildings. The project consortium is composed of 22 partners from 10 European countries. The *HIT2GAP* platform relies on an ontology allowing different partners to query data so to extract some information and events (through a set of services) from a smart building data. Figure 11 shows an extract of the ontological data model used for modeling and storing data within the platform. It shows its alignment with several main standards:

- IFC[4]: to represent the building related concepts,
- SSN[5]: to represent the data acquired from the sensors, and

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[2] http://spider.sigappfr.org/research-projects/ontomg/.
[3] http://www.hit2gap.eu.
[4] http://www.buildingsmart-tech.org/specifications/ifc-overview.
[5] https://www.w3.org/2005/Incubator/ssn/ssnx/ssn.

- *SSG*: to represent all the power system equipment since a smart building can be considered as an *SG*.

Related concepts are prefixed with `ifc:`, `ssn:`, and *SSG*`:`. As one can see, *SSG* is integrated as a backbone of the information model of HIT2GAP platform. The following concepts have been aligned with *HIT2GAP* ontology:

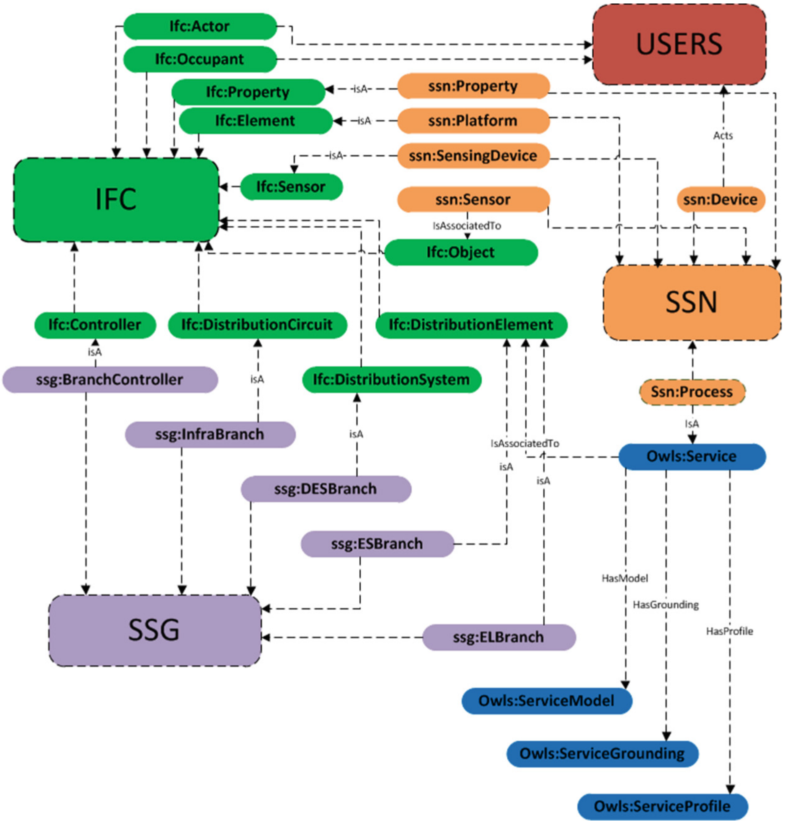


Fig. 11. Extract of HIT2GAP data model

1. *SSG*`:DERBranch` is aligned with `ifc:DistributionSystem` in order to extend the IFC with the distributed energy sources and their corresponding parameters,
2. *SSG*`:ESBranch` is aligned with `ifc:DistributionElement` in order to extend the IFC with the energy storage systems and their corresponding parameters,
3. *SSG*`:ELBranch` is aligned with `ifc:DistributionElement` in order to extend the IFC with the electrical loads and their corresponding parameters,
4. *SSG*`:InfraBranch` is aligned with `ifc:DistributionCircuit` in order to extend the IFC with the infrastructure equipment (e.g., cables, fiber optic, etc.) and their corresponding parameters,

5. *SSG*`:BranchController` is aligned with `ifc:Controller` in order to extend the IFC with the DES, ES, EL, Infrastructure controllers, and their corresponding parameters.

This alignment proves two main points:

- *SSG* is completely included in the HIT2GAP ontology since it allows to cover an important domain related to smart buildings: power domain. This will allow building actors to count on the expressiveness of *SSG* in order to represent/extract data and reason on it.
- *SSG* extends IFC which is the standard in building modelling that mainly focuses on the representation of the building equipment and constituents (e.g., floor, stair, wall, etc.), while neglecting the full coverage of the power related concepts in its vocabulary. This may weaken the building modeling since each equipment in the building can be considered as an energy source, storage or consumer, which highlights the importance of the *SSG* extension of the IFC.

It is to be noted that the *HIT2GAP* project is currently on-going. Hence, we have not had any feedback yet regarding the domain coverage of *SSG*. The feedback of partners are expected to be received by the end of 2018 and will be posted online on the project website (See footnote 2).

4.4.2 Aligning *SSG* with ISare

In collaboration of Jema Irizar Group, leader of the ISare Microgrid (MG) project, we fully implemented *SSG* in it in order to highlight the potential of the ontology in answering the needs and objectives. ISare MG is installed in Spain and electrifies 12 offices. The generation system comprises 10 kW of solar generation, a nominal 53 kWh battery bank, 105 kW of wind generation and a 120 kW diesel genset. A second solar array of about 15 kW, mounted on the roof of the control system building, is connected to an SMA inverter and a 70 kWh of gas turbine to provide power for monitoring and communication. In addition, 50 kW of electric vehicle charger were installed, equipped with a protection system, to ensure a mobile power. The ISare MG has been modeled using our *SSG*, resulting the *ISare-SSGmodel*. As a power system, the ISare MG has several needs. ISare MG needs to be modeled via an interoperable structure, that enables the integration and the validation of the various new heterogeneous renewable distributed generation systems and various storage technologies. In order to enable ISare MG managers to have intuitive data querying and management, we developed a dedicated framework with an easy-to-use pool of predefined services so to achieve the objectives.

The *ISare-SSGmodel* has been implemented (cf. Fig. 12) as an OWL graph, on a central entity. Queries are executed through a SPARQL querying interface. Note that, SPARQL is a query language, that is, a semantic query language, able to retrieve and manipulate data stored in Web Ontology Language (OWL). Then, the HermiT reasoner has been added in order to interfere new knowledge and to allow the autonomous behavior of the *MG*. The idea behing choosing

HermiT is that it can determine whether or not the ontology is consistent and identify subsumption relationships between classes. In order to highlight the advantages provided by our *ISare-SSG*, three scenarios are presented in the following for illustration.

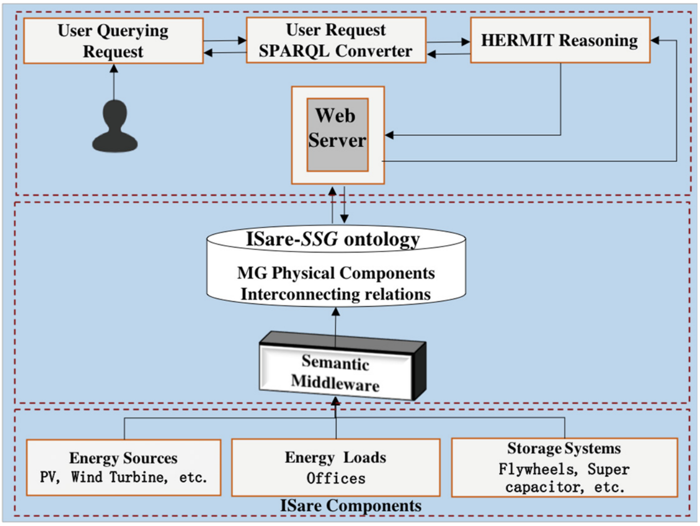
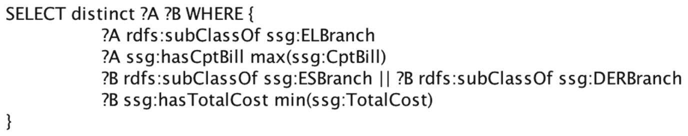


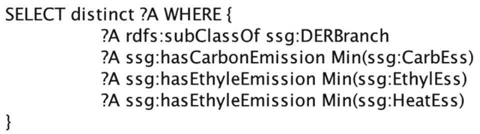
Fig. 12. ISare framework architecture

- Scenario 1 (Fig. 13): If an end-user needs to identify the consumer having the highest power consumption bill and advise him/her about the energy sources and storage systems that should be implemented in order to satisfy the demands at a lower cost, several concepts need to be used in the search engine from *ISare-SSG*. The basic-structure concepts are: $ELBranch$, $ESBranch$ and $DERBranch$. Those of the Extended Structure are: Operation and Economic, with the following properties: $CptBill$, $EqCost$, $MaintenanceCost$, $InstallCost$, $OpCost$, $TotalCost$, $StrCost$, $StopCost$, $PwrKWhPrice$, $PwrhPrice$ and $PwrCost$.
- Scenario 2 (Fig. 14): If an end-user needs to determine the most environmental friendly energy source, able to satisfy a consumer's power need at a certain weather condition, two basic-structure concepts are to be used: $ELBranch$ and $DERBranch$, with other extended-structure concepts such as: Operation and ecology, with the following properties: $CarbEss$, $EthylEss$, $HeatEss$.
- Scenario 3 (Fig. 15): If an end-user wants to visualize the type, brand and model of the most implemented renewable energy sources (e.g., solar plant, wind plant, etc.) in the power system, his/her query will include the following basic-structure concepts: $ELBranch$, $DERBranch$, $ESBranch$ and $InfraBranch$. It will also include one extended concept: Identification and all its properties (i.e., $Serial\#$, $Type$, $Brand$ and $Model$).



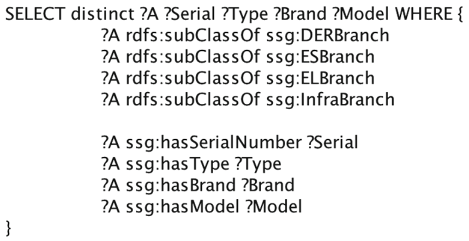
```
SELECT distinct ?A ?B WHERE {
            ?A rdfs:subClassOf ssg:ELBranch
            ?A ssg:hasCptBill max(ssg:CptBill)
            ?B rdfs:subClassOf ssg:ESBranch || ?B rdfs:subClassOf ssg:DERBranch
            ?B ssg:hasTotalCost min(ssg:TotalCost)
}
```

Fig. 13. Scenario 1 query example



```
SELECT distinct ?A WHERE {
            ?A rdfs:subClassOf ssg:DERBranch
            ?A ssg:hasCarbonEmission Min(ssg:CarbEss)
            ?A ssg:hasEthyleEmission Min(ssg:EthylEss)
            ?A ssg:hasEthyleEmission Min(ssg:HeatEss)
}
```

Fig. 14. Scenario 2 query example



```
SELECT distinct ?A ?Serial ?Type ?Brand ?Model WHERE {
            ?A rdfs:subClassOf ssg:DERBranch
            ?A rdfs:subClassOf ssg:ESBranch
            ?A rdfs:subClassOf ssg:ELBranch
            ?A rdfs:subClassOf ssg:InfraBranch

            ?A ssg:hasSerialNumber ?Serial
            ?A ssg:hasType ?Type
            ?A ssg:hasBrand ?Brand
            ?A ssg:hasModel ?Model
}
```

Fig. 15. Scenario 3 query example

4.4.3 Discussion

Those two applications show that our ontology provides a promising solid base for a better sharing of knowledge leading to a seamless communication between the components of the system (whether it is a smart building or a power system). In addition, it allows a better information querying and retrieval, and participates in increasing the reasoning capability of the system.

5 Conclusion

This paper introduces *SSG*, an ontology-based information model for *SGs*. The contributions of our work are four-folded: (1) it allows to resolve interoperability issues (syntactic and semantic) encountered between *SG* components, (2) it helps *SG* to represent and consider their (economical, ecological and operational) objectives directly in the information model (which is not the case of existing models) and allows to provide reasoning features to reach the fixed objectives, and (3) it allows to consider mobility and diversity of roles that can have each component involved in the *SGs*, and (4) it provides an evolutionary solution able to be extended easily to cover future needs. Several evaluations have been conducted to evaluate *SSG* resulting satisfactory results.

References

1. Brank, J., Grobelnik, M., Mladenic, D.: A survey of ontology evaluation techniques. In: Proceedings of the Conference on Data Mining and Data Warehouses (SiKDD 2005), pp. 166–170 (2005)
2. Catterson, V.M., Davidson, E.M., McArthur, S.D.: Issues in integrating existing multi-agent systems for power engineering applications. In: Proceedings of the 13th International Conference on, Intelligent Systems Application to Power Systems, 6-p. IEEE (2005)
3. Cox, W., Considine, T.: Energy, micromarkets, and microgrids. In: Grid-Interop 2011, pp. 1–8 (2011)
4. Cox, W., Holmberg, D., Sturek, D.: OASIS collaborative energy standards, facilities, and ZigBee smart energy. In: Grid-Interop Forum, pp. 1–8 (2011)
5. Cox, W.T., Considine, T., Principal, T.: Architecturally significant interfaces for the smart grid. In: Grid-Interop-The Road to an Interoperable Grid, Denver, Colorado, USA, pp. 17–19 (2009)
6. Dallinger, D., Wietschel, M.: Grid integration of intermittent renewable energy sources using price-responsive plug-in electric vehicles. Renew. Sustain. Energy Rev. **16**, 3370–3382 (2012)
7. BE Design: Facility smart grid information model (2017). https://www.iso.org/standard/71547.html. Accessed 30 July 2018
8. Fauzey, I.H.M., Nateghi, F., Mohammadi, F., Ismail, F.: Emergent occupational safety & health and environmental issues of demolition work: towards public environment. Procedia-Soc. Behav. Sci. **168**, 41–51 (2015)
9. Gillani, S., Laforest, F., Picard, G.: A generic ontology for prosumer-oriented smart grid. In: EDBT/ICDT Workshops, pp. 134–139 (2014)
10. Gómez-Pérez, A.: Ontology evaluation. In: Staab, S., Studer, R. (eds.) Handbook on Ontologies, pp. 251–273. Springer, Heidelberg (2004). https://doi.org/10.1007/978-3-540-24750-0_13
11. Goodwin, M., Yazidi, A.: A pattern recognition approach for peak prediction of electrical consumption. Integr. Comput.-Aided Eng. **23**, 101–113 (2016)
12. Grijalva, S., Costley, M., Ainsworth, N.: Prosumer-based control architecture for the future electricity grid. In: 2011 IEEE International Conference on Control Applications (CCA), pp. 43–48. IEEE (2011)
13. Guarino, N.: Formal ontology and information systems. In: Proceedings of FOIS, pp. 81–97. vol. 98 (1998)
14. Hammerstrom, D.J., et al.: Pacific northwest gridwise testbed demonstration projects. Part I. Olympic Peninsula Project, Technical report Pacific Northwest National Laboratory (PNNL), Richland, WA (US) (2007)
15. Hammerstrom, D.J., et al.: Pacific Northwest GridWise$^{\text{TM}}$ testbed demonstration projects; Part II. Grid Friendly$^{\text{TM}}$ Appliance Project. Technical report Pacific Northwest National Laboratory (PNNL), Richland, WA (US) (2007)
16. Ho, Q.-D., Le-Ngoc, T.: Smart grid communications networks: wireless technologies, protocols, issues and standards. In: Obaidat, M.S., Anpalagan, A., Woungang, I. (eds.) Handbook of Green Information and Communication Systems, pp. 115–146. Academic Press, New York (2012)
17. Kempton, W., Letendre, S.E.: Electric vehicles as a new power source for electric utilities. Transp. Res. Part D: Transp. Environ. **2**, 157–175 (1997)
18. Li, X., Liang, X., Lu, R., Shen, X., Lin, X., Zhu, H.: Securing smart grid: cyber attacks, countermeasures, and challenges. IEEE Commun. Mag. **50**(8), 38–45 (2012). https://doi.org/10.1109/MCOM.2012.6257525. ISSN 0163-6804

19. McMorran, A.W.: An introduction to IEC 61970–301 & 61968–11: The common information model. University of Strathclyde, 93, 124 (2007)
20. Mo, Y., et al.: Cyber-physical security of a smart grid infrastructure. Proc. IEEE **100**, 195–209 (2012)
21. Ritzer, G.: Focusing on the prosumer. In: Blättel-Mink, B., Hellmann, K.U. (eds.) Prosumer Revisited, pp. 61–79. Springer, Cham (2010)
22. Uschold, M., Gruninger, M.: Ontologies: principles, methods and applications. Knowl. Eng. Rev. **11**, 93–136 (1996)
23. Verhoosel, J., Rumph, F.-J., Konsman, M.: Modeling of flexibility in electricity demand and supply for renewables integration. In: Workshop on eeBuildings Data Models, Sophia Antipolis, France, pp. 1–8 (2011)
24. Wang, C., Liu, H., Wu, F.: The extend CIM for microgrid. In: 2012 China International Conference on Electricity Distribution (CICED), pp. 1–5 (2012). https://doi.org/10.1109/CICED.2012.6508543
25. Zowghi, D., Gervasi, V.: The three CS of requirements: consistency, completeness, and correctness. In: International Workshop on Requirements Engineering: Foundations for Software Quality, Essen, Germany: Essener Informatik Beitiage, pp. 155–164 (2002)