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An Ontological Meta-Model Framework for Implementation of IEC 61968

***Abstract**. The ontological meta-model abstract framework is the base for IEC 61968 implementation. The layered framework covers all aspects of process of information integration on utility level in smart grid. The ontology and methodology of model transformation, model modification, business context and integration pattern components are separately elaborated by using ontological meta-model. The formal method for the implementation algorism and verification tools is also presented.*

***Streszczenie.** W artykule przedstawiono propozycję ontologicznej struktury meta-modelu i komponentów standardu IEC 61968. Struktura ma na celu ustalenie specyfikacji standardu na potrzeby późniejszych prac. (**Ontologiczny meta-model struktury standardu IEC 61968**)*

Keywords: IEC 61968; meta-model; formal method; Ontology; Interoperability;
Słowa kluczowe: IEC 61968, meta-model, Ontologia, interoperacyjność

Introduction

Information Integration is one of foundations of smart grid that comprehensively utilizes all aspects of data from any possible source to facilitate the reliability and security of grid operation and utility management. IEC 61968 is a wide recognized standard dedicated to the feasible and effective data interaction from within and among utilities, which attempts to cover all potential domains from network calculation to asset management. Compared with IEC 61970 applied by Energy Management System (EMS) in control centre for intra-application integration and IEC 61850 that is resident in substation for Substation Automation System (SAS), IEC 61968 is at enterprise level for inter-application information exchange implemented by using Enterprise Service Bus (ESB) [1]. Part 3 through 9 of IEC 61968 define a set of interfaces relevant to each of the major business functions described by the Interface Reference Model (IRM) and provide the primary implementation profiles, namely Naming and Rules [2].

However, IEC 61968 is still in interoperability test stage and has yet to achieve deployment phase due to lack of the unified utility-wide model ontology and verification methodology. The following feeder application use case is a typical example to illustrate the integration requirements for smart grid. Automation control system or system operator switches feeders based on contingency analysis which is critical to the optimized utility operation by VAR and Voltage dispatch. Once the fault occurs or the operational parameter exceeds the limits, the calculations in control centre or local device run to analyse the contingency situation and issue predefined or corresponding actions in a limited period of time. During the switching sequence, data from different applications are bi-directional transmitted. The grid topological connectivity data modelled by CIM and feeder loads and various IED conditions monitored by using IEC 61850 are collected and integrated. After analysis, the control commands and some configuration changes should download to field devices and communication controllers, which are defined in IEC 61850 as well. On the other side, the related information are also needed by other utility management systems, such as illuminating the nearly real-time pictures from the field crew point of view in Geographical Information System (GIS) and recording the changed power supply scheme in Customer Information System (CIS). It is vital to guaranty the correctness and validity of each step of the sequence or integration process. As a result, the model gap and Interactive mode difference among systems will block the seamless information integration throughout the entire utility.

IEC 61968 takes CIM as the reference model and XML Schema (XSD) as message structure while IEC 61970 define simplified CIM/RDF to document the static transmission network model and the Generic Interface Definition (GID) for interaction pattern in various scenarios. But IEC 61850 adopts the totally different object-oriented run time and configuration model plus service coding system. Though the combination of CIM and IEC 61850 are discussed for many years [3], the harmonization is narrowed to the IED configuration model. One reason is that the Substation Configuration Language (SCL) is based on XML as similar as CIM file that is suite to transmit by web service as IEC 61968 messages does. The other is that IEC 61850 is extended to cover the power utility automation including distributed generation monitoring and control that is closely connected to distribution system and utility management systems requiring topological connectivity model and IED reconfiguration file exchange. Besides model harmonization, CIM model and interface extensions for additional applications and businesses are recommended [4, 5]. Although IEC 61968 interoperability tests [6, 7] and some implementation frameworks [8] have been carried out, the existing methodology and tools are still immature and do not fully cover all the situations and problems faced.

The IEC 61968 implementation should cover the three aspects of construction that are syntax, semantic and context. All of them are abstractly modelled by meta-model using ontology to standardize the methodology and rules without ambiguity. The formal methods transfer the modelling and integration processes into computer recognized and programmable language to facilitate the implementation and verification. This paper proposes an ontological meta-model abstract framework and its components for IEC 61968 to establish a standard specification for further instantiation and management.

Ontological Meta-Model Abstract Framework

Meta-model typically defines the language and processes from which to form a model [9]. Because model is an abstraction of object in real world, meta-model is the model of model that constructs the model semantics, method and process to fulfil data store, exchange and transformation. Meta model is a protocol model that defines the constraint of meta-class structure and relationship and has the ability to verify whether the corresponding model is reasonable or not. Fig. 1 presents the layered structure of meta-model for CIM and IEC 61850.

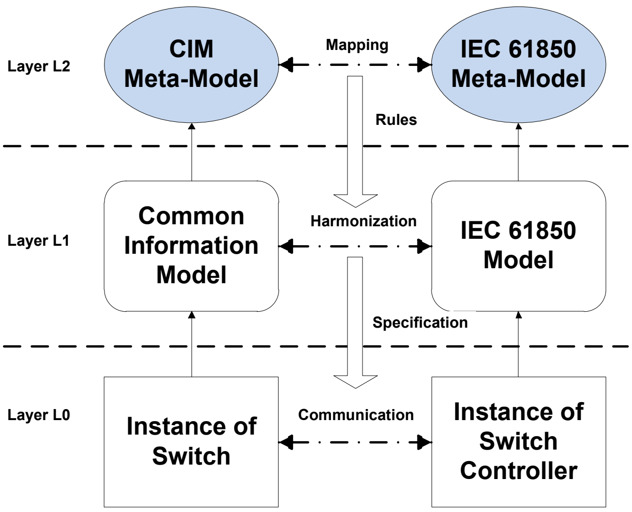


Fig.1. Three layered structure of model harmonization

Ontology is the explicit formalized norm explanation of the shared conceptualization model including formalization, explicit, conceptualization, and share [10]. Let D be the set of objects in domain, R be the relationships between objects, the conceptualization of objects $S = <D, R>$. XML, RDF and OWL are all ontology languages that support interoperability. So the combination of ontology and meta-model can provide the feasible scheme to construct static models and dynamic process rules for domain objects in one model simultaneously. Fig. 2 shows power system model meta-model by using ontology description language.

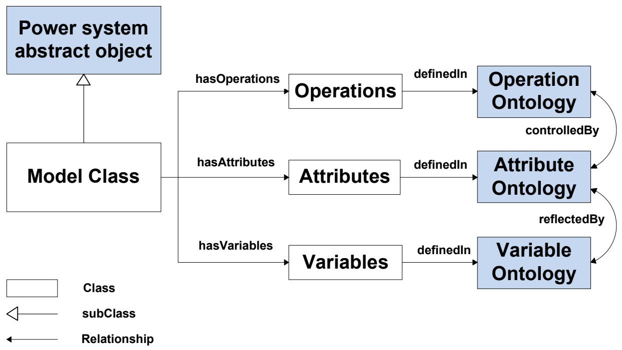


Fig.2. Power system ontological meta-model

Traditionally, CIM merely describes the static power system network models and IEC 61850 focuses on monitoring and control automation systems. Both of them are hard to elaborate the relationships between objects by solely using UML or any other ontology language. The gaps indeed separate the original associations into some limited domains. By using ontological meta-model, the internal connections are constructed as Fig. 2 shows. Model class inherits from power system abstract class and has its operations, attributes and variables that are classified by and defined in the corresponding ontology class. The meta-model indicates that the operation ontology may controlled by attributed ontology and variable ontology can reflect the attributes characteristics or vice versa. These relationships may contain logical deductions or physical calculation connections that depend on the objects. Consequently, the ontological meta-model is capable of establishing the combination of physical and logical model for power system.

Generally, IEC 61968 implementation includes model amendment and transformation, business context profile extraction, message exchange pattern and verification process. The syntax mapping from UML model to XSD and CIM/RDF is thoroughly defined by IEC 61968-100[2]. But the model modification rules are rarely mentioned because the revise processes almost all involve diverse sematic understandings and extensions that currently have yet to reach the agreement. The logical connections of instance data from different systems will be established. Besides the differences of model semantics, the business profile extraction should be based on local applications of utility and do not force to just conform the generic profiles defined by IEC 61968 that do not provide the rules and constraints for the specific context [11]. The message exchange pattern should be according to the local demand and system architecture service condition as well. The data flow direction, execution sequence and situational requirement needs formally and precisely defined by process model without conflict that will ensure the correctness of the integration process. All of these aspects of implementation should be auto-verified by tools that consist of various functional modules.

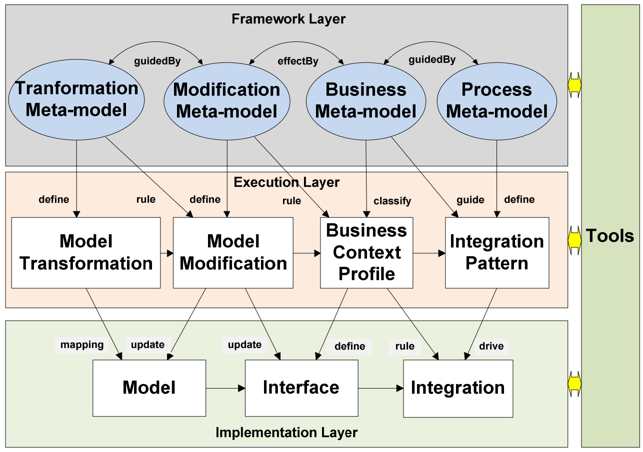


Fig.3. Ontological meta-model abstract framework of IEC 61968

Fig. 3 shows the complete abstract framework for IEC 61968 implementation by using ontology meta-model [12]. The framework is generally divided into four major parts that are framework layer, execution layer, implementation layer and relevant tools. Many current researches are at execution layer that provides the ontology and methodology of model mapping, model modification, profile design and integration mode for specific applications and scenarios. These ontology and methodology rules the real instance implementation of modelling, interface designing and message exchanging at implementation layer. However, the research works rarely pay attention to the higher level, namely framework layer that could normalize implementation behaviours and eliminate the ambiguity for the other two layers. Each layer of the framework also depends on the effective and practical tools. It is obvious that the advantage of the framework layer is that the abstract information model and physical operational behaviours of the power system objects are organically bound with each other to provide complete picture for all characteristics. So it is vital and necessary to add framework layer and tools into the architecture of IEC 61968. The next sections will present each component and their sub modules by using ontological meta-model and formal definition.

Model Transformation

Model transformation and model mapping are two closely related concepts in Model Driven Architecture

(MDA). Model transformation can realize both unidirectional and bidirectional transformation between different models that are separately specified by the different meta-model specification to which the models conform. Model mapping is one of key steps in model transformation process, which is the result according to the corresponding meta-model relationships between two elements of models. Normally, model transformation involves syntax and semantic mapping.

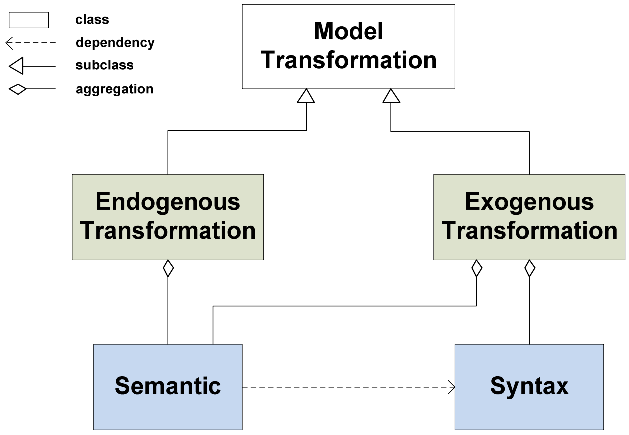


Fig.4. Model transformation ontological meta-model

There are two kinds of model transformations that are endogenous and exogenous transformation in Fig.4. The former happens between models expressed in the same language and the latter takes place between models in different meta-model. As a result, endogenous transformation just contains sematic matching and exogenous transformation has to aggregate both syntax and semantic mapping. Actually, the sematic interpretation is depending on syntax expression.

The example of model transformation for the switch and its controller between CIM and in IEC 61850 is illustrated in Fig.1. Let MM be the meta-model for switch, M be the switch model and m be the instance switch data. The conformity of m to meta-model specification MM can be defined as:

(1) $$Conform(m, MM) : M \times MM \rightarrow \{true\}$$

where: $m \in M$.

In this case, m_c is one of switch instance of M_C in CIM that conforms to CIM meta-model specification, MM_C. Similarly, $m_s \in M_s$ is in compliance with MM_s for IEC 61850. If the function $tF()$ can transform m_c to m_s, the process is described as:

(2) $$tF(m_c) : M_c \mapsto M_s \cup \varnothing$$

The function includes four components that are corresponding objects from two models, the syntax rules and sematic rules (3). The power system domain experts only need to care about sematic mappings that are formalized encoded into a set of description by using computer recognized language.

(3) $$tF() = \langle o_C, o_S, Syn, Sem \rangle$$

where: O_c,Os – model objects, Syn – syntax, Sem – sematic.

The loop steps of model transformation can be defined as:

(4) $$\begin{aligned} & Init : M_s = \varnothing \\ & \forall m_c \in M_c : \\ & \quad while(\exists m_c \in M_c : tF(m_c) \notin M_s) \\ & \qquad M_s = M_s \cup tF(m_c) \wedge Conform(tF(m_c), MM_s) \end{aligned}$$

From the equation and algorithm above, each step will check whether the presence of untreated model are left and add the post-transformed model into result set.

Model Modification

Under normal circumstance, model modification can be classified into three categories including add, delete and evolution. IEC 61970 provides a set of scheme using simplified CIM/RDF syntax to identify the difference model. However, this method is designed for instance data level application. Only the ontology can reflect the abstract model changes.

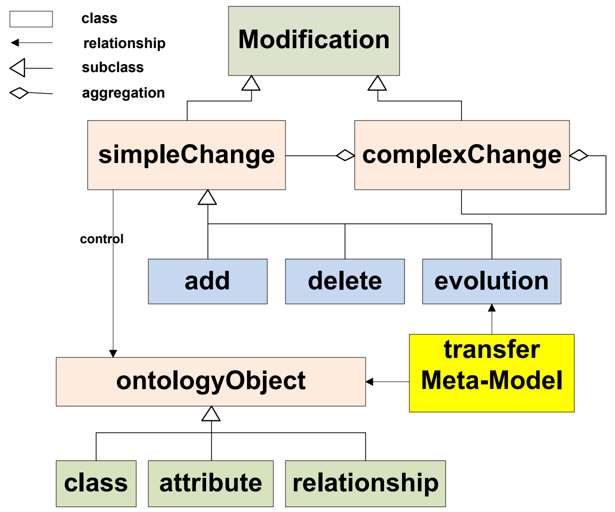


Fig.5. Model modification ontological meta-model

The complex change consists of simple changes or other complex changes shown in Fig.5. Each simple change can control ontology object including model class, attribute and relationship that are naturally complicatedly connect with each other. As a result, each simple modification could not complete just in one step. The impudent and ill-considered actions will destroy the logical concepts of model objects and violate the modelling and sematic rules. For example, switch class in CIM is an abstract class that generates breaker, disconnector, fuse and other concrete subclass. If power system domain expert deletes one attribute from switch class, all subclasses will no longer inherit it from its superclass and some common characteristic of switch device will be lost.

Evolution is slightly different than add and delete. It contains two level contents that are modelling language update and ontology object transformation. The transformation from UML 1.4 to UML 2.0 is a typical example of modelling language update. The power system domain experts are mainly concentrated on the latter because the model should always pursuit the accuracy. It is common to convert one attribute into relationship between classes, which is based on everlasting deeper recognitions and understandings. So the evolution must conform to the transfer meta-model that defines guidelines and actual rules.

Context and Process

Other than model transformation and modification that belong to the category of Platform Interdependent models

(PIM), context and process are one kind of Platform Specific Models (PSM). The sematic constraint and interaction pattern are closed related to the utility business requirements and the integration architecture configuration.

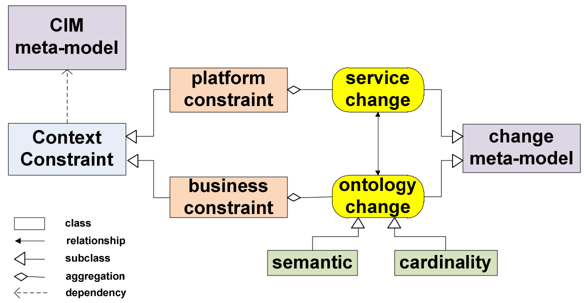
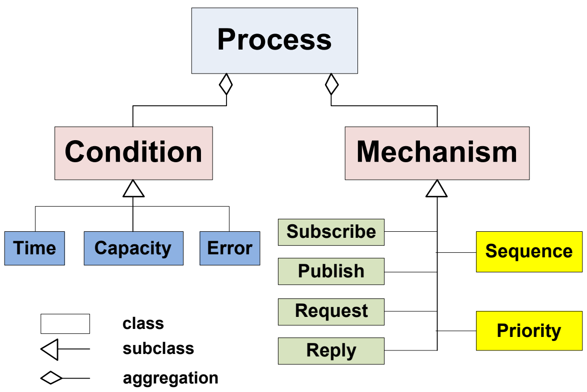


Fig.6. context constraint ontological meta-model

The context model or profile is the subset of CIM that extracts useful and simplified model according to the specific business data requirement. Generally, the Profiles do not completely conform to CIM, which allow the additional constraints depending on the business needs. Fig. 6 demonstrates that the context constraint comes from platform and utility business. The platform integrates lots of data services provided by various systems. Each service defines constraints by its output data domain. Similarly, the sematic and cardinality of the exchange interface will change as soon as business updates.



Process is one or more activities that occur over a period of time in which objects participate. The interaction pattern actually is a dynamic process that defines the data message flow direction and sequence based on IEC 61968 communication mechanisms. The condition and mechanism are two major parts of process. The transmission time for each message, the probability of error occurrence and maximum transaction capacity can reflect the process running performance and condition. The message exchange mode are composed of subscribe, publish, request and reply. Besides sequence execution of message queue, the service or interface could provide message priority scheduling mechanism for the special real-time data request, which is supported by IEC 61968.

Tools

Tools will cover all the components and their sub blocks of the ontological meta-model abstract framework for IEC 61968 implementation. It is vital to guaranty the correctness and effectiveness for every step within implementation process. The verification depends on the formal text and symbol languages to express rigorous algorisms that are executable by tools. By using Web Ontology Language (OWL), Business Process Execution Language for Web Service (BPEL4WS) and formal logical language, tools are capable to control and monitoring the progress.

Conclusion

The ontology meta-model abstract framework for IEC 61968 implementation is a complete and practical solution to facilitate the information integration on enterprise level for utility in smart grid. The layered framework consists of abstract components and their corresponding sub modules that apply ontological meta-model to elaborate the IEC 61968 mechanism and rules. The formal method and definition are used to describe the algorisms during the dynamic execution process, which contributes to the establishment of verification procedure.

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