Toward a model transformation for reliability analysis of power grids architecture

Vers une transformation de modèle pour l'analyse de la fiabilité d'architecture de réseaux électriques

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RÉSUMÉ —

L’énergie électrique est essentielle pour nos usages quotidiens et industriels. Les besoins en énergie électrique augmentant constamment, le système qui assure sa fourniture doit être sûr. Ainsi, le système électrique a évolué vers le concept de *Réseau Intelligent* pour faire face à ces divers usages. Dès lors, la définition de modèles de systèmes électriques se standardise. Cependant, un défi pour les acteurs industriels persiste : comment assurer la cohérence d'un système électrique plus fiable, interopérable et intégrant les exigences liées aux métiers, normes et technologies du secteur de l’énergie électrique ? Cette cohérence questionne les mécanismes d’échange de données facilitant les interactions à différents niveaux de l’infrastructure.

Pour le métier de la sûreté de fonctionnement, EDF a développé le langage FIGARO et l'outil KB3-K6 utilisant une approche basée sur des modèles de Markov, pour vérifier les exigences de fiabilité et de disponibilité de ses réseaux. Dans les domaines du transport et de la distribution de l’électricité, le standard CIM (Common Information Model) a été développé afin d’échanger des informations de réseaux électriques. Dans cet article, nous proposons une démarche pour identifier les correspondances entre des concepts du modèle CIM décrit en UML (Unified Modelling Language) et les concepts de la sûreté de fonctionnement décrits en langage FIGARO afin de définir une future transformation de modèles. Pour cela, il est nécessaire d’identifier le niveau sémantique des concepts des deux domaines.

L’objectif est de définir une approche pour construire des modèles de fiabilité à partir de données et éléments d’architecture de systèmes existants, sur la base de modèles standards de description de réseaux électriques. Le principal résultat est un ensemble de règles de transformation entre les concepts d’un modèle CIM et les concepts d’un modèle FIGARO.

MOTS-CLÉS

Réseau Électrique, Fiabilité, Common Information Model, FIGARO, Interopérabilité, Transformation de modèle

ABSTRACT —

Electrical energy is at the heart of our daily use and economic activities. As the demand for electrical energy is constantly increasing, the system that supplies it must be safe. Thus, the electricity system has evolved towards the concept of *Smart Grid* to cope with these various needs. As a result, the definition of standardized electrical system models is necessary. However, a challenge for industrial actors remains : How to ensure compliance of a more reliable electrical system, interoperable and integrating the different engineering fields requirements, standards, and technologies ? The adoption of electricity standards requires establishing an efficient framework for network data exchange at different levels of the electrical infrastructure.

The safety level of installations must be guaranteed, whatever the configurations. Electricité De France (EDF) has developed the FIGARO language and the KB3-K6 tool that uses a reliability approach based on Markov models, to verify electrical system reliability and availability performances. To enhance data exchange between stakeholders in electrical domains, the Common Information Model standard (CIM) has been defined on an international scale in UML (Unified Modelling Language). In this paper, the main objective is to define needs in terms of smart grid data to perform safety studies in relation to standards such as the CIM. The methodology adopted is based on CIM concepts analysis and dependability concepts described in FIGARO language.

This paper aims to define an approach to build reliability models from data and architecture elements of existing systems, based on a standard description of these models. The main result is a set of transformation rules between a CIM model concepts for dependability field and a FIGARO model concepts for reliability assessment.

KEYWORDS —

Smart Grid, Reliability, Common Information Model, FIGARO, Interoperability, Model Transformation.

INTRODUCTION —

Electrical energy is part of our daily use, our economic activities, industries, and domestic consumption. It cannot be stored and must be produced on schedule, to be fitted to the just necessary consumption with a minimum of losses. In order to ensure its production and an efficient delivery to the customers, the electrical network must be reliable, available, and capable of communicating information to other systems (Beillan et al., 2018). With the urbanization of cities, the new living standards, occurs a major evolution of our society. The new energy needs lead to a deep transformation of the electrical system. The involved requirements and necessity to develop new grid technologies, led to a deregulation in the electrical power sector and to the adoption of more efficient engineering practices and standards (Alotaibi, et al., 2020). To deal with this evolution of the practices, the Smart Grid concept on its different aspects and architecture layers has emerged (Andrén et al., 2013), (Chehri, et al., 2022). In order to ensure conformity to the new standards, the engineering and management activities in the electricity sector are progressively harmonized by industries such as EDF company (Lambert & Quéric, 2010). Nevertheless, an issue globally persists : How to design an interoperable and reliable electrical system through various operators, applications, and systems that satisfies the new standards ?

On one hand, the Smart Grid uses advanced technologies to work with intelligence, so in operation, it can be highly monitored, automatically supervised and configured. Therefore, the Smart Grid is vulnerable due to an intensive use of various nature of data and technologies (Anderson, et al., 2018), (Wang et al., 2015). The Smart Grid development is carried out by the adoption of Common Information Model serie of standards, to support the engineering and management of the new functions, services, and operators. Thus, the CIM enhances electrical network data and models representation (EPRI, 2022). Based on the general-purpose modelling language UML, it uses the notion of profile (Fuentes-Fernández& Vallecillo-Moreno, 2004) to adapt the UML to the specific needs of each Smart Grid domain activities such as **power system modelling** (Dinkelbach, et al. 2023).

On the other hand, the increased reliance of society on power energy makes more visible the preoccupations about network data integrity. Data are a particular aspect of involved power system. From the safety experts point of view who need to dispose of a model of power systems under study, the system's physical architecture criticality and safety are crucial aspects to be taken into account. When the power grid is solicited, the quality of the delivered service must be at a required level of performance. When it fails, the continuity of service must be ensured or recovered. Many approaches have been developed to assess electrical network dependability offering many benefits (Chrun & Cloarec, 2016), (Tamara et al., 2020) and, probabilistic approaches seem to appear as an efficient mean to contribute to the system safety assessment.

The Smart Grid infrastructure can be considered as a complex system (Gonzalez de Durana et al., 2010), (Guérard et al., 2012) and classical methods such as failure modes and effects analysis (FMEA), Fault Tree or Boolean logic driven Markov processes (BDMP) (Bouissou, 2009) are no longer suitable to assess its safety. Adopting model-based safety analysis (MBSA) approaches to address the potential gaps one of the central concerns (Petermann et al., 2012) (Batteux et al., 2016), (Sun et al., 2024). At its early stage of development, the CIM was implemented based on the system analysis function (Topology processing, state estimation and power flow) of the EMS (Energy Management System) in generation and distribution domains. Based on the edition of the IEC 61970/61968 CIM standards, this function was extended to provide a specification for the implementation of other applications such as the graphical visualization of single line diagrams (Kim et al., 2020). This paper investigates a mean to perform a **modelling activity** on power systems in a **MBSA process**, by reusing the information provided by a **CIM model**. Therefore, in many cases, a single line diagram tool that may provide a model of the power system that is CIM compliant is not available in the enterprise modelling frameworks. The information provided are basically document-based using single line diagram in a paper format. This generates inconsistencies between engineering fields and CIM domain that uses as input data a standard model to describe power network. The ambition is to explore a combined way to facilitate harmonization of network modelling and simulation, based on a safety analysts and integrators viewpoint. This harmonization focuses on transformation and simulation of models of smart grid architecture to perform a safety study.

In this paper, the main interest for safety engineers will be to understand how the CIM model can be used to build a dysfunctional model for reliability analysis. This contribution is presented in four sections. The section 1 establishes the link with related works on power grid model-based transformation and methodology and works done for safety analysis. The section 2 presents the methodology used to identify a framework for a model transformation specification, to transform a model describing an electrical network into a MBSA model to analyse reliability of the electrical network. The section 3 first shows how to transform a classical single line diagram into CIM model standard representation, and concisely presents the obtained results, by manually applying the transformation to analyse the feasibility of a transformation process. In the section 4, a discussion and the perspectives to be developed are also presented.

RELATED WORKS —

Developing Smart Grid interoperability can enhance network reliability by providing information to electrical network applications through a seamless end-to-end connection mechanism (Kim et al., 2020). There are numerous Smart Grid functions, technologies, and applications such as Energy Management System, Meter Data Management, Geographical Information System, Outage Management System that can be implemented and integrated to control and automate the grid (Alotaibi et al., 2020). Each of these applications using CIM models compliant and do not lead to reliability assessment but can be exploited to provide input data to a safety analysis tool, within a CIM framework integration capability. This integration can ensure a more interoperable network by improving information exchange between enterprise functions thanks to Model Driven Engineering (MDE) (Neureiter et al., 2016). In this section, we first present different methods that exist in the literature to analyse the safety of a smart grid. Then we present the related works on CIM model transformation using the Model Driven Approach (MDA) relying on MDE principles.

A. Safety evaluation in electricity domain

There are different methods based on analytical and Monte Carlo simulation and metrics to assess smart grid safety (Alotaibi et al., 2020). In Energy Distribution level, (Abdukhakimov et al., 2019) proposes a method for network reliability analysis, using indices such as failure rate, repair duration and unavailability and identify the System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI) and Average System Availability Index (ASAI) as the four reliability index that are often used to perform analyses. Their method needs to be integrated in MBSA framework to take into account **system modelling activity** to improve interoperability with CIM applications. (Legendre et al., 2020) proposes a MBSA framework that considers system modelling activity and calculates metrics like Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR). The CIM standards seems to address reliability concern by an outage-based analysis using the concept of contingency. Also called unplanned outage analysis, contingency analysis evaluates the effects and estimated overloads from each outage event when abnormal situations occur. The following definition of a contingency is proposed (SmartGrid.gov, 2010) :

> *"A contingency is the loss or failure of a small part of the power system (e.g. a transmission line), or the loss/failure of individual equipment such as a generator or transformer."*

B. Model Based Safety Assessment in Smart Grids

In power system, many data can be collected from the system network applications like Advanced Metering Infrastructure (AMI), Energy Management System (EMS), or Supervisory Control and Data Acquisition (SCADA) (Alotaibi et al., 2020). Many of these applications tend to adopt the CIM standards. Since the need is to define an efficient way to merge concerns of Smart Grid operators, including stakeholders (Uslar et al., 2012), safety engineers are also involved in this preoccupation. Thus, it is crucial to extend CIM domain to MBSA that is on the verge of becoming a standard for safety engineering field. The MBSA methodology presented in (Legendre et al., 2020) and describes in FIGARO (a language developed by EDF (Donat, & Bouissou, 2015), an efficient 4-activities process to assess MTFB and MTTR metrics (Data capitalization, **System modelling**, Indicators quantification and Results processing). A complex system like Smart Grid generates many data, and defining a common database or repository to provide these data to engineering teams and any application of the grid can be a benefit (Roy, et al., 2022). Since the MBSA approach described in (Legendre et al., 2020) requires input data and does not guarantee their consistency, the tool used needs to be merged to a model that can provide these data with a high level of confidence. The CIM models are standardized and can be reused to get a MBSA model to perform safety analysis with consistent data. So, how to transform a CIM standard model into a Model like FIGARO in order to improve the consistency between data and the model of the system?

C. Model Driven Engineering for Grid applications

Traditionally, electrical system energy is broken into mostly isolated systems and domains (generation, transmission, substation, distribution, and consumers) (Anderson et al., 2018). This siloed construction of the grid reduces its interoperability, and the CIM has been come to help to develop the exchange between smart grid systems and application (EPRI, 2022). Since the CIM is a layered conceptual model, many approaches and tools like RiseClipse (Macardet & Lambert, 2016) or CIM-2-MODelica (J. Gómez et al., 2015) that use CIM standard have been partially developed, and the global statement is that these tools do not provide an integrated framework to address the existing interoperability issues. A benchmark on CIM-compatible existing tools is presented in (Sanson, 2012). When some of them are available in a standalone version, the whole methodology from conceptual modelling to model instantiation is not supported. The network system functions, modelled through automation, communication or physical views of the network, need to be coupled to a grid safety view. The Model Driven Approach (MDA) enables models transformation (Biehl, 2010) and offers many benefits, by separating the implementation issues to the conceptual modelling preoccupations (Božić, 2023; EPRI, 2022). How to implement the MDA, relying on the CIM framework modelling to generate a MBSA model in FIGARO language? The authors deal with this question in the sequel.

METHODOLOGY —

I. PROBLEM(S) AT STAKE

The smart grid is being developed to be more flexible and efficient, thanks to new technological systems for communication, information, and grid control. These technologies are key elements enabling the development of model specific views for technical and network management processes such as Power Distribution. The current series of CIM standards such as IEC 61970, 61968 and IEC 61850 specify how to ensure interoperability between the domain models of the physical network, its communication and control within the different network systems (operators and applications). Thus, several approaches such as Integrating Semantic-driven Design Method (ISDM) (Andrén et al., 2013), Energy Open System Architecture Framework (ENOSAR) (Neureiter et al., 2016), are proposed based on these standards to develop these systems. The ISDM method complements this need by offering the HSGM (Holistic Smart Grid Model) platform, which aims to ensure exchanges between the different domain models. However, this need does not include an explicit definition of dependability analysis models. Safety engineers need to dispose of system's architecture models (functional and physical) to assess reliability metrics on the electrical network under study. Most of the time, the models of electrical networks between the different professions in the field of electrical energy distribution, for example, are developed with little exchange between the professions of plant operation, electrotechnical studies, telecoms, and those of operational safety and maintenance. Therefore, it is necessary to develop MBSA models that can be aligned with the various CIM standards.

The overview of our method is given in Fig. 1. The method consists of performing a model transformation from a source CIM model to a target FIGARO model. The first step is to understand the semantics, and relations can be defined or created between concepts of CIM and FIGARO domains. A CIM model provides a standard description of a power system model. This model can be built using a tool that implements CIM profiles, such as CIMTool (Medved & Kavšek, 2019). A FIGARO model used to assess reliability of power grid is composed of instance model describing power grid architecture. The instance model is enriched by a components library dedicated for safety analysis for electrical networks (here the EDF knowledge base K6 2.0, (Legendre et al., 2020)). The FIGARO model and the library K6 2.0 are implemented on the safety analysis tool KB3. The next step is to build the CIM and FIGARO metamodel specifying safety analysis concepts such as the boolean logic (logical operators) and failure modes concepts. The construction of metamodels in UML leads to identified correspondences that are independent of implementation technology. The last step is to define the functions of the needed transformation that map the concepts between CIM and FIGARO domains.

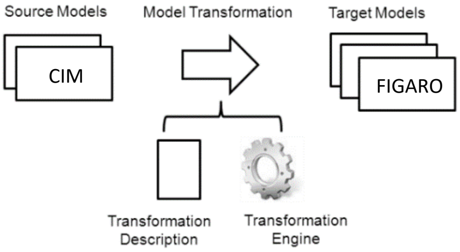

Fig. 1 Method overview, adapted from (Biehl, 2010).

II. METAMODEL OF FIGARO LANGUAGE AND CONSTRUCTION

A. FIGARO Language Analysis

The target model, to be constructed using transformation functions. This model is currently built manually as follows:

- Creation of an empty Figaro study (an instance of FIGARO metamodel) and importation of a metamodel (KB3Import) that describes the considered network, i.e., a list of grid objects, connections between these objects (electrical links, control links, etc.), and component configurations.

- Linking to a knowledge base (K6 2.0), a (meta)model that leads to describing a system using objects and behaviours that can be used and edited in a FIGARO study. So, in FIGARO language, components like power supply (*e.g., alimentation* concept), circuit breakers (e.g., *disjoncteur* concept), programmable logic controllers (e.g., *Porte_ET*) and generators (*e.g., source* concept) are defined using K6 2.0. Each object can be initialized with default values to define its initial state, its failure modes, and the possible evolutions of the network reconfigurations.

B. FIGARO Metamodel Construction with K6 2.0

The existing metamodel of FIGARO language is implemented by a XSD (XML Schema Definition) code describing, in XML (Extensible Markup Language), the structure of the model. The concepts identification and analysis in a code is a time-consuming effort and appears as a very complex task. A better way to carry out this analysis could be to perform a reverse-engineering of the metamodel KB3Import for XSD to UML, that presents many benefits for conceptual modelling. Since the FIGARO does not provide the semantic for power grid modelling, and requires to be linked to a knowledge base, the reverse engineering action performed must merge to K6 2.0. The new obtained FIGARO metamodel is a merge of both the KB3Import and K6 2.0 (KB3ImportK6) metamodels. First, the K6 knowledge base concepts are integrated in the KB3Import to form a unique metamodel. Then, the new metamodel KB3ImportK6 built in UML will be easier to implement to automatically generate the transformation needed. The element of type *Type* in this new metamodel, defines an enumeration of different electrical components and logical operators. A first correspondence between elements of type *Type* can be established with power grid components of a single line diagram. Fig. 2 shows a simplified view of KB3ImportK6 main concepts :

- a Root element that encloses all the concepts: *DocumentRoot class,*
- a complex type that defines any FIGARO concept, including model’s objects: *KB3ImportType,*
- a complex type that defines any model’s object (e.g., components, profiles, pages, failure modes): *ObjetType,*
- an enumeration that defines all the K6 concepts, including the safety attributes (e.g., components, failures models): *TypeType.*

C. Metamodel Implementation

A model of a safety study in FIGARO is built by importing the implemented knowledge base in an XML like format, the format KBI. The FIGARO model can be instantiated with input data from a repository including single line diagrams, points of interest (node of the network whose reliability will be assessed) and evolutions to manage changes on the system on purpose, for a specific modelling need and predefined safety objectives. To ensure compliance, the (meta)models are validated using the tools of Eclipse modelling environment. From the UML KB3ImportK6, the implemented metamodel (XSD model here) can be directly generated. And this implemented metamodel lead to automatically generate a model of a study. In addition, the consistency of the model has been validated based on a hypothetical electrical network on KB3 tool in KBI format that represents the target model of the transformation.

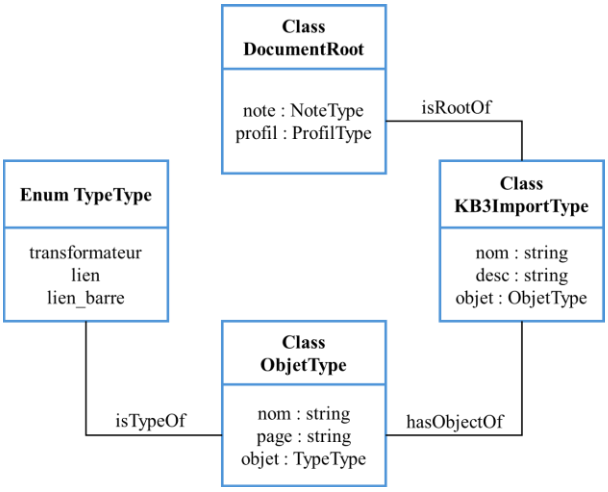

Fig. 2 : Simplified UML metamodel of KB3ImportK6

III. CIM SAFETY PROFILE ANALYSIS AND CONSTRUCTION

A. CIM standard analysis

CIM standard analysis consists of an identification of UML basic concepts, their particulars characteristics in electrical networks context and the principal information that are closer to FIGARO concepts. These characteristics are mainly about the relation between classes, their level of granularity and the type and nature of attributes of each class. Relations between classes are reserved for the concepts of inheritance and composition. Some classes are abstract, these classes lead to defining other classes. These kinds of classes are not defined when it is possible. This led to simplifying the adopted approach and distance between CIM and FIGARO concepts, in the CIM safety profile to be built.

B. CIM safety profile definition

The CIM is a UML information model dedicated to the electrical domain and claims to be application independent. So, creating a profile to define a contextual model that restricts the CIM concepts to a specific field such as safety is useful. This enhances mapping rules definition at the conceptual level. The contextual model is also an independent application. To implement the model of the system network in an application format (CIMXML, De Vos et al., 2001), a particular syntax for profile data must be chosen (Resource Description Framework Schema (RDFS) chosen here). The method to create a CIM profile based on an existing model, can be described as follows (EPRI, 2022):

- Analyse the CIM standards or the profiles of CIM that already exist,
- Create packages (to import different profiles for instance) and their dependencies,
- Create or extend classes and attributes to complete existing concepts. The extended classes, here, refer to a wide use for a specific context (safety context here).
- Create or extend associations and enumerations to complete existing concepts. Verify the semantic and syntactic new model.

The CIM profile built for safety analysis is a subset of CIM based on the IEC standard profile CDPSM (Common Distribution Power System Model), dedicated to the distribution domain (Back & Lambert, 2007), and the CGMES profile (Common Grid Model Exchange Specification) developed for data exchange systems development and operation fields by Transmission System Operators (TSO) (PowSyBL, 2024). The fragment, presented in Fig. 3, is a simplified view of the CIM safety profile built. In this profile, many concepts such as Power System Resource or Equipment are abstract classes and not relevant to perform some correspondences with FIGARO concepts. For coherence and simplification needs, these kinds of concepts must be conserved in the profile. No particular attributes are modelled for these classes, however, it can be helpful to define generic categories for and specify subclasses. For example, the abstract class Power System Resource can directly inherit Identified Object class attributes and does not require additional attributes. In the proposed safety profile, the class Equipment classifies equipment in two subclasses that specify a conducting equipment category such as Breaker subclass (concept of **disjoncteur** in FIGARO) and non-conducting equipment category such as RemoteUnit (concept of **automate** in FIGARO).

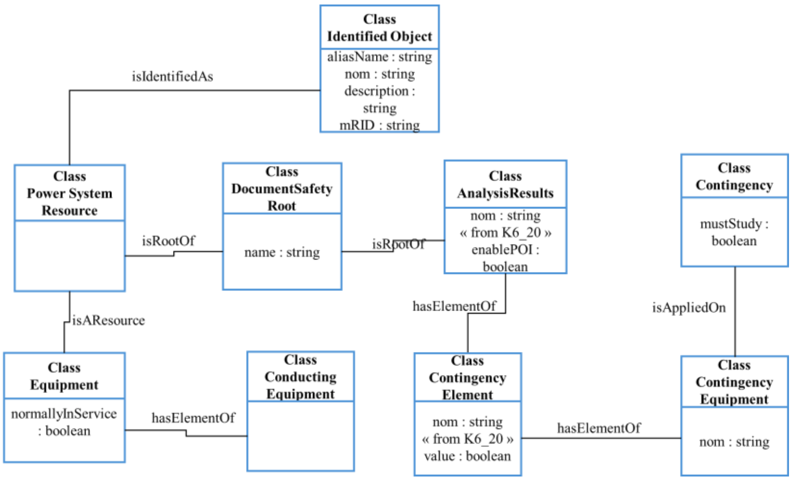

Fig. 3 : Simplified UML CIM profile

C. CIM profile implementation

Thus, the implementation of the safety profile leads to the generation a CIM model. The CIM model is instantiated with the particular values considering a given study. The instance consistency and the values are verified against the profile datatypes range and nature. The verification of the model using a tool is a good way to ensure the validity with CIM syntax. The profile has been validated (i.e., it can be used to generate a model) using add-on Eclipse CIMTool (Chandramohan et al., 2014) to build a CIMXML model that represents the source model of the transformation method.

IV. MODEL TRANSFORMATION SPECIFICATION

Since the CIM is much more expressive than the K6 2.0 knowledge base, it is necessary to restrict the number of concepts used in the CIM to only those concepts useful for building a FIGARO model. This exercise is difficult because the CIM contains several layers (abstraction level) because it is used for many purposes and the nuance between the concepts is not always easy to define.

A. Definition of CIM and FIGARO metamodels

The correspondences are defined at the conceptual level and the CIM and FIGARO metamodels can be defined based on the UML metamodels built. The following definitions as proposed:

- CIM Metamodel : a set of packages, classes, attributes, associations, aggregation (inheritance or composition) relations and enumerations, expressed in UML and datatypes around power system model concepts.

- FIGARO Metamodel : a set of classes, attributes, aggregation (inheritance) relations and enumerations, expressed in UML and datatypes around the safety power system model concepts of K6 2.0.

B. Definition of the specification

The adopted approach presented Fig. 4 tends to align both domains CIM and FIGARO concepts at a same hierarchical level in comparison with correspondence analysis performed. The specification is based on a Model Driven Architecture framework and requirements to build the mapping rules and functions and the transformation model (CIM to FIGARO algorithm). The specification requires defining 3 models in CIM and FIGARO at each layer of the MDA architecture:

- Contextual models (a UML CIM corresponding to a KB3ImportK6, here),
- Syntactic models (from RDF Schema to XML Schema here),
- Source and target models to generate instances (from CIMXML to KBI models here).

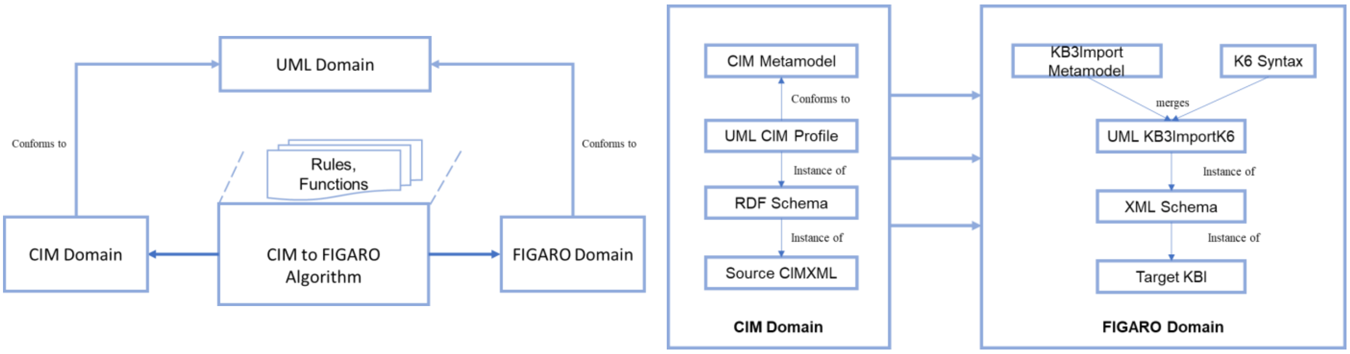

Fig. 4 : Adopted modelling framework

In Fig. 5, the mappings are globally defined between the basic UML classes of both CIM and FIGARO domains. These classes model the power system network components and artefacts to represent the grid. The three first functions of the algorithm are necessary to accommodate the transformation. The function *Launch Transformation* is an initializing function to set default parameters. *The Import CIM Model* function provides input data about source model. To ensure that the imported model is valid (its syntax conforms to the required standards), we use *the Validate Source Model* function. The proposed algorithm defines the main function **BuildTarget Model** to build the transformation using these rules. This function can be decomposed in 3 parts. The part 1 (**Build Target Model 0**) defines the structure of the model (root element, mandatory elements for model implementation compliance and graphical elements). Part 2 (**Build Target Model 1**), populates the system model, generates objects position and their safety attributes. The part 3 (**Build Target Model 2**) defines the flow directions, the main attributes (names of objects, failure models) and their links. For example, EquipmentToObjet rule, selects each object component in the source model that conforms to the CIM safety metamodel and creates the corresponding object in the target model, FIGARO. The functions *Trace Mappings* and *Save Target Model* are useful to the transformation termination.

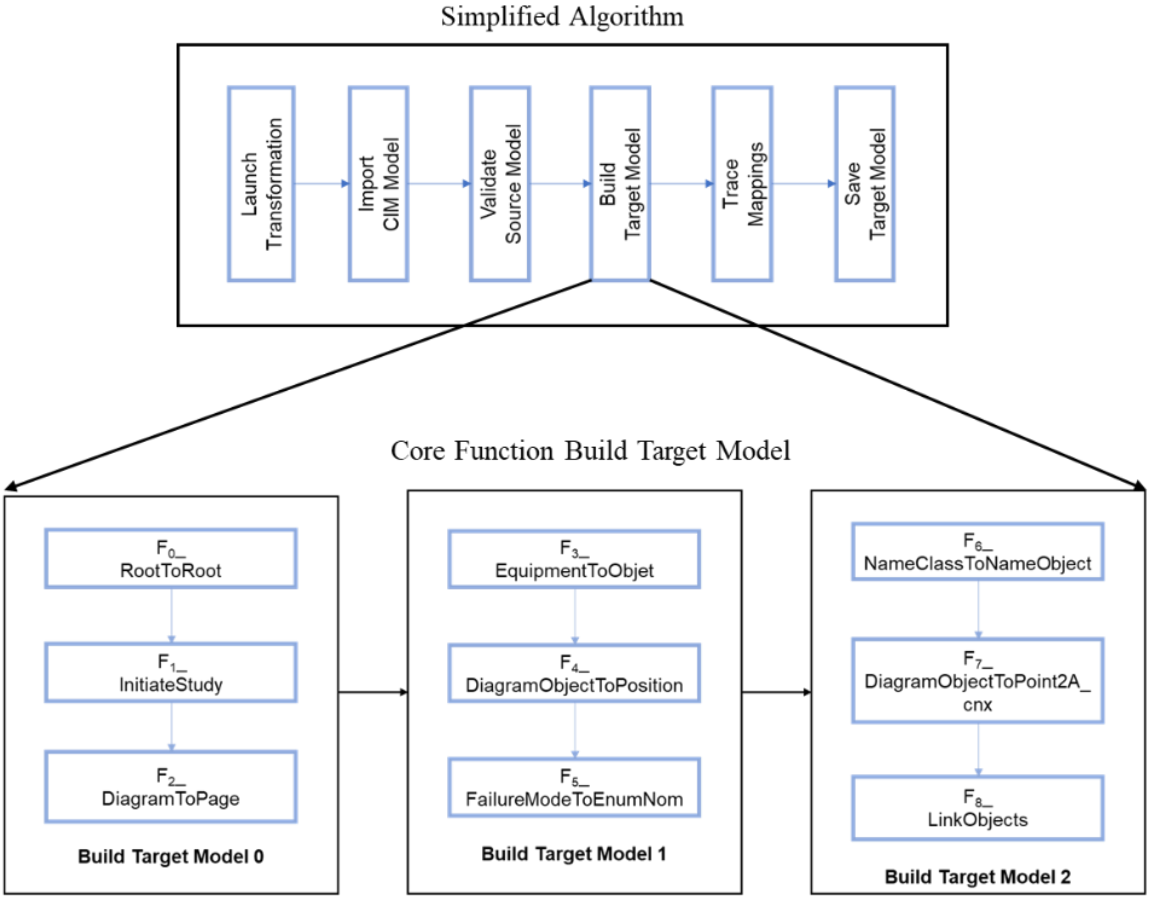

Fig. 5 : Proposed Algorithm (simplified version)

RESULTS —

A. *Case study description*

The application of the rules of transformation based on the function *Built Target Model* is proposed on a CIM model built from the single line diagram below. This diagram represents a simplified system network in the Substation SB1 composed of: 1 Busbar section, 2 disconnectors, 3 breakers, 1 load, 1 power transformer, 1 generator and 1 line segment.

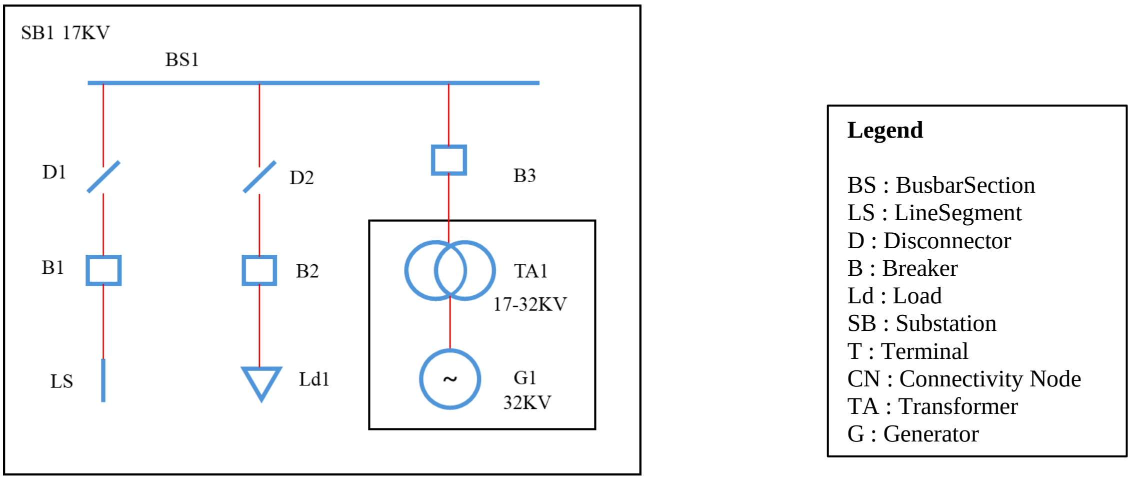

Fig. 6 : Case study

B. *Transformation application results*

To perform the transformation, the system described in Fig. 6 is defined with CIM concepts. The CIM representation of the model is composed of 9 connectivity nodes, 18 terminals, 1 power transformer, 1 generator, 1 load, 1 line segment, 3 breakers, 2 disconnectors, 1 busbar section and 1 substation. Each element is mapped at least into one CIM class. For example, the power transformer is mapped into 3 generic CIM classes (power transformer, its windings, and tap changer) and the generator G1 is mapped into 2 CIM classes (Synchronous Machine and Generating Unit).

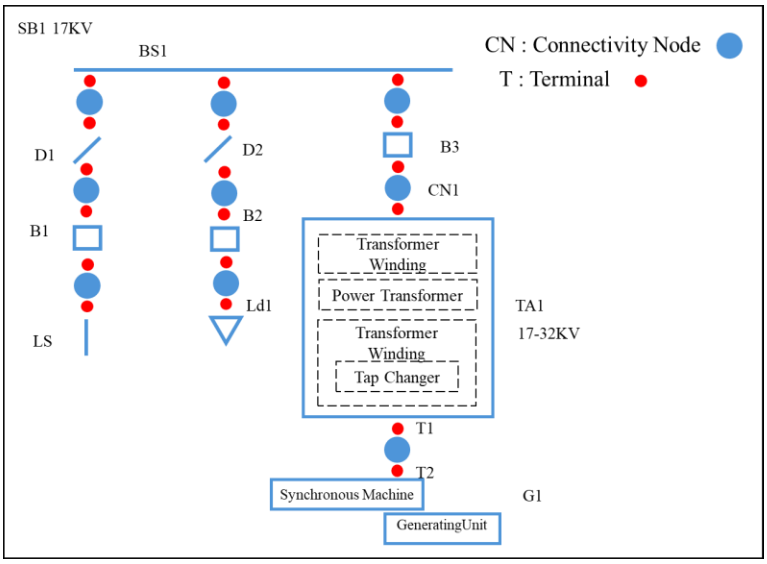

Fig. 7 : CIM representation of the case study

The result of the manual application of the functions of transformation (Fig. 8) defined by the mapping rules presented in the Functional links information is not provided by the source model. The semantics of the target model is given by K6 2.0.

Table 1). For example, the **busbar section** is mapped by the rule **F_3_ EquipmentToObjet** into 2 FIGARO K6 2.0 objects of type **barre** (BS1 and BS2) and 1 object of type **lien_barre** (LB1) to link each branch of the electrical circuit. In order to be consistent, the names of the directly mapped objects CIM are reused for the target objects of the model in FIGARO by the rule **F_6_ NameClassToNameObject**. The directly mapped objects are those who have direct corresponding elements in the target model. The rule **F_8_ LinkObjects** defines the functional and physical links (**A_cnx** concept in FIGARO) represented by the green links in the FIGARO model (Fig. 8). The connectivity nodes and terminals concepts from CIM have no corresponding concepts in FIGARO, therefore the information given by the concept of Terminal can be used by the rule F_8_ LinkObjects to identify physical links between objects in target model FIGARO. Functional links information is not provided by the source model. The semantics of the target model is given by K6 2.0.

Table 1 : Mappings between CIM Model and FIGARO Model

Source CIM objects	**Target FIGARO objects**
Load A	**dipole**
All the power transformer elements	**transformateur**
BaseVoltage	None
VoltageLevel	None
Terminal	None
ConnectivityNode	None
DiagramObject	Instantiation with **A_cnx** type element
Diagram	Graphical objects of a model import (.kbi format)
Breaker	**disjoncteur**
Busbar Section	**barre** and **lien_barre**
Synchronous machine + Generating Unit	Instantiation with generic objetcs of type **source**

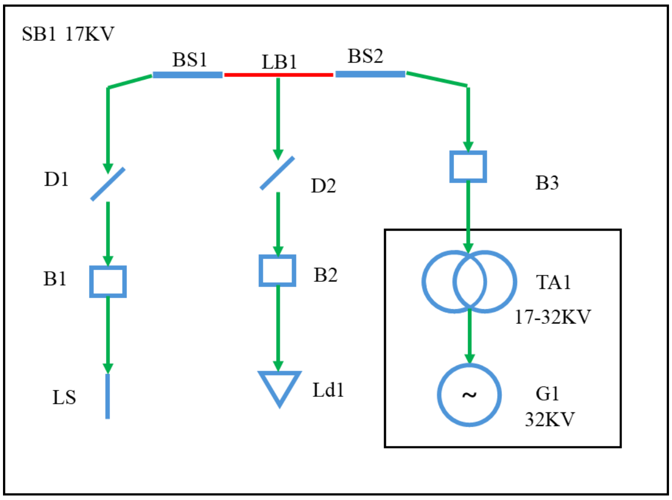

Fig. 8 : FIGARO representation of the CIM model

DISCUSSION AND PERSPECTIVES —

This is preparatory work carried out during an end-of-study internship at EDF. This work allowed to show the interest of such an approach for the model-based safety engineering within EDF. If this work continued, it could be linked to the development of a model transformation tool from a CIM model to a MBSA model with FIGARO. This would allow a significant time saving in the construction of the model by the safety engineer and would reduce the sources of human errors during modelling (in particular on complex systems). In addition, the safety engineer could guarantee that the model studied is consistent with the standard description of the system of a given network.

A. FIGARO and CIM correspondences gaps

The FIGARO model thus produced by manual transformation must be able to be configured by the reliability engineer in the KB3 tool to set failure rates and initial states of each component. In the case study described in CIM, the generator G1 is interpreted as the aggregation of two concepts (Synchronous Machine and Generating Unit) to fulfil the power supply function. Thus, in FIGARO these concepts can be transformed into one object using the concept of **source** representing this type of component. From the safety viewpoint, it is not exactly the same architecture and there may have significant impacts in the analysis to be performed on the system of interest. With this model, it is possible to define additional behaviour elements like reconfiguration mechanisms. The Figaro model can be directly used to conduct reliability assessment on points of interest. The transformation algorithm proposed relies on construction rules of the system. On the one hand, some concepts in the source model are transformed into a unique concept in the target model. This transformation mechanism can be generalized in merging rules. On the other hand, in many cases, a concept in the source model is transformed into more than one concept in the target model. This transformation mechanism can be generalized in splitting rules. We have noted that the specification and implementation of such model transformations can present certain limitations that should not be neglected. In particular, the fact that it is difficult to identify and validate the correct correspondence rules between two different business domains and that it is even more difficult to maintain them in operational condition over time if changes take place in the CIM standard, the K6 2.0 components library or in the FIGARO language. To face these limitations, many concepts can be merged, split or neglected from the source domain to the target domain.

B. CIM to FIGARO transformation specification

As can be seen in Table 2, many attributes of CIM concepts do not have logical equivalents in FIGARO. In FIGARO model, from the physical architecture viewpoint, only components with their attributes are modelled to perform a safety analysis. For example, the concept of ObjetType is abstract to build a generic object in FIGARO and must be associated to the concept of type TypeType that brings the semantics of K6 for electrical components. So any concept of power system can be defined through this type of element. In CIM, since the PowerSystemResource element has a closer definition, both can be equivalent. The level of detail between CIM and FIGARO is not always equivalent, for example, the concept of power transformer can be modelled with other components like windings. The CIM concept of terminal does not exist in FIGARO. However, the concept of **CnxPtType** that defined the orientation of a component (upstream or downstream) compare with the input/output of the functional flows. For traceability needs, the information about the concepts that are not relevant to be mapped can be reported in comments window of each object or modelled with the concept of type **note**.

Table 2 : Gap on main correspondences from CIM to FIGARO concepts

CIM concepts without equivalents in FIGARO	**Covering concepts CIM → FIGARO proposition**
IdentifiedObject	Instantiation with ObjetType concept
PowerSystemResource (abstract class)	ObjetType (abstract class)
BaseVoltage	Annotations with instances of type **note**
VoltageLevel	Annotations with instances of type **note**
Terminal	Annotations with instances of type **note**
ConnectivityNode	Annotations with instances of type **note**
DiagramObject	Instantiation with **A_cnx** type element
Diagram	Graphical object of a model import (.kbi format)
Equipment	None (lower-level concepts are directly used)
ConductingEquipment	Instantiation with generic objetcs of type **dipole**
Contingency	Extension to Failure concept
ContingencyElement	Extension to Failure Mode concept
ContingencyEquipment	Extension to faulty component concept
ACDCTeminal	Instantiation with objects of type **CnxPtType**

C. Perspectives

The CIM can cover a wide field of domains around smart grid delivery, and it is not mandatory to mobilize all its concepts for a specific application. Generating a contextual profile is necessary to take into consideration specific business requirements like requirements for safety assessment discipline. The CIM profile proposed for safety must be consolidated within the existing standard or mature profiles information that address directly or indirectly power grid reliability and safety of like the International Electrotechnical Commission (IEC) 61968 standard Part 3 for fault location, isolation, and service restoration. This part can provide useful data to diagnosis models definition. In addition, the contingency concept and analysis, not developed here, needs to be investigated to study the similarities with the classical safety analysis.

CONCLUSION —

The related works show that the CIM plays an important role in the interoperability aim of Smart Grids. And with the amount of data exchanged via the CIM on power grid systems, it is necessary to retrieve this data for various analysis purposes with a minimal loss of information, for example to assess system reliability. The construction of a profile that allows to build a physical architecture model of an electrical network with information about the safety attributes of each component such as failure modes of is interesting to collect data from applications and tools that use the CIM for model analysis and engineering like CIMSpy (Uslar et al., 2012). Thus, CIM adoption can reinforce more robust safety architectures models development and validation by providing critical information about systems. Therefore, it is useful to develop a tool that implements the proposed specification to cope with the presented issues.

In addition, the need to completely transform models can be a source of inconsistencies and errors. Transforming a model of power grid architecture is not always relevant. In some cases, the semantic distance between concepts and modelling objectives are sometimes divergent. The main challenges would be to define modelling objectives that require the implementation of a partial but trustworthy transformation, and automatically generate only the facets of architecture that do not require the expertise of the reliability analyst. Model synchronization also offers an interesting approach to dealing with this challenge. However, this approach is more relevant for system architectures coherence management, when the two architecture models have been already defined. For retro-engineering needs with a lack of interoperability possibilities or models reuse, the model transformation approach discussed in this article could be more suitable to bring the domains of CIM and FIGARO closer together.

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