

MODELLING I&C SYSTEMS WITH RELAYS FOR SIMULATION, ADAPTING CIM STANDARDS

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ABSTRACT

As the nuclear power plants are in operation for many years, a main issue is to integrate simulation activities in parallel to the present I&C design process in order to limit impacts on current operating I&C engineering process and commissioning activities. The objective is to keep the existing I&C data and diagrams format. EDF chose to build an intermediate file independent of the tool used for simulation to exchange and store data. This file has been created adapting CIM standards (IEC 61968-13 and IEC 61970-301). It is an XML file built according to an RDF schema. CIM standards are intended to model transport or distribution electrical networks and used to facilitate system integration and information exchanges. We chose to adapt CIM to model EDF electromechanical relay circuitries in order to re-use all methods and tools developed around CIM standards such as RDF schema and Riseclipse, an open source tool developed by EDF and SUPELEC engineering school that will be used to verify exported I&C data according to a data model and to EDF engineering rules.

This paper will describe the ongoing project on simulation in parallel to current I&C design process, focusing on how I&C electromechanical relays data are modelled based on CIM standards, and what benefits that model provides to I&C Verification and Validation activities.

Key Words: Modelling I&C systems, relays, I&C simulation, I&C verification, CIM standards

1 INTRODUCTION

The ageing of French Nuclear Power Plants, their lifetime extension up to sixty years and the necessity to take into account the international feedback from experience (IAEA recommendations, Fukushima accident, new environment code...) lead to an increasing number of evolutions in French operating nuclear power plants. EDF nuclear engineering departments are in charge of these evolutions. In order to be more efficient, to save time and to secure implementation evolutions, they are currently working on how to support engineers in their studies, and more especially in the verification and validation of I&C. One of the solutions studied together with EDF Research and Development, is to perform more simulations in the current I&C engineering process.

2 I&C DESIGN PROCESS AND SIMULATION

As the nuclear power plants are in operation for many years, the main issue is to integrate simulation activities in parallel with the existing design process in order to limit impacts on current operating I&C engineering process and commissioning activities, and to develop and maintain engineers' functional and technical skills. Current I&C design process includes three major parts: logic diagrams design (using FBD¹ format from IEC 61131-3), I&C working diagrams design, and tests on platform. As explained in Figure 1, the project plans to extract data from logic diagrams and I&C working diagrams to simulate both. The next step is to execute test cases automatically generated from logic diagrams on I&C working diagrams and on platforms, in order to verify if implementation is consistent with specifications. The objective is to keep I&C data and diagrams format. This paper is focused on I&C working diagrams of 900 MW French nuclear units, on how to export I&C data so that it can be used for simulation and verification activities.

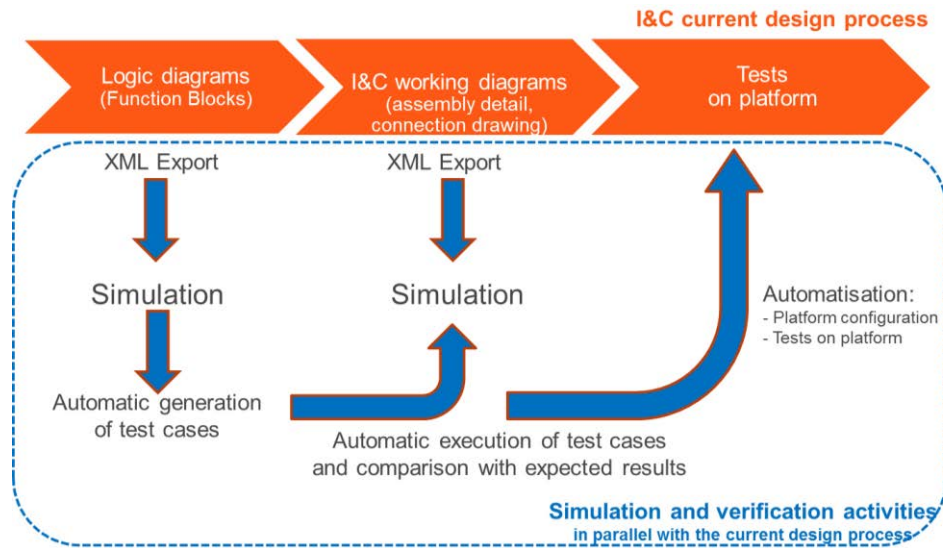


Figure 1: I&C current process and simulation and verification activities

For 900 MW French nuclear units, I&C systems are mostly based on electromechanical relays (for logic functions part).



Figure 2: Relay racks and a relay module

¹ The Function Block Diagram (FBD) is one of five languages for logic or control configuration supported by standard IEC 61131-3 for a control system such as a Programmable Logic Controller (PLC). It is a graphical language for programmable logic controller design that can describe the function between input variables and output variables. A function is described as a set of elementary blocks. Input and output variables are connected to blocks by connection lines.

I&C working diagrams of 900 MW French nuclear units are designed using a CAD tool, AutoCAD, in a closed-source EDF format.

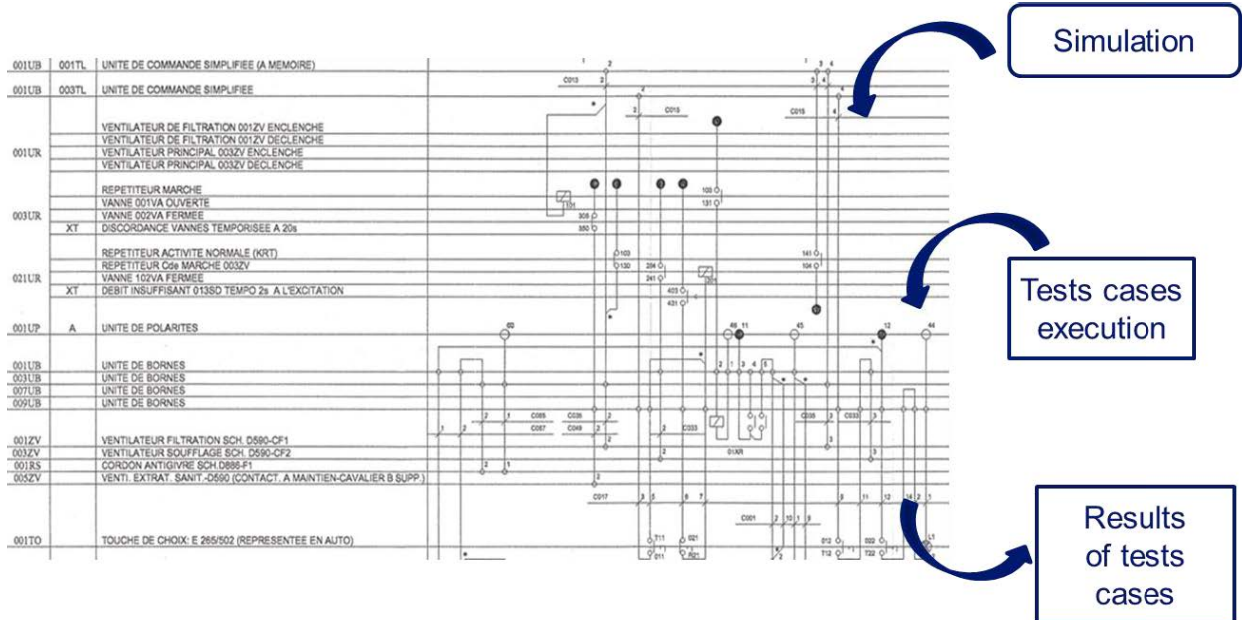


Figure 3: Part of relay circuit represented in working diagrams with simulation and verification activities

In order to simulate these diagrams, the first step is to retrieve all diagrams data from an existing AutoCAD format. EDF chose to build an intermediate file, in a pivot format independent of the source and of the tool used for simulation, to exchange and store data. This file structure (or data model) has been created adapting CIM standards (IEC 61970-301 and IEC 61968-11). The result is an XML file built according to an RDF schema, reflecting the data model created. The file and its structure are described in below paragraph (§3).

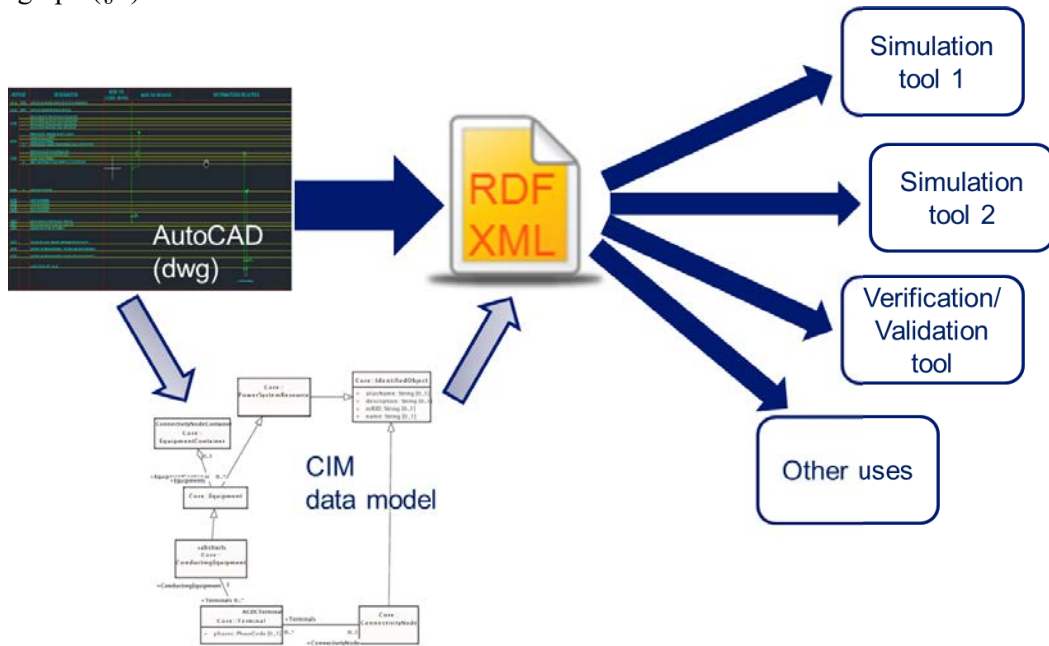


Figure 4: From AutoCAD format to simulation and verification tools

3 MODELLING RELAY SYSTEMS USING CIM STANDARDS

3.1 CIM standards

The need to exchange data between utility companies has become a major need since the start of the deregulation of the power industry in Europe. In electric power transmission and distribution, the Common Information Model (CIM), a standard developed by the electric power industry that has been officially adopted by the International Electrotechnical Commission (IEC), aims to allow application software to exchange information about an electrical network. The CIM logical information model is described as a set of UML² packages. It defines a common vocabulary and basic ontology for aspects of the electric power industry.

CIM (IEC series 61970, 61968, 62325) provides the information model containing equipment and functions and their properties for power system management, analysis and related use cases (Generation, market and grid).

3.2 Model

The model we created to represent relay circuits data was built reusing – as much as possible – the CIM model and principles. The UML diagrams below will present our model. Two colors are used: grey when the class comes from the CIM model, and orange when it is an extension we created. In the following paragraphs italic text is used to identify classes from the CIM model and bold text for new classes we created.

Figure 5 shows the model representing relay circuit **Drawing**, which is associated with a **PlantSystem** of a *Plant*. It is decomposed into several **Sheets**, which contain the graphical aspects of drawings, modelled with the CIM class *DiagramObject*. **Drawing** and **Sheet** inherit from the CIM class *Document*, and therefore carry attributes for revision number, author name, date of creation...

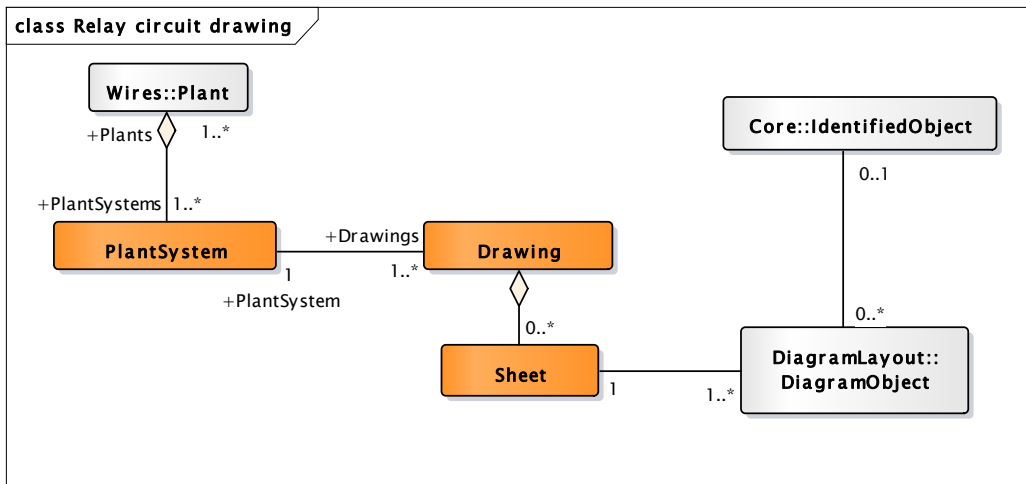


Figure 5: Relay circuitry drawing model

² The Unified Modeling Language (UML) is a general-purpose, developmental, modeling language in the field of software engineering that is intended to provide a standard way to visualize the design of a system. Since 1997 UML is a standard managed by the Object Management Group (OMG). Since 2005 UML is also an approved ISO (International Organization for Standardization) standard.

Figure 6 shows that **Relay Cabinet** may contain several modules which inherit from *EquipmentContainer* and as such, contain *Equipments*: **ControlModules** supply the relay circuits and contain **Positive and Negative Polarities**, **Terminal Block Modules** contain **LV Electric Terminals** to connect **Relay Cabinet** to other circuits and **Relay modules** contain **Relays**.

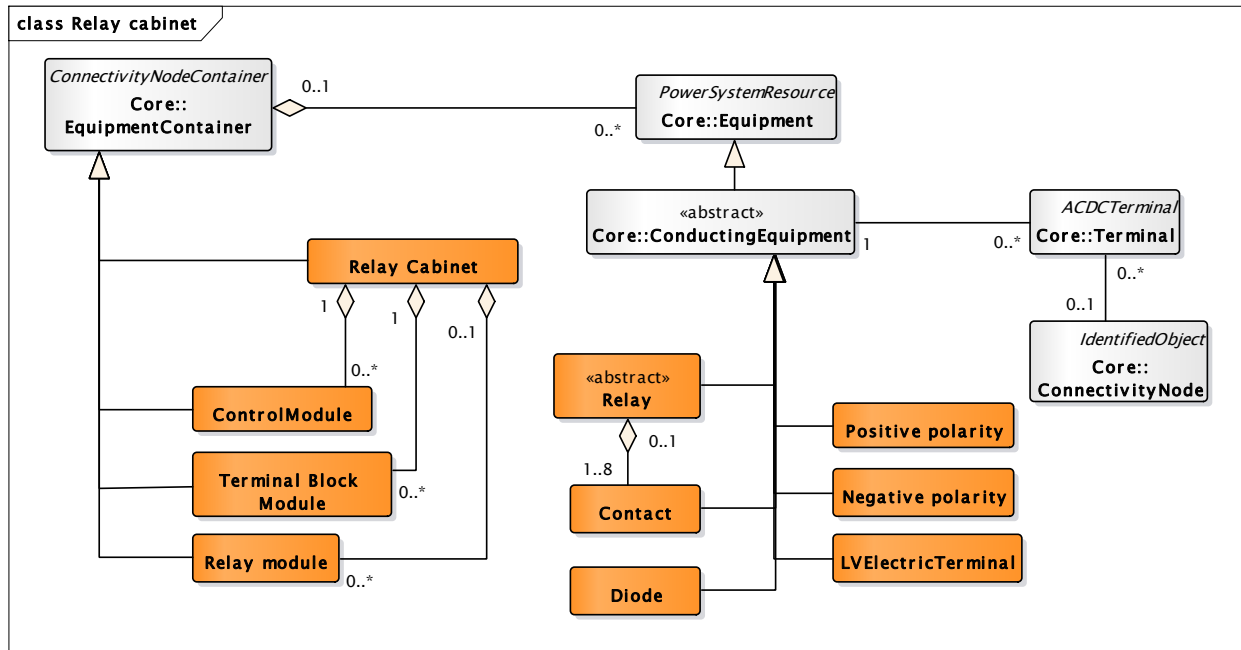


Figure 6: Relay cabinet model

Figure 7 details the different types of **Relays** that are found in our model. **Relays** contain **Contacts**.

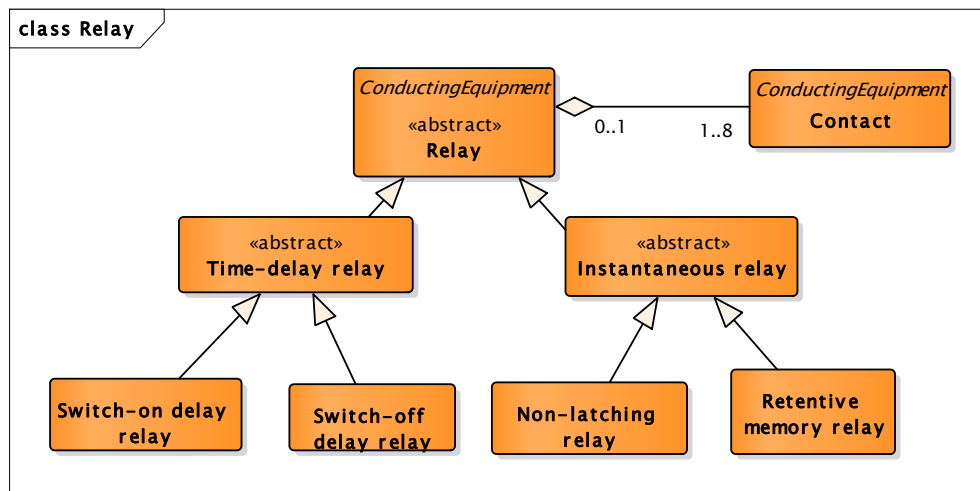


Figure 7: Relay model

Figure 8 shows the inputs and outputs of the relay circuits. Inputs include Control equipment such as **Turn Push Light Switches**, **Selector Switches** and **Push Buttons** which contain **Push Button Contacts** and **Selector Switch Positions**, and other on-off inputs such as **Sensor contacts**, **External plant system contacts**, and **Limit switch contacts**. Outputs include **Lamps**, **Power Commands of Equipment** (which are part of **Actuator**), **Electromagnets** and **Alarms**.

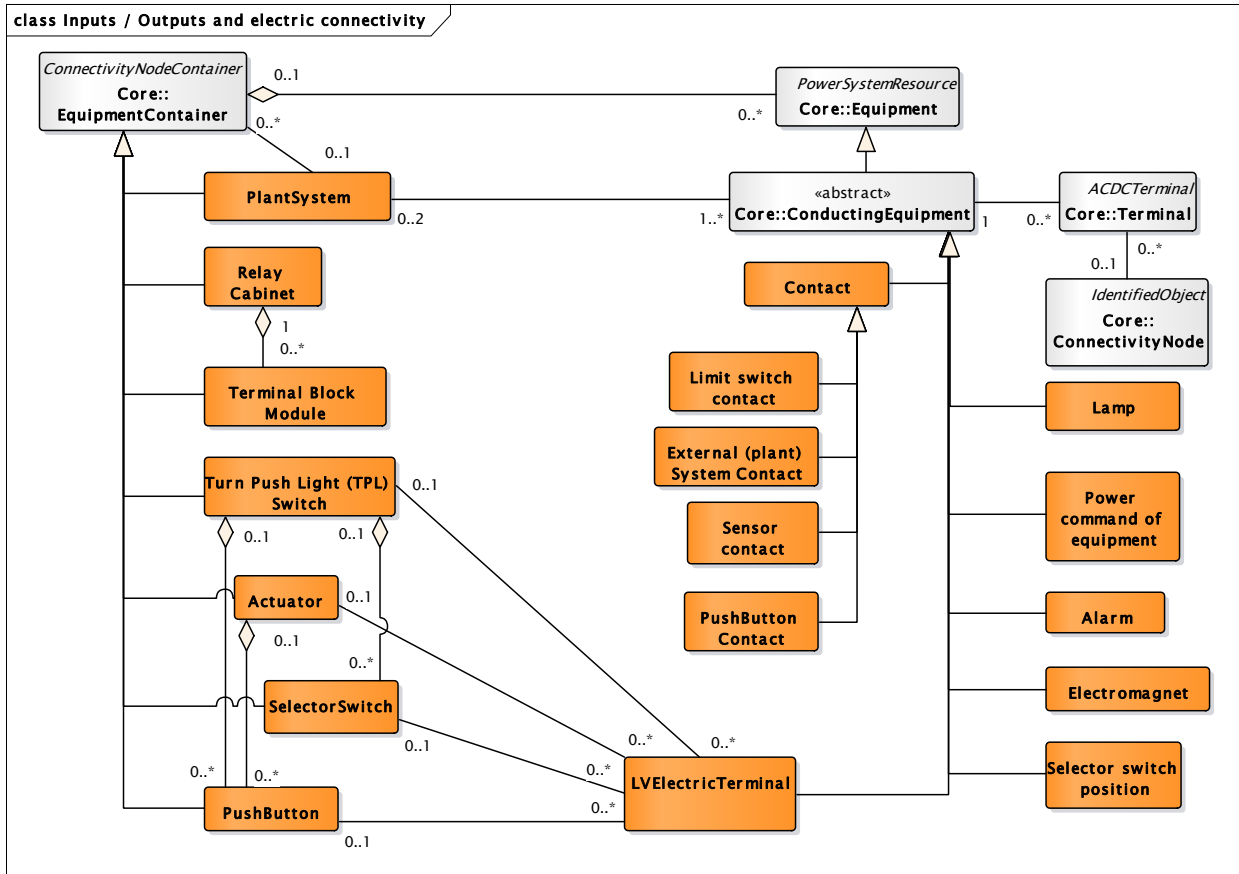


Figure 8: Inputs / Outputs model

Electric connectivity is modelled with the three CIM classes *ConductingEquipment*, *Terminal* and *ConnectivityNode* as shown in grey on Figure 6 and Figure 8. Equipment that conducts current inherits from the CIM class *ConductingEquipment*. As such, it inherits the association with *Terminal* that represents an electric connectivity point. A *ConductingEquipment* has one or more *Terminals* and each *Terminal* may be connected to a *ConnectivityNode*, which is a point where terminals of conducting equipment are connected together with zero impedance.

Figure 9 shows an example of how connectivity is modelled in the CIM by converting a relay circuit into boxes. Rectangular boxes with double borders represent *EquipmentContainers* (such as **Terminal Block module** or **Relay module**), boxes with rounded corners represent *ConductingEquipment* and ellipses represents other objects such as **Drawing**. Black circles represent *ConnectivityNodes* and white small circles represent *Terminals*. *ConnectivityNodes* are used to electrically connect *Terminals*, and as such the associated *ConductingEquipment*.

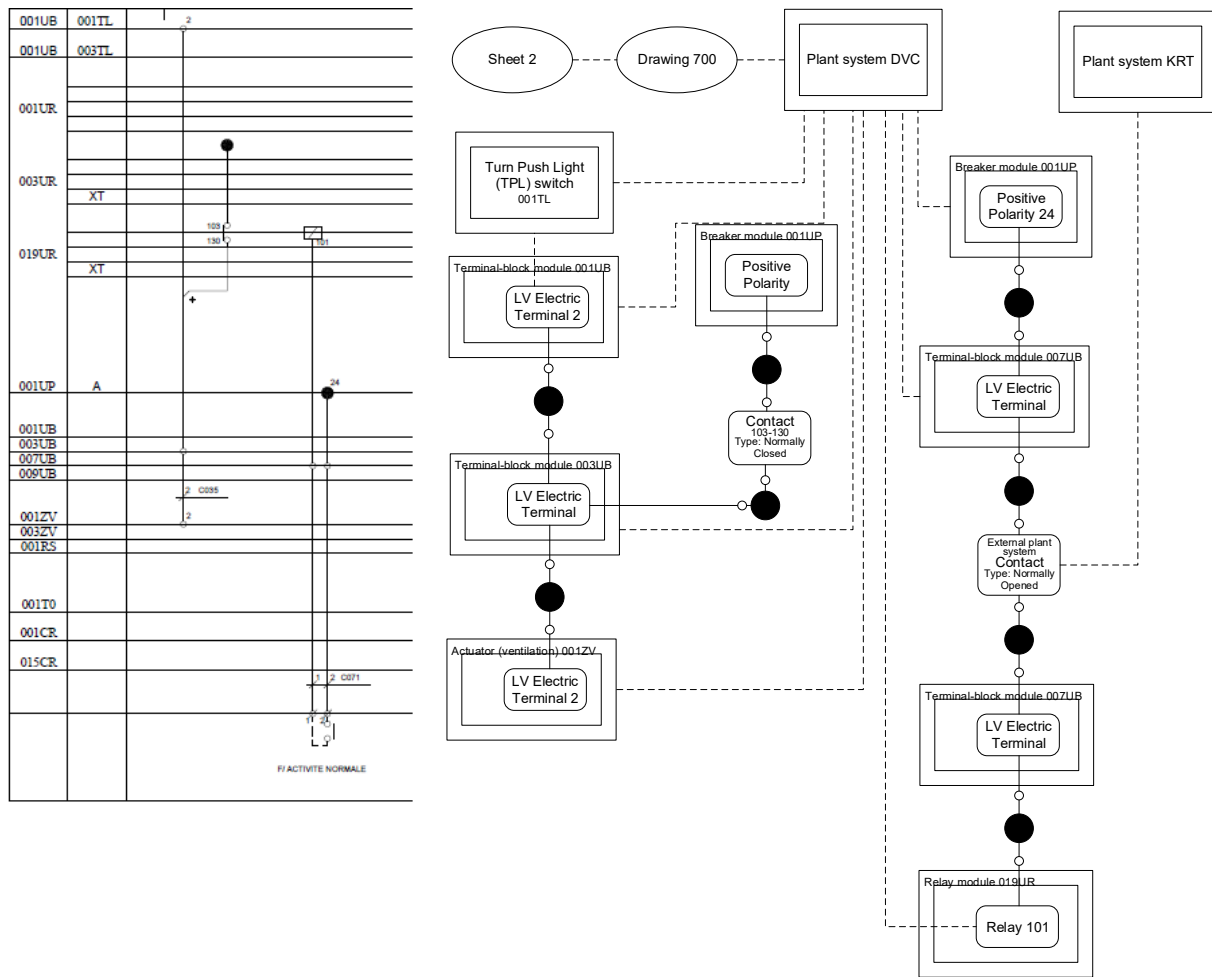


Figure 9: Instantiation of electric connectivity on an example of relay circuit

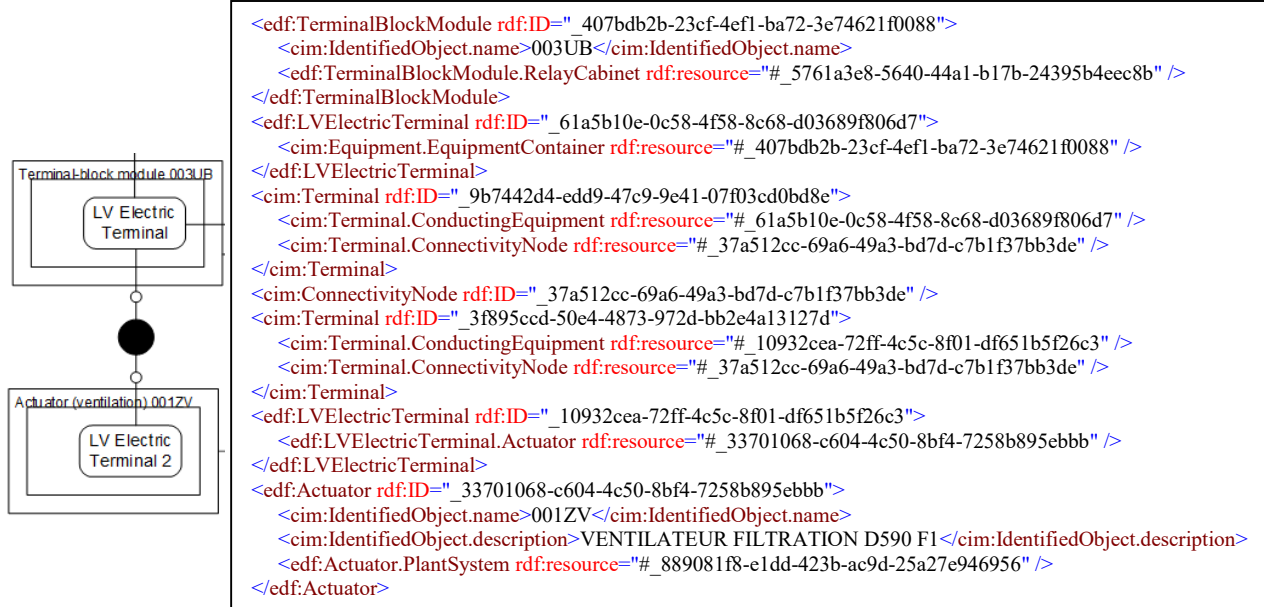
3.3 RDF File

As a semantic model, the CIM defines an ontology, a set of names (classes, attributes, association ends) and their relationships. To enable to exchange data conform to this model, a syntactic model, derived from the semantic one, has to be chosen. XML based syntactic formats are now quite common, and the IEC defines two XML grammars based on the CIM model: one (standard IEC 61970-552) is used for exchanging power system model data and is based on XML RDF, the other (standard IEC 61968-100) is used in the context of enterprise application integration and is based on XML XSD.

RDF (Resource Description Framework) is a W3C (World Wide Web Consortium) specification for modelling of information, one of its serialization format is based on XML. RDF uses so-called triples consisting of the subject (what is described), the predicate (name of the property) and the object (value of the property). RDFS (Resource Description Framework Schema) is another W3C specification used to define the vocabulary for RDF; it can describe classes with inheritance and typed properties for these classes. IEC has defined, in standard IEC 61970-501, a mapping from the CIM UML model to an RDF Schema.

This RDF serialization has been chosen for the relay circuit data.

Here is an example of the serialization of this particular instance from Figure 9:



4 WHAT BENEFITS THIS CIM INSPIRED MODEL PROVIDES

4.1 A well-structured model adapted to users

CIM standards offer a model based on experience and representation of the field/physical objects and not only a too conceptual or graphical model. Using that kind of model makes people focus on their business and not only on CAD. Thus the model will be more appropriate and easier to understand and to take in hand by users, who are not computer specialists.

CIM standards define a way to model electric network data separating:

- **functional** aspect, describing all the objects (for instance, a relay has contacts and is part of a relay module)
- **electrical connectivity** aspect, describing the network composed by all the objects *ConductingEquipment – Terminal - ConnectivityNode*
- **graphical** aspect to describe drawings and graphical links between objects, with their coordinates in the sheet, using *DiagramObject* classes, that can be associated with any identified object of the model.
- An **asset** aspect can be added to describe equipment and manufacturers. Asset description places emphasis on the physical characteristics of equipment (with for example serial numbers and lot numbers attributes).

All these aspects of an object are linked with UML relations, but as they are modelled separately, they can be modified independently. This will help our model to be more flexible and to face evolutions more easily.

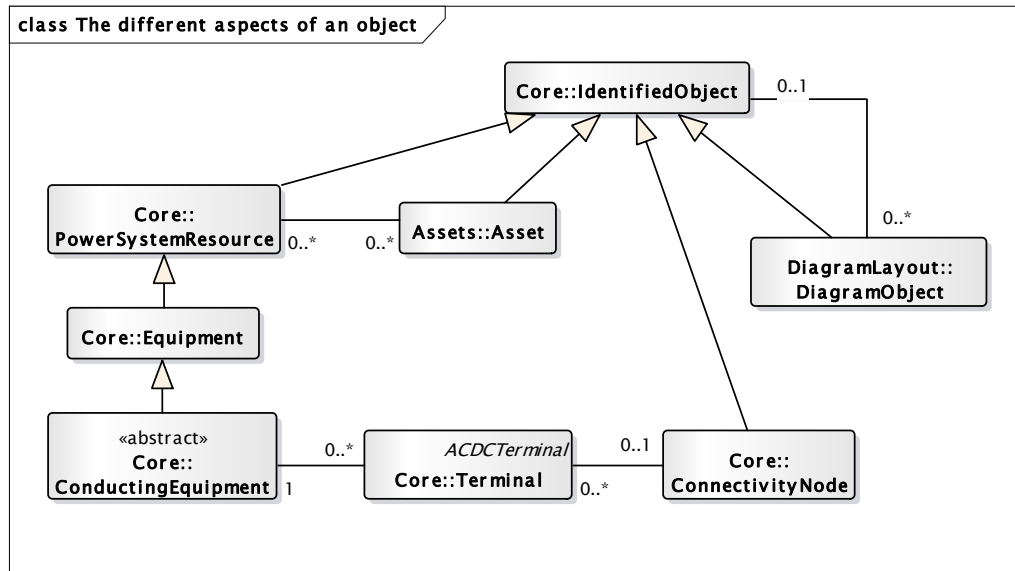


Figure 10: Different aspects of an object

4.2 An XML pivot format that can be used for simulation and more

The first objective of the project is to simulate relay circuitries. All of AutoCAD data are stored in a RDF-XML file. Because this file contains all graphic data (coordinates, links) and electric and connectivity data, it can easily be reconverted in any other specific format (cf. Figure 4), such as for example the ControlBuild XML format, that can be imported as a “low level schemes” (electrical format), interpreting electrical connectivities and relations between objects. The relations between a relay and its contacts are interpreted so that the activation and deactivation of the relay will close and open its related contacts. ControlBuild “low level scheme” format makes the simulation representative of physical behavior of the equipment: it is based on electric potentials motions in every node (connection point) of the circuit.

ControlBuild has been chosen for historical reasons. Actually a module of automatic generation of test cases was developed in ControlBuild during a previous French Research Agency VACSIM project in a partnership EDF R&D and Dassault Systemes. Once the relay circuitry is imported in ControlBuild, the idea is to execute the test cases that had been automatically generated from logic diagrams (cf. Figure 1), in order to compare if I&C working drawings are consistent with logic diagrams. This is a way to automate a part of verification and validation activities.

However that RDF file can also be used as an intermediary with other simulation tools, by means of a program converting it in a format the tool is able to import. I&C data stored in that file are also going to be used to manage racks and modules sizing.

4.3 Verifying I&C data according to a model and to EDF engineering rules with Riseclipse

Riseclipse is an open source tool, which performs semantic validations. This tool is the result of a collaboration between the computer science department of CentraleSupélec (a French engineering school) and EDF R&D since 2002. It has been first developed to check the conformance of data against the CIM standard, but can be used with any data model defined in UML. Indeed, the tool validates that data instances are compliant with a UML data model. Nevertheless, all the rules and constraints of CIM standards could not be expressed in “structural” UML, that is why Riseclipse allows to add additional rules expressed on the UML objects, using OCL (Object Constraint Language). OCL constraints are more precise and

complete, as rules depending on values of instantiated attributes can be expressed. These kinds of validation cannot be done with XSD based validators. The tool can be used either in the Eclipse environment, for navigation in the model and interactive validation, or in a command line context for batch validation.

We chose to use Riseclipse to validate that I&C data instances are compliant with a data model, and that they fulfill a set of engineering rules expressed with formal constraints in OCL. For instance in our model, we expressed in UML the constraint that a relay has 1 to 8 contacts (cf. Figure 6 and Figure 7). Riseclipse is going to check in the RDF-XML file that every relay has at least 1 contact, and no more than 8. Yet in UML model, a **Relay module** is an *EquipmentContainer*, and we use the relation between *Equipment* and *EquipmentContainer* to indicate that a **Relay** is part of a **Relay module**. There is no constraint in UML model on that association. Nevertheless with Riseclipse, it is possible to add an OCL constraint to specify that a **Relay module** could not include more than 6 **Relays**. The tool is going to check for each **Relay module** if that the requirement is fulfilled.

If all the engineering rules are expressed in OCL, Riseclipse can validate RDF XML files created for relay circuits and thus verify that the drawing is well designed, with all data needed and fulfilling all requirements specified.

5 CONCLUSIONS AND PROSPECTS

Modelling I&C systems with relays using CIM standards is a good way to get a solid relay circuitry data model and to benefit from studies and tools realized around CIM standards.

Today another EDF project aims at modelling nuclear power plant electrical network to help engineering units analyze power losses. In that project, the data model is also based on CIM standards and relay cabinets are considered as power consumers (*EnergyConsumer*). Using the same standards in both projects will make it possible to link HV and LV electrical networks and logical relay circuitries, so that impacts of power losses could be even more precisely analyzed.

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