Automation of model exchange between planning and EMT tools

C. Martin, Y. Fillion

***Abstract*-- To perform static and dynamic simulations from planning to real events analysis, a large number of tools are used at RTE. The key point for any study is the uniqueness of databases to guaranty the coherency of grid modelling. RTE identified the need to develop a tool to automatically transfer electrical network data from the planning simulation platform CONVERGENCE to its EMT simulation tools.**

The main idea is to consider planning simulation models as references for the static representation of the French transmission grid. This interface, based on the Common Information Model (CIM) export module of CONVERGENCE, allows to import large scale networks data that represents a specific network topology and a load situation. This is useful to get a relevant starting point for time-domain simulations and to get an accurate model of the network for frequency scan studies.

***Keywords*: Electromagnetic transient studies, Model exchange, Data portability, UML, Common Information Model (CIM), Component Object Model (COM), Software development, Network equivalent**

I. INTRODUCTION

The exchange of power system information between simulation tools is becoming more and more important. Each computer program has its own proprietary data format and it is not easy task to define portability or interoperability standards even between applications of the same type. Therefore, there are many challenges in interfacing with external applications. Exporting and importing models are constrained not only through a lack of common data set but also because of disparities in modeling and solving methods. Within a company, these compatibility issues can lead to unreliable models and time consuming problems for the users who are often appealed to perform studies either on different applications or with manufacturer models using different tools.

There are several methods for creating modeling portability between applications. Using a standard facilitates interoperable exchanges of power system network data between and within organizations and is substantial to become a durable portable method. This paper targets CIM standard solution [1] to data portability in relation to an EMT-type application. CIM is a format that attempts to be accessible and understandable to all. The tool described in this document allows to import static data from planning tools into EMT tools that is the first step for frequency scan studies and time-domain simulations.

A link from CIM to the EMTP [2] software has already been developed in [3] but is only compatible with an old version of CIM and was mainly used to generate the model in a text file format (netlist) without graphical interface because of the lack of positioning data. The proposed solution is compliant with the latest version of CIM including graphical information and is easy to maintain for future versions of EMT programs and the CIM standard. It is, as much as possible, independent from the EMT simulation package used by the end user.

This paper includes an introduction of the CIM Common Grid Model Exchange Standard (CGMES) and development techniques to perform data exchanges. Then, the EMT import tool from CONVERGENCE is described in details. This tool is widely used at RTE for most of EMT studies. Practical study cases are presented to prove the effectiveness of the proposed solution. This paper also presents the development of a more generic CIM import tool that does not depend on the base software and discusses the current limitations of the CIM approach for data portability between EMT tools.

II. CIM STANDARD FOR MODEL EXCHANGE

A. CIM, UML and XML RDF

CIM, originated as an Electric Power Research Institute (EPRI) project in 1994, is rapidly gaining acceptance throughout the world as a semantic model which helps to have a common understanding between power system engineers and to unify the data from electric utility software.

Developed by the working groups of the International Electrotechnical Commission (IEC) Technical Committee (TC) 57, CIM was adopted as the standard whose the core package is described in 61970-301[4].

CIM Standard is based on Unified Modeling Language (UML) to define the semantic information of a real power system using a graphical representation. UML follows the Object-Oriented Programming (OOP) principles [5] defining classes, that contain attributes, and their different relations to clearly represent behavior of physical objects.

Serialization in the eXtensible Markup Language (XML) [6] format has been adopted to exchange CIM instantiated objects. The main motivations for using XML is the availability of tools and libraries for decoding information [7]. The IEC proposed a Resource Description Framework (RDF) schema [8] as a proper way to codify the CIM's abstract model. As a result, IEC 61970-501 is the RDF schema version of CIM.

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B. Common Grid Model Exchange Standard (CGMES)

European Network of Transmission System Operators for Electricity (ENTSO-E) has made large efforts to meet necessary requirements for Transmission System Operators (TSOs) data exchanges and as a result the CGMES was approved in 2014 [9]. The CGMES is based on CIM standards and further extended in order to cover use cases not currently supported by IEC standards. The standard defines a set of data model exchange profiles shown in Fig. 1. Each one refers to a subset of classes, associations and attributes allowing to answer a business need.

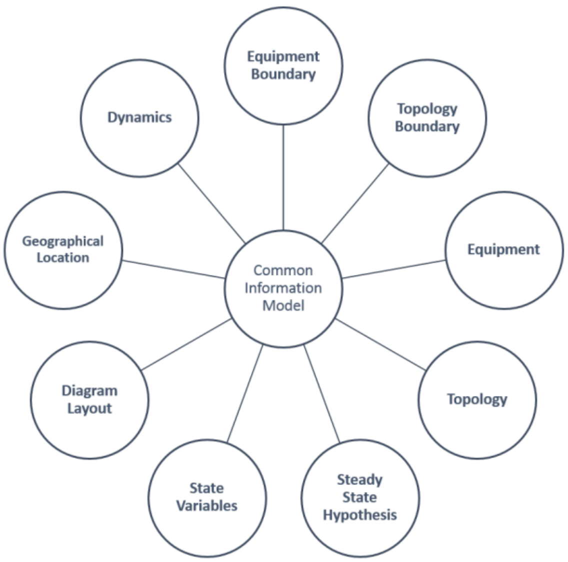

Fig. 1 CGMES profiles

The CGMES supports a node-breaker and a bus-branch model exchange. In a bus-branch topology, busbar sections with closed switches are modeled as a single bus.

Since 2010, ENTSO-E regularly conducts interoperability (IOP) tests [10] in order to prove that the profiles are correctly implemented by vendors and TSOs.

III. From Planning to EMT Tools

Several years ago, RTE identified the need of a platform gathering network data and tools for steady-state simulations. This platform, named CONVERGENCE, describes the entire RTE network from 400 kV to 63 kV including sequence impedances of lines (direct and zero-sequence), transformer parameters (impedances, tap changer positions), generators (sequence impedances, voltage and power references), loads, FACTS parameters and substation configurations.

The CIM files export module of CONVERGENCE is compliant with the CGMES. The flow diagram of the CONVERGENCE to EMTP interface is shown on Fig. 2.

A. Data export from CONVERGENCE

CONVERGENCE allows to export network data to CGMES bus-branch format. Users are able to choose the part of the network to export by selecting graphically the desired area or by applying exclusionary rules on regions, voltage levels, etc. The required profiles for planning models exchanges are Equipment (EQ), Topology (TP), Steady State Hypothesis (SSH) and State Variables (SV) profiles. Unlike the SSH file, which is used to initialize calculations, the SV file is not required for model import. It contains load flow final values and is appropriate to compare results between the two software. Additional data, which correspond to machines reactances and associated transformers impedances, need to be extracted in CSV format. This is mainly due to CIM stereotype attributes, which are not yet supported by the current version of CONVERGENCE CIM export module. The same goes for graphical information export which is not handled yet (GL or DL profiles) that compels to find an alternative way, explained below, for positioning EMTP components.

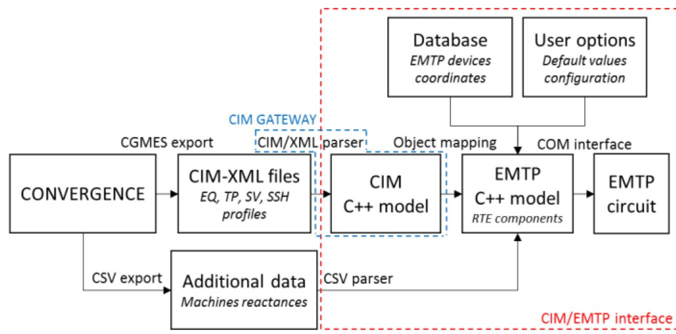

Fig. 2 CONVERGENCE to EMTP interface flow diagram

B. CIM/XML parsing

A key point of the CIM/EMTP interface is the C++ library of CIM classes, which is automatically generated by CIM GATEWAY, another program developed at RTE whose principle scheme is described on Fig. 3.

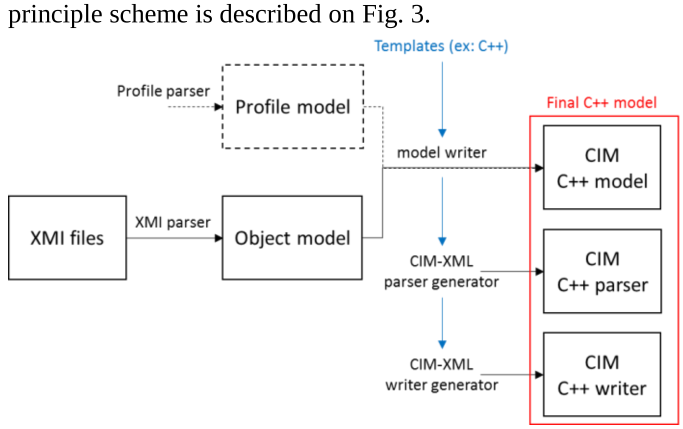

Fig. 3 Principle scheme of CIM Gateway

This tool is based on CIM UML specifications in XML Metadata Interchange (XMI) format [11]. Objects of every CGMES profile are taken into account as well as the different topologies (bus-branch and node-breaker). It is also compatible with older versions of CIM where the profile model was separated from the XMI input files (dashed lines on Fig. 3). Not only classes but also CIM parser and writer are generated. The CIM/EMTP interface uses the C++ version of the CIM library. However, thanks to a set of templates written in the Velocity Template Language (VTL) [12], CIM

GATEWAY is not limited to C++ and can handle other languages such as Java or Python. This software is substantial for the maintenance of any CIM interfaces since it can easily comply with future versions of CIM standard.

At the end, the resulting CIM C++ library allows to parse and to load CGMES XML files, while also verifying syntax and Object Constraint Language (OCL) restrictions. Conversely, XML serialization is also possible from a CGMES model loaded into memory.

C. CIM to EMTP RTE components

RTE built its own CONVERGENCE-like library of EMTP components in the GUI. This library is used during the CIM-to-EMTP object mapping process for several reasons. First, it is more convenient for users to analyze the imported circuit and to implement changes in accordance with CONVERGENCE drawing. RTE components are more suitable for the representation of substations structure. Besides a mapping algorithm is more easily achieved when there is a one-to-one relation between objects. For example, a generating unit is represented in EMTP by an encapsulation of load-flow buses and voltage sources in a subcircuit (Fig. 4) with a mask in order to simply edit the type of regulation, the source impedance, etc.

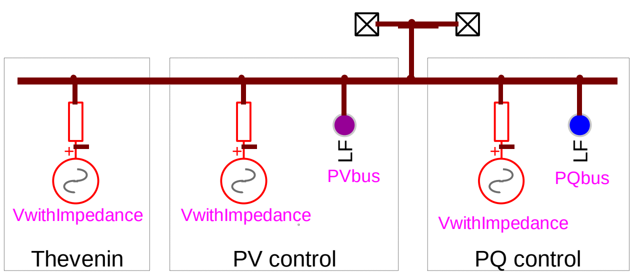

Fig. 4 Subcircuit of a generating unit in EMTP

To complete CIM data with positioning information, a database of EMTP devices coordinates was created based on existing EMTP circuits, formerly manually built by users at RTE. The correspondence is achieved by names. Furthermore, EMTP may require data that cannot be extracted directly from CIM. In such a case default values are needed. A configuration options tab defines default values that can be altered by the operator before each import. For example, it allows to change the slope value of Static Var Compensators (SVC) or the distortionless option of Constant Parameter (CP) transmission lines.

D. Import and validation

Currently, the database of EMTP devices coordinates is limited to the whole French 400 and 225 kV grid. The entire 400 and 225 kV network is composed of 1280 substations, 2049 lines, 244 autotransformers, 12 phase-shifting transformers, 841 synchronous machines, 2007 loads, 115 shunt compensators and 7 SVC. The obtained circuit for the 225 kV network is presented on Fig. 5.

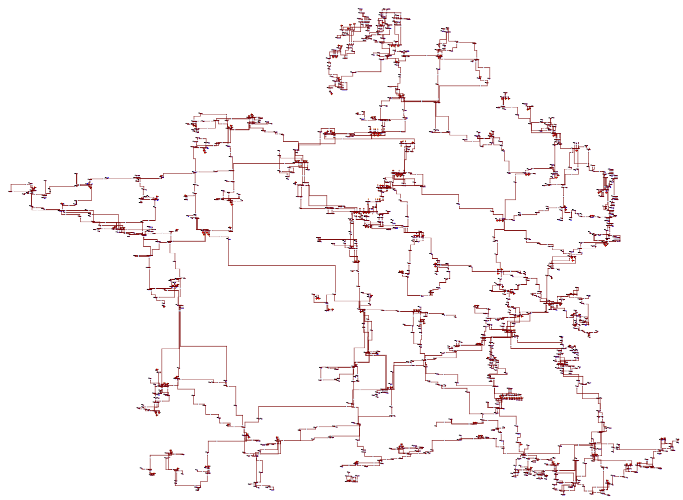

Fig. 5 French 225 kV grid after CIM import in EMTP

TABLE 1 compares the translation time for two massive grid data import cases on a 3.00 GHz Intel Core i7 CPU laptop computer. The most time consuming process in the circuit drawing is the execution of scripts using COM interface to interact with EMTP graphical user interface.

A report file is generated at the end of the circuit building. It helps users to make adjustments and to keep a critical eye on imported data. The CIM/CGMES translator was validated using several networks situations of CONVERGENCE platform. Load flow simulations can be run on each tool and exported in CSV format. Automatic comparison of voltages (magnitude and angle) at each node is achieved between the two software using JavaScript scripting methods in EMTP and Visual Basic for Applications (VBA) macros. Load-flow results obtained in the two tools are quite close. After several test cases, the maximum relative error at a node for the entire 400 + 225 kV French grid is around 0.8%. In any case, such differences are normal and explained in the next section.

TABLE 1
CPU TIME COMPARISON FOR CIM/EMTP IMPORT TOOL

Test case	Nb devices (1 and 3 phases)	Nb 3 phases buses	CIM C++ model building time (s)	Circuit drawing time (s)	Load flow calculation time (s)
400 kV Fr. grid	2156	2807	7.5	82	3.5
400 + 225 kV Fr. grid	11123	14891	41.1	1002	118.4

E. Challenges in data translation

The three levels of modelling (CONVERGENCE, CIM and EMTP) are quite challenging for ensuring the quality of the exchanged information. It is even more complex when the base and the targeted software are different in their use (planning and EMT tools).

1) Lack of data or disinformation of the original model

Accuracy of power system networks is crucial for any EMT studies. Even if the strong point of CIM is not to worry about where files are coming from, knowing the base software specific characteristics gives a great advantage to improve the imported final model. Indeed, the EMTP C++ model building algorithm compensates the lack of data, by adding for example, the neutral reactor of autotransformers. It is also common to improve approximations, for example by using real representations of filters in HVDC converters stations and sometimes to take advantage of the French network knowledge to correct erroneous data.

2) Light version of CIM export

The CIM export module of CONVERGENCE takes into account only the required profiles for planning models exchanges. Even if the database of coordinates substitutes the graphical layout profile, for distant future network configurations containing new components, the database is incomplete. Thus, automatic drawing becomes impossible for some parts of the grid.

Then, in addition to lightened bus-branch version of CIM, optional data are sometimes not considered like BusbarSection CIM objects. This makes it difficult to faithfully transpose substations structures with the correct number of busbars. Despite this, the network topology is always respected.

Further information is not delivered during CONVERGENCE CIM export such as slack bus position or machines reactance as considered previously.

3) Different solving methods

A final verification must be carried out before parameters assignation to EMT objects to comply with internal constraints of the destination program. For example, the positive sequence shunt susceptance of a CP-line in EMTP cannot be zero. Then, EMTP does not accept two or more PV load-flow buses at the same node that forces to switch some machine regulation types to PQ constraints.

To ensure that all these differences in modelling are responsible for the load flow disparities previously described and to validate the data mapping, an update mode of the CIM/EMTP interface was created to degrade the EMTP circuit in order to move closer to the CONVERGENCE model. After a new results comparison, the maximum relative deviation in voltages is less than 0.1%. Indeed, by analyzing the network, the most significant differences were observed near substations with shunt compensators whose voltage set points were incorrect in CONVERGENCE.

F. Application cases for EMT studies

In the case of transient phenomena simulations, a limited part of the network is usually accurately modeled, especially power electronic dominated devices (HVDC links, wind farms, photovoltaic systems, etc.). However, a large scale network model that represents a specific network topology and a load situation is also required to get a relevant starting point of EMT time-domain studies and to get an accurate model for frequency scan studies. Examples of both types of study are presented below.

1) Background harmonic amplifications study

RTE was involved in the commissioning of a long HVAC cable named Normandy 3 (N3) between the Jersey island and France. The first energization of this cable was an excellent opportunity to address correctly the background harmonic amplification issue that can occur within future offshore wind farm connection projects. RTE performed on-site measurements and analyzed background harmonic amplification phenomena [13].

The RTE's 400 kV grid has a decisive influence on harmonic resonances. CIM import tool was used to transfer the network into EMTP. To shorten time-domain simulations, a Frequency Dependent Network Equivalent (FDNE) [14] based on sparse matrix algorithm [15] was applied on the 400 kV network seen from the Taute 400 kV substation. The resulting EMT model is shown on Fig. 6.

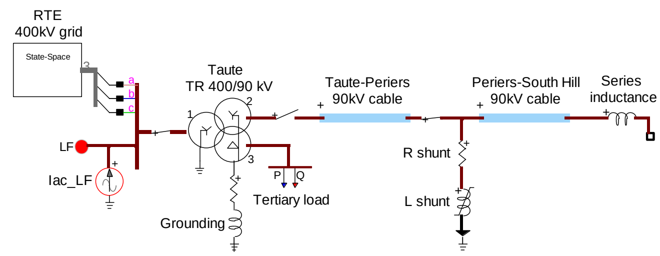

Fig. 6 EMT model for the commissioning of N3 cable

In order to validate the model, EMT simulations were run and compared with switching transient records. Results, presented in [13], demonstrate the reliability of the EMT model compared to on-site measurements and confirm the validity of CIM/EMTP interface in time-domain.

2) System harmonic impedance for offshore wind farm connection

For Wind farm connection to transmission grids, the harmonic impedances are usually provided by the TSO to the Point of Common Coupling. This study is performed at RTE on the basis of two grid situations from CONVERGENCE. They correspond to minimal and maximal system short-circuit powers. The document [16] recommends to model a limited zone of the main transmission network but it is more practical for users to import automatically the entire 400 kV grid for each network configuration. However, the 225 kV area is carefully selected in CONVERGENCE before the export to EMTP. In some cases, parts of lower voltage level network (90 kV) must be modeled manually because of the incomplete database of coordinates.

In most cases, a network reduction into a frequency equivalent is not required for this type of study because the simulation time remains short with the whole detailed circuit.

The final study gathers almost 1000 simulations that correspond to different network topologies and configurations for filters switches of a LCC converter. Results are surfaces in the RX plan (R: real part of the impedance, X: imaginary part of the impedance). An example at a given substation is illustrated on Fig. 7.

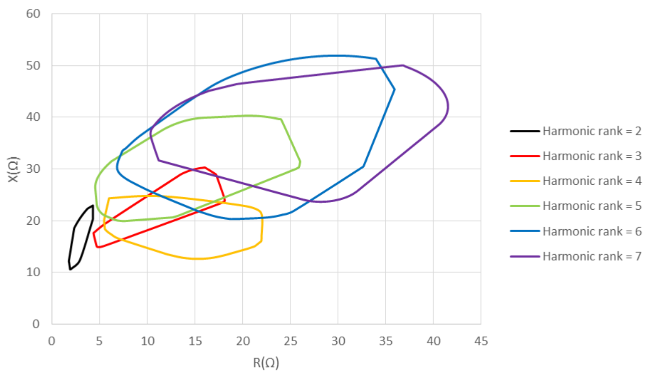

Fig. 7 First ranks of system harmonic impedance at Penly substation

IV. Towards a Generic CIM Interface for EMT Tools

A. *Implementation of CIM to EMT data translation*

The CIM tool presented above is closely linked to the base software and was created to meet the specific needs of users at RTE. Indeed, it is based on a RTE library of EMT components. It uses a database of graphical information and applies particular rules to tackle incorrect data as pointed out in section III. E.

The purpose of a generic CIM interface is to be independent from the source of CIM files. Another challenge is to use directly native components of the targeted software and not to create a CIM-like EMT library. In [17], issues in translating from CIM-XML to a proprietary format are reported. Some methods to exchange CIM-XML data are described in [18].

The principle scheme of the proposed generic CIM interface for EMT programs is presented on Fig. 8.

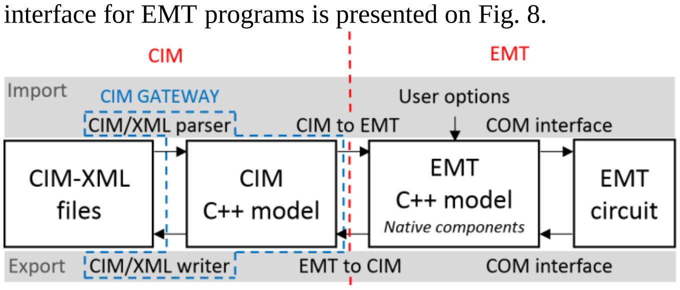

Fig. 8 Proposed generic CIM/EMT interface flow diagram

This diagram offers several benefits with regard to modeling portability. At first, the syntax, the profiles and all UML constraints of the CIM standard are automatically checked during CIM-XML files import and export thanks to CIM GATEWAY. Then, loading a model into memory (CIM C++ model in our case) provides better performance to query a data source. Indeed, it is often required to retrieve equipment data from CIM objects distant from more than three UML associations, which can become a time-consuming process if requests are sent directly to XML files. Another very important point is the clear separation between the CIM and EMT fields. This structure makes it easy to integrate other formats than CIM and to adapt to any simulation tools.

For now, the interface was tested with EMTP and works only with the CGMES (EQ, TP, SV, SSH and DL profiles) even though CIM GATEWAY is compatible with other CIM versions. An export mode is also implemented.

B. *Test case for CIM/EMT interface*

The test cases provided by ENTSOE [19] were designed to contain a large variety of components: transformers, generators, lines, switches, breakers, shunt compensators and loads. They also include graphical information (DL and GL profiles). The simplest example named Micro Grid Test Configuration Base Case was selected to test both import and export features of the interface. It contains 34 conducting equipment and represents the ENTSOE smallest possible data set for focusing on the syntax, connectivity and file management. The base case model is a bus-branch model and consists of three Model Authority Sets (MAS): two TSO type of model (Belgium and Netherlands) and one boundary (BD) file. It also includes an assembled model to standardize diagram layout and state variables information.

1) *Import mode*

Before each execution, this mode displays a user configuration options window. Users can define default values and behaviors. For example, the CIM object ACLineSegment can be represented by a PI-line or a CP-line in EMTP.

Only native EMTP objects except one component (EMTP terminal) are used. The latest is specially created for the CIM interface which is based on the same position data as the CIM object Terminal. This intermediate electrical connection point, between conducting equipment, allows to get a better visual appearance.

The translation algorithm has to respect specific needs of the targeted software such as having a unique PV load-flow bus at a node. The main challenge is the mapping between CIM and proprietary format that is difficult to achieve when there is no bijection between objects. A concrete example in this base case is the presence of a polynomial static load model, which has no direct equivalent in EMTP. Since an exponential load model is implemented, one solution is to combine several instances of this model to represent a polynomial load. The same goes for a synchronous machine, whose PV or PQ constraint is set in a separate component in EMTP.

At the end, an EMTP circuit was automatically created. It is composed of 12 lines, 7 transformers, 5 synchronous machines, 6 loads, 3 shunt compensators and 1 breaker. A power flow simulation was run and successfully completed. Both graphical aspect and load-flow results were validated when compared with the Micro Grid Test Configuration Documentation. The maximum relative deviation in voltages is less than 0.2%.

2) Export mode

The export mode was tested on the EMTP circuit imported from the previous test case. Translating back to CIM format raises several issues. For example, different actions can be taken to handle the previous case of several exponential loads at the same node: to generate as many CIM exponential loads as in EMTP or to amalgamate these components into a single CIM polynomial load. Then, the conversion is often a one-way process. Information can be lost during the import, as the nominal voltage of a topological node for the CIM/EMTP interface, which shows that it is impossible to get back the source values. Finally, EMTP terminal components specially created for the CIM interface facilitate graphical data exchange. This becomes more complicated to correctly export CIM terminals coordinates if the EMTP circuit does not contain such components.

As a first step, the CIM C++ model is created without all CIM components parameters attribution in order to validate CIM objects generation and association, mandatory parameters and graphical correspondence. CIM-XML files were successfully generated. As the mapping is incomplete, the validation process cannot be fully achieved but a test of re-import was performed in EMTP and the obtained scheme was identical to the first import one.

V. Future objectives for CIM/EMT interface

No major improvements are expected for the CIM interface between CONVERGENCE and EMTP in a close future.

Regarding the generic CIM interface for EMT tools, there is still much work to be done. Reflections on the export method must be pursued to finally achieve a complete comparison of input and output XML files after an import-export loop. Efforts should continue to handle more CIM objects and to perform parameters identification for data exchange. More complex ENTSOE test cases [19] should be considered to be consistent with the node-breaker configuration, integrate detailed models, handle various operations (transformers tap changing during load flow calculation) and also take into account difference files to move from one model to another. Difference files is a new feature introduced by CIM standard with the aim of reducing volume and complexity of data exchange. This process consists of supplying only changes of a CIM-XML file in order to update it.

CIM GATEWAY maintenance should also be taken into account to comply with future evolutions of CIM, especially the distinction between subset and profile so as to separate data in greater detail. So far, these two notions were quite similar because they hold exactly the same data. Minor adjustments are also needed regarding objects constraints check. This question is sensitive in particular for the more generic CIM object, IdentifiedObject, whose name attribute can be mandatory or optional according to the profile of the involved concrete object.

Exchange of dynamic information is considered in CIM through IEC 61970-302 [20] and IEC 61970-457 [21]. The dynamic profile is divided into two main categories, standard models and user-defined models [22]. User-defined models support the exchange of proprietary models and, later, elementary control blocks. Exchanging CIM dynamic data is a future effort. Libraries of standard machines control must be created in EMT tools. It is important to note that current dynamic models provide power system data related to the parameters of an associated block diagram. Each platform has its own internal implementation of these models that can lead to ambiguous model exchange. It would be wise to keep an eye on alternative solution like the mapping between CIM and MODELICA code [23].

Extending the CIM standard to include EMT data is also a key point for data portability between EMT tools. A preliminary analysis of the CGMES existing objects and attributes [24] is needed before defining required extensions to accommodate various EMT-type modeling details. For example, the Switch CIM class could be augmented with two new attributes to represent events in time-domain simulations: the opening and closing time. However, the issue becomes more complex for high-frequency transients. In the case of the CIM line model (ACLineSegment), additional data like the representation of towers, insulators and grounding impedances are required. Besides, surge arrester model implemented in any EMT-type tool has no CIM equivalent to date. This gives an insight of the complexity of converting EMT data to CIM formats. The lack of standard models for transient analysis is also a serious limitation in exchanging models between EMT-type simulation tools. For example, the book [25] proposes many transformer models for any frequency range.

VI. Conclusions

Using a standard for data portability facilitates exchange of power system networks between and within companies. CIM has proved to be the most prominent data model for power systems information exchange and is now an international reference standard for simulation tools portable data format.

Two CIM interfaces are presented in this document. The first one is a link between the planning simulation and EMT platforms currently used at RTE. The challenge was not only to faithfully transcribe original information into EMT programs but also to provide a higher-resolution data gleaning additional information and user-defined accurate models. The second one is generic and were developed for a more general purpose. Both data import and export are managed by this software. The emphasis is on the flexibility and maintainability of the program to allow an easy adaptation to any EMT tool and data format. Efforts need to be pursued to comply with all existing CIM components.

Exchanging models between EMT-type simulation tools is the next step. Some key technical challenges have to be addressed in the coming years in order to make CIM a portable data format for EMT simulation programs. Although the lack of a common representation for some EMT power equipment makes the full standardization of CIM attributes complex, several EMT parameters may already be adopted by CIM.

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