Information exchange with CIM for the Energy Industry

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Abstract
To produce, transfer and deliver energy within the power system, reliable and available information systems are a part of the key to success. Information about the grid states, outages, assets, locations, customers etc. is required to operate the business. Information systems need to exchange information, both within a utility and with external utilities. Since different utilities use different information systems with different information models an incentive for a standardized information model occurs. The Common Information Model (CIM) is an information model standardized by International Electrotechnical Commission (IEC). Since this information model is a standard and covers many areas of business it becomes abstract, complex and intangible. Therefore adaptation and delimitation is required before implementation. In this study CIM is analyzed and then compatibility tested in the context of network model data exchange. The data is provided from a network operations unit within a company in the energy distribution business. The information exchange specification is used to adapt CIM to the specific situation. Then the corresponding CIM data is located in the source data. At last a transformation example is provided with a suggested syntax. According to this study and the observations made from the sample data an implementation should be feasible. However such an implementation will require engineering.
Foreword

This project was initiated by Sigma Solutions as a master thesis proposal. Richard and Andreas signed up for the thesis and involved the institution ICS at KTH. Lars Littorin at Sigma Solutions involved an energy company that prefers to be anonymous (in this report: “the energy company”), “the energy company” provided data in the form of proprietary network data that’s intended to be converted to CIM. Supervisor at KTH where Phd student Kun Zhu. Supervisors at Sigma were Johan Berneskog and Lars Littorin.

Since the thesis was performed by two students the table below specifies the contribution for each student with a scale 1-3 where 3 maximum contribution.

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Glossary

AM - Asset Management
AMR - Advanced Meter Reading
CDM - Canonical Data Model
CDPSM - Common Distribution Power System Model
CIM - Common Information Model
CIS - Customer Information System
COTS - Commercial Of The Shelf
CPM - Common Power System Model
CRM - Customer Relationship Management
DMS - Distribution Management System
EA - Enterprise Architecture
EDA - Event Driven Architecture
EMS - Energy Management System
ERDF - Electricité Réseau Distribution France
ERP - Enterprise Resource Planning
ESB - Enterprise Service Bus
GIS - Geographical Information System
GMS - Generation Management System
GUI - Graphical User Interface
HV - High Voltage
IEC - International Electrotechnical Commission
IS - Information System
IT - Information Technology
LV - Low Voltage
MDM - Meter Data Management
MOM - Middleware Oriented Messages
MV - Mid Voltage
NIS - Network Information System
OCL - Object Constraint Language
OMG - Object Management Group
OMS - Outage Management System
OWL - Web Ontology Language
RDF - Resource Description Framework
RFI - Request For Information
SCADA - Supervisory Control And Data Acquisition
SOA - Service Oriented Architecture
SOAP - Simple Object Access Protocol
TC57 - Technical Committee 57
UML - Unified Modeling Language
WMS - Web Map Service
WS - Web Services
XMI - XML Metadata Interchange
XML - eXtensible Markup Language
XSD - XML Schema Definition
1. Introduction and background

Incentive and problem formulation

To produce, transfer and deliver energy within the power system, reliable and available information systems are a part of the key to success. Information about the grid states, outages, assets, locations, customers etc. is required to operate the business. This business typically has a huge SCADA system which collects a large amount of data. A lot of equipment to needs to be maintained and the typical business has many customers. Also information exchange with other utilities and market operators are required. Therefore the energy industry is a very information intensive business. To handle this information, information models aids a lot. Ideally the information is unambiguously defined, to eliminate misinterpretation, and available at the right time in the right place to support business. See Figure 1. Since there are a lot of system vendors with different information system solutions, information models often differ. Different information models in the same system of systems create problems when communication between different systems and applications is required; the architecture gets messy. Manual ineffective solutions are not uncommon (Holm, 2010) partly due to the inter-operability issues (but also due to lack of usability), i.e. the ability for different system to work together. The manual solution might lead to misinterpretation and it’s a time consuming alternative.

Figure 1, organization is the same organization in different situations, information models prevent misinterpretation (Saxton, 2010)

Problem solutions

Dr McMoran presents four solutions to the inter-operability problem. (Dr McMoran, 2007):

1. Maintain multiple copies of the same data in multiple formats
2. Store the data in a format compatible with every piece of software, requiring the removal of application-specific data and a subsequent loss in precision
3. Store the data in a single, highly-detailed format and create software to translate from this highly-detail format to the desired application file formats
4. Use a highly detailed format that is compatible with every application and whose standard format contains the basic data required to represent the power system while
simultaneously allowing additional, detailed, application-specific data to be contained without invalidating the format.

The fourth alternative is the ideal solution. However, this alternative requires a detailed model over the electrical network, a file format able to store extended data without affecting the core data and software vendor's adaptation to the model (Dr McMoran, 2007). CIM is a detailed model over the electrical network and allows extensions but software vendor adaptation is more of a vision. Implementation of CIM is a big investment since the model is complex and therefore requires a lot of resources to implement. The main effort is in the context of data modeling (Rotem-Gal-Oz). The cost and payoff is related to the system of systems complexity (a system of systems is a system that consists of different systems). Figure 2 is a simplified example of the complexity before and after CIM implementation. Note that CIM is a Canonical Data Model (CDM) (TC57, IEC 61968-13 Rev08, 2006). Imagine if a “system 7” shall be integrated, instead of 6 new data transformations according to the “before scenario” only one new data transformation is required when a CDM is implemented (Britton, 2010). I.e. one transformation from the internal systems data model format to CDM format and one transformation from CDM format to the internal systems data model format. To summarize the following anecdote is suitable:

“CIM isn’t the easiest way to do anything but it’s the easiest way to do everything” (Britton, 2010)

![Figure 2, benefits of a Canonical Data Model (Britton, 2010)]

**1.1 Purpose**

The purpose of this research is to analyze CIM, measure the feasibility of implementing CIM at “the energy company” and to build an education platform to serve courses at ICS, KTH.
1.2 Goals

This master thesis has three separate goals:

- Analyze CIM with subject to the following aspects specified by Sigma:
  1. What standards and profiles are used in these situations?
     a. Distribution: HV, MV, LV
     b. Heat
     c. Power
  2. What tools are there and in what situations are they suitable?
     a. SPARX
     b. CIM Tool
  3. What reference models/architectures are defined?
     a. ESB (Enterprise Service Bus)
     b. WS (Web Service)
     c. MDM (Meter Data Management)
     d. CDM (Common Diagnostics Model)
  4. What support is there for CIM in different COTS?
     a. Maximo
     b. SCADA
     c. GIS
  5. Define reference implementations for different areas:
     a. NIS/GIS (Network Information System / Geographical Information System)

- Estimate the feasibility of implementing CIM in the context of network model exchange at “the energy company”, the output will be a report that includes examples of implementation and an implementation methodology.

- Create an education platform to serve courses at ICS, the output will be a report describing the education platform and practical step by step instructions that let the students learn CIM.
2. Theory

In order to handle the information systems used within the energy industry information models aid. If the information systems use a common information model the information model is even more beneficial when communication and integrations trough middleware are required. If the information model is canonical flexibility is provided because systems can be more easily added or removed since all the information travels through the middleware. The middleware makes sure the communication between sender and receiver is provided, therefore point to point connections can be avoided. If the information model is based on a class structure (like UML) that use inheritance flexibility in the information model is achieved. Partly since generalization and specialization of classes is provided but also because classes can be added and removed without destroying the structure.

2.1 Enterprise Architecture (EA)

“Enterprise Architecture is a complete expression of the enterprise; a master plan which “acts as a collaboration force” between aspects of business planning such as goals, visions, strategies and governance principles; aspects of business operations such as business terms, organization structures, processes and data; aspects of automation such as information systems and databases; and the enabling technological infrastructure of the business such as computers, operating systems and networks.” (Enterprise Architecture Standards, 2009)

Information models are a part of Enterprise Architecture.

2.2 Information models

Information models define the conceptuality and structure of the information that supports business in order to make the information available and interpretable. Most important is the consistency about how the information is stored and exchanged within and between internal and external information systems (Magnusson, 2010).

Figure 3 exemplifies an information model. It's a CIM profile, a subset of CIM (TC57, 2010), adapted for a Customer Information System expressed in UML. The information model defines what information about customers there is and how the information is related.

![Figure 3](image_url)
2.3 Information system, concepts and related notations used by the energy industry

This section describes the types of information systems, notations, applications and system of systems used by the energy industry in a generalized manner. The sources for this section are research articles and some system specifications from information system vendors. The information systems and their respective vendor are composed in Table 1. It’s important to point out that some of these notations vary between different users and situations. For example an end user might believe the Geographical Information System is discussed when the Energy Management System is discussed since the Energy Management System and the Geographical Information System shares the same GUI. Therefore it’s appropriate to keep the notations consistent in this study. The CIM support for information systems in table 1 is based on the systems specifications. Therefore some systems might support CIM without declaring it in the specification. I.e. N/A in table 1 means that CIM isn’t mentioned in the system specification.

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Information system</th>
<th>Segment</th>
<th>CIM support</th>
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<td>General electric</td>
<td>ENMAC PowerON</td>
<td>SCADA/DMS</td>
<td>N/A</td>
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<td>XA/21</td>
<td>SCADA/EMS</td>
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<td>Spectrum power</td>
<td>SCADA/DMS or SCADA/EMS</td>
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<td>ABB – Ventyx</td>
<td>Network manager</td>
<td>SCADA/DMS or SCADA/EMS</td>
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<td>DMS 600 + Micro SCADA</td>
<td>SCADA/DMS</td>
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<td>Net control</td>
<td>Netcon 3000</td>
<td>SCADA/EMS</td>
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<td>IBM</td>
<td>Maximo EAM/ITSM</td>
<td>Asset Management</td>
<td>N/A</td>
</tr>
<tr>
<td>PSI</td>
<td>PSlcommand + PSlcontrol</td>
<td>SCADA/DMS</td>
<td>N/A</td>
</tr>
<tr>
<td>Areva (Alstom &amp; Schneider electric)</td>
<td>e-terrascada, e-terradistribution</td>
<td>SCADA/DMS</td>
<td>N/A</td>
</tr>
<tr>
<td>Digpro</td>
<td>Facilplus Spatial/E operator</td>
<td>DMS</td>
<td>Yes</td>
</tr>
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</table>

Table 1, information system vendors and their information systems
The following section describes commonly used information systems and applications.

- **Asset Management (AM)**
  Power system maintenance can be divided into the following areas (Nordström, 2006):
  - Asset documentation, e.g. equipment location, its age, type, status
  - Resource management, e.g. activities such as budgeting
  - Production management, e.g. event reporting, outage management
  - Work flow management, e.g. the chain of events that need to happen after a fault has been detected
  - Maintenance planning, e.g. planning of maintenance

  Asset management systems typically provide information about the equipment age, equipment condition, maintenance, resources, etc.

- **Customer Information System (CIS)**
  Information about customers is managed within this system, e.g. location, billing address, energy consumption.

- **CRM (Customer Relation Management)**
  CRM systems provide information about the customer that helps the employees to shape a view of the customer in order to strengthen the relationship with the customer.

- **Distribution Management System (DMS)**
  A DMS consists of applications that are relevant when running an electrical distribution business. Examples of business functions that a DMS system supports according to the IEC are: (Närman, 2006)
  - Network Operation
  - Record and Asset Management
  - Operational Planning and Optimization
  - Maintenance and Construction
  - Network Extension Planning
  - Customer Support
  - Meter Reading and Control.

- **Energy Management System (EMS)**
  EMSs consist of applications used to operate the transmission networks (Närman, 2006). Typical activities within an EMS are:
  - State estimation
  - Contingency analysis
  - Post fault analysis
  - System stability monitoring
  - Transmission planning
  - Load flow calculations
  - Short circuit calculation
• **ERP (Enterprise Resource Planning)**
  ERP systems are implemented in order to plan an organization's internal and external resource usage.

• **Generation Management System (GMS)**
  This type of system provides services relevant to generation. E.g. load forecasting, power plant control, generation scheduling, long term operations planning.

• **Geographical Information System (GIS)**
  To successfully operate the electrical network location is important. The GIS provides geographical information of where objects are located, typically plotted onto a map. Examples of objects can be customers, electrical networks, outage location. Therefore integration between GISs and other information systems is useful.

• **Network Information System (NIS)**
  This type of system supplies the business with equipment information and is a central information system (Nordström, 2006). Topological information about the equipment is provided, e.g. connectivity between equipment in a certain state.

• **Outage Management System (OMS)**
  OMSs are designed to provide the business with services relevant when an outage occurs to minimize restoration time and inform about the outage. Examples of services are: prediction of short circuit location, estimation of restoration time, information about extent of outages.

• **Supervisory Control And Data Acquisition (SCADA)**
  The SCADA system is probably the most central system for a power system operating business. The system gathers data such as voltage measurements. Device control is typically performed by a SCADA system.
2.4 CIM, UML and XML

The information model composed in the two standards IEC 61970-301 and IEC 61968-11 are collectively known as the Common Information Model (CIM) (Dr McMoran, 2007), (Närman, 2006). The first standard IEC 61970-301 describes the electrical components in a power system, the connectivity between them and various objects related to operation of the transmission network such as the SCADA system. The second standard IEC 61968-11 extends this model to cover information exchanges between systems in the energy distribution business. Note that CIM is an information model. It only defines how the data shall be composed and how it’s related, not how the systems store or use the information.

CIM is a class structure. The model follows the Unified Modeling Language (UML) where inheritance between parent and child is the main idea.

![Diagram of CIM classes](image)

Figure 4, the breaker class (Dr McMoran, 2007)
Each class can have attributes and relationships to other classes. A class can be a sub-class which means the class inherits the parents’ attributes which is additional to the child’s unique attributes. A popular example when describing CIM is the Breaker class, Figure 4.

Every sub-class inherits attributes from the classes above. For example, in Figure 5 the “Switch” is at type of “ConductingEquipment” with the attributes “normalOpen” and “phases”.

When defining connections between equipment with CIM, terminals and connectivity nodes are introduced. Terminals are needed e.g. to know which side of a breaker other equipment are connected. Connectivity nodes are used to join terminals.

Figure 5 Connected equipment with terminals and connectivity nodes (Dr McMoran, 2007)
Another UML relationship in CIM is the “Association” relationship. In Figure 6 the “Association” relationship relates the Terminal with ConductingEquipment and Terminal with ConnectivityNode. The “multiplicities” indicates that ConductingEquipment can have associations with zero or n Terminal, but Terminal can only have association with one ConductingEquipment. In the same way ConnectivityNode have associations with zero to n Terminal, but a Terminal can only be connected to one ConnectivityNode.

Figure 6, ConductingEquipment, Terminals and ConnectivityNodes (Dr McMoran, 2007)
The “Aggregation” relationship indicates that a class is a container class for the child. An example is found in Figure 7. The TransformerWinding is a type of ConductingEquipment, therefore the relation is of generalization type. The TransformerWinding is a part of PowerTransformer, therefore the relation is of aggregation type.

![Figure 7, model of PowerTransformer (Dr McMoran, 2007)](image)

The Common information model can be downloaded from CIM user group homepage, www.cimug.org. The read-only version of SPARX Enterprise Architect can be used to view the UML model.

CIM machine language is XML. The main reasons why XML is suitable are because it’s both human and machine readable, it’s a well known language and together with a RDF syntax network models can be expressed in machine language. There are two different types of XML used by CIM, the RDF-XML and the XSD-XML. The XSD structure is more relevant for sending messages (message payloads) and RDF structure is more relevant for network model description. TC57 investigates the differences between the syntaxes in (TC57, 2006), this investigation can be found in Appendix D.
CIM UML together with RDF syntax then defines a CIM RDF Schema, typically a subset of CIM classes and relations in RDF format which is a profile (TC57, 2010). This profile then defines the information’s conceptuality and the semantic relations between the information for a specific situation, system or application. The profile specifies an interface for information exchange between the proprietary data and CIM XML data (TC57, 2009).

Figure 8, CIM interface architecture (TC57, 2009)

Figure 9 illustrates the information exchange between two systems, the transformations needed and the dependencies between them. CIM contextual model is a profile that specifies the transformations and CIM XML data (Britton, 2010).

Figure 9, CIM transformations (Britton, 2010)

The following mappings between Figure 8 and Figure 9 unify the figures. “Producer App Instance Data” and “Consumer App Instance Data” in Figure 9 are represented as “Proprietary Power System Data” in Figure 8. “Transform” in Figure 9 is represented as “Importer/Exporter” in Figure 8. “Exchanged CIM Standard Data” in Figure 9 is represented as “Power System Data as CIM XML” in Figure 8. “CIM Contextual Model” in Figure 9 is represented as “CIM RDF Schema” in Figure 8. “Producer App Semantic Mdl” and “Consumer App Semantic Mdl” in Figure 9 is the meta-model of the proprietary systems, correspondent to a CIM profile.
Information that can’t be described in CIM can still be included in the same instance data file. CIM XML files use the tag `<cim:Object>…</cim:Object>`. Extensions can be made by just changing the tag from `<cim>` to something else, for example `<heat>`. XML instance data that contains extensions still can be CIM compliant since the applications receiving the XML file can ignore the data that has extension tags.

2.5 Middleware architecture and integration
CIM is an abstract and comprehensive data model that provides support for standardized information exchange. In order to make the information exchange possible, the information systems needs to communicate through a platform. There are different integration solutions and this section will briefly discuss the Service Oriented Architecture (SOA), in particular the Enterprise Service Bus (ESB) software infrastructure which consists of Web Services (WS) and MOM (Middleware Oriented Messages) (Chande, 2004).

**Service Oriented Architecture (SOA)**
SOA is an architecture that’s designed after business processes packaged as services, in order to increase the alignment between business and IT. SOA increases the IT agility since the applications are infrastructure independent, i.e. an application doesn’t know what other systems or applications it communicates with. Therefore specific applications can be removed or added with less effort than if the infrastructure would have to be totally reshaped when new applications shall be removed or added. Since IT supports business and business might change, IT agility is important in order for IT to keep support the business when the business changes. However, SOA is a widely misunderstood acronym. For example SOA sometimes is defined as Web Services (WS). This definition isn’t correct according to (Rotem-Gal-Oz), (Chande, 2004) since WS is only the technology to make components accessible through standard internet protocols and therefore only supports architectures like SOA. There’s a conception that SOA alone make integration between systems easier because of the interface focus and the use of standard protocols such as XML and WS. Most of the errors within information systems are conceptual according to Fred Brooks (Rotem-Gal-Oz) therefore a detailed system independent data model that describes conceptuality and semantic relations is required in order to make integration possible (Rotem-Gal-Oz). However, if a system independent data model is defined, infrastructure like ESBs simplifies the actual integration (Rotem-Gal-Oz) (Chande, 2004). In the case of CIM (which is a system independent data model) an infrastructure like the ESB suits well as an integration platform. It’s important to not focus too much on the technology, if a system independent data model is lacking the technology won’t help.
Figure 10 and 11 exemplifies the benefits of CIM and the SOA approach with a simplified model over a utilities system of systems and their connection before and after CIM implementation through an ESB. However, it’s important to point out that this is more of an academic vision and that figure 11 isn’t the solution to the practical problem, it just visualizes possible benefits. An implementation of this sort requires a lot of effort, you can’t just buy the ESB, connect the systems and say problem solved since, as explained, system independent information models and interfaces are required.

![Diagram of system of systems before CIM implementation](image1)

**Figure 10, theoretical scenario before CIM implementation**

![Diagram of system of systems after CIM implementation](image2)

**Figure 11, theoretical scenario after CIM implementation**

As seen in the theoretical scenario in Figure 11 the CIM compliant ESB in combination with CIM compliant interfaces connects the systems and eliminates the spaghetti architecture. A customer reports a trouble ticket which is stored in the Customer Information System. The trouble ticket is then sent to Outage Management System which confirms the outage and an
outage record is created. The outage record is then sent to the Distribution Management System where the record is stored.

**The Enterprise Service Bus (ESB)**

The ESB is a combination of Middleware Oriented Messages (MOM) and Web Services (WS), an integration broker based on standards such as XML and WS (Chande, 2004), in other words, the ESB is an infrastructure technology. Gartner describes the ESB as follows in (Chande, 2004):

“An Enterprise Service Bus is a new architecture that exploits Web Services, messaging middleware, intelligent routing and transformation. ESBs acts as lightweight, ubiquitous integration backbone trough which software services and application components flow.”

The ESB provide a communication channel for XML-message based exchanges very suitable for CIM based information exchange. The standard shaped infrastructure utilizes WS technologies such as reliable messaging, intelligent routing and data transforming (Chande, 2004).

The IEC 61968-1-1 is an ESB implementation profile and defines how the ESB message structure shall be shaped in order to be CIM compliant. The 61968 is intended to support applications that need to exchange information on an event driven basis. To exemplify the clients can subscribe to updates. If a master send an event that some object is deleted, the ESB informs and make sure all subscriber clients makes this change. This type of architecture is called Event Driven Architecture (EDA).

In Figure 12 Goodrich illustrates that the client does not need to know the location of the server since the ESB does the processing and integration work. The client requests information with the command Request(), the ESB processes the request and make a request to an appropriate server. The server then replies to the ESB which replies to the client.
3. CIM and related standards analysis

In this section CIM will be analyzed. Implementation areas will be discussed in the form of profiles (61970-x and 61968-x) which are subsets of CIM classes and attributes (TC57, 2010). CIM is comprehensive and complex. At first glance the model feels abstract and intangible, therefore the different CIM packages will be briefly explained to provide insight.

3.1 IEC 61970

The IEC 61970 standard is developed to support EMSs used in transmission (Wang, 2003).

**Packages**

To better manage the large model CIM is divided into packages. Figure 13 shows the packages included in IEC 61970. Three main packages (Wires, Topology and Core) contain the main classes to describe the physical characteristics of the transmission network. However that's not enough to describe the power system and the related information therefore there are 12 additional packages. The packages can be viewed in Figure 13 and will be shortly described. For more information about the packages, classes and their relation download CIM model from cimug.org and view it with the freeware SPARX EA Lite.

- The Wires package includes information about electrical characteristics of the components used in the transmission and distribution network. Includes classes like ACLineSegment, Conductor, TransformerWinding and SynchronousMachine.
The Topology package together with terminals from the core package describes connectivity. Includes the two classes TopologicalNode and BusNameMarker.

The Core package describes common classes that relate to most parts of the model such as: Terminal, BasePower, EquipmentContainer and IdentifiedObject.

The Production package describes generators. Includes classes like HydroPowerPlant and ThermalGeneration.

The GenerationDynamics package describes the prime movers involved at generation such as turbine types. Includes classes like DrumBoiler and SteamSupply.

The LoadModel package describes information about energy consumers such as load demand. Typical classes are LoadArea and StationSupply.

The Meas package describes information about measurements either at, for example, Power System Resource or at a Terminal. Includes classes such as Analog and SetPoint.

The Outage package defines schedules for network planning, e.g. when switches will be open. A typical class is: OutageSchedule.

The Protection package describes information about protection of switches, one class is: CurrentRelay

The SCADA package describes typical control information used in a SCADA system. Includes classes like RemoteControl and RemoteSource

The Domain package defines data types and includes classes such as Boolean and Frequency.

The Equivalents package describes information about networks modeled as an equivalent. Includes classes like EquivalentInjections.

The OperationalLimits describe limits within the power system at a Power System Resource or a Terminal. Includes classes like ActivePowerLimit and CurrentLimit.

The ControlArea package describes the Control Area related information and what information it’s associated with in the model. One of the classes is AltTieMeas.
• The StateVariables package isn’t finished. The package describes information such as the power flow state. Includes classes like SvPowerFlow and SvStatus.

• The Contingency package isn’t finished. The package describes information about contingency, a class is Contingency.
Profiles and data flows

A CIM profile is a delimitation of CIM which consists of a subset of classes and attributes that specifies information conceptuality and the relations between the information objects. These profiles are thoroughly created and the objects included are chosen for specific situations. Interfaces for information exchange are specified by the profiles. In combination with appropriate tools the profiles also can be used to validate low-level XML models compliance to their CIM profile. The IEC provides a couple of standard based profiles for electrical transmission power system modeling. The core profiles are included in the standards IEC 61970-452, IEC 61970-453 and IEC 61970-456. Figure 14 illustrates these profiles (clouds), their provenance (rectangles) and the metadata relational structure (arrows). An arrow from A to B indicates that there are relationships between the classes in A and B. The direction enlightens that classes in A are dependent on classes in B (WG13, 2010).

- State Variables is a profile for state variables which are calculations or measurements for a specific state in a time varying system.
- The Topology profile specifies data about topology which is the network in a specific connectivity state (how the networks switches are set, if generators are connected etc.).
- The Analog Meas Set, Status Meas Set and Measurement Specification profiles specifies how information about measurement data shall be structured.
- Equipment Model is a core profile for description of the electrical network and includes classes like Breaker, Disconnector, Substation and TransformerWinding.
- The interconnectivity objects connectivity node and terminal are included in the Connectivity profile.
- The Schedules profile includes the classes about time varying variable objects.
- The Schematic Layouts profile includes classes about graphic schematic layouts.

Figure 14, the core profiles provided by IEC (WG13, 2010).
Figure 15 maps typical network analysis applications and their respective data (instance data) to the profiles (metadata) in order to enhance the understanding. The ovals represent applications, the clouds represent the profiles and the rectangles represent the instances of data consumed and produced by applications and governed by the profiles.

For example the topology & scheduling application consumes Equip model, Connectivity, Schedules and Status Set data. The output is Topology and State Var data which are consumed by the state estimation application, which in turn, produces another set of State Var data. This data is consumed by the contingency analysis application. The grey arrows from instance data to the metadata profiles indicate that the instance data is specified by their respective metadata profiles (WG13, 2010).

Figure 16 maps typical power-flow analysis applications and their respective data (instance data) to the profiles (metadata) in order to enhance the understanding.
Figure 17, export to external applications (WG13, 2010).

Figure 17 illustrates 6 different interfaces for external consumers. The list below is a brief explanation of CIM data sets (WG13, 2010).

1. Network model data exchange
2. Network switch status set
3. Network analog measurement set
4. Topology, i.e. the network model in a particular switch state.
5. State variables, a) for input values b) state estimator results
3.2 IEC 61968

The IEC 61968 is a series of standards developed to ease integration of different applications and systems related to distribution management (Närman, 2006). The standard covers Interface Reference Models mapped to different business functions, semantic relationships and conceptual definitions on how information shall be shaped in order to be CIM compliant. In comparison to the IEC 61970, IEC 61968 also covers areas in the context of business, for example Asset Management. The distribution power system model needs extensions since IEC 61970 was created for transmission (Dr McMoran, 2007). For example, transmission models often assume balanced three-phase. That assumption isn’t appropriate for a distribution model since, for example, the applications associated with distribution networks might be dependent on data about unbalanced three-phase, two-phase and single-phase (Wang, 2003). It’s important to point out that IEC 61968 is a standard that’s still under development.

Figure 18 is a model over the business functions and their respective interface (and part of 61968-x) connected to a bus compliant with IEC 61968-1-1 & IEC 61968-1-2 (which are standards that define how a bus shall be shaped).
Packages

In figure 19 the different packages of 61968-11 are mapped to their standard interface part. However, since the IEC 61968-11 still is under development all the packages aren’t available in the latest CIM release.

The packages in the latest release will be briefly explained below which are the Common package, the WiresExt package, the Assets package, the AssetModels package, the Work package, the Customers package, the Meetering package, the LoadControl package, the PaymentMeetering package and the Informative package.

- The Common package describes information about commonly used objects and includes classes like Agreement, Location, Organisation and PositionPoint.

- The WiresExt package describes information about electrical extensions required when modeling distribution networks. Examples of classes are DistributionLineSegment, DistributionTransformer, PerLengthPhaseImpedance and WindingPiImpedance.

- The Assets package handles information about assets. A class included in this
package is AssetFunction.

- The AssetModels package provides information objects for storing information about different assets. Examples of classes are CableInfo, ConductorInfo, DistributionWindingTest, ShortCircuitTest, WireType and WireArrangement.

- The Work package only includes the two classes WorkKind and Work which are objects that define work documents.

- The Customers package describes information about customers. Typical classes are Customer, CustomerAgreement, ServiceLocation and Tariff.

- The Metering package describes information about metering. Some classes are DeviceFunction, EndDeviceAsset, MeterAsset, MeterReading and ServiceDeliveryPoint.

- The LoadControl package describes information about disconnecting or reconnecting a specific load. The two classes included are RemoteConnectDisconnectInfo and ConnectDisconnectFunction.

- The PaymentMetering package describes information regarding payment and different payment options. Some classes are Card, Cashier, MerchantAccount, Receipt and Transaction.

- The Informative package is comprehensive and contains 14 sub-packages. The Informative package describes different types of information. Some classes are IncidentRecord, NetworkDataSet, OutageRecord, PlannedOutage, TroubleTicket, PowerRating, TransformerAsset and FinancialInfo.
**IEC 61968-x, the different parts**

The IEC 61968 is divided into different parts for different purposes. The different parts and their purpose will be briefly explained below.

**The IEC 61968-1 Interface architecture and general requirements**

This part specifies an interface architecture and general middleware recommendations, it’s an important part and will therefore be examined further in a subchapter below. This part is published.

**The IEC 61968-2 Glossary**

This part is a glossary and is published.

**The IEC 61968-3 to 9 and part “external to DMS”**

These parts define Interface Reference Models segmented by business functions, e.g. what information that is recommended for message payloads (TC57, 2010). These message payloads are constructed using the XML schema (XSD). Figure 20 maps the business functions to their standard part. Part 3, part 4 and part 9 is published, the rest is under development.

![Application Integration Infrastructure](image)

Figure 20, different business functions mapped to their standard part (TC57, 2010)
The IEC 61968-11 Common Information Model (CIM) extensions for distribution

This part defines the extensions to IEC 61970 for distribution information models, namely the additional classes, attributes and relations required for distribution business. This part is under development.

The IEC 61968-13 CIM RDF Model Exchange Format for distribution

This part is known as the Common Distribution Power System Model (CDPSM) and is a subset of classes, attributes and relations recommended for distribution power system model exchange. The instance data is constructed using the RDF schema. This part is an international standard since August 2008 (Fremont, 2009) and will be examined further in the section with the study at “the energy company”.

IEC 61968-1 Interface Architecture and General Recommendations

In IEC 61968-1 Figure 20 and the different components are explained. The following infrastructure recommendations are provided in (TC57, IEC 61968-1, 2010).

“IEC 61968 recommends that a compliant utility inter-application infrastructure:

1. Should allow components to exchange information of arbitrary complexity.
2. Should be able to be implemented using various forms of integration technology (e.g., web services, J2EE, message brokers, message oriented middleware, databases, or others). (refer to Clause 5)
3. Should provide an Information Exchange Model facility (refer to Clause 6) that users employ to describe the information to be exchanged. This facility presents the user with the models of events and the components to which they relate, and it allows the new exchange to be added to the old, so that a comprehensive corporate exchange model, tailored to a utility’s specific needs, can be built rather than a collection of independent models.
4. Should allow publisher and/or subscriber component to be deployed by system administrators independently of other components as far as interfaces remain the same.
5. Should ensure that, once a given type of event is published, additional subscribing components can be configured to receive the event without having to make any changes or additions in the publisher component.”

Nouns and verbs are introduced for ESB events. A noun is used to identify the type of the payload which contains the relevant instance data defined by the profiles. A verb is used to identify the type of action being taken. Examples of nouns are “MeterReadings” and “EndDeviceControl”. Examples of verbs are “get()”, “create()” and “reply()”. An application level message might be, “get(MeterReading)” to which some application, determined by the ESB, replies “reply(MeterReadings)” (Goodrich, 2010).

The detailed ESB message structures are defined in IEC 61968-1-1 and a SOAP structure for Web Services is defined in IEC 61968-1-2.

Distribution power system model example

IEC TC57 provide two examples of CIM network models with network representation and corresponding CIM XML in (TC57, 2006), one of these can be found in Appendix D.
3.3 Implementation methodology

To transform non-standardized data to standardized data a methodology has been developed by EDF R&D in (Fremont, 2009). EDF R&D supports ERDF (Electricité Réseau Distribution France) which is a distribution utility in France. ERDF has used CIM as a framework for implementing a model driven integration approach. They get return on investment by having a consistent approach for maintaining their information systems which helps them minimizing their maintenance costs. In Figure 21 their implementation methodology is presented, a generalized description is provided below.

![Diagram of implementation methodology]

Figure 21, a implementation methodology presented by EDF R&D (Fremont, 2009)

1. Analyze the specifications of the exchange, identify the business concepts and the involved business objects. This involves the business stakeholders.
2. Map these business objects to CIM model. If needed, new objects can be created in the form of extensions.
3. Contextualize CIM for the specific exchange. In other words, create an appropriate profile for the exchange.
4. Define the message specification, create a transformation specification.
5. Express the data in CIM format.
3.4 Profiles used in the context of information exchange patterns

Profiles can also be used to control the volume of data that needs to be exchanged (Kun, 2010). For example, the name of a component will not change rapidly but an analog value that’s being measured probably updates very rapidly. Therefore, an application that consumes information from these sources has different update frequency needs, depending on the source. The traffic between information systems can therefore be optimized by choosing different update frequencies for the different profiles. In (Kun, 2010) a methodology for estimating the data volume of instance data specified by the standard profiles based on the knowledge about the grid (how many buses, transformers etc.) is provided.
4. Oracle spatial to CIM investigation at “the energy company”

This part of the report is a study at “the energy company” regarding implementation of CIM in the context of network model exchange between Oracle Spatial proprietary format and CIM XML format.

4.1 Background and goals

“The energy company” plans to buy a new DMS which requires the network model data that’s stored in an Oracle Spatial database. Strategic guiding principles at “the energy company” state that information exchange, if possible, shall be performed in a standardized manner. Since CIM is a standardized format, an exchange based on CIM is a suitable alternative. The goal of this study is to estimate the feasibility of an exchange based on CIM. This can be done by investigating what information the new DMS requires in order to find/create an appropriate CIM profile, map this profile to the Oracle Spatial information model, derive examples of transformation rules based on the CIM profile and the Oracle spatial data and by identifying all sorts of possible implementation problems. If a transformation from Oracle spatial format to CIM format is a preferable choice then ”the energy company” can request their vendor to make the new DMS CIM compliant. Therefore a CIM transformation to the new DMS format isn’t in the scope of this study. Figure 22 illustrates the information exchange map with the different investigation components.

![Figure 22, the visional information exchange and transformation architecture proposed](image)

In the context of this investigation, the CIM profile, the Interface and the “Mapping relation” is unknown. The CIM profile can be derived from the new DMS requirements, the interface can be derived from the CIM profile and the Oracle Spatial data format. The mapping relation, of course, is derived from the CIM profile and the Oracle spatial information model.
4.2 The CIM profile and the New DMS requirements

The requirements of the new DMS will be used to create a CIM profile that specifies an interface between Oracle Spatial and CIM according to Figure 22. A Request For Information (RFI) ("the energy company", 2010) has been created by "the energy company" in order to specify the functionalities of the new DMS.

The following functionalities of the new DMS specified by the RFI relevant for this study are listed below.

The new DMS shall be able to:

- Perform load-flow calculations
- Perform short circuit calculations
- Represent electrical schemas
- Represent the geographical network

The new DMS functionalities specify that the CIM profile must be able to express information about the following:

- Components and the electrical properties of the components.
- Electrical connectivity between the components.
- Geographical location of the components.

The IEC 61968-13 profile, also known as the Common Distribution Power System Model (CDPSM) (TC57, 2006), specifies the format and rules for exchanging modeling information based on CIM related to distribution network data. According to IEC TC 57 the network model, in the format of CIM, shall be sufficient enough to perform network connectivity analysis including network tracing, outage analysis and load-flow calculations etc. “This part could be used for synchronizing Geographical information system databases with remote control system databases” (TC57, 2006). These core analysis components correspond well to functionalities specified by “the energy company” RFI, therefore the CDPSM profile seems like a suitable CIM profile framework. This profile is an international standard since August 2008 (Fremont, 2009), however in this study a beta version of the standard is used. Due to the feasibility of this study, the beta version of this profile will most likely be sufficient enough for investigating the feasibility of implementing CIM.

It’s important to point out that when practically implementing CIM the CDPSM is used as a framework, additional classes might be needed. Data that can’t expressed in CIM format can still be added as extensions (then the core CIM data won’t be affected).
The classes included in CDP2M are listed below (CIM version 10). It’s important to note that these are the classes and that these classes have attributes and relations (both between each other but also to other classes).

- BaseVoltage
- VoltageLevel
- Substation
- Location
- PositionPoint
- Breaker
- LoadBreakSwitch
- Disconnector
- Fuse
- Jumper
- GroundDisconnector
- Bay
- BusbarSection
- Terminal
- ConnectivityNode
- PowerTransformer
- TransformerWinding
- Line
- ACLineSegment
- WireArrangement
- ConductorType
- WireType
- EquivalentSource
- Compensator
- StaticVarCompensator
- EquivalentLoad
- CustomerMeter
- GeneratingUnit
- SynchronousMachine
- HostControlArea
- SubControlArea
4.3 Oracle Spatial to CIM profile mappings

Examples of mappings between Oracle Spatial and CDPSM are provided in tables below. The example objects are a power transformer, a line, a switch, a load and a generator with related classes and attributes specified by CDPSM. These objects then are located in the Oracle Spatial information model in order to see if the information exists in the Oracle Spatial database and if it does, where it’s located. This study has shown that this kind of mapping might be misleading since the Oracle Spatial information model might have objects that are non-existent in the Oracle Spatial instance data. Balanced three phase is assumed since “the energy company” assumes balanced three phase.

**Transformer:**
The classes and attributes relevant (according to CDPSM) for the transformer mapping are listed in Table 2.

<table>
<thead>
<tr>
<th>CIM class and attribute [class.attribute]</th>
<th>CIM object description</th>
<th>Corresponding Oracle spatial object</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaseVoltage.nominalVoltage</td>
<td>Base voltage on primary and secondary side required</td>
<td>tee_transformer; un1 and tee_transformer; un2. Where un1 describes the nominal voltage on the primary side and un2 describes the nominal voltage on the secondary side.</td>
</tr>
<tr>
<td>TransformerWinding.windingType</td>
<td>Determines if the transformer winding is primary or secondary.</td>
<td>Can’t be found, but can eventually be derived from tee_transformer; un1, tee_transformer; un2, tee_transformer; snom, etc.</td>
</tr>
<tr>
<td>TransformerWinding.ratedkV</td>
<td>The transformer windings rated voltage level, usually the same as the neutral voltage level. Primary and secondary rated winding voltage level required.</td>
<td>tee_transformer; un1 and tee_transformer; un2. Where un1 describes the nominal voltage on the primary side, un2 describes the nominal voltage on the secondary side.</td>
</tr>
<tr>
<td>TransformerWinding.ratedMVA</td>
<td>The transformer windings rated apparent power, primary and secondary winding rated apparent power required.</td>
<td>tee_transformer; snom and tee_transformer; snom2. Where Snom describes the rated apparent on the power on the primary side and Snom2</td>
</tr>
</tbody>
</table>
describes the apparent rated power on the secondary side. If only Snom is given it describes the rated apparent power for both sides.

<table>
<thead>
<tr>
<th>TransformerWinding.r</th>
<th>The transformer windings resistance, primary and secondary resistance required.</th>
<th>tee_transformer; mv_resistance. tee_transformer; lv_resistance is lacking.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TransformerWinding.x</td>
<td>The transformer windings reactance, primary and secondary reactance required.</td>
<td>tee_transformer; mv_reactance. tee_transformer; lv_reactance is lacking.</td>
</tr>
<tr>
<td>TransformerWinding.g</td>
<td>The transformer windings conductance, primary and secondary conductance required.</td>
<td>This object is lacking</td>
</tr>
<tr>
<td>TransformerWinding.shortTermMVA Apparent power that the winding can carry for a short period of time.</td>
<td>This object is lacking.</td>
<td></td>
</tr>
</tbody>
</table>

Table 2, transformer mapping

**Line:**
The classes and attributes relevant (according to CDPSM) for the line mapping are listed in Table 3.

<table>
<thead>
<tr>
<th>CIM class and attribute [class.attribute]</th>
<th>CIM object description</th>
<th>Corresponding Oracle spatial object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductor.length</td>
<td>Segment length for calculating line segment capabilities.</td>
<td>tee_section; measured_length</td>
</tr>
<tr>
<td>ACLineSegment.bch</td>
<td>Positive sequence shunt susceptance uniformly distributed over the entire line section</td>
<td>This object is lacking but can probably be described from: tee_cable_catalogue; earth_capacitance</td>
</tr>
<tr>
<td>ACLineSegment.r</td>
<td>Positive sequence resistance of the entire line section.</td>
<td>tee_cable_catalogue; resistance</td>
</tr>
<tr>
<td>ACLineSegment.x</td>
<td>Positive sequence reactance of the entire line section</td>
<td>tee_cable_catalogue; reactance</td>
</tr>
<tr>
<td>BaseVoltage.nominalVoltage</td>
<td>The operational voltage level for the line</td>
<td>tee_section; construction_voltage_level</td>
</tr>
</tbody>
</table>
PositionPoint.xPosition  | X coordinates of the line  | Is not present in the information model, but exists according to “the energy company”
---|---|---
PositionPoint.yPosition  | Y coordinates of the line  | Is not present in the information model, but exists according to “the energy company”
PositionPoint.sequenceNumber  | Sequence of the coordinates  | Is not present in the information model, but exists according to “the energy company”

Table 3, line mapping

**Switch:**
The classes and attributes relevant (according to CDPSM) for the switch mapping are listed in Table 4.

Switch.normalOpen  | If the switch is normally opened or closed.  | tee_lv_switch; state_type (depending on the type of switch, could also be disconnector; state_type, for example)

Table 4, switch mapping

**Load:**
The classes and attributes relevant (according to CDPSM) for the load mapping are listed in Table 5.

EnergyConsumer.pfixed  | Active power of the load that is a fixed quantity  | Can be expressed from tee_load_information; energy_mwh
EnergyConsumer.qfixed  | Reactive power of the load that is a fixed quantity  | tee_load_information; reactive_power
EnergyConsumer.powerFactor  | The load power factor  | tee_load_information; power_factor
EnergyConsumer.customerCount  | How many customers represented by the load  | tee_load_information; number_of_customers

Table 5, load mapping
**Generator:**
The classes and attributes relevant (according to CDPSM) for the generator mapping are listed in table 6.

<table>
<thead>
<tr>
<th>GeneratingUnit.initialP</th>
<th>Default initial active power which is used to store a powerflow result for the initial active power for this unit in this network configuration</th>
<th>This object is lacking. Can eventually be described from tee_generator; initial_reactance</th>
</tr>
</thead>
<tbody>
<tr>
<td>SynchronousMachine.baseQ</td>
<td>Default base reactive power value.</td>
<td>This object is lacking but can probably be described from tee_generator; snom, tee_generator; sync_reactance and tee_generator; sync_resistance</td>
</tr>
</tbody>
</table>

Table 6, generator mapping

As seen in the tables some objects are missing which implies that full CDPSM compliance won’t be achievable. However, that doesn’t imply that CIM compliance can’t be achieved since profiles are customizable and some attributes, like shortTermMVA in Table 2, eventually can be removed from the profile without big impact on the performance of the new DMS. Though consideration shall be taken when removing classes from the profile. If for example ratedMVA in Table 2 is removed there will be lack of information to perform some electrical analysis. However some information that’s non-existent in Oracle Spatial probably are available at other sources at “the energy company” according to “the energy company”.
4.4 Interface and transformation example

In the following subchapter a transformation example from Oracle Spatial to CIM will be provided.

Data

The data collected from ”the energy company” is a substation with relevant components. The information is extracted from Oracle Spatial as raw data to an excel spreadsheet (figure 23) and as screenshots from the GIS GUI including a geographical map with location and a network schema (figure 24 and 25).

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IDENTIFICATION</td>
<td>STATUS</td>
<td>X</td>
<td>Y</td>
<td>CREATED BY</td>
<td>CREATED DATE</td>
<td>MODIFIED BY</td>
<td>MODIFIED DATE</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>Drift</td>
<td>1336859</td>
<td>6656646 Maldie</td>
<td>2004-05-18 PowerGrid</td>
<td>2006-08-02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>Drift</td>
<td>1336860</td>
<td>6656646 Maldie</td>
<td>2004-05-18 PowerGrid</td>
<td>2006-08-02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>Drift</td>
<td>1336859</td>
<td>6656657 Maldie</td>
<td>2005-10-24 PowerGrid</td>
<td>2006-08-02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>Drift</td>
<td>1336860</td>
<td>6656657 Maldie</td>
<td>2004-05-18 PowerGrid</td>
<td>2006-08-02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>Drift</td>
<td>1336855</td>
<td>6656646 Maldie</td>
<td>2004-05-18 PowerGrid</td>
<td>2006-08-02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>Drift</td>
<td>1336856</td>
<td>6656648 Maldie</td>
<td>2004-05-18 PowerGrid</td>
<td>2006-08-02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>Drift</td>
<td>1336857</td>
<td>6656648 Maldie</td>
<td>2004-05-18 PowerGrid</td>
<td>2006-08-02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>Drift</td>
<td>1336858</td>
<td>6656648 Maldie</td>
<td>2004-05-18 PowerGrid</td>
<td>2006-08-02</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 23, a screenshot of the Oracle spatial raw data

Figure 24, a screenshot from the GIS with geographical position of the substation
Figure 25, a screenshot of the electrical schema of the substation corresponding to the Oracle spatial data
The data from the excel spreadsheet is divided into objects and every object has a set of attributes. Table 7 describes the information from the excel spreadsheet, observe that the comments is our interpretation of the data. Relevant attributes from TEE_CABLE_CATALOGUE will be added to TEE_SECTION.

<table>
<thead>
<tr>
<th>Object</th>
<th>Object attributes</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attributes used in all classes</td>
<td></td>
<td>The following attributes exists in all classes</td>
</tr>
<tr>
<td></td>
<td>CREATED_BY</td>
<td>The data creator.</td>
</tr>
<tr>
<td></td>
<td>CREATED_DATE</td>
<td>Data creation date</td>
</tr>
<tr>
<td></td>
<td>MODIFIED_BY</td>
<td>The data modifier</td>
</tr>
<tr>
<td></td>
<td>MODIFIED_DATE</td>
<td>Data modification date</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>X coordinate, TEE_BUSBAR and TEE_SECTION are excluded since they got more than one X coordinate. Catalogues are excluded since they don’t have coordinates.</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>Y coordinate, TEE_BUSBAR and TEE_SECTION are excluded since they got more than one Y coordinate. Catalogues are excluded since they don’t have coordinates.</td>
</tr>
<tr>
<td>TEE_SUBSTATION</td>
<td>ID</td>
<td>Substation database ID number</td>
</tr>
<tr>
<td></td>
<td>IDENTIFACATION</td>
<td>Physical identification name</td>
</tr>
<tr>
<td></td>
<td>CONSTRUCTION</td>
<td>Construction type of the substation.</td>
</tr>
<tr>
<td></td>
<td>NAME</td>
<td>Local name of the substation.</td>
</tr>
<tr>
<td></td>
<td>OWNER</td>
<td>Owner of the substation</td>
</tr>
<tr>
<td></td>
<td>LOGICAL_MANUFACTURER</td>
<td>The catalogue manufacturer</td>
</tr>
<tr>
<td>Field</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>STATUS</td>
<td>Operational status</td>
<td></td>
</tr>
<tr>
<td>LOGICAL_COMMUNE</td>
<td>The logical commune</td>
<td></td>
</tr>
<tr>
<td>TEE_TRANSFORMER</td>
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<tr>
<td>UNOM2</td>
<td>The nominal voltage on the secondary side</td>
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<td>The nominal voltage for the third winding if the transformer is a three winding transformer</td>
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<tr>
<td>ZK_12</td>
<td>The short circuit impedance between the primary and secondary side</td>
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</tr>
<tr>
<td>ZK_13</td>
<td>The short circuit impedance between the primary side and third side.</td>
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<td>Active power loss between winding one and two with load</td>
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<tr>
<td>PCU_13</td>
<td>Active power loss between winding one and three with load</td>
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<tr>
<td>P0</td>
<td>Active power loss without load</td>
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<td>How the transformer is connected. For example if it is Y or Delta connected.</td>
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**TEE_BUSBAR**

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<td>The voltage level intended for the bus bar</td>
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<td>Conductor type</td>
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<td><strong>STATUS</strong></td>
<td>Operational status</td>
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<td>The artificial length used to visualize the network model</td>
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<td>X coordinates, bus bars got two coordinates, one for each side of the bus bar. These coordinates describe the electrical connectivity within the substation.</td>
</tr>
<tr>
<td><strong>Y</strong></td>
<td>Y coordinates, bus bars got two coordinates, one for each side of the bus bar. These coordinates describe the electrical connectivity within the substation.</td>
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<td>If the switch is opened or closed</td>
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<td>If the state of the fuse is normal or if the fuse has opened</td>
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<td>The owner of the line.</td>
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<td>The schema the line is feeding</td>
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<td>What output on the schema the line is feeding/being fed from.</td>
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<td>The capacitance while the cable is used</td>
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Table 7, description of the Oracle Spatial objects
Corresponding CIM objects

Table 8 maps the Oracle Spatial attributes to the corresponding CIM object and attribute. Some of the Oracle Spatial attributes are irrelevant according to the "the energy company" RFI ("the energy company", 2010), but if they are needed they can be included in the information model, if possible in CIM format otherwise as extensions. Some of the Oracle Spatial attributes corresponding CIM class has relations to other relevant CIM classes (due to the hierarchal structure).

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<tr>
<td></td>
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<td>ACLineSegment</td>
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<tr>
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<td></td>
</tr>
<tr>
<td></td>
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<td>ACLineSegment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PHASE_CONDUCTOR_AREA</td>
<td>Irrelevant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NULL_CONDUCTOR_AREA</td>
<td>Irrelevant</td>
<td></td>
</tr>
<tr>
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<td>NULL_CONDUCTOR_RESISTANCE</td>
<td>Irrelevant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EARTH_CAPACITANCE</td>
<td>ACLineSegment</td>
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</tr>
<tr>
<td></td>
<td>USAGE_CAPACITANCE</td>
<td>Irrelevant</td>
<td></td>
</tr>
</tbody>
</table>

Table 8, corresponding CIM objects
Lack of data

Table 9 describes the lack of information in the Oracle Spatial example data in order to achieve CDPSM compliance. However this information is with high certainty available at other sources within “the energy company” according to “the energy company”.

<table>
<thead>
<tr>
<th>CIM class</th>
<th>CIM Attribute</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>TransformerWinding</td>
<td>r</td>
<td>The windings resistance</td>
</tr>
<tr>
<td>TransformerWinding</td>
<td>x</td>
<td>The windings reactance</td>
</tr>
<tr>
<td>TransformerWinding</td>
<td>g</td>
<td>The windings conductance</td>
</tr>
<tr>
<td>TransformerWinding</td>
<td>b</td>
<td>The windings susceptance</td>
</tr>
<tr>
<td>TransformerWinding</td>
<td>shortTermMVA</td>
<td>The amount of apparent power the transformer winding can carry for a short period of time.</td>
</tr>
</tbody>
</table>

Table 9, lack of data

Connectivity

Schema connectivity is described with equipment coordinates in Oracle Spatial and with connectivity nodes and terminals in CIM. In Oracle Spatial “busbars” connects the equipment (switches, transformers etc.). By plotting the coordinates in Excel a schema, corresponding to the screenshot in Figure 25, is created. Since the two schemas are equivalent this method for describing connectivity is valid according to our observation. See Figure 26 for the Excel generated schema.
Each “busbar” has two coordinates. Therefore connectivity points are points where there are more than one bus bar coordinate. An exception is the output coordinates were lines connect. Here the connectivity is described with TEE_FEEDING_SCHEMA_OUTPUT. Only one equipment (“busbars” aren’t considered as equipment) can be at one coordinate in order to avoid ambiguousness. The transformer orientation is determined by the “busbars” voltage levels. The “busbar” with the higher voltage level corresponds to the primary side of the transformer and the one with the lower voltage level corresponds to the secondary side.

Figure 27 describes the corresponding CIM schema on top of the Excel generated schema. As seen there are connectivity nodes at nodes where equipment connects. And all equipment has specific terminals.

![Figure 27, the Excel generated schema with CIM components on top.](image)
Figure 28 describes CIM components and their connectivity. The corresponding data in XML format can be found in Appendix B. It’s important to point out that the schema in figure 28 and the XML data has been created manually from Excel data. However, algorithms probably can generate the same schema according to Johan Ullberg who is a PhD student at KTH.

Figure 28, CIM components corresponding to the Excel generated schema
**Connectivity steps**

The steps involved in order to manually create a CIM schema corresponding to the excel data is described below.

**Step 1:**

- The “outputs” object implies that this is a line connection point. A “busbar” coordinate is present which implies that the line is connected to other equipment.
  - Create a “CIM Line” with a “CIM Terminal” and a “CIM Connectivity node” and connect the CIM Line terminal to the “CIM Connectivity node”.

**Step 2:**

- An “lv switches” object and two “busbars” coordinates are present at each of the six points.
  - Create a CIM switch corresponding to “lv switch” and two “CIM Terminals”, one “CIM Terminal” for each side. Connect one “CIM Terminal” to the “CIM Connectivity node” created in step 1.
Step 3:

- “busbars” objects are present. The “busbar” objects connect six switches and one transformer.
  - Create one “CIM Connectivity node”. Connect the switch terminals to the new connectivity node. Create a “CIM Busbar” and a “CIM Terminal” since there are more than two equipments connected to this “CIM Connectivity node”. Connect the “CIM Busbar” “CIM Terminal” to the new connectivity node.

Step 4:

- One “transformer” coordinate and 6 “busbar” coordinates are present. The “busbar” objects have different voltage levels.
  - Create a “CIM Transformer”, one “CIM Connectivity node” and two “CIM Terminals”. Connect one “CIM Terminal” to the “CIM Connectivity node” created in step 3 and one “CIM Terminal” to the new “CIM Connectivity node”. The orientation of the transformer is determined by the “busbar” objects different voltage levels.
Step 5:

- A “disconnectors” object and two “busbar” coordinates are present.
  - Create a “CIM switch” corresponding to “disconnectors” object and two “CIM Terminals”, one “CIM Terminal” for each side. Connect one “CIM Terminal” to the “CIM Connectivity node” created in step 4.

Step 6:

- “busbars” objects are present. The “busbar” object connects three “disconnectors” objects.
  - Create one “CIM Connectivity node”. Connect the “disconnectors” object “CIM Terminal” (that was created in step 5) to the new “CIM Connectivity node”. Create a “CIM Busbar” and a “CIM Terminal” since there are more than two equipments connected to this connectivity node. Connect the “CIM Busbar” terminal to the new “CIM Connectivity node”.


Step 7:

- A “disconnectors” object and two “busbars” coordinates are present at the two points.
  - Create a CIM switch corresponding to the “disconnectors” object and two “CIM Terminals”, one “CIM Terminal” for each side. Connect one “CIM Terminal” to the “CIM Connectivity node” created in step 6.

Step 8:

- The “outputs” object implies that this is a line connection point. A “busbar” coordinate is present which implies that the “CIM Line” is connected to other equipment.
  - Create a “CIM Line” with a “CIM Terminal” and a “CIM Connectivity node” and connect the “CIM Line” terminal to the “CIM Connectivity node”. Connect the terminal connected in step 7 to the new connectivity node.
4.5 XML syntax

An XML syntax needs to be determined. Since CIM is evolving there are inconsistencies in the syntax between different versions of CIM. For example, coordinates are described with the class GmlPosition in CIM version 10. In CIM version 14 coordinates are described with the class PositionPoint. Below is an example of a transformation between CIM version 14 and Oracle Spatial. This example provides the XML syntax for a line and shows were the corresponding oracle spatial data shall be placed. The Oracle Spatial data is inserted as follows [OBJECT:ATTRIBUTE]

```xml
<cim:Line rdf:ID="_ID_Line_ [TEE SECTION:ID ]">
  <cim:IdentifiedObject.name>Line_ [TEE SECTION:ID]
</cim:IdentifiedObject.name>
  <cim:IdentifiedObject.localName>Line_ [TEE SECTION:ID]
</cim:IdentifiedObject.localName>
  <cim:Line.Region rdf:resource="#_ID_SubGeographicalRegion"/>
  <cim:PowerSystemResource.Line rdf:resource=""_ID_Location _[TEE SECTION:ID]">
</cim:Line>

<cim:Location rdf:ID="_ID_Location _[TEE SECTION:ID]">
  <cim:Location.PowerSystemResource rdf:resource=""_ID_Line_ [TEE SECTION:ID]">
</cim:Location>

<cim:CoordinateSystem rdf:ID="CS1">
  <cim:CoordinateSystem.name>RT90</cim:CoordinateSystem.name>
  <cim:CoordinateSystem.Location rdf:resource="#_ID_Location _[TEE SECTION:ID]"/>
</cim:CoordinateSystem>

<cim:PositionPoint rdf:ID="_ID_PP_[TEE SECTION:ID]">
  <cim:PositionPoint.xPosition>[TEE SECTION:X]</cim:PositionPoint.xPosition>
  <cim:PositionPoint.sequenceNumber>[TEE SECTION:ORDERNO]
</cim:PositionPoint>

<cim:ACLineSegment rdf:ID="_ID_Line_ [TEE SECTION:ID]_S1">
  <cim:IdentifiedObject.name>“Line_ [TEE SECTION:ID]_S1”
</cim:IdentifiedObject.name>
  <cim:IdentifiedObject.pathName>”Line_ [TEE SECTION:ID ]_S1”
</cim:IdentifiedObject.pathName>
  <cim:ACLineSegment.bch>”2*pi*[TEE_CABLE_CATALOGUE: EARTH_ CAPACITANCE]”
</cim:ACLineSegment.bch>
```
4.6 InterPSS OpenCIM test

The CIM XML file created from the Oracle Spatial example data (that can be found in Appendix B) was tested in InterPSS OpenCIM, see Figure 29. As seen the network corresponds to the Oracle Spatial example data. Load-flow analysis works which implies there’s no errors in the connectivity. “Feeding Substation1” is a fictional substation created in order to test the Load-Flow functionality. Only one line was created to reduce the XML file size (the other ones can be created with the same syntax). Fictional data has been inserted to the transformer where there was lack of data. PositionPoints aren’t included since they don’t have any affect in InterPSS OpenCIM.

![Figure 29, screenshot from InterPSS](image-url)
4.7 Identified implementation problems

The problems found are listed below.

- CDPSM isn’t finished. The latest release of IEC 61968-13 (CDPSM) is aligned to CIM version 11. The latest release of CIM is version 14.
- CIM is still under development even if a standard is published. When building interfaces to CIM, the interfaces should be easy to update to work with different CIM versions.
- After integration, how is SCADA measurements coupled to the right point in the network within the DMS? The network model comes in CIM, SCADA measurements in some other way.
- The Oracle Spatial database includes information in the context of Asset Management, the RFI does not directly specify that Asset Management functions are necessary.
- Electrical information missing for transformers.
- There is a lack of explanation to what attributes mean and values don’t have units.
- How to handle “tapped distribution lines” and pole mounted equipment since that type of equipment needs to be inside a substation? Maybe by creating fictional substations?
- Electrical definitions are important. For example, exactly what is the TEE_DISCONNECTOR object definition in Oracle Spatial and how does it compares to the CIM definitions? (Breakers, disconnector or loadbreakswitch)
- Loadflow calculations are going to be performed within the new DMS. Maybe CIM is a good way to transfer the load models?
- When determine the orientation of a MV/MV (same base voltage at both primary and secondary side) transformer, busbar voltage levels can’t be used.
4.8 Implementation methodology

This section suggests a methodology for implementing CIM. It is similar to the EDF R&D methodology provided in (Fremont, 2009).

1. Identify what information the receiver requires
2. Find the corresponding CIM objects and create extensions if needed, this is the profile
3. Find the relevant information in the source database
4. Build an interface that expresses the data in CIM XML syntax (provided by the profile).
4.9 Discussion and conclusions

According to this study an implementation of CIM should be possible. The most critical factor is the connectivity which can be expressed. Some critical object attributes are missing in the source data, for example transformer winding resistance. However some of these attributes eventually can be found at other sources within “the energy company” or calculated from other attributes present in Oracle Spatial.

The RFI ("the energy company", 2010) specifies that the new DMS shall be able to perform

1. Load-flow calculations
2. Short circuit calculations
3. Electrical schema representation
4. Geographical network presentation

1 and 2 probably will require more data, like transformer winding resistance. 3 and 4 is possible to express with CIM according to our observations.

Our proposals for further work are:

1. Investigate the practical parts in more detail, for example, exactly how to get all the information in CIM XML.
2. Investigate more example data in the same way as is in this study.

Further investigation will require collaboration between persons that have great knowledge about the proprietary data, persons that understands CIM and also to some extent the new DMS vendor.
5. Tools survey

There are several CIM related tools, some are freeware and some requires a license. Most of them are used for profile management and model validation. CIM viewers are convenient when visualization of meta-information models or contextual models (profiles) is required, usually for understandability issues. It's not recommended to view a large network model in UML since the models often are comprehensive with a lot of redundancy, for example, one transformer model consists of more than ten classes and a network model probably consists of more than one transformer. To build network models there are tools that enable the user to build networks with electrical components. Then a corresponding CIM schema is generated and the model can be imported/exported in CIM XML.

5.1 CIM Tool

About

CIMtool is an open source plug-in for the Eclipse platform. Download and installation instructions can be found at www.cimtool.org. The tool enables browsing between CIM packages and classes in a hierarchal manner, create/edit CIM profiles and performs validation of models.

Features

- Read and merge CIM and local UML models in XMI form
- Browse models and check inconsistencies
- Generate equivalent OWL ontologies
- Create and edit profiles
- Generate XML schemas, OWL and RDFS ontologies for profiles
- Validate instances against profiles (including very large CIM/XML instances)
- Free

Drawbacks

- No UML visualization
Basic features table

<table>
<thead>
<tr>
<th>Feature</th>
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</thead>
<tbody>
<tr>
<td>Edit and create profiles</td>
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<tr>
<td>Import/Export CIM RDF XML</td>
<td>X</td>
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<tr>
<td>Viewing the tree view XML model structure</td>
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<td>Editing XML network model</td>
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<td>UML Visualization</td>
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<td>Validation</td>
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<tr>
<td>Merge XML network models</td>
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</table>

5.2 SPARX Enterprise Architect (EA) with CIMEA add-in

About
CIM is released in the EA format (*.eap). There is a free viewer that visualizes the UML model available at [www.sparxsystems.com](http://www.sparxsystems.com) that’s called EA Lite. CIMEA is an Add-in for EA that enables CIM profile creation and editing. The add-in also enables EA to generate artifacts such as CIM RDF. The plug-in can be downloaded at [www.cimea.org](http://www.cimea.org). The Add-in is for free but an EA license is required to create and edit profiles. EA is a good tool for browsing and learning CIM since the model is visualized with entities, attributes and relationships.

Features
- CIM is released in the SPARX Enterprise Architect format, *.eap format, therefore possible UML tool inter-operability problems are eliminated
- Lets the user browse through CIM classes and packages
- CIMEA enables profile creation, editing and artifact creation (CIM RDF for example)
- Enables UML model viewing

**Drawbacks**
- Profile management requires a lot of computer resources
- A license is required for creating/editing

**Screenshots**

![Image of UML diagram]

**Basic features table**

<table>
<thead>
<tr>
<th>Feature</th>
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<tr>
<td>Validation</td>
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</tr>
<tr>
<td>Merge XML network models</td>
<td></td>
</tr>
</tbody>
</table>

### 5.3 CIMspy

**About**

CIMspy SE (Standard Edition) is a freeware including model browsing and limited validation functionalities. CIMspy sorts the entities within a model into a tree structure which gives an overview of the components in the model. CIMspy EE (Enterprise Edition) has extra functionalities such as browsing, editing, validation, merging/partition, comparison, and visualization. Download from [www.powerinfo.us](http://www.powerinfo.us).

**Features**

- Organizing flat CIM/XML documents into various model hierarchies, making it
possible to explore the information model from different points of view.

- Transforming computer-friendly XML documents into human-friendly HTML Web pages, supporting visualization features like animation, highlighting, and sorting, etc.
- Providing several navigation mechanisms to facilitate model browsing, including tree-based hierarchical navigation, backward/forward display navigation, and instance-to-instance hyperlink navigation.
- Offering a variety of searching strategies including by-name, by-rdf:ID, content matching, and XPath query, etc.
- Facilitating model debugging by offering two types of CIM model validators, i.e. the schema-driven model validators designed to validate CIM/XML against CIM/CPSM schema for standard compliance and the rule-based validator aimed to detect any domain-specific modeling errors such as network topology errors.
- Supporting both full and incremental CIM/XML, allowing users to check an incremental model update against its base model.
- Optimized to handle large power system models and capable of loading CIM/XML documents of hundreds of MB in size.
- CIMSpy SE was built as a standalone DHTML application hosted in Internet Explorer. It is extremely easy to use. All you need is the basic Web browsing experience.

**Drawbacks**

- The enterprise edition requires a license.

**Screenshots**
### 5.4 CIMphony

**About**
CIMphony is an immature but exciting tool written in Java created by Dr. Alan McMoran owned by his company Open Grid Systems Ltd. The first versions of CIMphony were web-based but the newest version (though non-official) is based on open software and utilizes the OSGi modular system and an Eclipse UI to provide a multi-platform framework for data management and load-flow analysis. CIMphony has been used at a number of interoperability tests for validation of model instances. The tool is still evolving and more features like a full UI for validation, transformation, analysis and support for more additional schemas, formats, transformations etc. are planned in future releases, no release date has been set. CIMphony support a number of open standards such as CIM, MultiSpeak and IEC 61850. Transformation and validation services that use these standards are defined with the OMG standard languages allowing the rapid development of transformation mappings between data models. Besides model management, CIMphony provides power system related services such as load flow analysis on balanced three-phase using the Jacobi load-flow engine (see the screenshots below). These results can then be exported in CIM state estimation profile format (IEC 61970-456). Preliminary support for a single diagram graphical editor that enables graphical model creation and editing (see the screenshots below).

**Features**
- UI for model validation.
- UI for data model transformation.
- Single line diagram graphical editor.
- Importing CIM data in RDF XML.
- Exporting in RDF XML.
- Viewing and editing data.
- Defining Validation rules through OCL.
- Performing Validation of models with OCL rules.
- QVTO based transformation framework for registering and running transformations on data.
- Support for exposing functionality through Web Services.

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### Basic features table

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<td>Merge XML network models</td>
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Drawbacks

- Unofficial and unavailable descriptions.

Screenshots
### Basic features table

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### 5.5 CIMvian

**About**

CIMvian can visualize and analyze CIM. It’s a freeware that imports CIM RDF for visualization and validation. Download from www.uisol.com.

**Features**

- Graphically browse and navigate CIM XML model files, using lists of objects organized by class and graphical 'subgraphs'
- Graphically navigate model using subgraphs, with zoom in, zoom out, forward and back controls
- Find objects
- View CIM XML incremental (difference) model files as applied to a base model, clearly showing those objects that have been added and those that have been deleted
- View object properties
- Edit object properties
- Set filters for classes and properties
- Execute SPARQL queries
- Browse CIM RDF Schema files
- Edit RDF schemas
- Browse CIM OWL files
- Edit OWL files
- Validate a CIM XML model file against an RDF Schema.
Screenshots

Basic features table

<table>
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5.6 CIMclipse

About
CIMclipse is an umbrella name for open source tools that uses Eclipse as a platform and is used for CIM related tasks. CIMclipse offers a broader set of tools for Model Driven Engineering (MDE), which is a way of building software focusing on models instead of algorithms and code.

Features
- CIM models as Eclipse/UML2 models manual modifications on EA XMI exports
- CIM models as Ecore models M2M (with ATL) transformation
- OCL Validator to validate a CIMXML file against a set of constraints written in OCL (Object Constraint Language)

Ecore Modeling Framework features
- Java API for model manipulation
• XML (de)serialization
• Comparison
• Query and transaction
• Validation
• Storage, sharing

**OCL features**
• OCL is easy to read/write
• Values of attributes can be checked

**Drawbacks**
• The full network must be loaded into the memory
• Maturity of tools is variable
• Support for tools is not always available

**Basic features table**

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**5.7 InterPSS Open CIM**

**About**
Open CIM provides services such as load flow analysis, CIM RDF file analysis and CIM model analysis. The software imports CIM RDF files and converts them to a hierarchal model with different network components and maps them to their CIM class and attributes. Transmission load flow calculations can be performed on the network model. Open CIM does not require expensive database tools to import large RDF files. It runs smoothly on a laptop. If the RDF model consists of less then 10,000 objects the software is free, otherwise a license is required.

**Features**
• A graphical tool that can show all details of a CIM model, or selectively show only the interested/relevant part of the model.
• An innovative RDF parser that parses large RDF model files quickly and efficiently.
- A flexible architecture design that can adapt quickly to different CIM extensions by different ISOs.
- Intrinsic capability to convert CIM to ODM model and feed load-flow simulation.

Screenshots

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5.8 Power Modeler Studio (PMS)

About
Power Modeler Studio (PMS) is a commercial CIM-based power system modeling tool. It handles both electrical network models and extensions to the network model in order to support other business applications. Network models can’t be built by visualizing every class in UML since that model would become huge and non-interpretable. A network model already is huge. PMS can generate one-line diagrams of systems and substations with electrical components. But the data and its structure are saved as CIM XML.

Features
- Enables the user to model the network with electrical components and save it as CIM XML.

Drawbacks
- Commercial tool which requires a license.

Screenshots

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</table>
5.9 Conclusions

The tools mostly used in this master thesis are SPARX EAlite, CIMtool and InterPSS OpenCIM. Mainly because they come for free, they actually work and they have the functionality that supports model understanding, creating and testing. See table 10. Software that provides functionality to build and/or view network models with electrical components has not been available when this study was performed. CIMphony were under a redevelopment (for an unspecified long time), Power Modeler Studio was too expensive and a license for CIMvian wasn’t available.

<table>
<thead>
<tr>
<th></th>
<th>SPARX</th>
<th>CIMtool</th>
<th>InterPSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edit and create profiles</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Import/Export CIM RDF XML</td>
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<td>x</td>
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<tr>
<td>Viewing the tree view XML model structure</td>
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<tr>
<td>Editing XML network model</td>
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<tr>
<td>UML Visualization</td>
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<td>Validation</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Merge XML network models</td>
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<td></td>
<td>x</td>
</tr>
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</table>

Table 10, comparison between the tools mainly used in this study
6. Education platform and CIM validation

The purpose of this part is to test the compliance between two CIM related softwares from different vendors. The method will also be used in an education platform at the department of industrial information- and control systems, Royal Institute of Technology, Stockholm, Sweden.

Method
In many CIM related softwares there are sample CIM/XML files provided used in tutorials. These sample models are tested with two software’s from different vendors. CIMtool is used for CIM/XML model validation, and OpenCIM InterPSS is used for load flow calculation.

The profile used for validation is the “Equipment” profile defined in 61970-452. This profile is used for models used for model exchange between control centers with data necessary to execute state estimation or power flow applications (TC57, 2010) A network model that is consistent with this profile should also work with InterPSS.

It is important to use the same CIM version. CIM version is stated in the schema, profile or model namespace. Syntax: xmlns:cim=http://iec.ch/TC57/2009/CIM-schema-cim14#. If the namespace differs between schema, profile or model the validation in CIMtool won’t work.

There are no tested sample models that are fully compliant with the CPSM. Electrical characteristics and some measurement data and control values is needed to run a load-flow. Input values for InterPSS are Analog.normalValue for both active- and reactive three phase power in a node where these two are known. In a generator node the input is RegulatingControl.targetValue, and Analog.normalValue for three phase active power. Note that this is only valid for these small sample models. Other equipment like phase shifting transformers is not considered.

In the education platform it is stated that CIM/XML-model was exported from a SCADA/DMS system. In fact the model is a sample file with a planted error which gives the load flow result unrealistic values. The error will be exposed in CIMtool after validation as “Maximum cardinality of property”. The error is an extra voltage target value in a PV-node (Active power “P” and Voltage “V” magnitude known). The error is corrected by deleting this row with the unrealistic target value.

The education platform is found in Appendix A.
7. Discussion and conclusion

CIM is a standard. It’s a proposal for a best practice. A standard is abstract and generalized since it’s supposed to support a lot of different scenarios. There are different levels of abstraction and CIM has a high level of abstraction in comparison to information models used in the industry which are of low level of abstraction and are contextual in order to support the company specific needs. The utilities, of course, need contextual models and contextual models can be based on abstract models. So why not base the contextual model on a standard in order to ease future information exchange. It’s important to note that integration between two CIM compliant systems won’t be a plug and play scenario. Partly since CIM is always evolving and therefore comes in different versions but also because two utilities might interpret and implement the standard slightly different. This can lead to inconsistencies between the two CIM information models. However, if both utilities got their information in CIM format it will ease the integration a lot since both uses the same structure and both utilities have many consistencies between their information in CIM format.
References

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- Kun, Z. X. (2010). Investigation of data exchange requirements for cooperative grid planning and operation. ICS, KTH.
Literature base

This study is based on the references above and the following literature.

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- **Schwarz, K. (2004).** *IEC 61850, IEC 61400-25, and IEC 61970: Information models and information exchange for electric power systems.* Schwarz consulting company.
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- **TC57, I. (2004).** *61968-3.*
- **TC57, I. (2010).** *IEC 61968-1. IEC.*
Appendices

Appendix A – Education platform

Appendix B – Oracle Spatial example data to CIM XML transformation

Appendix C – RDF vs. XSD comparison

Appendix D – Example of a distribution power system model
Appendix A -

Education platform

Background
A quite new company in the energy distribution and generation business (due to deregulation in the energy market) has hired a consultant (you), to develop a method for exchanging network connectivity models between the company’s SCADA/DMS and a load-flow calculation program. Load-flow calculation is used in the network planning and extension unit. Engineers can easily test different load scenarios to see what happens if a new heavy industry is connected, or if someone wants to inject power from a wind farm. Load-flow calculations are also important to ensure that the network can stand a fault without getting in a severe outage situation. The “n-1 criteria” is used to measure the networks robustness. The network should withstand faults causing one heavily loaded line to be disconnected without overloading other lines.

The SCADA system (Supervisory control and data acquisition) collects measurement values from points in the network. There are sensors for voltage magnitudes (RMS), power flow, breaker positions and tap-changer positions. It also sends control messages to equipment like breakers and voltage regulating equipment.

The functions in the DMS (Distribution Management System) differ from vendor to vendor. In this case it displays SCADA information in the network connectivity model trough a GUI, with fault signaling and automatic fault isolation.

Purpose
The company wants to set some pressure on the vendors to have interfaces for standardized CIM. When vendors start to have interfaces and support for CIM/XML model exchanges, energy companies no longer are locked to one vendor for all their systems. It will also be easy to share information with other companies (e.g. sending measurements to the Transmission system operator, TSO), and it will be a lot easier to integrate systems during a fusion between two energy companies.
**CIM (Common Information Model)**

CIM is an information model. It only defines how the data shall be composed and how it’s related, not how the systems store or use the information.

CIM is a class structure. The model follows the Unified Modeling Language (UML) where inheritance between parent and child is the main idea.

Each class can have attributes and relationships to other classes. A class can be a sub-class which means the class inherits the parents’ attributes which is additional to the child’s unique attributes. A popular example when describing CIM is the Breaker class, Figure 1.

![Diagram of CIM classes](image)

*Figure 1, the breaker class (Dr. McMoran, 2007)*

Every sub-class inherits attributes from the classes above. For example, in Figure 1 the “Switch” is at type of “ConductingEquipment” with the attributes “normalOpen” and “Phases”.
When defining connections between equipment with CIM, terminals and connectivity nodes are introduced. Terminals are needed e.g. to know which side of a breaker other equipment are connected. Connectivity nodes are used to join Terminals.

Figure 2, terminals and connectivity nodes to join equipment (Dr. McMoran 2007)

Another UML relationship in CIM is the “Association” relationship. In Figure 3 the “Association” relationship relates the Terminals with ConductingEquipment and Terminals with connectivity nodes. The “multiplicities” indicates that ConductingEquipment can have associations with zero or n Terminals, but Terminals can only have association with zero or one ConductingEquipment. In the same way ConnectivityNodes have associations with zero to n Terminals, but a Terminal can only be connected to zero or one ConnectivityNode.

Figure 3, association and multipliciy, (Dr. McMoran 2007)
The “Aggregation” relationship indicates that a class is a container class for the child. An example is found in Figure 4. The TransformerWinding is a type of ConductingEquipment, therefore the relation is of generalization type. The TransformerWinding is a part of PowerTransformer, therefore the relation is of aggregation type.

![UML Diagram](image_url)

Figure 4, aggregation (Dr. McMoran 2007)

The Common information model can be downloaded from the CIM user group homepage, [www.cimug.org](http://www.cimug.org). The read-only version of SPARX Enterprise Architect can be used to view the UML model.
The Assignment
The company’s network model is built in the DMS. But the model stored in the DMS isn’t according to CIM (Which is not strange since CIM is an information model for exchange, not how information is stored in a database). The model can however be exported in CIM/XML format. To ensure that the model will work correct in the Load-flow calculation, the model is to be validated in the CIMtool software. See figure 5.

1. Import and validate the model versus a subset of CIM components (profile)
2. Correct errors in XML-file

Work flow
1. Find the exported CIM/XML model file. (3sub_ICS_eduplatform.xml)
2. Import the CIM/XML model in InterPSS and try running a load-flow calculation.
   2.1. Start InterPSS OpenCIM
   2.2. Start “New Project” under “File”-menu.
   2.3. Select “OpenCIM Project” as wizard.
   2.4. Chose a project name. Use default location.
   2.5. Import “3sub_ICS_eduplatform.xml”. Click finish.
   2.6. In the “Project explorer”, right click the .xml-file – click “Build OpenCIM model”
   2.7. Highlight the folder “OpenCIM Model View(3bus_ICSeduplatform)”
2.8. View “Loadflow Analysis” under View-menu.

3. The loadflow results were not reasonable, there are errors in the model!

4. Validate the model file.

   4.1. Be sure to have the model (.xml), the schema (.xmi) and the profile (.owl)

   4.2. Start CIMtool–eclipse platform. Start a new project (File – New – CIMtool project)

   4.3. Choose project name at default location. Hit Finish! Not Next!


   4.5. File- Import, select “Import Profile” under folder “CIMTool”. Import the profile CPSM_2009_CIM_14-Equipment.owl

   4.6. Double click the CPSM_2009_CIM_14-Equipment.owl. Select the “summary tab”. Click “Reorganize and Repair”, check the “Stereotype leaf classes as Concrete”. Close the profile editor, save when prompted.

   4.7. Switch to validation perspective by selecting Window-Open Perspective – Validation.

   4.8. Import the power system model (3sub_ICSeduplatform.xml): File – Import, choose “Import Model (CIM/XML file)”. In field “Namespace URI” change “2007” to “2009”. Select the project and profile. Hit “Finish”, validation is now in progress.

   4.9. Browse the errors by clicking the .diagnostic file.

5. Fix the errors in the CIM/XML file. There are several errors that don’t affect the loadflow, concentrate on maximum cardinality errors (multiplicity).

6. Validate and correct until there are no errors.

7. Try InterPSS again. Voltages should be around 1 p.u.
Appendix B –

Oracle Spatial example data to CIM XML transformation

<?xml version="1.0" encoding="UTF-8"?>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  <!-- Units -->
  <cim:Unit rdf:ID="_34BC3ABA7AEF48D3B6C125ACC74C2FD5">
    <cim:IdentifiedObject.name>MW</cim:IdentifiedObject.name>
  </cim:Unit>
  <cim:Unit rdf:ID="_552837A6A28144EB9ACC0263C658E5DD">
    <cim:IdentifiedObject.name>MVA</cim:IdentifiedObject.name>
  </cim:Unit>
  <cim:Unit rdf:ID="_96D78FFD1233469BA7683486BE983CD4">
    <cim:IdentifiedObject.name>MVAr</cim:IdentifiedObject.name>
  </cim:Unit>
  <cim:Unit rdf:ID="_C31191E137FF4C919CC74DA15D1E170A">
    <cim:IdentifiedObject.name>kV</cim:IdentifiedObject.name>
  </cim:Unit>

  <cim:GeographicalRegion rdf:ID="_37C0E10300D40CD812C47572C31C0AD">
    <cim:IdentifiedObject.name>Hedas</cim:IdentifiedObject.name>
    <cim:IdentifiedObject.localName>Hedas</cim:IdentifiedObject.localName>
  </cim:GeographicalRegion>

  <cim:SubGeographicalRegion rdf:ID="_ID_SubGeographicalRegion">
    <cim:IdentifiedObject.name>Hedas</cim:IdentifiedObject.name>
    <cim:IdentifiedObject.localName>Hedas</cim:IdentifiedObject.localName>
    <cim:SubGeographicalRegion.Region rdf:resource="#_37C0E10300D40CD812C47572C31C0AD"/>
  </cim:SubGeographicalRegion>

  <!-- BaseVoltage -->
  <cim:BaseVoltage rdf:ID="_ID_BaseVoltage_11KV">
    <cim:IdentifiedObject.name>BaseVoltage 11KV</cim:IdentifiedObject.name>
    <cim:IdentifiedObject.localName>11KV</cim:IdentifiedObject.localName>
    <cim:BaseVoltage.nominalVoltage>11</cim:BaseVoltage.nominalVoltage>
  </cim:BaseVoltage>
  <cim:BaseVoltage rdf:ID="_ID_BaseVoltage_0.42KV">
    <cim:IdentifiedObject.name>BaseVoltage 0.42KV</cim:IdentifiedObject.name>
    <cim:IdentifiedObject.localName>0.42KV</cim:IdentifiedObject.localName>
    <cim:BaseVoltage.nominalVoltage>0.42</cim:BaseVoltage.nominalVoltage>
  </cim:BaseVoltage>

  <!-- substationHedas -->
  <cim:Substation rdf:ID="_ID_SUBSTATION_Hedas">
    <cim:IdentifiedObject.name>L183E-T724</cim:IdentifiedObject.name>
    <cim:IdentifiedObject.localName>SubstationHedas</cim:IdentifiedObject.localName>
    <cim:Substation.Region rdf:resource="#_ID_SubGeographicalRegion"/>
  </cim:Substation>

  <cim:VoltageLevel rdf:ID="_ID_SUB1_VLevel_11KV">
    <cim:IdentifiedObject.name>Substation-1 11KV</cim:IdentifiedObject.name>
    <cim:IdentifiedObject.localName>Sub1H_VOLT</cim:IdentifiedObject.localName>
  </cim:VoltageLevel>
</rdf:RDF>
<cim:BusbarSection rdf:ID="Busbar_0.42kV">
  <cim:IdentifiedObject.name>BUSBAR_1</cim:IdentifiedObject.name>
  <cim:IdentifiedObject.localName>BUSBAR_1</cim:IdentifiedObject.localName>
  <cim:Equipment.MemberOf_EquipmentContainer rdf:resource="#ID_SUB1_VLevel_0.42KV"/>
  <cim:ConductingEquipment.BaseVoltage rdf:resource="#ID_BaseVoltage_0.42KV"/>
</cim:BusbarSection>

<cim:Terminal rdf:ID="BUSBAR1_T1">
  <cim:IdentifiedObject.name>BUSBAR1_T1</cim:IdentifiedObject.name>
  <cim:IdentifiedObject.localName>BUSBAR1_T1</cim:IdentifiedObject.localName>
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  <cim:Terminal.ConnectivityNode rdf:resource="#342959597"/>
</cim:Terminal>

<cim:Terminal rdf:ID="LoadBreakSwitch_1">
  <cim:IdentifiedObject.name>LoadBreakSwitch_1</cim:IdentifiedObject.name>
  <cim:IdentifiedObject.localName>LoadBreakSwitch_1</cim:IdentifiedObject.localName>
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  <cim:Terminal.ConnectivityNode rdf:resource="#342959597"/>
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<cim:Terminal rdf:ID="LoadBreakSwitch_1_T2">
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  <cim:IdentifiedObject.localName>LBS1_T2</cim:IdentifiedObject.localName>
  <cim:Terminal.ConductingEquipment rdf:resource="#LoadBreakSwitch_1"/>
  <cim:Terminal.ConnectivityNode rdf:resource="#342959597"/>
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  <cim:IdentifiedObject.localName>LoadBreakSwitch_2</cim:IdentifiedObject.localName>
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</cim:Terminal>

<cim:ConnectivityNode rdf:id="_342959528">
  <cim:IdentifiedObject.name>C2_LBS6</cim:IdentifiedObject.name>
  <cim:IdentifiedObject.localName>C2_LBS6</cim:IdentifiedObject.localName>
  <cim:ConnectivityNode.ConnectivityNodeContainer rdf:resource="#_ID_SUB1_VLevel_0.42KV"/>
</cim:ConnectivityNode>

<substation1 Feeding substation -->
</cim:Substation>

<cim:Substation rdf:id="#_ID_SUBSTATION_1">
  <cim:IdentifiedObject.name>Feeding Substation1</cim:IdentifiedObject.name>
  <cim:IdentifiedObject.localName>Feeding Substation1</cim:IdentifiedObject.localName>
  <cim:Substation.Region rdf:resource="#_ID_SubGeographicalRegion"/>
</cim:Substation>

<cim:VoltageLevel rdf:id="#_ID_FeedSUB1_VLevel_11KV">
  <cim:IdentifiedObject.name>Feeding Substation1 11KV</cim:IdentifiedObject.name>
  <cim:IdentifiedObject.localName>Feeding Substation1 11kV</cim:IdentifiedObject.localName>
  <cim:VoltageLevel.Substation rdf:resource="#_ID_SUBSTATION_1"/>
  <cim:VoltageLevel.BaseVoltage rdf:resource="#_ID_BaseVoltage_11KV"/>
</cim:VoltageLevel>

<cim:BusbarSection rdf:id="#_ID_FeedSUB1_Busbar_11kV">
  <cim:IdentifiedObject.name>BUSBAR_1</cim:IdentifiedObject.name>
  <cim:IdentifiedObject.localName>BUSBAR_1</cim:IdentifiedObject.localName>
  <cim:Equipment.EquipmentContainer rdf:resource="#_ID_FeedSUB1_VLevel_11KV"/>
  <cim:ConductingEquipment.BaseVoltage rdf:resource="#_ID_BaseVoltage_11KV"/>
</cim:BusbarSection>

<cim:Terminal rdf:id="#_ID_FeedSUB1_Busbar_11kV_T1">
  <cim:IdentifiedObject.name>BUSBAR1_T1</cim:IdentifiedObject.name>
  <cim:IdentifiedObject.localName>BUSBAR1_T1</cim:IdentifiedObject.localName>
  <cim:Terminal.ConductingEquipment rdf:resource="#_ID_FeedSUB1_Busbar_11kV"/>
  <cim:Terminal.ConnectivityNode rdf:resource="#Line_376230386_C1"/>
</cim:Terminal>

<-- AC Lines Middle Voltage -->
</cim:Line>

<cim:ACLineSegment rdf:id="#_ID_376230386_1">
  <cim:ACLineSegment.bch>0.000348</cim:ACLineSegment.bch>
  <cim:ACLineSegment.r>0.231</cim:ACLineSegment.r>
  <cim:ACLineSegment.x>130.25</cim:ACLineSegment.x>
  <cim:Conductor.length>0</cim:Conductor.length>
  <cim:IdentifiedObject.name>Line_376230386_S1</cim:IdentifiedObject.name>
  <cim:IdentifiedObject.localName>Line_376230386_S1</cim:IdentifiedObject.localName>
</cim:ACLineSegment>
<cim:ConductingEquipment.BaseVoltage rdf:resource="#_ID_BaseVoltage_11KV"/>
<cim:Equipment.MemberOf_EquipmentContainer rdf:resource="#_ID_Line_376230386"/>
</cim:ACLineSegment>

<cim:Terminal rdf:ID="_ID_376230386_1_T1">
    <cim:IdentifiedObject.name>Line_376230386_T1</cim:IdentifiedObject.name>
    <cim:IdentifiedObject.localName>Line_376230386_T1</cim:IdentifiedObject.localName>
    <cim:Terminal.ConductingEquipment rdf:resource="#_ID_376230386_1"/>
    <cim:Terminal.ConnectivityNode rdf:resource="#Line_376230386_C1"/>
</cim:Terminal>

<cim:Terminal rdf:ID="_ID_376230386_1_T2">
    <cim:IdentifiedObject.name>Line_376230386_T2</cim:IdentifiedObject.name>
    <cim:IdentifiedObject.localName>Line_376230386_T2</cim:IdentifiedObject.localName>
    <cim:Terminal.ConductingEquipment rdf:resource="#_ID_376230386_1"/>
    <cim:Terminal.ConnectivityNode rdf:resource="#_342959686"/>
</cim:Terminal>

<cim:ConnectivityNode rdf:ID="Line_376230386_C1">
    <cim:IdentifiedObject.name>Line_376230386_C1</cim:IdentifiedObject.name>
    <cim:IdentifiedObject.localName>Line_376230386_C1</cim:IdentifiedObject.localName>
    <cim:ConnectivityNode.ConnectivityNodeContainer rdf:resource="#_ID_FeedSUB1_VLevel_11KV"/>
</cim:ConnectivityNode>
</rdf:RDF>
### Appendix C - RDF vs. XSD comparison

The following comparison between RDF (Resource Description Framework) and XSD (XML Schema Definition) is made by TC57 in (TC57, 2006). In CIM, the RDF syntax is used for network modeling and the XSD syntax is used for message payloads.

<table>
<thead>
<tr>
<th>Categories</th>
<th>CIM/RDF</th>
<th>CIM/XSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technologies</td>
<td>RDF, RDF(S), XSD and XML</td>
<td>XSD and XML</td>
</tr>
<tr>
<td>Semantics</td>
<td>A semantic model for CIM modelled by RDF(S) and namespace extension “cims”. It is a schema for describing the CIM semantics</td>
<td>It is a schema for describing format and structure of the model for defining messages. It is a XSD representation of CIM with embedded semantic information.</td>
</tr>
<tr>
<td>Data Types and Instances</td>
<td>String</td>
<td>Wide range of data types</td>
</tr>
<tr>
<td>Format and Structure</td>
<td>Additional specification needs to be provided on top of RDF. WG13 has produced two documents, 61970-501 and 503 that specify how to use RDF Schema for power system model transfers.</td>
<td>XSD structure</td>
</tr>
<tr>
<td>Technology Development Status</td>
<td>RDF(S) is a W3C recommendation but cims namespace is a WG13 extension</td>
<td>XML Schema is a W3C recommendation</td>
</tr>
</tbody>
</table>
| Technology acceptance and support | • Continues to be modified and developed  
• Requires time for more people to appreciate it  
• Limited supporting tools  
• Has evolved  | • Wide acceptance  
• Ease of use  
• Many supporting and companion standards such as XSLT  
• Lots of supporting tools |
| Base File        | RDF representation of CIM UML model | XSD representation of CIM UML model                      |
| **CIM Classes** | Represented as an element with the CIM class name and identified by rdf:ID  
- Defined by complexType with an identifier. | Defined by complexType with mrid attribute as a unique identifier |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CIM Attributes</strong></td>
<td>Represented as an element with the CIM attribute name</td>
<td>Defined as local elements</td>
</tr>
</tbody>
</table>
| **CIM Relationships** | Represented as an element with a reference pointing to the related instance | Flexible structure. Can use:  
- Containment  
- Reference  
- Reference with key/keyref |
| **Message Schema Generation** | Not available for a direct XML representation of RDF schema;  
Manually identify classes and attributes for the message schema | Messages are modelled using UML and then messages schemas are automatically generated based on user selected message configuration options. |
| **Message Schema structure** |  
- Fixed and flat structure without conforming schemas  
- Once the message schema is defined, there is no programmatic connection between the message and CIM/RDF base file. The message schema is defined using CIM but can not be validated afterwards. Changes made to the schema that deviate from CIM will not make it invalid.  
- Certain CIM definitions are not carried into the schema, and definitions are repeated in every schema. | Options are provided for message structure. Individual message schemas are based on the base file and therefore always conform to CIM semantics, and they can easily be made backward compatible. |
| **Schema Level Validation** | A specialized CIM Validator is provided, but is designed for Network Model Data exchange.  
- Data type checking is not included.  
- The referenced relationship | The message schema provides the schema level validation. Relationships can be checked either by the containment or the key/keyref. |
<table>
<thead>
<tr>
<th>Required Element Validation</th>
<th>Validation is by convention. By selecting the class and attribute profile to be included in the schema.</th>
<th>All CIM attributes are included in the schema design as optional elements. Required elements are checked by using XSLT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business Rule Validation</td>
<td>Not available.</td>
<td>Business rules can be defined using XSLT.</td>
</tr>
</tbody>
</table>
Appendix D -  
Example of a distribution power system model

These examples can be found in (TC57, 2006).

An example of a MV European distribution network is presented below.
The corresponding CIM RDF (CIM version 10)
<cim:LoadBreakSwitch rdf:ID="LoadBreakSwitch_2">
  <cim:Naming name>30189P0205_LBS2</cim:Naming>  
  <cim:Switch.normalOpen>false</cim:Switch.normalOpen>  
  <cim:Equipment.MemberOf_EquipmentContainer rdf:resource="#VL_05"/>
</cim:LoadBreakSwitch>
<cim:Terminal rdf:ID="Terminal_26">
  <cim:Terminal.ConductingEquipment rdf:resource="#LoadBreakSwitch_2"/>
  <cim:Terminal.ConnectivityNode rdf:resource="#CN_15"/>
</cim:Terminal>
<cim:ConnectivityNode rdf:ID="CN_15">
  <cim:ConnectivityNode.MemberOf_EquipmentContainer rdf:resource="#VL_05"/>
</cim:ConnectivityNode>