

Engineering Design Tool Standards and Interfacing Possibilities to Modelica Simulation Tools

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Abstract

This paper briefly describes some international standards used for engineering design tools that precede simulation in the product development process. Very much information in such design tools can be reused when developing Modelica simulation models. Examples are product structures, component parameters, and component connection information.

The Modelica Standard Library (MSL) with the latest version 2.2.1 has grown significantly the last years. An analysis of the contents of MSL is provided, and a classification method described to ease the work of mapping structures, component parameters and connections in engineering design tools such that their information content can be reused for development of Modelica simulation models.

ModelicaXML has been upgraded to support Modelica 2.2, and is briefly described as one of the most promising intermediate formats for exchange of models between engineering design tools and Modelica simulation tools.

1 Introduction

Modelica is currently the most promising language for developing integrated simulation models of power plants that cover the process-, electrical- and control system aspects. Today such integrated simulation models of a whole power plant are in practice not possible to develop at reasonable costs, because of the lack of compatible interoperating standards.

Currently plant industry struggles with classification standards for electronic data exchange of plant models. When this struggle has settled on a reasonable set of working standardized solutions, one coming large standards struggle will be in exchange of simulation models for power plants, subsystems, and components provided by the supply chain. Integrated simulation mod-

els can provide significant added value to the current engineering systems during the whole life cycle of a power plant.

This paper outlines a path to bridge the gap between different standardized engineering languages supported by commercial engineering tools and Modelica simulation tools.

2 Contents of International Standards for Engineering Design Tools

ISO, IEC, DIN and VGB provide standards for the power plant industry, which are supported by commercial engineering tools for power plant system design. These standards apply to:

- 1) Structures and designation systems
- 2) Symbols on graphical diagrams
- 3) Document classification
- 4) Component classification
- 5) Electronic information exchange

Figure 1. Standardized Plant Model Features

The systems engineering [2] of a power plant is usually divided into:

- 1) Process Engineering
- 2) Electrical Engineering
- 3) Control Systems Engineering

Figure 2. Engineering Disciplines

Each of these engineering disciplines has their special views on a product model of a power plant, which often follow an international standard.

A designation system standard specifies how to name an object in the plant, and how to refer to it with relative names on printed documentation like diagrams and data listings. Power plant designation system stan-

standards like KKS [27] and IEC 61346 [13] provide three major aspects:

- 1) Function aspect – the function and functional organization of a modeled system
- 2) Location aspect – the physical locations of subsystems and components
- 3) Product aspect – the assembly structure of the system implementation

Figure 3. Major aspects

The same modeled object (e.g. a pump, or electrical motor) participates in all these aspects, but provides different types of component related information in each of them. Each aspect has its own structure, so it is possible to navigate to an object using a functional structure, then change to the location aspect and find out where it is located in the plant.

The functional aspect contains most relevant information for Modelica simulation models. However, the location aspect, together with geometric layout drawings, provide additional parameter information like the length of pipes, positions with regards to height, lengths of electrical cables to calculate losses due to resistance, etc.

3 Illustration Example

This section illustrates the contents of standardization listed in Figure 1 to Figure 3.

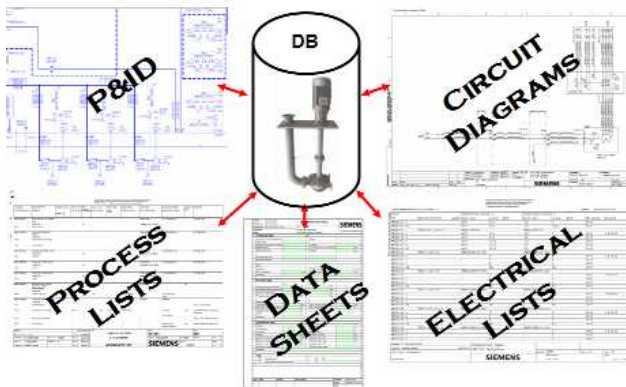


Figure 4. Aspects on a lubrication oil pump

Figure 4 shows a pump object in a plant product model database, and how this object's information is made available in various standardized document views in an engineering design system. More specifically it is a centrifugal oil pump immersed in the oil tank. This pump is driven by an electrical motor on the top of the oil tank.

3.1 Process Diagrams

A Process and Instrumentation Diagram (P&ID) shows what function the pump has in the lubrication oil system. The P&ID is developed by process engineers, and is part of the function aspect of the plant. The symbols on the P&ID are standardized (e.g. acc to DIN 2481 or ISO 14617), and the P&ID belongs to a standardized document class (acc to IEC 61355). The designations of objects on the P&ID are standardized according to KKS.

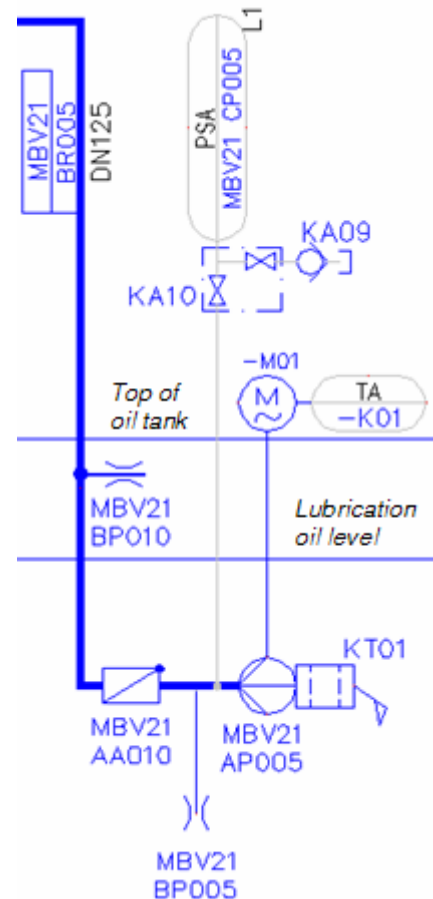


Figure 5. Detail from P&ID

Figure 5 shows a part of the P&ID in detail. The KKS standard for the structure and designation system decides the name of the different objects on the P&ID. The designation of the pump is **MBV21 AP005**. This standardized designation tells that the pump is a part of a lubrication system (KKS Function Key MBV), and that it is a pump (KKS Equipment Unit Key AP). When the designation is printed on a Process List with adjacent parameter data, a user can directly infer from its name that it is a pump within a lubrication system.

The complete KKS designation of the electrical motor is **MBV21 AP005 -M01**, which tells that it is an electrical motor (KKS Component Key -M), which is mounted on the pump equipment unit.

Similarly, the standardized graphical shape of the

symbols and their KKS designations provide information like: **MBV21 CP005** represents a pressure measurement instrument, **MBV21 BP005** a flow restrictor, **MBV21 AA010** a non-return valve, **MBV21 BR005** a pipe where the flag is oriented in the direction of the flow. The symbols are all according to DIN 2481, which is mostly compatible with the more modern and extendable process symbol standard ISO 14617.

3.2 Process Lists and Data Sheets

Back to Figure 4, different types of process lists provide selected parameter data from all components within the lubrication system. These are used for various process engineering purposes. A component class specific data sheet collects all parameter data for the pump object in one document. The data sheet may be used as information supply by several engineering disciplines.

A pump belongs to a certain class (e.g. the KKS Equipment Unit Key AP), which tells what class specific attributes should be available to fill in on data sheets or display on listings. Different component classification standards (e.g. IEC 61346-2) may organize the classification of objects in other ways. For historical reasons different tool vendors and engineering companies have had to invent their own component classification standards, to provide the necessary functionality for entering parameter data. This is what the big struggle towards common classification standards is all about.

3.3 Electrical Diagrams, Lists, and Data Sheets

To proceed with another engineering discipline, with its own aspects in Figure 4, the circuit diagram shows how the power to the electrical motor is connected through protection devices, and how a built-in thermistor for temperature measurement is connected through various terminal boxes. Other circuit diagrams show how the wires, identified by their reference designations finally end up at an IO card in the control system. Circuit diagrams are developed by electrical engineers and follows IEC 61082 which provides general guidelines of what information to present in electrical documents. A specific standard IEC 60617 specifies the graphical appearance of the symbols.

Various electrical lists, for example cable tables, connection tables for wires etc., provide connection information. Other electrical lists provide subsets of parameter data from different electrical devices. The overall course classification of electrical devices, which in turn determines what attributes should be available follows IEC 61346-2, or now obsolete standards like IEC 750.

3.4 Document Classification

A complete plant installation contains several thousands of objects, and there is a large number of P&IDs, circuit diagrams, lists and data sheets. These documents must be organized into structures to be easy to find. A document classification standard is used for identification and searching for different kinds of document types. More specifically each document class has a document kind classification code (DCC), whose lettering and format is determined by IEC 61355.

4 International Standards for Engineering Design Tools

In the following a number of standards will be described according to the structuring introduced in section 2, and brief comments given.

4.1 Structures and Designation Systems

Process and Electrical design

- KKS – "Kraftwerk Kennzeichen System" [22]-[28] is divided into two parts. 1) KKS Rules [25],[27] and 2) KKS Application Commentaries [26],[28]. 2) shows examples of how to designate (give a name to) engineering objects in different disciplines like Process, Electrical and Control systems engineering. 1) describes how the designation system is organized, and provides 3 listings of classification keys and their descriptions.
- Function Keys – 3 letter hierarchical classification of system functions within a plant. **Examples:** Level 1: **M** *Main machine sets*, Level 2: **MB** *Gas turbine plant*, Level 3: **MBV** *Lubricant supply system*. There are about 800 standardized keys with many letter code series on level 3 left open for company- or project specific standardization.
- Equipment Unit Keys – 2 letter hierarchical classification of equipment unit functions. **Examples:** Level 1: **A** *Mechanical equipment*; **C** *Direct measuring circuits*. Level 2: **AP** *Pump units*; **AC** *Heat exchangers, heat transfer surfaces*; **CP** *Pressure*. About 130 standardized keys.
- Component Keys – 2-letter hierarchical classification of component functions. **Examples:** Level 1: - *Electrical components*; **K** *Mechanical components*. Level 2: -**M** *Motors*; **KA** *Gate valves, globe valves, dampers, cocks, rupture disks, orifices*. About 90 standardized keys.
- IEC 61346 - Industrial systems, installations and

equipment and industrial products – Structuring principles and reference designations [13]-[17]. Provides a framework for a designation system with similar functionality as KKS. IEC 61346-2 [15] standardizes a 1 letter functional classification system for components that can be extended with appended letters for more specific subclasses according to industrial branch, company or project specific standards. Examples: Level 1: **M** *Drive, act*; **Q** *Open, close, vary*; **R** *Restrict flow or motion*; **W** *Guide*; **X** *Connect*. The classification letters can be used in the component designations to indicate the class of the object.

- IEC 61082 - Preparation of documents used in electro technology [31]-[35] provides very general rules and guidelines for electrical documents like circuit diagrams, electrical tables and lists. It establishes a kind of minimum criteria for documents suitable for electrical engineering purposes and gives much freedom to tool developers.

4.2 Symbols on Graphical Diagrams

Process design:

- DIN 2481 Thermal Power Generating Plants, graphical symbols [29] – provides a library of graphical symbols with description, identification code and short application examples. Contains commonly used process design symbols.
- DIN 1219 Fluid Power systems and components [30] – provides a library of graphical symbols of which a subset complements DIN 2481 for process design, with regards to hydraulically operated valve arrangements for steam inlets etc.
- ISO 14617 Graphical symbols for diagrams - Part 1-15 [52]-[67] - The best engineered graphical symbols standard available today for process design. A major benefit compared to other standards is its consistency and extensibility. By reusing existing standardized graphical symbols and following the standardized application rules, new symbols can be assembled that still conform to the standard.

Electrical design:

- IEC 60617 Graphical Symbols for Diagrams - online database [50] – The most comprehensive standard library of electrical symbols. Symbols are built from standard primitive symbols. They are annotated with a function class according to IEC 61346-2. The on-line database succeeds the original document release of IEC 617 [36].
- ISO 14617 – See above. Sometimes it is necessary to draw symbols of process equipment on circuit diagrams to adequately specify the circuit function.

Control system design

- IEC 61131-3 Programmable controllers - Part 3: Programming languages [51] – provides a textual and graphical language that consists of programs, function blocks and configuration elements. Configuration elements are configurations, resources, tasks, global variables, access paths, and instance-specific initializations, which support the installation of PLC programs into programmable controller systems. The **function block diagram** (FBD) is a graphic language for PLC programming which is consistent, as far as possible, with IEC 60617-12 Binary logic elements [48].

4.3 Document Classification

All engineering disciplines:

IEC 61355 Classification and designation of documents for plants, systems, and equipment – provides document kind classification codes (DCCs) which is based only on the content of information in the document. It also provides a document designation system that starts with the designation of the object that the document describes (e.g. a KKS or IEC 61346 designation), adds a "&" and the DCC to create the unique document designation.

DCC Examples: **FB103** *Piping and instrument diagram (P&ID)*; **FS101** *Circuit diagram*.

The general DCC format is A1 A2 A3 NNN, where the code letter A1 is an optional identifier for the technical area¹, A2 and A3 hierarchical classification codes, and NNN a document kind counting number for company or project specific standardization.

The code letter A2 may be:

- A Documentation-describing documents
- B Management documents
- C Contractual and non-technical documents
- D General technical information documents
- E Technical requirement and dimensioning documents
- F Function-describing documents
- L Location documents
- M Connection-describing documents
- P Product listings
- Q Quality management documents; safety-describing documents
- T Geometry-related documents
- W Operation records

¹ E.g. A1 = **P** *Process engineering*, **E** *Electrotechnology*

The code letter A3 provides a subclass to A2.

4.4 Component Classification

Process design:

- KKS Equipment Unit and Component keys – see Section 4.1

Electrical design:

- IEC 61346-2– see section 4.1.

4.5 Information Exchange

The following international classification standards are primarily developed for conducting e-business. However, a significant fraction of these standards are applicable to simulation models.

- IEC 61360 Standard data element types with associated classification scheme for electric components [19] – The first sustainable engineered international standard for information exchange.
- ecl@ss [21] – a non-profit organization of German origin who together with its ~30 German and European member companies provide the probably largest classification system in the world today. The dictionary version 5.1.1 contains ~27 000 classes, ~7000 attributes that are reused on the classes ~440 000 times, and ~4500 value codes (enumeration literals) for enumeration attributes. It is free for download after registration.
- RosettaNet technical Dictionary (RNTD) [23] – RosettaNet is a non-profit consortium of more than 500 organizations working to create, implement and promote open e-business standards and services. RNTD version 4.1.1 contains 966 classes, 888 sets of attributes that are reused on many different classes and 4147 attributes which are reused in the sets of attributes.

A classification system standard defines:

- 1) A basic terminology framework for describing classes, attributes and value codes.
- 2) An electronic exchange format for a dictionary of classes, attributes and value codes.
- 3) Maintenance procedures for updating the dictionary
- 4) A standard library with a large number of classes, attributes and value codes.

The above examples lack many technical attributes for parameters used during design and simulation. They are however extendable, and build on the IEC 61360 framework for an international classification system.

Such a framework stays stable and working for a large fleet of integrated continuously operating e-business systems, which must remain operational over successive upgrades of the standard library. Such issues must be taken into consideration already in the standard, since it may take several years before all integrated systems have upgraded to a new standard library release.

5 Analysis of Modelica Standard Libraries

An analysis of Modelica Standard Libraries (MSL) version 1.5, 2.1, 2.2 and 2.2.1 gives the following results:

MSL Version:	1_5	2_1	2_2	2_2_1
Source files	36	87	106	111
Imports	93	286	411	488
Definitions	910	1447	3823	4209
Components	1628	4636	10182	11444
Equations	1055	2768	3841	4269
Algorithms	99	633	3067	3351
Connect-equations	370	903	1574	1801
Component-references	30304	60838	123217	136900
Expression-lists	14736	23715	38535	41795
Real literals	4413	5833	38418	38251
Comments	1720	4755	9052	10482
String-Comments	1322	3722	8805	10282
Annotations	1326	3120	6377	7633
String-literals	3503	7218	17575	20579
Integer-literals	33187	59604	88609	98174
Other	88621	156857	310638	339147
Total elements:	183323	336422	664230	728916

Figure 6. Analysis of MSL versions

The number columns show the Modelica language element count from different releases of the Modelica standard libraries. MSL 1_5 was downloaded from the public library page [5]. MSL 2_1 were obtained from the Modelica CVS repository 2004-11-15. MSL 2.2 and 2.2.1 were accessed from the Modelica SVN repository.

The source code directory contents of these libraries was converted to a single xml file for each library release by ModelicaXML [9], which then were preprocessed for import into ModelicaDB [11].

The *Imports* row is an indicator of reuse. The *Component-references* row gives the count of the uses of component variables in expressions. *Connect-equations* give the number of connections amongst components within the libraries.

The *Comment* row is a higher level parse node for *String_comments* and *Annotations*.

String literals and *Integer literals* are heavily used within annotations, especially for graphical object annotations in Modelica diagrams.

The above analysis shows that the sizes of the standard library versions are substantial. Commercial Modelica development tools like [1],[3] provide user interfaces with tree views of the package hierarchy, connection diagrams, and string based text searches, for quick navigation in the libraries.

6 Method for Classification of MSL Components

Commercial design tools for process and electrical engineering usually contain a classification system for organizing and implementing their component library catalogues. Classification trees allow a user to with a few clicks down the tree to find a set of relevant component models. The classification tree itself is an aid for remembering where to find certain components. Many tools use an existing standard like IEC 61346-2 or KKS to organize the upper hierarchical levels and have tool specific customizable classification structures at lower levels. Users familiar with the standard can thus easily find the tree branch that may contain the component searched for.

This section briefly describes a successful approach to add classification information to a large class library, how to implement a mapping between different classification system standards, and some suggestions how to apply this method for classifying MSL components according to different standards.

6.1 The ecl@ss and its Mapping to KKS and IEC 61346-2

Within a larger project at Siemens Industrial Turbo machinery AB in Finspång, Sweden, a method and tool support was developed for mapping different classification systems.

Figure 7 shows an example of a navigator for a classification tree that enables users familiar with the 4-

level ecl@ss (see section 4.5) classification structure to quickly find a class of interest, its attributes, their units, or value codes (if it was an enumeration attribute).

L1	preferred_name_EN			coded_name
27	Electric engineering, automation, process control engineering			27000000
L2	preferred_name_EN			coded_name
+ 01	Generator			27010000
+ 02	Electrical drive			27020000
L3	preferred_name_EN			coded_name
+ 21	Low-voltage three-phase current asynchronous motor			27022100
+ 22	High voltage three-phase current asynchronous motor			27022200
+ 23	Single-phase alternating current motor			27022300
+ 24	Synchronous motor			27022400
+ 25	DC engine			27022500
+ 26	Servo motor			27022600
L4	preferred_name			coded_name
+ 03	Servo DC motor			27022603
	idatt	preferred_name	definition	unit_of
	+ BAC077001	Rated voltage	Manufacturer's value for the voltage, which is derived from measured values that have been obtained	V
	+ BAE088001	Rotation speed at continuous torque	Rotation speed which is reached with continuous torque.	1/min
	+ BAE129001	Thermal motor protection	Protection of the motor against overload and/or short circuit, particularly protection of the coil insulation	
	idvl	preferred_name	definition	preferred
	+ BAB643001	Cold conductor		Kaltleit
	+ BAB648001	continual temp. recording		kontinu
	+ BAB693001	Thermostats		Thermo
	+ WAA090001	Other		Sonstig
	+ WPA050001	without		ohne

Figure 7. ecl@ss navigator

Siemens uses KKS as a designation system for their power plants. There was a need to map the KKS classification to ecl@ss. A mapping tool was implemented that enables product experts familiar with KKS to map KKS classes to ecl@ss classes. This tool provides interactive associative navigation and search facilities through several different categorization/classification standards like KKS, ISO 31 [20] and IEC 61360 [19].

Once the experts had become familiar with ecl@ss and categorized a business relevant set of ecl@ss classes according to KKS by assigning KKS keys, the result was browsable in a navigator that enables users familiar with KKS to quickly find the relevant ecl@ss classes, their attributes and value codes.

Figure 8 shows parts of the resulting navigation tree for KKS Equipment Units to ecl@ss classes.

The same approach may be used for mapping international classification standards like KKS and IEC 61346-2 to Modelica components in MSL.

The versions of the Modelica Standard Library (MSL) already have a standard classification structure in their package hierarchies. However, secondary categorization trees organized according to different standards can be implemented as an “add-on” feature to the Modelica Standard Library, given some tool support for reading the classification tree from a file, indexing the Modelica components according to the classification

key, and display the tree in a navigator.

	A1	description_EN			
▶	A	Mechanical equipment			
	A1A2	description_EN			
	+	AA	Valves, dampers, etc., incl. actuators, also manual, r		
	+	AB	Isolating elements, air locks		
	+	AC	Heat exchangers, heat transfer surfaces		
	+	AE	Turning, driving, lifting and slewing gear (also manipu		
	+	AF	Continuous conveyors, feeders (escalators)		
	+	AG	Generator units		
	+	AH	Heating, cooling and air conditioning units		
	+	AJ	Size reduction equipment, only as part of process		
	+	AK	Compacting and packaging equipment, only as part c		
	+	AM	Mixers, agitators		
	+	AN	Compressor units, fans		
	▶	AP	Pump units		
			L1	L2	L3 L4 preferred_name
	+	36	41	01	01 Radial centrifugal pump
	+	36	41	01	02 Submersible motor pump
	+	36	41	01	03 Pump with non-clogging impeller
	+	36	41	01	04 Regenerative pump
	+	36	41	01	05 Circulation accelerating pump
	+	36	41	01	06 Axial-, semiaxial-flow pump
	+	36	41	01	07 Fluid draw works/booster pump
	+	36	41	01	90 Centrifugal pump (unclassified)
	*				
	+	AS	Adjusting and tensioning equipment for non-electrical		
	+	AT	Cleaning, drying, filtering and separating equipment, r		
	+	AU	Braking, gearbox, coupling equipment, non-electrical		
	+	AV	Combustion equipment		
	+	AW	Stationary tooling, treatment equipment		
	+	AX	Test and monitoring equipment for plant maintenance		
	+	AZ	(not provided in KKS AggregateKeyImport)		
	*				
+	B	Mechanical equipment			
+	C	Direct measuring circuits			
+	D	Closed loop control circuits			
+	E	Analog and binary signal conditioning			
+	F	Indirect measuring circuits (gated, corrected, suppressed, c			
+	G	Electrical equipment			
+	H	Subassemblies of main and heavy machinery			

Figure 8. Classification navigator for a mapping between KKS Equipment Unit keys and ecl@ss classes

The one-time library effort required is for an expert familiar with the classification standard and the to-be-classified part of MSL to assign a classification key to each MSL component. The assignment can be implemented in several ways:

1) As an external mapping table, where the mapping key is the classification key from the standard and the mapping value is a fully qualified MSL component name, including the path in the Modelica package hierarchy.

+ Nothing has to change in MSL.

- The table has to be maintained when new versions of MSL appear, where the classes have moved or have been renamed.

2) As an annotation that specifies the kind of category, (i.e. IEC 61346-2, KKS Equipment Unit, KKS Component) and the classification key that applies to the particular Modelica component, for building the

index. An annotation example for a Motor model:

```
annotation (category1="IEC61346-2=M");
annotation (category2="KKS_Component=-M");
```

There are many alternative ways to implement this using Modelica annotations. Investigations and practical evaluations are needed to find the best long-term sustainable approach.

+ The library developer has control over the classification.

- The library developer has to learn the classification standard and do the classification work.

At the moment of this writing, the interactive performance of the ModelicaDB implementation is still not adequate for launching a classification effort of MSL. The current object-oriented information model of ModelicaDB [11] contains 73 classes, 69 relationships and 170 attributes, which is more complicated than the one of the ecl@ss navigator which contains 13 tables, 5 relationships and 135 attributes. An efficient MSL classification effort for relevant international standards will probably also require fast interactive inspection of Modelica diagrams, which is currently not supported by the ModelicaDB front-end.

7 Using ModelicaXML as Exchange Format between Engineering Design Systems and Modelica Tools

ModelicaXML is a program that converts Modelica source code into XML-files [9]. A whole Modelica Library stored in a directory structure can be converted into one XML-file. Recent additions allows ModelicaXML to parse Modelica 2.2 source code [4]. The sizes of the created files for MSL version 1.5, 2.1, 2.2 and 2.2.1 are 16MB, 39 MB, 58 MB and 62 MB respectively. Their collected Modelica .mo source code files contained 1.0 MB, 2.9 MB, 4.8 MB and 5.3 MB.

ModelicaXML files were used as input for the analysis presented in Figure 6, and for loading the libraries into ModelicaDB for further analyses with SQL queries. The experiences with ModelicaXML are promising, and it could serve as a standardized vehicle to speed up development of working integrations between engineering design tools and Modelica simulation tools. Some benefits with the XML approach are:

- Easier to generate XML structures than syntactically correct Modelica source code.
- Easier to parse XML structures than Modelica source code.
- Commercial and open source software available for processing XML structures. See also [12].

- The Modelica community could share a lot of troublesome development effort if using ModelicaXML as a standard intermediate exchange format.
- ModelicaXML could serve as clipboard format for copy/paste, drag/drop of models between different tools. One drawback may be the size of the clipboard format when copying large models.

8 Summary and Conclusion

An investigation of international standards relevant for interfacing Modelica simulation modeling tools with engineering design tools that precede simulation modeling has been done and has briefly been described.

An analysis of the Modelica Standard Library contents has been conducted with aid of an upgraded version of ModelicaXML that supports Modelica 2.2.

A tool supported method for classification of MSL components has been developed and shown promising results for a simpler classification domain. Classification of components speed up mapping efforts significantly, since they efficiently narrow the search space.

The overall experience from this effort indicates that providing navigational access to Modelica components through classification trees organized according to well established international standards may significantly improve the take-up rate and learning curve for an expanding Modelica user community.

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References

- [1] Dynasim, "Dymola", <http://www.dynasim.se/>.
- [2] INCOSE, "International Council on System Engineering", <http://www.incose.org>.
- [3] MathCore, "MathModelica", <http://www.mathcore.se/>.
- [4] Modelica Association, "Modelica: A Unified Object-Oriented Language for Physical Systems Modeling, - Language Specification version 2.2", February 2, 2005, <http://www.modelica.org>
- [5] Modelica Association, "Modelica Libraries", <http://www.modelica.org/library/>
- [6] Peter Fritzson. *Principles of Object-Oriented Modeling and Simulation with Modelica 2.1*, Wiley-IEEE Press, 2003, <http://www.mathcore.com/drmodelica>.
- [7] Peter Fritzson, Peter Aronsson, Peter Bunus, Vadim Engelson, Levon Saldamli, Henrik Johansson and Andreas Karstöm, "The Open Source Modelica Project", in *Proceedings of The 2th International Modelica Conference*, March 18-19, 2002, Munich, Germany.
- [8] Peter Fritzson, Peter Aronsson, Håkan Lundvall, Kaj Nyström, Adrian Pop, Levon Saldamli, and David Broman. The OpenModelica Modeling, Simulation, and Software Development Environment. In *Simulation News Europe*, 44/45, December 2005. See also: <http://www.ida.liu.se/projects/OpenModelica>
- [9] Adrian Pop, Peter Fritzson. "ModelicaXML: A Modelica XML representation with Applications", in *International Modelica Conference*, 3-4 November, 2003, Linköping, Sweden, <http://www.ida.liu.se/~adpo/modelica/>
- [10] Olof Johansson, Adrian Pop, Peter Fritzson, "A functionality Coverage Analysis of Industrially used Ontology Languages", in *Model Driven Architecture: Foundations and Applications (MDAFA)*, 2004, 10-11 June, 2004, Linköping, Sweden.
- [11] Olof Johansson, Adrian Pop, Peter Fritzson, "ModelicaDB - A Tool for Searching, Analysing, Cross-referencing and Checking of Modelica Libraries", in *Proc of 4th International Modelica Conference*, 8-10 March, 2005, Hamburg, Germany, <http://www.modelica.org/events/Conference2005>
- [12] Michael Tiller, "Implementation of a Generic Data Retrieval API for Modelica", in *Proc of 4th International Modelica Conference*, 8-10 March, 2005, Hamburg, Germany, <http://www.modelica.org/events/Conference2005>.
- [13] IEC, "IEC 61346: Industrial systems, installations and equipment and industrial products – Structuring principles and reference designations", 1996, <http://webstore.iec.ch>
- [14] IEC, "IEC 61346-1: Part 1: Basic rules", First Edition 1996-03
- [15] IEC, "IEC 61346-2: Part 2: Classification of objects and codes for classes". First Edition 2000-04
- [16] IEC, "IEC 61346-3: Part 3: Application guidelines", First Edition 2001-01
- [17] IEC, "IEC 61346-4: Part 4: Discussion of concepts", First Edition 1998-01
- [18] IEC, "IEC 61355 Classification and designation of documents for plants, systems and equipment", First edition 1997-04
- [19] IEC, "IEC 61360 Standard data element types with associated classification scheme for electric compo-

- nents", <http://webstore.iec.ch>
- [20] ISO, "ISO 31 Quantities and Units, Part 0-13", <http://www.iso.org>
- [21] ecl@ss, "ecl@ss Organization", www.eclass.de
- [22] RosettaNet, <http://www.rosettanel.org>
- [23] RosettaNet, *RosettaNet Technical Dictionary*, <http://www.rosettanel.org/technicaldictionary>
- [24] VGB, "Verband der Großkessel-Besitzer", <http://www.vgb.org>
- [25] VGB, "B105 KKS Kraftwerk-Kennzeichensystem; Richtlinie zur Anwendung und Schlüsselteil"
- [26] VGB, "B106 KKS Anwendungs-Erläuterungen"
- [27] VGB, "B105e KKS Power Plant Classification System – Guidelines for Application and Key Part"
- [28] VGB, "B106e KKS Application Explanations"
- [29] DIN, "DIN 2481 Thermal Power Generating Plants, graphical symbols", Jun 1979
- [30] DIN, "DIN 1219 Fluid Power systems and components - Part 1: Graphic symbols for conventional use and data processing applications"
- [31] IEC, "IEC 61082 Preparation of documents used in electrotechnology"
- [32] IEC, "IEC 61082 - Part 1: General requirements", First edition 1991-12
- [33] IEC, "IEC 61082 - Part 2: Function-oriented diagrams", First edition 1993-12
- [34] IEC, "IEC 61082 - Part 3: Connection diagrams, tables and lists", First edition 1993-12
- [35] IEC, "IEC 61082 - Part 4: Location and installation documents", First edition 1996-02
- [36] IEC, "IEC 617, Graphical symbols for diagrams - part 1 to 13", issued 1983
- [37] IEC, "IEC 617 - Part 1: Conventions concerning electric and magnetic circuits. (issued 1985)
- [38] IEC, "IEC 617 - Part 2: Symbol elements, qualifying symbols and other symbols having general application"
- [39] IEC, "IEC 617 - Part 3: Conductors and connecting devices"
- [40] IEC, "IEC 617 - Part 4: Passive components"
- [41] IEC, "IEC 617 - Part 5: Semiconductors and electron tubes"
- [42] IEC, "IEC 617 - Part 6: Production and conversion of electrical energy"
- [43] IEC, "IEC 617 - Part 7: Switchgear, controlgear and protective devices"
- [44] IEC, "IEC 617 - Part 8: Measuring instruments, lamps and signalling devices"
- [45] IEC, "IEC 617 - Part 9: Telecommunications: Switching and peripheral equipment"
- [46] IEC, "IEC 617 - Part 10: Telecommunications: Transmission"
- [47] IEC, "IEC 617 - Part 11: Architectural and topographical installation plans and diagram"
- [48] IEC, "IEC 617 - Part 12: Binary logic elements (issued 1991)"
- [49] IEC, "IEC 617 - Part 13: Analogue elements (issued 1993)"
- [50] IEC, "IEC 60617 Graphical Symbols for Diagrams - online database", ~ 1850 symbols and 350 application notes in an on-line database (<http://dom2.iec.ch/iec60617>)
- [51] IEC, "IEC 61131-3 Programmable controllers - Part 3: Programming languages", Second edition 2003-01
- [52] ISO, "ISO 14617 Graphical symbols for diagrams - Part 1-15", First edition 2002-09-01
- [53] ISO, "ISO 14617-1 Part 1: General information and indexes", Second edition 2005-07-15
- [54] ISO, "ISO 14617-2 Part 2: Symbols having general application"
- [55] ISO, "ISO 14617-3 Part 3: Connections and related devices"
- [56] ISO, "ISO 14617-4 Part 4: Actuators and related devices"
- [57] ISO, "ISO 14617-5 Part 5: Measurement and control components"
- [58] ISO, "ISO 14617-6 Part 6: Measurement and control functions"
- [59] ISO, "ISO 14617-7 Part 7: Basic mechanical components"
- [60] ISO, "ISO 14617-8 Part 8: Valves and dampers", Corrected version 2003-12-01
- [61] ISO, "ISO 14617-9 Part 9: Pumps, compressors and fans"
- [62] ISO, "ISO 14617-10 Part 10: Fluid power converters"
- [63] ISO, "ISO 14617-11 Part 11: Devices for heat transfer and heat engines"
- [64] ISO, "ISO 14617-12 Part 12: Devices for separating, purification and mixing"
- [65] ISO, "ISO 14617-13 Part 13: Devices for material processing", First edition 2004-11-15
- [66] ISO, "ISO 14617-14 Part 14: Devices for transport and handling of material", First edition 2004-11-15

- [67] ISO, "ISO 14617-15 Part 15: Symbols for use on installation diagrams and network maps", First edition 2002-11-01