BOOK OF ABSTRACTS

11th INTERNATIONAL MODELICA CONFERENCE

September 21–23, 2015
Palais des Congrès de Versailles, France
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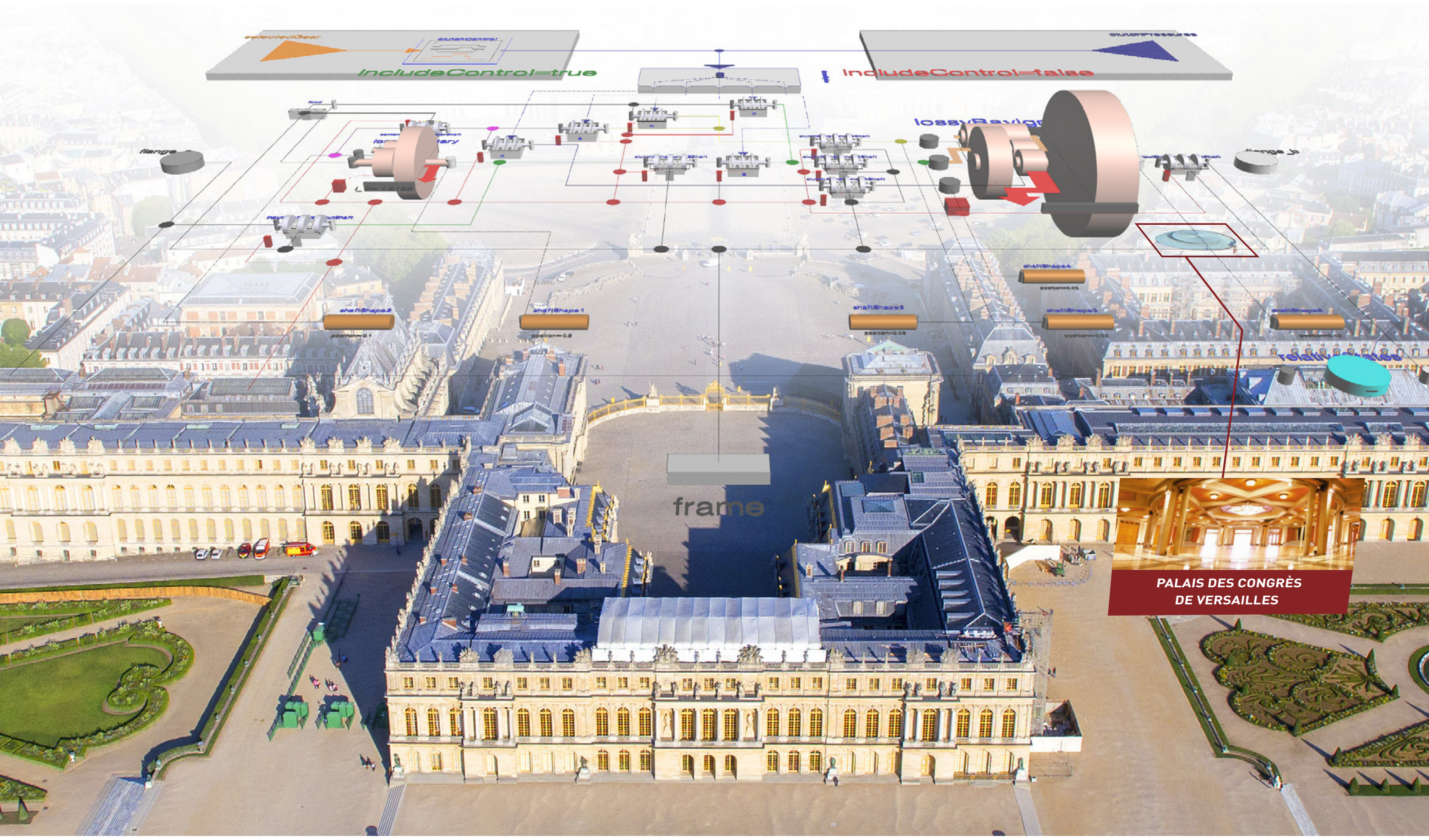

EDITORS: PROF. PETER FRITZSON AND DR. HILDING ELMQVIST

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Contents

Experience with Industrial In-House Application of FMI

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This paper discusses FMI usage in an in-house simulation tool landscape where it helps to open doors between different tools. The industrial application of Functional Mock-Up Interface (FMI) has already been discussed several times, e.g. (Bertsch, 2014). The goal of this paper is to add another aspect to this discussion. Our focus lies on the in-house applicability of FMI in coupling different tools and propriety models.

Two kinds of use cases are described in this chapter, one targeting the utilization of FMI for model exchange, the other addressing FMI for co-simulation, see Figure 1. Apart from different application areas major similarities exist: The use cases focus on tool interoperability, all FMUs reside in-house only and the models are huge with respect to number of parameters, dynamic states and internal/local variables.

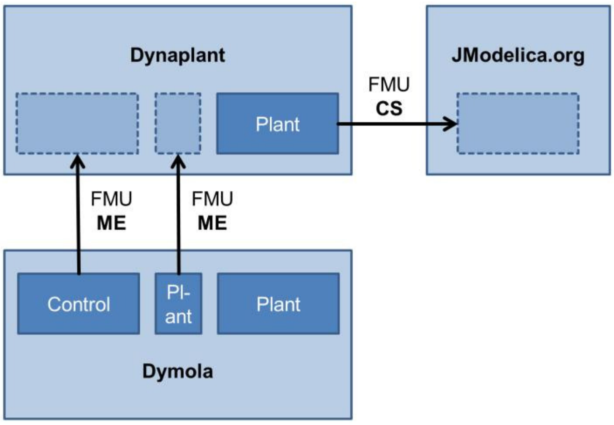

Figure 1. Use Cases.

As the use cases require the implementation of FMI support in our in-house tool Dynaplant we try to share our experience with the implementation of FMI support. Even if the implementation of FMI support implies a great effort, it is useful for many different applications as shown in this paper. In principle, FMI can help or even enable some of the shown examples and some of our target applications, but still we face several limitations.

The existing scalar signal interface is definitely not powerful enough to allow the convenient application of FMI. A future FMI standard perfectly suited to our in-house applications would also need to support the concepts of acausal modeling - similar to the built-in behavior of Dynaplant and the basic principles of Modelica. Moreover, we face a mismatch between the intention of FMI to hide information and a need to reveal as much information as possible for in-house application. At the current state we want to encourage users to carefully investigate all implications before introducing FMI.

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Christian Bertsch, Elmar Ahle, Ulrich Schulmeister (2014): The Functional Mockup Interface - seen from an industrial perspective, *Proceedings of the 10th International Modelica Conference*, March 10-12, 2014, Lund, Sweden. doi:10.3384/ecp1409627

A Novel Proposal on how to Parameterize Models in Dymola Utilizing External Files under Consideration of a Subsequent Model Export using the Functional Mock-Up Interface

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This paper shall deal with a topic not yet intensely discussed by the Modelica community but of central importance for industrial use cases: Parameterization of models, considering a subsequent model export and the handling of data in this case.

During model export the parameters are either assigned with values directly or they are linked to external data-files. If the design of models or libraries is done without considering how data is handled in an exported model, e.g. Functional Mock-Up Unit (FMU), those concepts are often mixed, resulting in an inconsistent data management which is cumbersome or even error prone for the user.

In Modelica it is common to specify parameter values in records. The parameterization can either be done by coding values into the record or by reading the data from an external file. Both solutions have their pros and cons and are absolutely justifiable.

In this paper we will focus on the export of Functional Mock-Up Units (FMUs) from Dymola, discussing different use-cases in which the FMU is utilized after the export. Depending on the particular use-case the model export underlies different requirements regarding convenient data handling. To our experience the following use-cases cover most of the applications used in industry today:

1. Parameter values are stored inside the FMU.
2. Parameters are stored in an external data-file. The FMU reads the parameter values during initialization of the simulation.
3. The data-file is stored inside the FMU's `resources` folder, i.e. the FMU reads the parameters during initialization, but no external files are necessary.

Each of those use-cases requires a different implementation - in terms of model parameterization:

1. Parameters are assigned in the record directly
2. Read data from file during model translation
3. Read data from file during model initialization
4. Read data from file during model initialization with data in the FMU

Whereas use-case 1 can either be accomplished by implementation 1 or 2. For this reason all of them will be discussed in detail in the paper.

Design choices for thermofluid flow components and systems that are exported as Functional Mockup Units

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[2]RWTH Aachen University, E.ON Energy Research Center, Institute for Energy Efficient Buildings and Indoor Climate, Aachen, Germany, mfuchs@eonerc.rwth-aachen.de

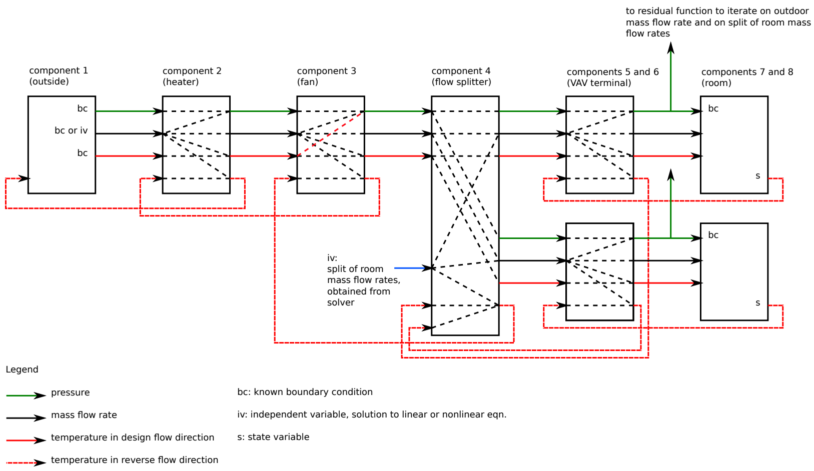

Figure 1. Direct input-output dependencies of FMUs connected in series that serve two rooms.

This paper discusses design decisions for exporting Modelica thermofluid flow components as Functional Mockup Units. It provides guidelines that will allow to effectively use FMUs for modeling of thermofluid flow components and systems. We provide an analysis for direct input-output dependencies of such components and systems, using directed graphs for different model formulations such as shown in Figure 1.

Based on this analysis, we provide recommendations that increase the computing efficiency of such components and systems that are formed by connecting multiple components. We explain what code optimizations are lost when providing thermofluid flow components as FMUs rather than Modelica code. We present an implementation of a package for FMU export of thermofluid flow components using replaceable models as shown in Figure 2.

We also explain the rationale for selecting the connector variables of the FMUs and provide computing benchmarks for different design choices.

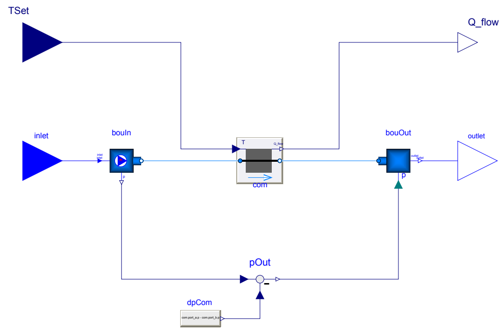

Figure 2. Block that contains a replaceable model of a heater and that defines input and output signals for export as an FMU.

FMI for physical models on automotive embedded targets

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From the beginning in the MODELISAR project, a wide range of possible simulation target platforms for FMI (Blochwitz et al. 2011) was foreseen, ranging from offline simulation platforms over Hardware-in-the-Loop (HiL) real-time systems to embedded systems. While in the offline simulation world FMI is well-established, this is not the case for embedded applications.

This paper presents results of a prototypical FMI implementation for physical models on automotive embedded targets. Especially, the possibility to include and execute source code functional mockup units on Bosch electronic control units is explored. After giving an overview of the state of the art of physical models on real-time systems, a prototype implementation of FMI on a Bosch MDG1 Electronic Control Unit (Rüger et al. 2014) is introduced. Assumptions and limitations are documented and special emphasis is laid on requirements for the contained C-code.

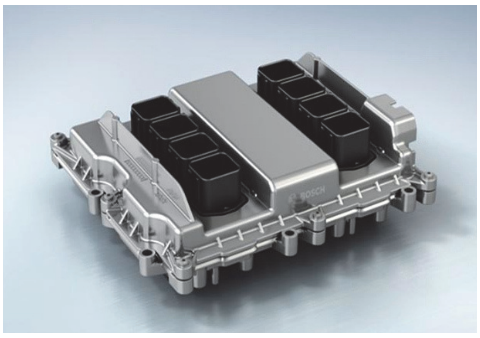

Figure 1. Bosch MDG1 ECU

As an outlook, aspects for an adaptation of the FMI standard to the usage on automotive embedded real-time systems are proposed.

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Rüger, J.-J., Wernet, A., Kececi, H.-F., Thiel, T., MDG1: The New, Scalable, and Powerful ECU Platform from Bosch, Proceedings of the FISITA 2012 World Automotive Congress - Volume 6: Vehicle Electronics, Springer, 2014

Methodology for Obtaining Linear State Space Building Envelope Models

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Heating, Ventilation and Air Conditioning (HVAC) equipment for building systems consumes around 18 % of the total end energy in Europe[1]. One way of reducing energy use in buildings is to use optimal control techniques such as Model Predictive Control (MPC). MPC is facilitated by linear, low-order models of the building structure and of its HVAC systems. However, obtaining these models in a practical form is often difficult, which greatly hampers the commercial implementation of optimal controllers. This work describes a methodology for obtaining a linear state space model of building energy simulation (BES) models, consisting of walls, windows, floors and the zone air. The methodology uses the Modelica library IDEAS to develop a BES model including its non-linearities and automates its linearisation in Dymola. All non-linear equations were identified and either linearised or moved outside of the model by replacing them by input signals, as shown in Figure 1. Dymola function `Linearize2` is used to generate the state space model (SSM) of the now linear model, facilitating further mathematical manipulations, or simulation in different environments.

The methodology is illustrated for an office building. The obtained 50 state SSM shows a maximum zone temperature error of 1 K and a mean deviation of 0.21 K compared to the non-linear BES model. We further show that applying model order reduction to the original SSM still generates excellent predictions for model orders up to 15 states. The low order but high accuracy of the reduced model makes it very suitable for applications such as MPC.

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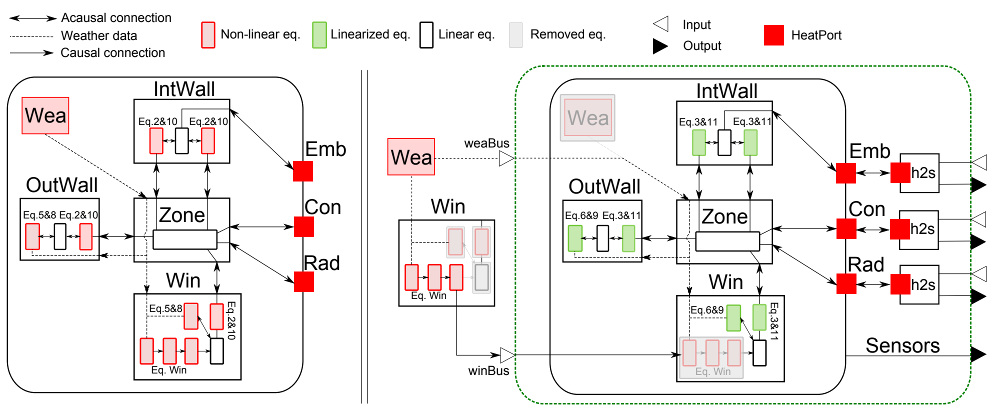

Figure 1. Left: original model with non-linear equations. Right: Adjusted model structure with moved and/or linearized non-linear equations. Component models are outer wall ‘OutWall’, interior wall ‘IntWall’, Window ‘Win’, weather model inputs ‘Wea’ and HeatPorts ‘Emb’, ‘Con’ and ‘Rad’.

Simulation Speed Analysis and Improvements of Modelica Models for Building Energy Simulation

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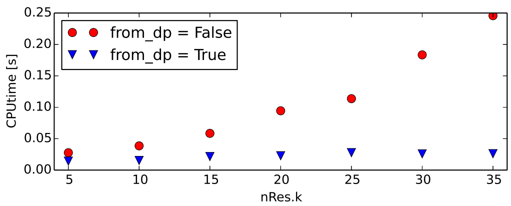
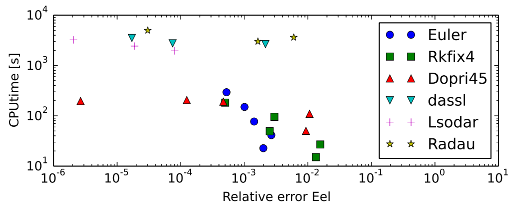
This paper presents an approach for speeding up Modelica models.

Firstly insight is provided into how Modelica models are solved and what determines the tool's computational speed. Aspects such as algebraic loops, Modelica code efficiency, time constants, numeric/analytic Jacobians and debugging options are discussed and illustrated using simple building simulation examples and Dymola. OpenModelica is used to verify the generality of the results. These examples demonstrate that implementing relatively simple measures can lead to significant reductions in computation time, such as in Figure 1a. The examples are based on the IEA-EBC Annex 60 Modelica library (Wetter et al., 2015) and are available on Github and are also applicable to other types of problems.



(a) Example illustrating computation time for solving mass flow rates through *nRes.k* parallel resistances with and without code optimization



(b) Relative errors for various solvers and tolerances or fixed time step sizes for a large building model

Figure 1. Result of a) an individual code optimization and b) solver choice on CPUtime

Secondly we discuss how for large models the elimination of fast dynamics, together with good integrator choice can lead to high simulation speeds. A medium sized office building including building envelope, heating ventilation and air conditioning (HVAC) and control strategy was simulated at a speed five hundred times faster than real time using a fixed step explicit integrator, which is one hundred times faster than Dassl, as illustrated in Figure 1b.

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Energy Efficient Design for Hotels in the Tropical Climate using Modelica

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Wangda Zuo[1*]

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For hotels located in the tropical climate, a significant amount of energy is attributed to the domestic hot water (DHW) usage and the space cooling. To improve the energy efficiency of hotels in the tropical climate, we proposed a heat recovery system that could utilize the waste heat from the space cooling to pre-heat the city water supplied to the DHW system (Figure 1). To support the system design, we selected Modelica to model the heat recovery system and its control, which is difficult to be simulated by conventional building simulation tools. The Modelica *Buildings* library (Wetter, et al. 2014) and the *Modelica_StateGraph2* library (Otter, et al. 2005) were employed to build the system model. A hotel in Miami, Florida, U.S., was selected for the case study. The simulation results showed that the proposed heat recovery system could save up to around 30% boiler energy use in the DHW system.

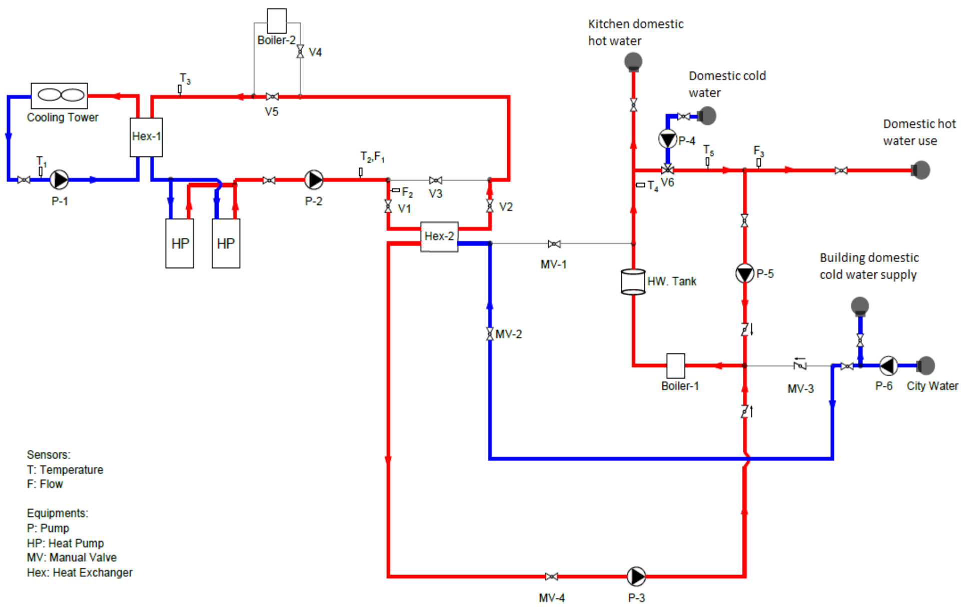

Figure 1. Heat recovery system

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Presentation, Validation and Application of the *DistrictHeating* Modelica Library

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District heating (DH) systems are a relevant solution for reducing CO2 emissions, especially in densely populated areas where the average thermal performance of the building stock is low. Due to heavy investment costs, there is a great interest in simulation and software solutions to optimize DH systems. In this paper, we describe how we designed, validated and used a library of fast, precise and robust components for DH systems.

In the first part, we describe the design of our *DistrictHeating* library. We give an overview of the packages and we focus on two essential models: pipes and substations. We detail two pipe models developed using two different numerical methods. One of them provides a reduction by a factor of 40 of the number of equations compared to *Modelica.Fluid DynamicPipe*. We also give an overview of several substation models for which details can be found in (Giraud *et al*, 2015).

In the second part, we present the validation process, focusing on pipe models. For this validation we use experimental data available in the open literature (Ciuprinskas *et al*, 1999). Figure 1 plots the experimental and the numerical results for two pipe models of our library. The numerical results are comparable to those obtained by other research group (Gabrielaitiene *et al*, 2008) relying on non-Modelica tools. The reasons invoked by (Gabrielaitiene *et al*, 2008) to explain the remaining numerical vs. experimental differences are challenged and a new explanation is proposed.

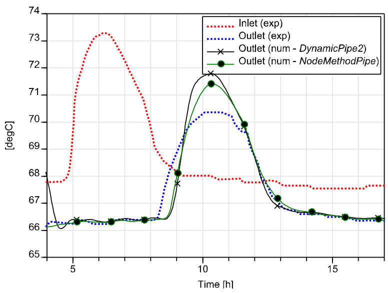

Figure 1. Numerical vs. experimental comparison of the temperature evolutions at both ends of an horizontal district heating pre-insulated pipe, 470 m in length.

In the third part, we present the application of the *DistrictHeating* library for computing an optimized supply temperature for a realistic DH network. Due to the non-linear influence of supply temperature on the network behavior, we perform this optimization in an iterative process, thanks to the computational efficiency of our library. In our example, we obtain a reduction of heat losses of about 18% compared to a standard control. Our next step will be to develop a model-predictive control approach for supply temperature optimization, with regular heat load predictions updates.

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Multi-Mode DAE Systems with Varying Index

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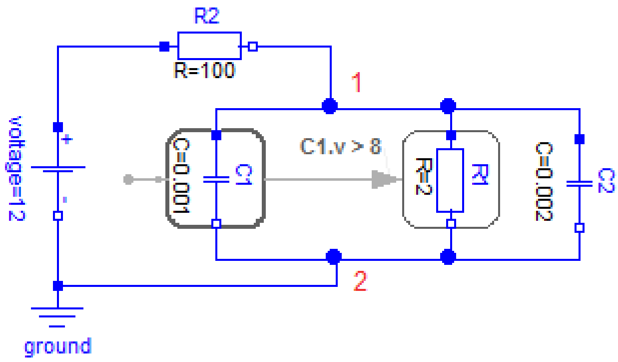
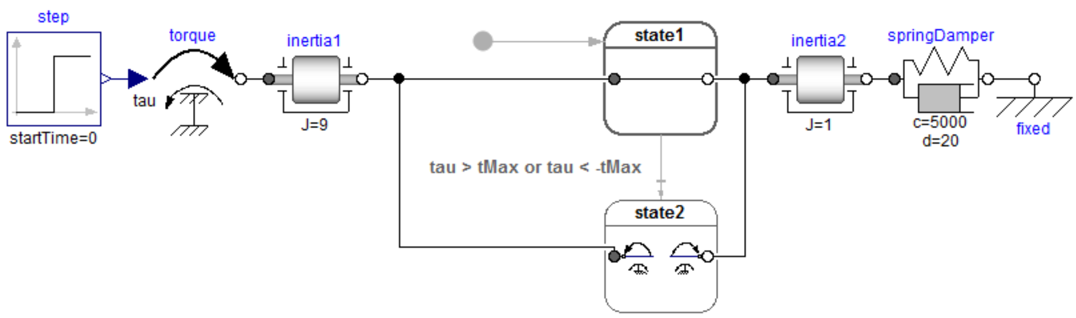
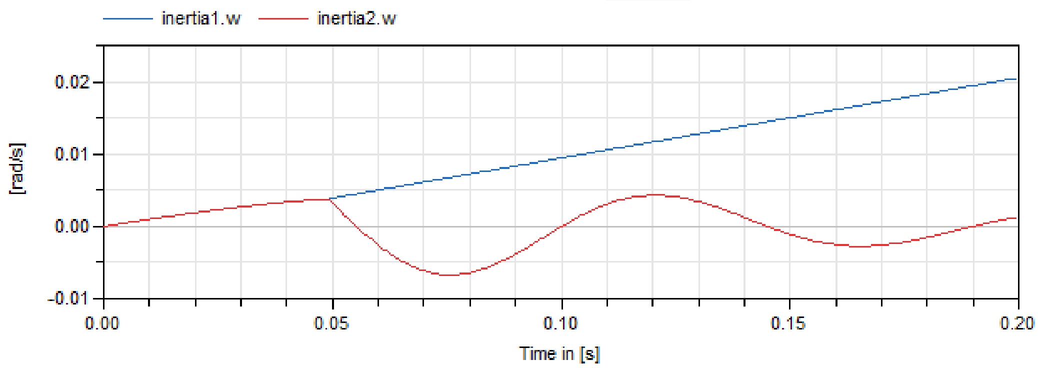
This paper discusses an approach to handle multi-mode DAE systems described by continuous-time state machines where mode-dependent state constraints are present. The goal is to perform static symbolic analysis and to generate efficient run-time code. This technique extends the class of multi-mode systems that can be handled by Modelica tools.

An example is shown in the figure to the right: This circuit describes a capacitor C1 that is destroyed when the voltage becomes too large. The destroyed capacitor is modelled with a small resistor R1. The switching between C1 to R1 is described by an acausal continuous-time state machine. When C1 is active, there are two capacitors in parallel, C1 and C2, and therefore there is a constraint between the states of these two elements. When R1 is active, there is no such constraint. The paper describes a new method to handle such systems by generalizing the Pantelides algorithm to multi-mode systems. The technique has been evaluated and tested with several examples using a Dymola prototype.



In the figure below another example is shown modeling a breaking shaft: In the beginning two inertias are rigidly connected together. When the absolute value of the cut-torque tau = inertia2.flange_b.tau becomes too large, the shaft breaks and two not-connected inertias remain. Such systems can also be analyzed with the multi-mode Pantelides algorithm and simulated with the Dymola prototype.





Internalized State-Selection: Generation and Integration of Quasi-Linear Differential-Algebraic Equations

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MODELICA is a language for modeling of dynamical processes. In general, the model equations that describe the dynamical process consist of differential equations in combination with algebraic constraints, i.e., we have to deal with so-called *differential-algebraic equations* (DAEs). The solutions of such systems have to satisfy the algebraic constraints, but, in general, not all constraints are stated in an explicit way. In particular, if the resulting system of DAEs is of higher index there exist so-called *hidden constraints* and the numerical treatment leads to instabilities, inconsistencies and possibly non-convergence of the numerical methods.

We present a novel (i.e. different from the dummy derivative method of Mattsson and Söderlind (1993)) regularization approach for the remodeling of dynamical systems that uses the hidden constraints information provided by the structural analysis, in particular by the Signature Method of Pryce (2001), to construct an over-determined system regularization that can be solved using a specially adapted numerical integrator implemented in the software package `QUALIDAES` (`QUA`si `LI`near `DAE` `S`olver) (see (Steinbrecher, 2006) for details). This integrator is developed for the numerical treatment of *quasi-linear DAEs* of the form

$$E(x,t)\dot{x} = k(x,t) \tag{1}$$

Practical application demands to transform a general MODELICA-style equation into such a quasi-linear form. Naturally, there is a trivial transformation that replaces all derivative with simple identities of the form $\mathrm{DER}(u_i) = u_j$. Since these identities are trivially quasi-linear, this does not violate the requirements for the output of the transformation. However, the resulting system would be unnecessary large and not leverage the structure of the system for efficient simulation. In fact, `QUALIDAES` would have to solve the whole nonlinear system as hidden constraints.

In this paper we show how such a transformation can be implemented and how the result of this transformation can be differentiated up to an arbitrary degree. This allows for the distinction between transformation and regularization, which is in turn a prerequisite for variable structure modeling and simulation.

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Fractional-Order Modelling in Modelica

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Most dynamic systems with a basis in nature can be described using Differential-Algebraic Equations (DAE), and hence be modelled using the modelling language Modelica. However, the concept of DAEs can still be generalized, when differential operators of non-integer order are considered. These so called fractional order systems have counterparts in naturally occurring systems, like electrochemistry and viscoelasticity.

A simple application is given by the relationship between heat flow and temperature at the boundary of a semi-infinite domain. Here, fractional differential operators appear:

$$T(t) = \frac{\alpha^{1/2}}{2 \cdot A \cdot k} \cdot \frac{\delta^{-1/2} Q(t)}{\delta t^{-1/2}} + T_0$$

This paper presents an implementation of approximate fractional-order differential operators in Modelica, increasing the scope of systems that can be described in a meaningful way. Properties of fractional-order systems are discussed and some approximation methods are presented. An implementation in Modelica is proposed for the first time. Several testing procedures and their results are displayed. The work is then illustrated by the application of the model to several physically motivated examples. A possible usability-enhancement using the concept of "Calling Blocks as functions" is suggested.

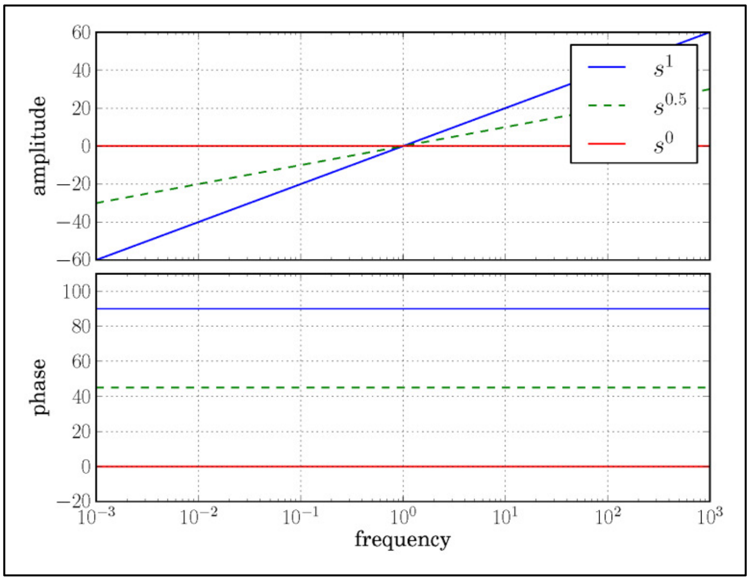

Figure 1. Bodeplots of the unity operator, half-derivator and derivator

Modelica Library for Feed Drive Systems

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As a part of machine tools and production machines, the primary task of feed drives is to create the contour of a workpiece by moving it and/or the tool along one or more axes according to the control input. At the engineering stage of a design process for feed drives the characteristic quantities are determined and affect the whole process of the product design. Simulation models can be used to predict system behavior in this stage of a development. However, their usability is limited if the models need parametrization with quantities that are not available at this stage of the development.

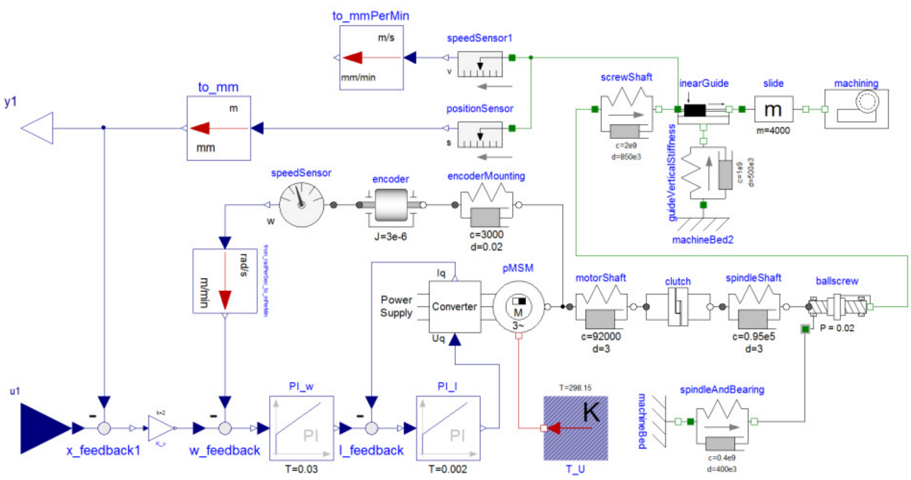

Figure 1: Model of the translational movement axis of a machine tool center

The paper presents several models regarding the topic of feed drives including rotational and translational systems. A special feature is the consideration of the insufficient availability of data during early development stages, which is contrary to the standard Modelica models. Therefore it helps solving the dilemma between less data and simulation quality. Considering manufacturer's catalogue data one is able to parametrize a model for the drive system and to make first investigations regarding the system behavior, including system dynamics or frequency domain analysis. The models are augmented with metrics to consider system restrictions that are naturally given in real systems. Examples for such restrictions are for instance maximum converter voltage for electrical drives, maximum temperatures or performance defining quantities. Beside the feed drive library, approaches for using the library in combination with databases and optimization tools are proposed at the end of the paper.

Model-based Development of a Holistic Thermal Management System for an Electric Car with a High Temperature Fuel Cell Range Extender

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In conventional automobiles with combustion engines, waste heat is used to heat the passenger cabin. Electric cars do not dispose of sufficient waste heat to cover all caloric demands. Furthermore, additional components, such as the traction battery, have a more sensitive operating temperature and require thermal conditioning. The thermal management system of the vehicle must therefore provide sufficient cooling and heating power. The range of an electric car is already limited due to the low energy density of the traction battery compared to conventional combustion fuels, and these thermal restrictions can cause a further range reduction.

Within the Fraunhofer innovation cluster “Regional Eco Mobility 2030” (REM2030) concept developments to improve the energy efficiency of regional eco mobility of the future are investigated. An AUDI A1 Sportback is used as a technology demonstrator with an entirely electric powertrain, completed to a serial hybrid by a fuel cell range extender. A methanol reformer provides hydrogen for the high temperature fuel cell.

Using Modelica, a holistic thermal management system for the considered vehicle is developed. The goal is to keep each thermally sensitive component (cabin, traction battery, power electronics, fuel cell and electric motor) in its optimal thermal operating range, while minimizing the electric energy demand of the thermal management system. Furthermore, the system must be designed to enable local zero emission operation. This is achieved by using all heat sources and sinks in a holistic approach. A heat pump, which uses the ambient heat and the waste heat from the powertrain components as heat source, is integrated. A four-way-valve within the heat pump allows then a flow reversal of the refrigerant to establish the A/C function of the system. The traction battery can be heated and cooled down independently from the cabin demand.

Owing to this developed system, the range of the considered vehicle can be extended in cold winter days by up to 30% depending on the ambient temperature and the chosen reference driving cycle.

Predicting the Effect of Gearbox Preconditioning on Vehicle Efficiency

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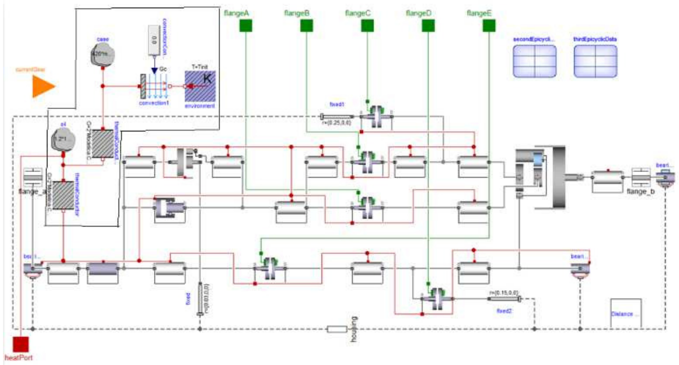

Figure 1. 6-speed automatic transmission gear set with thermal mass and heat dissipation network

Responding to the ever growing need to reduce vehicle fuel consumption and pollutant emissions, new technologies have been developed and successfully implemented in a large number of vehicles over the last few years. However, if engine efficiency has recently dramatically increased thanks to ongoing design improvements and new technologies, the question is how much further we can push the limits to improve efficiency in use and at what price.

One way to achieve better performance from the powertrain is to improve its efficiency. To do so, we have to keep in mind that our vehicles are rarely operated in their optimal efficiency region due mainly to the road layouts, road traffic, driver behaviour, short range operation and the climatic conditions. We can at least seek to counteract the effects of the latter on vehicle efficiency. Vehicle transmission oil viscosity increases exponentially at low temperatures, affecting the vehicle transmission efficiency. Until the oil has fully warmed-up, which can take a rather long time under extreme cold weather conditions, the transmission losses are high due to drag on the gears, clutches and bearings caused by the viscous oil. Poor range and fuel economy can result in customer dissatisfaction compounded by the fact that the vehicle is only being used exploiting a small percentage of its certified power. The idea is then to put the transmission (and in future other subsystems such as engine and traction battery as part of a larger study) in the best conditions whatever the weather is in order to increase its efficiency.

In this paper we build a vehicle model in Dymola using components from the Powertrain Dynamics Library developed by Claytex. We then precondition the transmission lubricant to several temperatures and run the vehicle model over the standard NEDC and ARTEMIS drive cycles. The ARTEMIS drive cycle combines an urban and a highway portion. The models involved in this study are predictive equation based models in order to show how the efficiency would benefit from higher oil temperatures without the constraints of map/empirical based models. The benefits of preconditioning are then highlighted as well as the costs of doing so.

Model Based Development of Future Small Electric Vehicle by Modelica

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To satisfy needs for future low-carbon mobility society, development of many new small electric vehicles (EVs) is increasingly active in recent years. Those vehicles are often smaller and lighter than conventional vehicles and are often equipped with low RRC (Rolling Resistance Coefficients) tires for less energy consumption. On the other hand, low RRC tires tend to have less cornering performance than conventional tires in general. Because of light weight and low RRC tires, those vehicles become to have reduced dynamic stability against external disturbances. To analyze and cope with all the problems about energy consumption and vehicle stability, a holistic approach of vehicle system design considering multi-physics of mechanics, electrics, aerodynamics, control and so on is necessary.

In the previous paper (Hirano, 2014), authors showed the capability of new construction of the new EV using new type tire based on 'Large and Narrow concept' and torque vectoring differential (TVD) gear. In this paper, a multi-physics full vehicle model of the new EV is expanded to consider the detailed loss of motors and inverters as shown in Figure 1. Additionally 3D mechanical gear train model of TVD was modified to consider mechanical loss. Also front and rear suspension model which has same 3D mechanical design as the real experimental vehicle was made and verified. By technical investigations using this full vehicle model, structure, specifications and control of the new EV system were researched about vehicle dynamics and energy consumption.

Finally the trade-off between vehicle dynamic performance and energy consumption of TVD system was clarified by simulation results of stead state cornering and winding road driving.

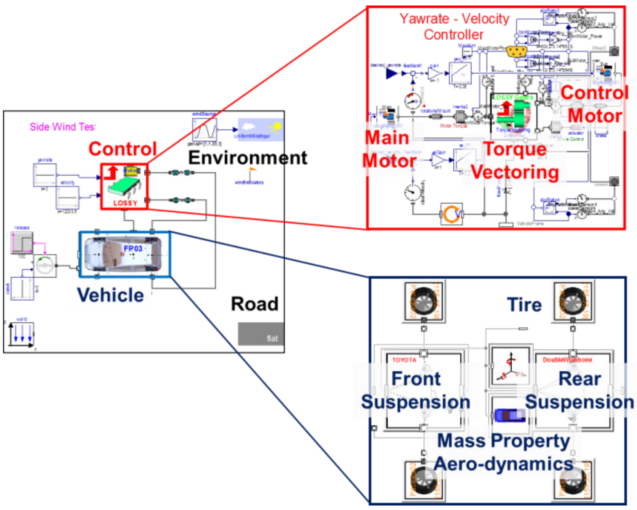

Figure 1. Top level structure of full vehicle mode

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Modeling of Torque Vectoring Drives for Electric Vehicles: a Case Study

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This paper shows some aspects of the implementation of a gear model with losses, nonlinear elasticity and forcing errors in the Modelica language utilizing concept of replaceable functions. Using such gear model for a torque vectoring drive modeling, a case study about a powertrain dynamic behavior in a simplified vehicle model is carried out. The total vehicle model is analyzed in several detail stages of the powertrain reaching from a fixed efficiency with constant spring stiffness to a model using nonlinear losses and nonlinear tooth stiffness. Subsequently, the simulation results of such levels of modeling detail proving tendency to drive line oscillation are presented and discussed.

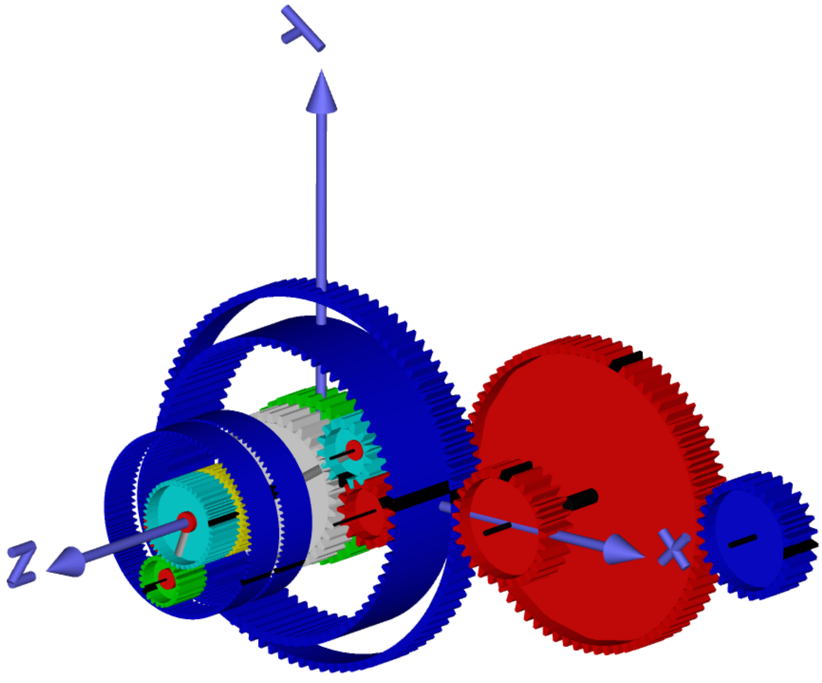

Figure 1. Torque vectoring drive consisting of a differential, superimposing unit and spur gear train. Note that only single planets are shown for simplification of the calculations.

Co-Simulation of Hybrid Systems with SpaceEx and Uppaal

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Marius Mikučionis[3] Thomas Strump[2] Stavros Tripakis[4]

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Despite advances in model checking and other formal verification techniques, simulation remains the workhorse for system analysis. A plethora of simulation tools are available today, from academia as well as from industry. These tools support a large variety of modeling languages, targeted at different types of systems from various disciplines, e.g., mechanical, electrical, digital, continuous or discrete, or mixes thereof. Unfortunately, these tools can rarely interoperate. This is a problem because modern cyber-physical systems are highly complex and multidisciplinary, requiring specialized modeling languages and tools from several domains.

The Functional Mock-up Interface (FMI) is a standard developed to address this problem. In particular, FMI enables co-simulation of complex heterogeneous systems using multiple simulation engines. In this paper, we show how to use FMI in order to co-simulate two state-of-the-art modeling and verification tools for cyber-physical systems: SPACEEX (Frehse et al., 2011) and UPPAAL (Larsen et al., 1997). SPACEEX is a tool for modeling and verifying *hybrid systems*. UPPAAL is primarily a model-checker for *timed automata*, however, it also supports statistical model-checking of hybrid systems. We also show how FMI components can be automatically generated from SPACEEX and UPPAAL models.

We validate the co-simulation approach by comparing the results of our case study in two settings: (a) when the benchmark is modeled and simulated in a single tool, and (b) when the various components of the benchmark are modeled in two tools and co-simulated using our framework. We show that the simulation trajectories induced by our co-simulation framework can be made arbitrary close to the trajectories in the setting (a) provided that the maximum simulation step size of co-simulation is sufficiently small. Finally, we perform a measurement experiment on a composite model to show a potential for statistical model checking using stochastic co-simulations.

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Automated Deployment of Modelica Models in Excel via Functional Mockup Interface and Integration with modeFRONTIER

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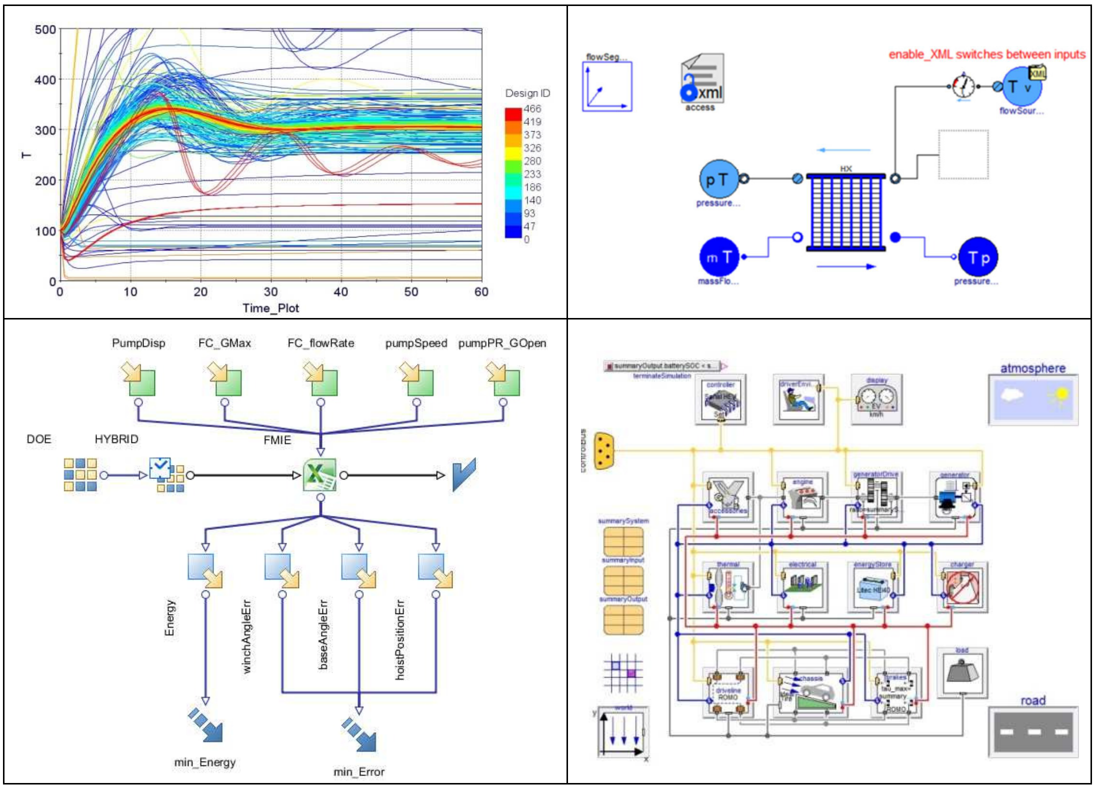
This paper describes a method for automated deployment of Modelica models as simulators in Microsoft Excel using Functional Mockup Interface (FMI) and FMI Add-in for Excel. Using existing interfaces, integration with modeFRONTIER, a process automation and design optimization tool widely used in industry, is demonstrated and illustrated with several different example models in different physical domains to highlight the range of applications and types of analyses that can be covered with the automated toolchain. This toolchain can be applied to any FMU and streamlined with automation enabled by the supporting annotations. The sample applications include model correlation with an HIV virus dynamics model, hydraulic crane optimization, heat exchanger robust design, and hybrid vehicle electric range fleet population estimation.



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An Open-Source Graphical Composite Modeling Editor and Simulation Tool Based on FMI and TLM Co-Simulation

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A common situation in industry is that a system model (here a composite model) is composed of several sub-models which may have been developed using different tools. FMI is one important technology for exporting/importing models between tools and/or connecting them via co-simulation. TLM based modeling and co-simulation is another important technique for modeling, connecting, and simulation of especially mechanical systems, which is simple, numerically stable, and efficient. A number of tool-specific simulation models, such as Modelica models, SimuLink models, Adams models, BEAST models, etc., have successfully been connected and simulated using TLM based co-simulation (Siemers et al, 2005). However, previously there was no general open source tool for creation, graphic editing, and simulation of composite models connected via FMI or TLM based co-simulation. In this paper we present a graphical composite model editor, shown in Figure 1, based on OpenModelica which is integrated with the OpenModelica and the SKF TLM co-simulation frameworks to support both FMI and TLM based composite model editing and simulation.

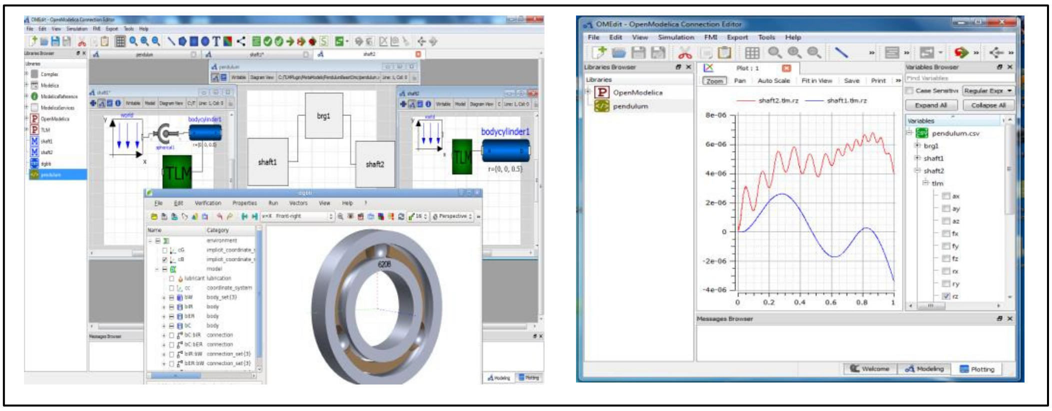

Figure 1. Graphical composite model editor.

The editor supports creating, viewing and editing a composite model both in textual and graphical representation. The system supports simulation of composite models consisting of sub-models created using different tools.

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The Modelica language and the FMI standard for modeling and simulation of Smart Grids

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The smart power grids will extensively rely on network control to increase efficiency, reliability, and safety; to enable plug-and-play asset integration, such as in the case of distributed generation and alternative energy sources; to support market dynamics as well as reduce peak prices and stabilize costs when supply is limited. In turn, network control requires an advanced communication infrastructure with support for safety and real-time communication (Figure1). Simulating such complex systems is required for the development of Smart Grids. Several simulation tools are available on the market but these tools have two major drawbacks: they are generally not designed to import models developed for other tools, they are not adapted to large scale complex system of systems or cyber-physical systems as smart grids which require time-consuming calculation.

One solution to bypass these drawbacks is to use a co-simulation platform which can connect together several simulators and FMUs (Functional Mock-up unit). EDF R&D is funding the development of its own co-simulation platform (MECSYCO) dedicated to the Smart Grids in partnership with LORIA-INRIA.

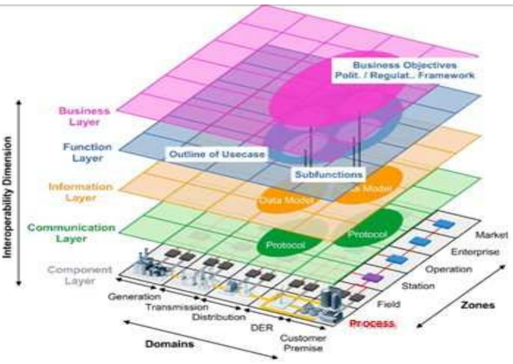

Figure 1. The Smart Grid Architecture Model (SGAM)

This paper provides first an overview of the EDF R&D Modelica library **G**rid**S**ys**P**ro (GSP) composed of electrical components mapped on the zone related to the process of a Smart Grid (Figure1). Besides that, to comply with the modeling of large scale electrical networks, a solution to co-initialize several interconnected FMUs exported from Dymola is described.

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Coupled modeling of a District Heating System with Aquifer Thermal Energy Storage and Absorption Heat Transformer

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Aquifer thermal energy storages (ATES) are a promising technology for seasonal thermal energy storage which can bridge the gap between constant production and seasonally varying demand. This paper presents first simulation results of an energy concept proposed for the university campus Berlin-Charlottenburg, which is characterized by the combination of an ATES system as a seasonal thermal energy storage and an absorption heat transformer (AHT), which supplies 50 buildings of the campus with heating energy. Furthermore, the paper deals with the modeling of the different subsystems, described in Modelica; energy production, storage, consumption and distribution and their integration in a coupled Modelica system model.

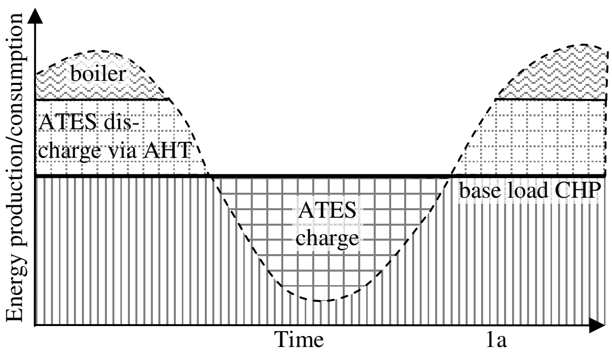

Figure 1. Seasonally fluctuating energy demand (dashed) covered by combined heat and power plant (CHP, solid) and previously stored CHP surplus recovered from aquifer thermal energy storage (ATES), topped up by a boiler.

Energy-Efficient Design of a Research Greenhouse with Modelica

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Greenhouses, especially for research applications, have high requirements on indoor climate control. The technical systems for heating, cooling, and moistening are more complex than in typical dwelling houses or office blocks and are highly dependent on local weather conditions. Increasing the energy efficiency and integrating renewable power into these systems is a sophisticated engineering task which requires extensive investigation.

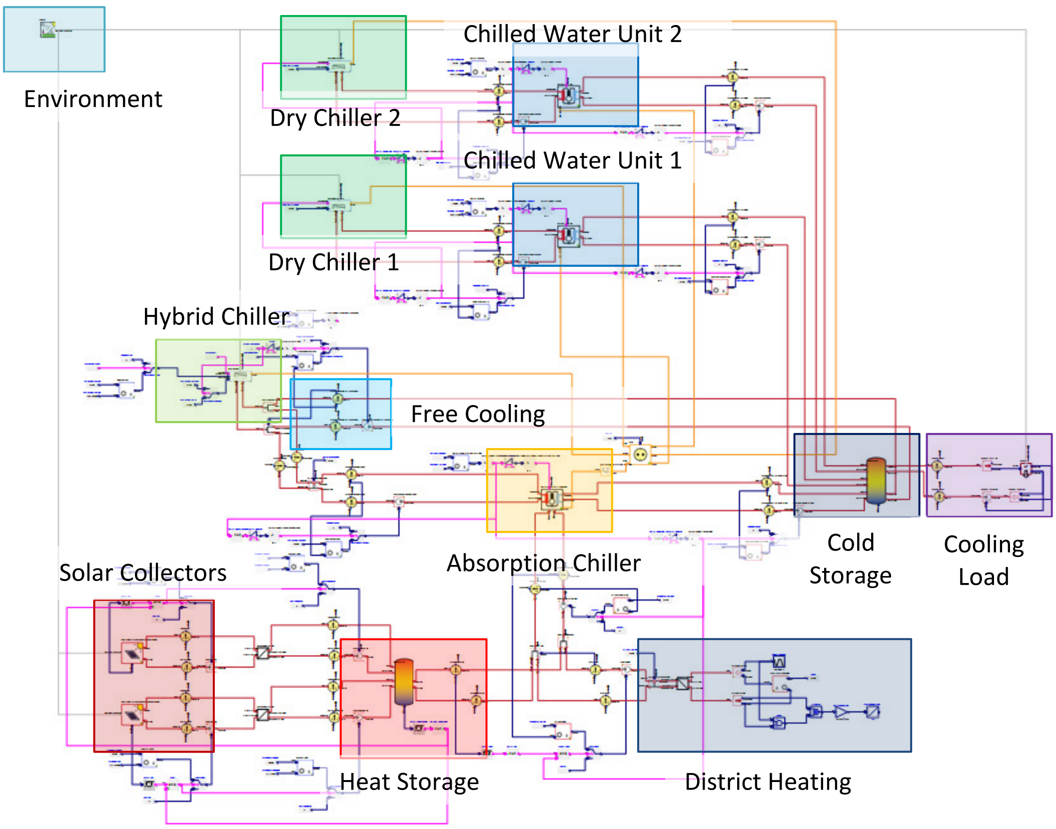

Figure 1. Modelica cooling system model of a research greenhouse based on Green Building library

This paper describes a combined approach to model and simulate building operation and HVAC (Heating, Ventilation, Air Conditioning) system behavior of a research greenhouse with Modelica. This includes the presentation of some important modelling paradigms as well as system concept validation with some interesting simulation results.

Production Planning for Distributed District Heating Networks with JModelica.org

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Production planning for district heating networks aims at finding the most profitable scheduling of the production units of the system. This task is typically handled as an optimization problem. The standard approach for solving this problem is to create a highly simplified model of the system, so that the optimization problem can be solved using linear methods. In this paper an alternative method, previously implemented in (Velut et al, 2013), is presented, in the context of distributed networks.

The production planning problem is solved in two steps by integrating physics-based models into the standard approach. The first optimization step solves for the discrete variables of the unit commitment problem (UCP) using mixed integer linear models and standard mixed-integer solvers. The second step, the economic dispatch problem (EDP), considers dynamic optimization using physics-based non-linear models that utilize the unit statuses from the first step. For this purpose the nonlinear optimization features of JModelica.org (Modelon AB, 2015) is used. All optimizations aim at maximizing production profit using fuel, electricity and heat prices as well as maintenance and start-up/stop costs as variables. The physics-based modeling in the EDP means that important physical variables such as supply temperature, supply flow rate, pump speeds and condenser pressures are included in the formulation. This makes it possible to formulate constraints on these variables corresponding to the limitations of the physical system, which will be utilized in the optimization.

The modeling has focused on distributed consumption and production. The goal has been to represent the most important production units and network distribution of the Uppsala district heating network in Sweden. The district heating network has been modelled using physics-based pipes, including mass flow dependent delays and temperature dependent (district heating water and outdoor temperature) heat losses. The total heat demand is divided between several customers. Comparisons between optimizations with and without distribution network models have been performed, showing that more detailed modeling of the net impacts the production planning in several ways. Most notable is the reduction of costly production peaks which is achieved by considering the different transportation times to different customers. Experiments show that costly unit start-ups can be delayed when this effect is considered. Other results of the distribution model include production compensation for heat losses and time delays and usage of the net for heat storage (accumulation). The optimizations also result in production plans where supply temperature and flow rate is minimized and maximized, respectively, and there is a balance between heat production and heat consumption.

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Hardware-in-the-Loop-Simulation of a Building Energy and Control System to Investigate Circulating Pump Control Using Modelica

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This paper presents an application of the hardware-in-the-loop-method to a building energy and control system (BECS). We focus on investigating the interaction of a real circulating pump with the hydronic network of a virtual building energy and control system. For real-time simulation the building envelope is modelled using the Modelica-based library AixLib (https://github.com/RWTH-EBC/AixLib). With the presented setup model-based designed control algorithms are tested directly on real hardware.
We describe in detail the solutions found for the emulation of the hydraulic boundary conditions and a socket-based data interface. HIL-simulations are performed on an implementation of the concept. The quality of the implementation is evaluated by comparing results obtained from HIL-simulations where a constant and a variable pressure control scheme are applied to the pump. We report the root mean squared error and the relative mean error for a comparison of measured data against simulated results of the volume flow rates and pressure difference for both control schemes.
The main focus of this work is to evaluate the application of the method towards bridging the gap between model-based design and commissioning of energy efficient control for heating ventilation and air conditioning (HVAC) components.

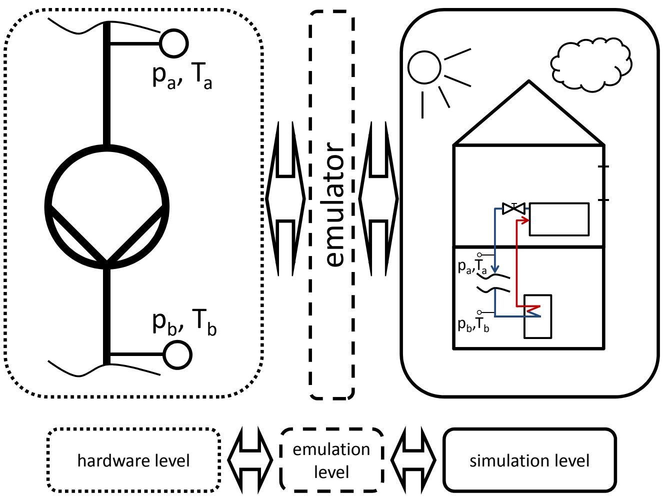

Figure 1. Scheme of a three level HIL-concept of a real pump in a virtual BECS.

Automatic GPU Code Generation of Modelica Functions

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Modelica users can and want to build more realistic and complex models. This typically means slower simulations. In the past, the speed of single CPUs has increased significantly to partly compensate, but more recently, there has been a shift to multi-core architectures. This is taken to the extreme in Graphics Processing Units (GPUs).

This paper discusses code generation for GPU cores. This is important when the model has regular structure, for example, discretization of PDEs. The behavior of each cell can then be partly described by a function call. The evaluation of such calls can then be made in parallel on the GPU cores. The same function is thus executed on every GPU core, but operates on different data; the data of its cell.

Our GPU code generator automatically generates code for Modelica functions, i.e. no additional language constructs are needed. The function is just annotated as suitable for execution on a GPU.

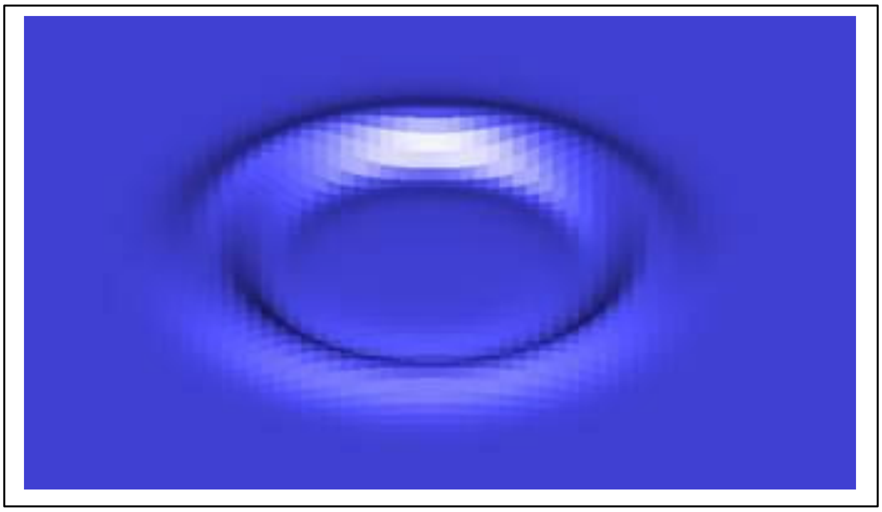

Figure 1. Dymola animation of a circular wave front, calculated by a GPU

Constructs for Meta Properties Modeling in Modelica

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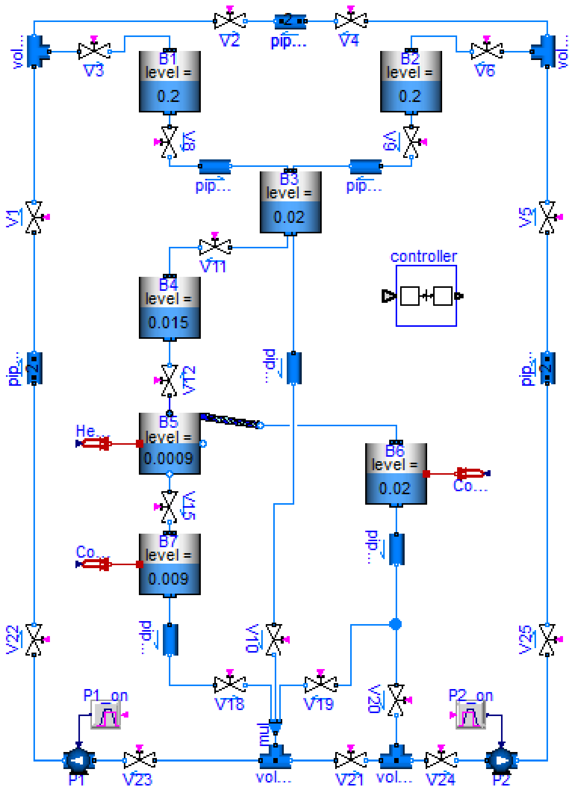
This article proposes two new language constructs for meta-properties modeling in Modelica:

1. Accessing all instances of a given class in a simulation model with an extended iterator, e.g. Real u[:] = {c.v for c in Class};
2. Extracting in a convenient way the desired information from such instances by allowing to pass type compatible model instances as arguments to functions. For example: Real r=get(sub); where get(..); is a function call with a record input argument and sub is an instance of a model that contains all elements of the record as public variables.

Both extension proposals can be formally described with rewriting rules.

In several applications the usefulness of the proposed features are shown. In particular global properties of a model can be computed, such as total power, total mass, total center of mass, or kinetic and potential energy of a multi-body system. An important application is to bind behavioral models and requirement models in a convenient way, for example checking requirements for all instances of a class in a behavioral model, without changing the behavioral model. An example is given below for a fluid system, where requirements shall be checked for all pumps present in this system:



The following statement declares instance req of class PumpRequirements and passes all instances of class PrescribedPump that are present in the fluid system to the left. The req instance checks whether all pumps fulfill the defined requirements, e.g,
when in operation, the pump should not cavitate:

```
PumpRequirements req(
   obs={fromPrescribedPump(p,
                  getInstanceName())
          for p in  PrescribedPump});
```

Flattening of Modelica State Machines: A Practical Symbolic Representation

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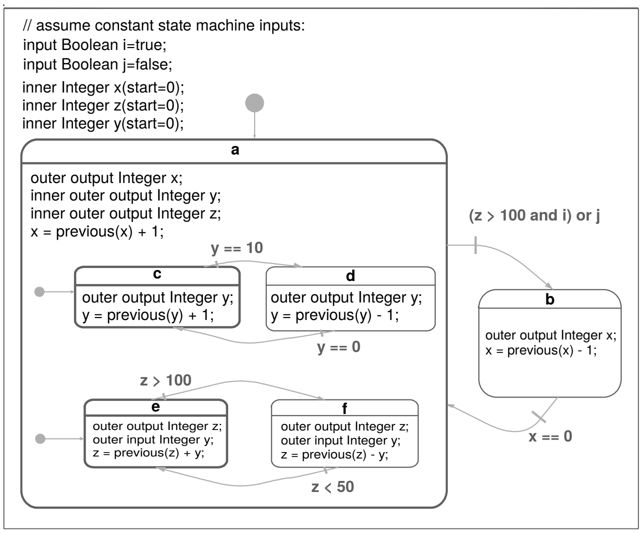
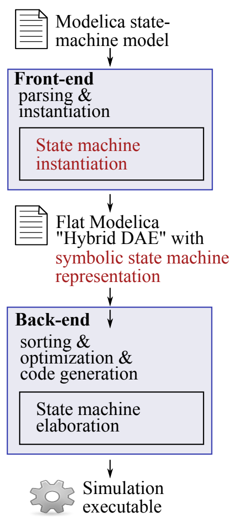
Modelica 3.3 introduced dedicated built-in language support for *state machines* that was inspired by semantics known from *Statechart* and *mode automata* formalisms. The specification describes the semantics of these constructs in terms of data-flow equations that allows it to be related to the Modelica DAE representation which is the conceptual intermediate format of Modelica code after instance creation (flattening). However, a complete transformation of state machine constructs into data-flow equations at the stage of flattening requires an early commitment to implementation details that potentially hinders model optimizations at subsequent translation phases. Also, due to the required substantial model transformation the semantic distance between the original source model and the *flattened* representation is rather large. Hence, this paper proposes a more versatile symbolic representation for flattened state machine constructs that preserves the state machine's composition structure and allows postponing optimizations to subsequent compiler phases.

The proposed approach has been implemented for the OpenModelica compiler. Figure **(a)** shows an example of a Modelica state machine using hierarchical and parallel composition of state machines. Figure **(b)** illustrates the compilation process using the intermediate representation for state machines.



(a) Modelica state machine using hierarchical and parallel composition of state machines[a].



(b) Outline of the state machine compilation process.

[a]Motivated by the example shown in F. Maraninchi and Y. Rémond: Mode-Automata: a new domain-specific construct for the development of safe critical systems, *Science of Computer Programming*, 46:219–254, 2003.

Exploiting Repeated Structures and Vectorization in Modelica

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Large and highly-detailed Modelica models are frequently modeled by utilizing repeated structures, which is a repetition of various elements that are linked together in an iterative manner. While the Modelica language standard supports the representation of repeated structures, it is still not clear how repeated structures can be handled efficiently during model compilation. Instead of preserving the compact notation from the model, all repeated equations are flattened and all array variables are expanded. This leads to unnecessary long compilation times and higher memory consumption. Another aspect that has been yet inadequately considered and is closely connected to repeated structures is vectorization. The vector units of modern CPUs can be engaged to perform SIMD (Single Instruction, Multiple Data) operations, executing the same instruction on multiple data points in parallel. This reveals a high potential for faster simulations. This paper discusses the advantages of utilizing repeated structures for modeling in order to achieve both faster compilation and simulation times. The potentials of preserving for loops throughout compilation are demonstrated using a basic implementation in the OpenModelica Compiler. The effect on the simulation time by enabling vectorization is demonstrated for an appropriate model.

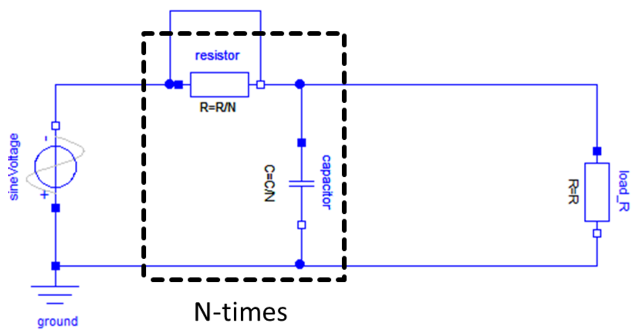

Figure 1. Discretized model of an electric transmission line utilizing a repetition of RC-elements.

High Fidelity Multibody Vehicle Dynamics Models for Driver-in-the-Loop Simulators

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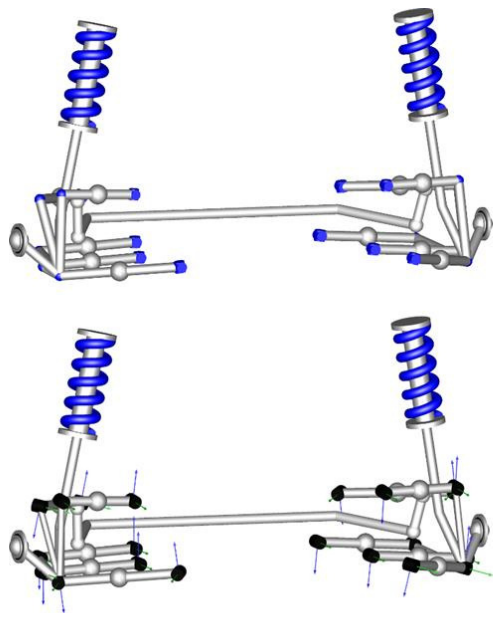
Modern Driver-in-the-Loop (DiL) simulators are sophisticated engineering tools that have been developed within Motorsport to support the development and optimization of race cars in Formula 1, NASCAR and Indycar. At the heart of the simulator is the vehicle model which has to accurately capture the behavior of the whole car. Modelica based vehicle models are used by many of the top teams because it enables a multi-domain vehicle model to be used in the simulators and support all the other simulation activities within the team. These technologies are now being deployed into road car applications which presents a number of additional challenges.

In the last few years driving simulators have been developed that can be used for more than basic procedural simulation such as driver training, evaluating human factors such as fatigue and stress, ergonomics and testing new man-machine-interfaces. The latest generation of systems make it possible to simulate a mathematical model of a car, over an exact replica of a road surface, with identical scenery and visual reference, with a *human* driver, in a safe, controlled, environment. These developments have been led by motorsport teams and organisations due to the restrictions in testing imposed by the governing bodies and the increasing complexity of the cars.

For Automotive OEM's the appeal of high fidelity driving simulators is that they can move the testing of new vehicle designs and parts into the virtual world and start the assessment of design decisions with professional drivers before committing to the production of a prototype.

There are many technological developments that have enabled the development of these engineering class of driving simulators including new software, new motion platforms, high fidelity real-time vehicle models and high precision track data. This paper focuses on the recent enhancements in the vehicle models and the related interface to track data.

A new interface to a system that can provide high fidelity road data, that is generated as a result of LiDAR scans, is presented together with the implications that the use of this data has on the tyre models and contact point calculations. The Modelica TerrainServer Library provides an interface between the Vehicle Dynamics Library and the rFpro TerrainServer enabling simulations in Dymola to use the same track data as the DiL system. To accompany this a new closed loop driver model has been developed to work with these tracks and to provide improved tracking performance.



New suspension models are introduced for road cars to support both kinematic and elastic suspenion models. These are being developed to support both offline and real-time simulation in a DiL system. New bush models have been developed that can capture the frequency and amplitude dependency in the damping characteristics of rubber bushes. The new multi-threading capabilities of Dymola are explored to enable the suspension models, with bushes, to be run in real-time as part of a DiL system.

Modeling and Validation of a Multiple Evaporator Refrigeration Cycle for Electric Vehicles

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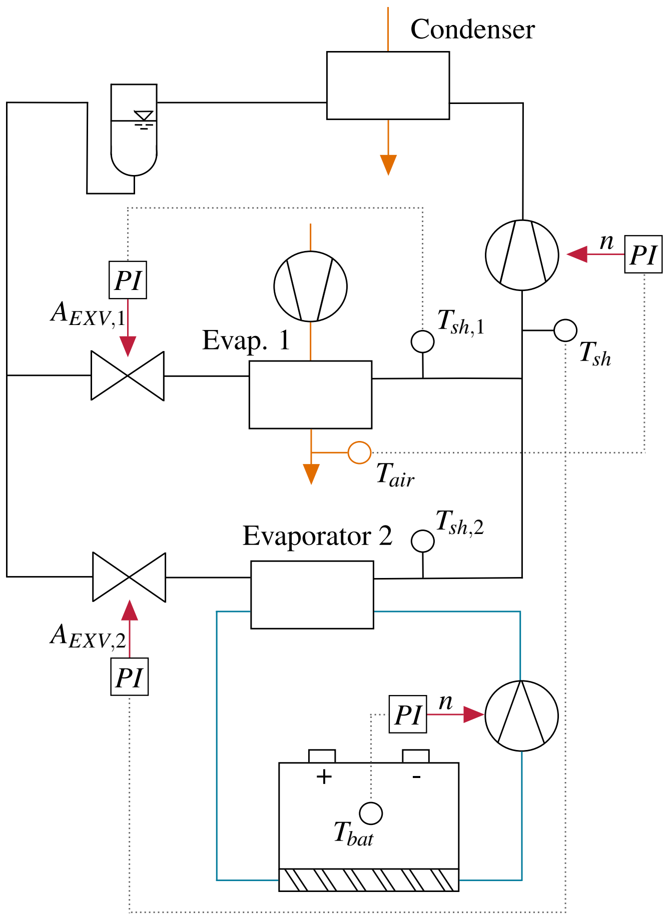
Multiple evaporator vapor compression cycles become relevant for thermal systems in electric vehicles since batteries and other electric components demand cooling for a secure operation. In difference to most other applications with parallel evaporators cooling demands and temperature levels vary between the different secondary fluids. This leads to a more complex system behavior that needs to be described for optimality and control analysis.

In this paper a dynamic model for an automotive air conditioning cycle with an additional evaporator for battery cooling is developed and validated. A battery model library for calculating temperatures and waste heat flows of battery cells and modules is presented. Multi-evaporator effects and their consequences are discussed. Reasonable actuating and control variables are chosen and a discussion regarding possible control schemes is given.



Modeling the Effects of Energy Efficient Glazing on Cabin Thermal Energy & Vehicle Efficiency

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Abstract

Automotive manufacturers are continually seeking to improve overall vehicle efficiency, one particular area of high energy consumption is the vehicle's HVAC system which can have a significant impact on fuel economy or range in electrically powered vehicles. Presented in this paper is the work undertaken to understand the ability to model an automotive cabin for a luxury SUV in the Modelica environment including how energy efficient glazing can be modelled to determine improvements in heating or cooling efficiency at extreme ambient temperatures which will have an effect on fuel economy.

The effect of air conditioning systems on fuel economy are typically not measured on cycle therefore the real world effect on energy consumption should be quantified.
The whole vehicle model and its sub-systems including the cabin and HVAC models are built using the Dymola (DYnamic MOdelling LAboratory) multi-domain physical systems engineering tool, the modelling approach to each subsystem will be discussed in this paper. The air conditioning system model has been created using 1d thermo-fluid physical models. The cabin has been modelled as a multi-zone 1d thermo-fluid model with layering effects.

A Framework for Nonlinear Model Predictive Control in JModelica.org

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Nonlinear Model Predictive Control (NMPC) is a control strategy based on repeatedly solving an optimal control problem. In this paper we present a new framework for the JModelica.org platform, developed specifically for use in NMPC schemes. JModelica.org is an open-source software for simulation, optimization and analysis of complex dynamic systems described by Modelica models. The new framework, the *MPC framework*, utilizes the fact that the structure of the optimal control problem to be solved does not change between solutions, thus decreasing the computation time needed to solve it. The new framework is compared to the old optimization framework, the *open-loop framework*, in JModelica.org in regards to computation time and solution obtained through a benchmark on a combined cycle power plant. The results show that the MPC framework obtains the same solution as the open-loop framework, but in less than half the time.

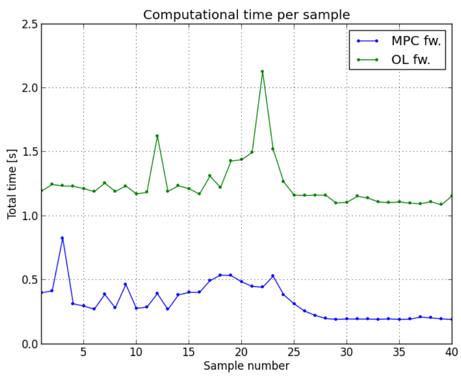

Figure 1. Total computation time for each sample in the benchmark, using the MPC framework and the open-loop framework respectively.

For the benchmark system presented in this article, the total computation time for each sample was decreased by an average of 70 %, as shown in Figure 1. The MPC framework also includes some features which makes JModelica.org easier to use for NMPC applications.

A Toolchain for Solving Dynamic Optimization Problems Using Symbolic and Parallel Computing

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Significant progresses in developing approaches to dynamic optimization have been made. However, its practical implementation poses a difficult task and its real-time application such as in nonlinear model predictive control (NMPC) remains challenging. A toolchain is developed in this work to relieve the implementation burden and, meanwhile, to speed up the computations for solving the dynamic optimization problem after transforming it to a nonlinear programming problem (NLP). To achieve these targets, symbolic computing is utilized for calculating the first and second order sensitivities on the one hand and parallel computing is used for separately accomplishing the computations for the individual time intervals on the other hand.

The toolchain consists of several open-source tools. The Modelica language is used to establish object-oriented models. The Optimica extension serves for the formulation of the optimal control problem. JModelica.org transforms the optimization model to a symbolic optimization model. The automatic differentiation and symbolic manipulations are done by means of CasADi. The interior-point optimizer Ipopt is applied to solve the NLP. The entire approach of the parallelized modified combined multiple-shooting and collocation (MCMSC) method is realized in the Python scripting language using the standard multiprocessing module without any additional software packages.

Two optimal control problems, a satellite control and a combined cycle power plant start-up process, are solved. The efficiency of the developed toolchain, which solves one of the problems with approximately 25,000 variables in a reasonable CPU time, is demonstrated by speed-up factors. A comparison with the collocation approach in JModelica.org is also given.

In general, the larger the NLP and the more CPU cores are available, the greater the advantages of the proposed parallelized MCMSC approach will be.

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NMPC Application using JModelica.org: Features and Performance

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Nonlinear Model Predictive Control (NMPC) is a control algorithm where an optimizer generates control inputs based on a prediction of the nonlinear system behaviour. Main advantage of this method is the explicit consideration of system limitations (constraints) and improved control quality for dynamic load changes and systems with a wide range of operating points. Main disadvantage is the computational cost. Hence performance is an important key to extend the scope of application for this control strategy.

In this presentation we show the recent performance improvements for NMPC using JModelica.org. These were achieved by using variable elimination based on Block Lower Triangle (BLT) transformation and exploiting of specific problem characteristics. This includes initializing the optimization with data from a previous optimization (warmstart) and reducing the computional overhead by reusing the optimization discretization. Their effect is explained theoretically, followed by performance tests for an industrial application. Specifically steam temperature control for a Heat Recovery Steam Generator (HRSG) with 4 control inputs, 6 states and 2 control outputs was chosen. Performance increases by a factor of two and five were observed for the mentioned features.

At the end of presentation you should have a realistic impression whether NMPC is a suitable control strategy for your specific control problem and whether the performance of the openly available tool JModelica.org matches your needs.

A Modelica Library for Manual Tracking

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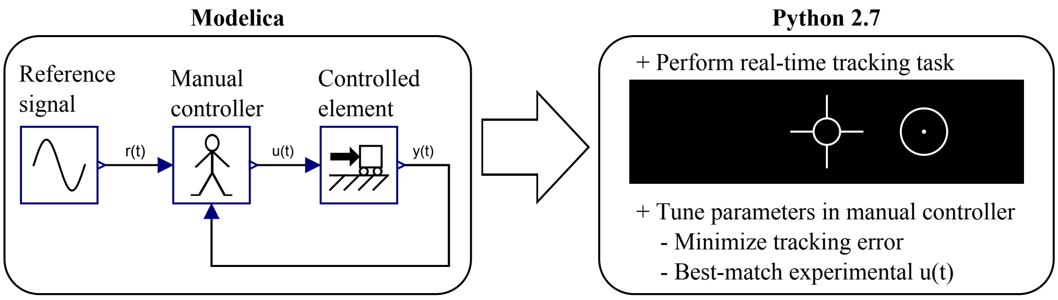
Many systems require a human to perform real-time control. Examples include aiming a tank turret [1], driving an automobile [2], and piloting an aircraft [3].To simulate these systems, a dynamic model of the human's control behavior is needed. The field of manual control has developed and validated such models, and their implementation in Modelica could support researchers of human-machine systems. This paper presents a Modelica library with models from the manual control literature. Python-based tools allow users to perform, in real time, the manual tracking tasks they design in Modelica. Parameter values in the manual controller models can be automatically tuned to either maximize tracking performance, or to match recorded control input from a user experiment.



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Model-based control with FMI and a C++ runtime for Modelica

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Abstract

Modelica describes physical systems on a high level, using model objects, multi-dimensional arrays and other data structures as well as graphical representations. Modelica models are translated to differential-algebraic equation systems and compiled to executable code prior to their execution in numerical solvers. The translation gives a lot of possibilities for code optimization. This is particularly important for model-based control applications.

This paper investigates the exploitation of C++ for Modelica code optimization. C++ supports advanced programming concepts and at the same time aims to "leave no room for a lower-level language … (except for assembly code in rare cases)" (B. Stroustrup: The C++ Programming Language, 2014). The features exploited here include polymorphism, templates, built-in exception handling and object destructors.

The ideas have been implemented in the OpenModelica C++ runtime. The paper describes its enhancement with new array features and with an FMI 2.0 interface. FMI serves as interface between modeling tools and control applications. In particular the new FMI 2.0 meets requirements of numerical optimization solvers in model-based control.

A publically available application example demonstrates the achievements. CPU times obtained with the OpenModelica C++ runtime are significantly faster than CPU times obtained with the C runtime or with Dymola.

Keywords: Modelica, OpenModelica, FMI, C++, model-based control, MPC, MHE, SQP, HQP.

Application example

The findings are demonstrated on a DrumBoiler example that bases on the Modelica Standard Library. Exploiting FMI 2.0, the same model is translated and exported as different FMUs using different Modelica tools, tool options and compiler flags.

Table: Obtained CPU times using different Modelica tools and tool options for FMI export

Modelica Tool for FMU export	CPU time with gcc flag		
	-O0	-O2	-Ofast
OpenModelica 1.9.3	16.6 s	15.5 s	**13.5 s**
OpenModelica 1.9.3 +cseCall	6.0 s	5.5 s	**5.2 s**
Dymola 2015FD01	3.4 s	1.7 s	**1.3 s**
OpenModelica 1.9.3 +simCodeTaget=Cpp	5.6 s	1.9 s	**1.0 s**
OpenModelica 1.9.3 +simCodeTaget=Cpp +cseCall	2.7 s	1.0 s	**0.6 s**

The widely used optimization solver HQP provides FMI import. It solves the same startup optimization program for each FMU. Amazing runtime differences of more than a factor of 25 are observed for the example, depending on how the FMU was generated.

The paper describes the optimization approach giving that much flexibility and investigates why the C++ runtime of OpenModelica is superior.

The described optimization technology serves as basis for model-based control in many industrial applications.

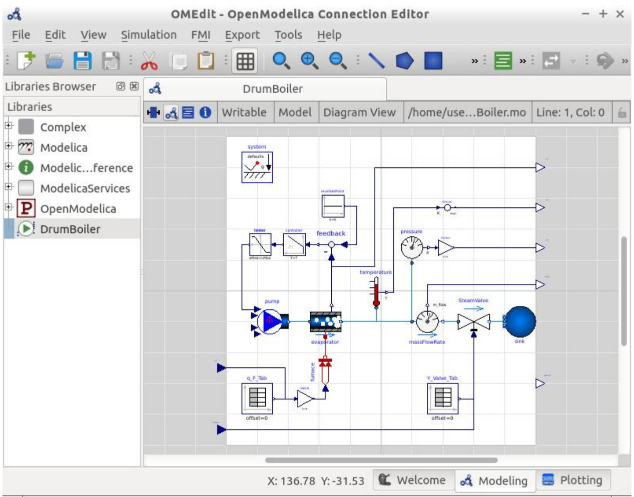

Figure: DrumBoiler model in OMEdit

Nonlinear Dynamic Inversion Control for Wind Turbine Load Mitigation based on Wind Speed Measurement

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Wind energy has become an important energy source with worldwide growing capacities. Advanced control design can help to improve the energy generation and extend turbine lifetime. While the nominal control of wind turbine is already well handled by the state of the art, there is still much potential in the field of load reduction. Other aspects are key-technologies such as LIDAR systems that enable better on-line wind measurement.

This paper shows the potential of an advanced controller for wind turbine load mitigation. The controller is based on Nonlinear Dynamic Inversion control methods combined with Pseudo Control Hedging to account for the actuator limits and a two degree of freedom control system for the collective pitch control of the rotor blades. The controller uses wind speed measurement information to adjust to wind gust load. The simulation results show a large reduction of the gust load on the wind turbine using the proposed controller.

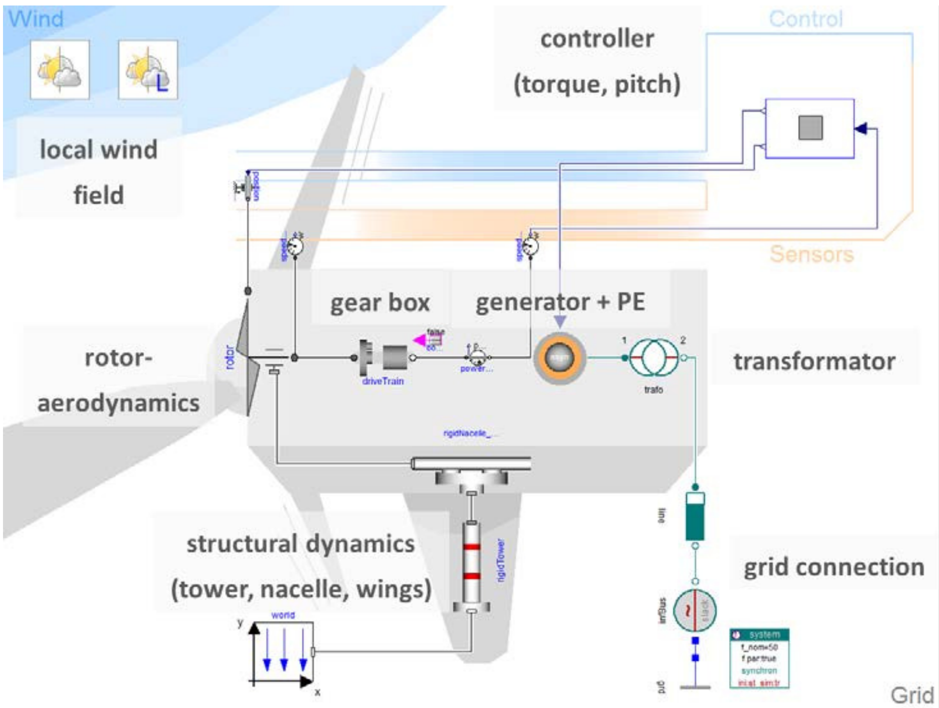

Figure 1. Top-level model diagram of a wind turbine.

For the design and development of this controller, a DLR library for wind-turbines has been used. Such a multi-domain Modelica library for wind turbines with non-causal and hence invertible models forms an optimal basis for the development of suitable NDI controllers.

Free Modelica Library of Chemical and Electrochemical Processes

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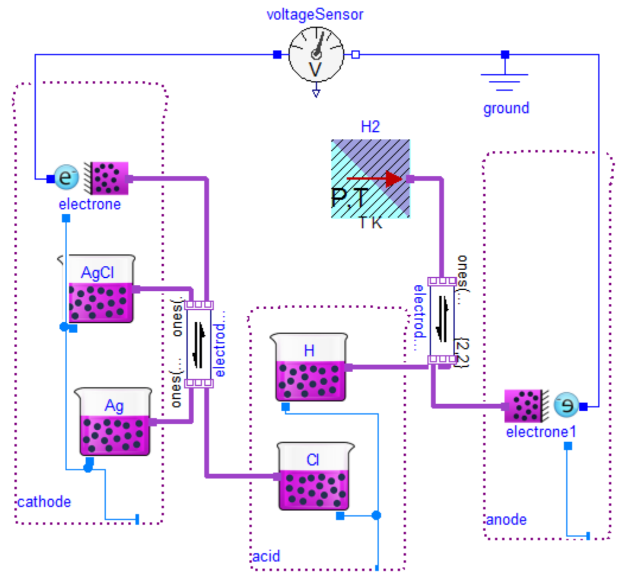
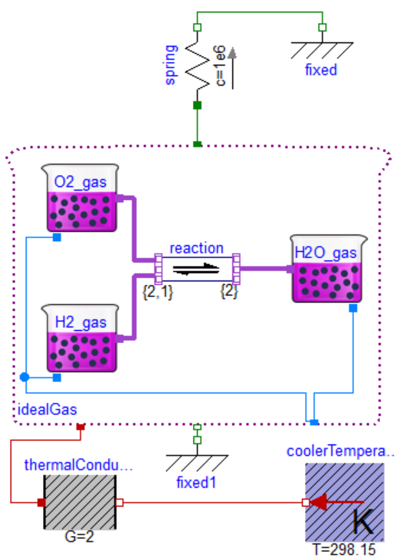
A new, free Modelica library for electrochemical processes has been released - accessible as “Chemical” at https://www.modelica.org/libraries. It is based on equilibrating the electrochemical potentials of the substances involved, following the modern theories of physical chemistry. It dynamically solves the chemical equilibration of homogeneous chemical solutions with fully thermodynamic states, supported also through thermal, mechanical, electrical and fluid components of Modelica Standard Library 3.2.1.



Electrochemical cell. The chemical reactions on the electrodes are connected to electrical circuit via electron transfers, where is the molar flow of electrons scaled to electric current.



Hydrogen burning. The chemical reaction $H_2 + O_2 \leftrightarrow H_2O$ in closed gaseous homogenous solution as piston with spring upside and with external cooling.

The properties such as activity coefficients, molar mass, formation energies or heat capacity of each chemical substance can be specified by user as functions of new “state of matter model” or selected as predefined ideal gas or predefined ideal incompressible solid or liquid.

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Modeling Biology in Modelica: The Human Baroreflex

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Systems biology is a field that requires complex multi-scale models of systems that are evolved rather than engineered. No unifying theory exists for biology as it does for engineering domains. Thus, models appear in very diverse forms. Components can be genes, cells, organs, organisms or even whole ecosystems. These components can intuitively be represented as classes in an object-oriented language, making systems biology a perfect application for Modelica.

However, we still only see very few models from this domain. In an attempt to change this, we show that Modelica can exactly reproduce the simulation results of a reference implementation of the Seidel-Herzel model (SHM), an established biological model of the human baroreflex. The model can be seen in Figure 1. It features 30 mathematical equations that capture the essential functionality of the heart, the baroreceptors that measure our blood pressure, the autonomic nervous system, the lung and the windkessel arteries that dampen the blood pressure spike after a contraction. The model is able to realistically reproduce heart rate variability characteristics and can also be used to simulate disease conditions.

Our implementation highlights the strengths of Modelica like the event finding mechanism, which makes the model more precise compared to the original reference implementation. We also show that biological systems pose interesting modeling challenges. The interaction of complex rhythms in the contraction model leads to nontrivial conditions in when-equations that constitute a discrete equation system and the presence of non-uniform delays in the baroreceptors requires a convolution that cannot be implemented efficiently with conventional means. Both problems may point to areas where Modelica compilers or the language itself may be improved.

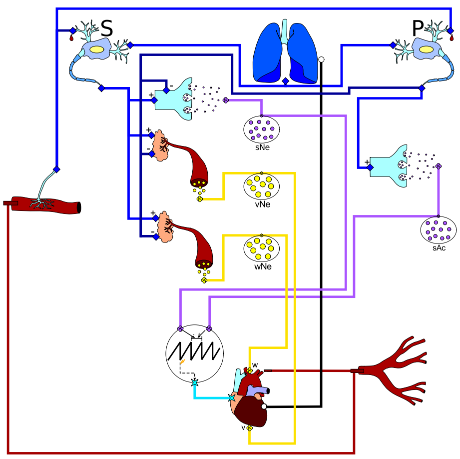

Figure 1. Diagram view of our Modelica implementation of the Seidel-Herzel model.

A library for City Traffic

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City traffic management and reduction of emission of pollutants by vehicles are more newsworthy than ever.

As part of the MODRIO project (MOdel DRIven physical systems Operation), a European project financed by the ITEA2 program and led by EDF, Digital Product Simulation (DPS) created a library targeting city traffic Modeling and Simulation.

This library is designed for the development and evaluation of control strategies, rendered possible when vehicles are able to communicate between each other and with their infrastructure. CityTraffic library allows for the implementation of control strategies by all of the players acting in an urban environment (e.g. located in vehicles, with a global server computing set points for the vehicles, or with a traffic management system setting speed limits and traffic light cycles).

The library is divided in two sections, macroscopic traffic and microscopic traffic. Macroscopic components are used to describe road networks such as highways whereas microscopic components allow for modeling city traffic where interactions between vehicles and their environment are many.

Figure 1: Modeling scales for a roundabout intersection.

Connections between environments are available to reduce the simulation time by modeling roads without intersections at the macroscopic scale.

The library uses objects set on a map defined by the user. On this map, intersection types can be changed and vehicles movements can be visualized. Currently, eight intersection models were developed such as yield, right of way or bus stops. Others are currently being created.

The vehicle model includes fuel consumption and CO2 emission functions defining the environmental impact of each type of vehicle (car, bus…).

By using this City Traffic library, cities can decrease the number of traffic jams on their road network, and improve the overall impact of the traffic on the environment.

Figure 2: Intersection models developed.

An open toolchain for generating Modelica code from Building Information Models

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Buildings become increasingly integrated to reduce energy and peak power and to increase occupant health and productivity, leading to complex building design. Building Performance Simulation (BPS) is a key element in the design of energy efficient buildings, and there is increasing interest in using the Modelica modelling language for BPS. The International Energy Agency's Energy in Buildings and Communities Programme (IEA-EBC) coordinates development of BPS in Modelica in the project "Computational Tools for Building and Community Energy Systems", also known as Annex 60.

Even with advanced BPS libraries at hand, developing BPS models and collecting required input data are time-consuming and error-prone processes, preventing practitioners from using BPS more extensively in standard planning processes. Building Information Modelling (BIM) is a well established technology to model and manage the digital representation of a building over its entire lifecycle. Reusing existing Building Information Models (BIM) as basis for Building Performance Simulation (BPS) has the potential to make BPS model development and subsequent simulation easier, faster and more reliable.

Activity 1.3 of the Annex 60 project is working on an open-source toolchain that can semi-automatically generate code for BPS Modelica models from a BIM data source. In this contribution, we give an overview over the toolchain and the involved steps as well as a more detailed description of those parts of the toolchain that are used for controlling the workflow and for the actual generation of Modelica source code files.

Lessons learnt from network modelling in a low heat density district heating system

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This paper presents the lessons learnt during the development of a library for the modelling of district heating systems (DH systems), especially focusing on the distribution network. The library was built based on elements from the Modelica Standard Library (Modelica Association, 2012) and the NewThermal library (Lopez, del Hoyo, 2014).

The modelling strategy chosen is described. Furthermore, the requirements established by the DH networks are set out as well as the models created in response to these demands.

Finally, the artificial diffusion phenomenon, present in the simulation of this kind of thermo-fluid systems, is described.

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Modelica based Design and Optimisation of Control Systems for Solar Heat Systems and Low Energy Buildings

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The goal of the research project enerMAT is the reduction of energy consumption and CO2 emissions of buildings. Especially solar heating systems are installed in more and more buildings. This paper introduces a novel approach for simulation and optimisation that aims to improve the performance of building controllers and especially solar heating controllers such as the UVR 1611 by simulation and model-in-the-loop tests. A new generation of energy-aware optimised building energy management systems (BEMS) will be discussed and its advantages over the older controllers highlighted. The energy-aware optimisation will be shown on a model-based approach with an overall building system model enabling the assessment of the energy performance for different design and operation alternatives of the building automation system in interaction with the building. This system model will allow a simulation-based, energy-aware, global, dynamic, multi-criterial optimisation of BEMS. In this paper, the idea, the approach, and the actual state of the project research is presented with a focus on solar heating controllers.

The UVR 1611 is a control unit for HVAC and solar heating systems. Its function can be edited by using pre-programmed function blocks (FB) such a PID controllers, timers, counters, logical and arithmetic functions. For the implementation of a sophisticated BEMS the UVR functionality is however not sufficient and an additional top-level controller is required. The UVR FB's were modelled in Modelica by using a detailed specification as template. They are stored in a library and were tested on their own and by comparing simulation with measured data from UVR controllers. The UVR FB library enables the model-in-the-loop test of UVR programs along with complete building models. Preconfigured building models along with standard UVR application models will be employed by civil engineers to obtain optimised parameters for the control units to be installed in new houses.

A building model of an existing solar-heated office building with controller, solar collectors, heat storage, building zones and heating systems is composed of an energy source model and a heat consumption model. Both models are validated with measured data from the real building to find inaccuracies and modelling errors. The complete model is used for the validation of the buildings energy characteristics and to improve utilisation of the solar energy. Certain strategies for saving energy such as temperature setback were simulated and analysed. Because of the limited functionality of the solar heat controllers the requirements for a top-level BEMS were established and implemented in a control model within the building model. The BEMS model features functions which contain certain optimisation parameters. A particle swarm optimisation was executed to find parameter values that result in low energy consumption while maintaining comfort. Because the building model is quite large a reduced model for the optimisation was developed. The optimised parameters were then verified with the full scale model.

How to Shape Noise Spectra for Continuous System Simulation

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Modeling stochastic signals is of interest in a wide range of applications, such as sensor modeling, aerodynamic turbulence, and rail irregularities. A Modelica `Noise` library has thus recently been released in order to enable the engineer to conveniently and consistently define noise signals (Klöckner et al., 2014).

The `Noise` library also introduces a new class of random number generators. They eliminate the need for time-events, but can be used to generate a random signal directly from the `time` variable. This has been shown to positively affect the simulation performance (van der Linden et al., 2015). Additionally, it allows to define noise signals in dimensions other than the time. Rail irregularities e.g. are typically defined with respect to the location on the track.

Unfortunately, it is not at all obvious how to parametrize the frequency properties of such noise signals. We thus present a systematic method to shape the frequency content of noise signals. The contributions of this paper are as follows:

1. Using the example of rail irregularities, we summarize how noise is typically specified.
2. We then shortly define the probability distribution of the noise signals generated in this paper.
3. Starting from a given power spectral density (PSD) we rigorously derive a way to shape this frequency content onto a noise signal. This method will turn out to be perfectly simple to use and to be applicable to almost any kind of noise spectrum.
4. We finally implement the approach and verify that it yields the same results as conventional methods.

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Franciscus L. J. van der Linden, Andreas Klöckner, and Dirk Zimmer. Effects of event-free noise signals on continuous-time simulation perfomance. In Felix Breitenecker, Andreas Kugi, and Inge Troch, editors, *8th Vienna International Conference on Mathematical Modelling*, volume 8 of *Mathematical Modelling*, pages 280–285, Vienna, Austria, 2015. IFAC-PapersOnLine. doi:10.3182/20150218-3-AU-30250.

Dynamic Modelling of a Flat-Plate Solar Collector for Control Purposes

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Two different dynamic models of a flat-plate solar collector with different levels of detail have been developed in the Modelica language under Dymola® software: Detailed Model, and Simplified Model.

These models have been both worked out within the Ambassador Project (Onillon, 2014). In this project, models of district heating components are conducted for control purposes, including a solar plant model.

The present article describes in detail each of these flat-plate solar collector models along with their development process (e.g., assumptions taken into account). Both models have been favourably validated, and the corresponding validation process along with the results obtained are presented, as well as the corresponding discussion and conclusions. The model's validation has been conducted by comparing the model's simulation results with the experimental results obtained in the IK4-TEKNIKER Solar Thermal Test Rig.

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Generic Modelica Framework for MultiBody Contacts and Discrete Element Method

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A generic framework for mechanical modeling of objects that collide and have contact is presented. It can be used in combination with the Modelica MultiBody library and to model granular objects using DEM (Discrete Element Method). The shapes of the objects are given by general triangular meshes. The special case of spheres is also supported in order to handle tens thousands of objects for DEM.

The contact handling is organized using ExternalObjects, i.e. C and C++ code. Each body in the scene registers its current position which is given as the solution of the Modelica motion equations. After that a centralized routine of the scene calculates and adds all forces between pairs of bodies in contact. The force calculation is done using the intersection volume found by the CSG (Constructive Solid Geometry) intersect operator. We have used a generalization of the Hertz contact model, where the force is proportional to $\sqrt{Vd}$, with V=penetration volume and d=penetration depth. The force is acting at the centroid of the penetration volume.

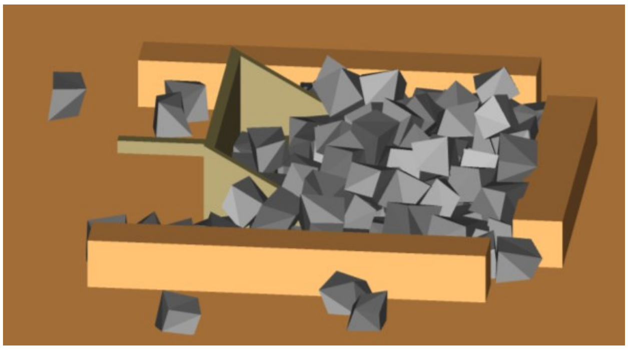

Figure 1. Bucket digging in a pile of Belgian Block stones

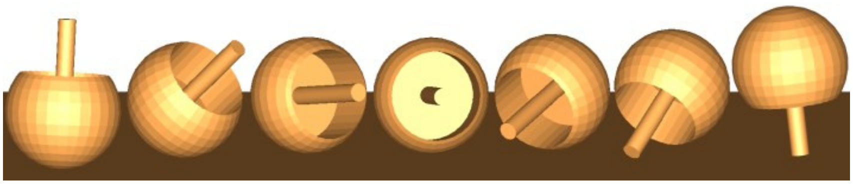

Figure 2: Snapshot of Tippe Top inversion, from left to right

Different Models of a Scaled Experimental Running Gear for the DLR RailwayDynamics Library

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The DLR internal project "Next Generation Train" (NGT) deals with a high-speed train in a double-deck configuration. To realize the two continuous floors, a single wheel running gear configuration is selected. Equipped with independently rotating wheels instead of a usual wheel-set, a track guidance control becomes necessary. In terms of an advanced control and observer development the implementation of validated simulation models is absolutely essential.

Therefore, the paper gives a short overview of the hardware of the scaled Experimental Running Gear on the DLR roller rig representing the NGT single wheel running gear. Using the DLR RailwayDynamics Library three different models of the running gear are implemented. The first model is a detailed multibody model, whose frequency response is validated with respect to the running gear hardware using Closed-Loop-Identification (Saupe and Knoblach, 2012). Furthermore, a nonlinear analytical model is implemented, that can be used for example to develope a feed-forward control (Heckmann et al., 2015). The third model generated by linearizing the nonlinear analytical model allows for a stability analysis of the running gear configuration. Finally, some simulation results are presented, that point out the conformity of the particular simulation models, see Figure 1.

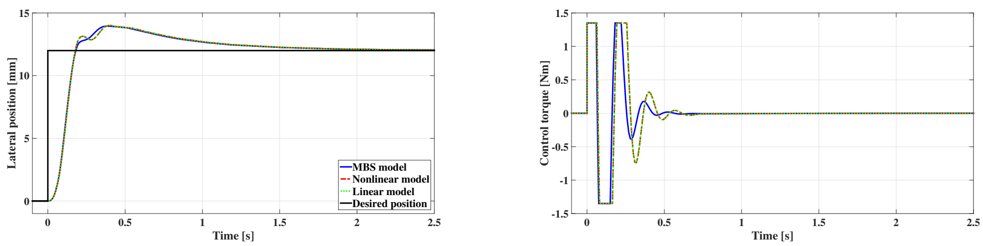

Figure 1. Lateral displacement and control torque of the three presented simulation models at $v_R = 6\ \frac{\mathrm{m}}{\mathrm{s}}$.

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Efficient Compilation of Large Scale Dynamical Systems

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In this work, we present a novel methodology to efficiently compile large scale dynamical systems described as Modelica models, and its implementation in a prototype Modelica Compiler called ModelicaCC. The methodology allows to perform the different stages of the compilation process without expanding the content of repetitive structures so the resources (CPU time and memory) used by the compiler result independent on the model size. Besides introducing the methodology with their algorithms and the implementation in the ModelicaCC compiler, we analyze their efficiency comparing its performance with that of OpenModelica in different large scale models.

Flattening Phase We present an article to efficiently flatten large scale models without expanding equation and array variables. The first step is obtaining equivalent flat non-expanded models from each component. The second step is replacing the `connect` equations amongst these components for equality equations. This is achieved thorough an algorithm thats computes the connected components in a augmented graph.

Causalization Phase The DAE system resulting from then flattening stage must be then sorted into an ODE. This works presents also an extension on the Tarjan algorithm to deal with iterative equations and array variables without unrolling them. This is again achieved with the use of an augmented graph holding information about array indexes and `for` iterative variable.

Results The presented algorithms were implemented in a prototype Modelica C++ Compiler in order to study their behavior. The results show that over the two case studies presented this approach has a constant compilation time with respect to the model size.

Work is being done to include algebraic loops in the causalization phase. Index Reduction must also be included based on the work of [1].

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Simulation of Large-Scale Models in Modelica: State of the Art and Future Perspectives

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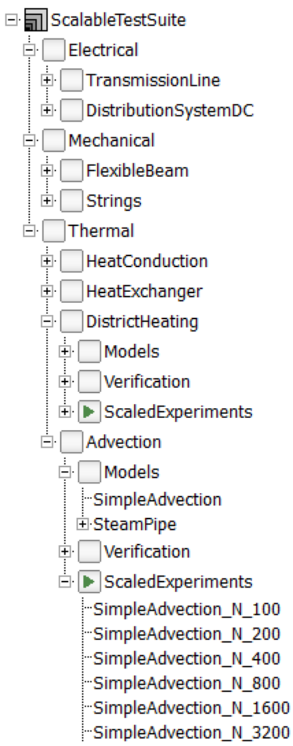
State-of-the-art Modelica tools are very effective at converting declarative models based on differential-algebraic equations into ordinary differential equations. However, when confronted with large-scale models of distributed systems with a high number of states (1000 or more) or with large algebraic systems of equations (1000 or more unknowns), they face a number of serious efficiency issues, that hamper their practical use for system design:

- Localized interaction is not exploited
- Localized system activity is not exploited
- Systems with activity on widely different time scales are penalized
- Localized influence of events and discontinuities is not exploited
- Systems with large-scale algebraic constraints are not considered
- Repetitive structures are not exploited

Overcoming these limitations would enable Modelica tools to effectively support the design of large-scale, distributed cyber-physical systems.

The paper analyses these issues in detail, reviews promising research trends from the literature, and points out strategies for improvement. It also introduces the ScalableTestSuite package, a library of scalable test models that can be used to assess the performance of existing tools with large-scale systems, as well as to help developing advanced solution methods in this field.



Developing Mathematical Models of Batteries in Modelica for Energy Storage Applications

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Battery modeling is a challenging field that has been receiving a great amount of interest recently due to the great push from the portable electronic devices and the electric and hybrid electric vehicles (EV/HEV) industries. Despite of the differences in the power ranges and battery sizes in these applications, the two industries share a common goal: developing a new generation of batteries that allow devices to run for a longer period of time, while operating within a range that maximizes the battery's service life. In both of these areas, accurate and efficient battery modeling is vital to help maximize the performance of a device and its battery.

In this paper, effective and systematic steps in the mathematical modeling of high-fidelity battery models for simulating energy storage systems (ESS) will be presented. Two approaches to battery modeling will be discussed in this paper: (1) equivalent electrical circuit approach, and (2) electrochemical approach.

While equivalent electrical models attempt to model the electrochemical physics of a battery using only electrical components, the resulting battery component, which is computationally inexpensive to incorporate into system models, has many limitations. Electrochemical models on the other hand, are the most accurate because they describe the physics of a battery by explicitly representing the chemical processes that take place within it.

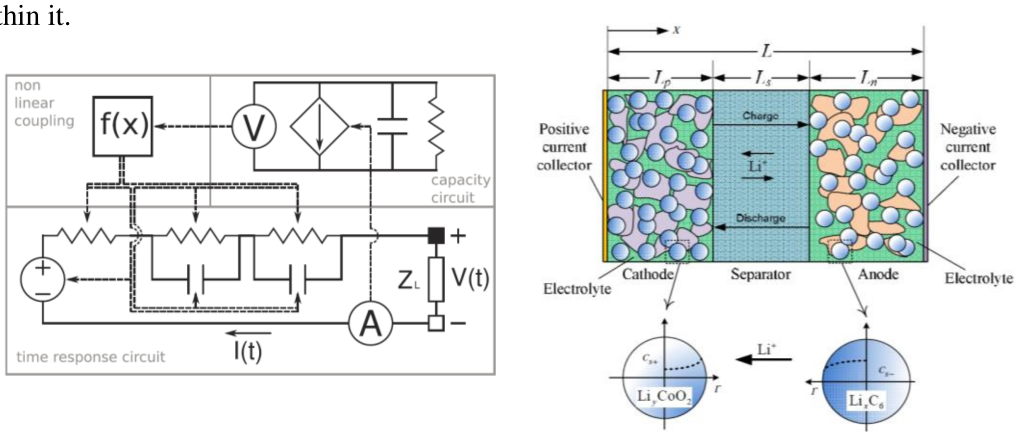

Figure 1. Schematic of an equivalent circuit model, and anatomy of a Lithium-ion cell

Capacity fade and thermal effects are incorporated into both the equivalent circuit and electrochemical battery components. The battery library also comes with a parameters identification worksheet which ensures a high level of fidelity in the battery components, making them suitable for a wide range of applications.

The battery models discussed in this article are developed based on the Modelica Standard Library specification 3.2.1 and commercialized as part of the Battery Component Library in MapleSim® 2015.

Average model of a synchronous half-bridge DC/DC converter considering losses and dynamics

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Nowadays, power electronic systems play a major role in almost every large system. Due to the high switching frequencies, the simulation of these devices is computationally very expensive and not suitable for system simulation. Average models of these power electronic systems are needed to simulate the basic terminal characteristics of these devices without the need to simulate every switching operation. This paper describes a Modelica implementation of a synchronous half-bridge converter for the use in an automotive power net simulation as well as in real-time environments. The model takes into account the losses in the semiconductors as well as the dynamic behavior of the converter. For the parametrization of the model, only the switching frequency and some values from the datasheets of the used components are required. To validate the proposed model, an equivalent SPICE model is developed, serving as a reference model. The dynamic behavior of the two models is compared using step responses of the load current. The relative deviation of the model's output voltage compared to the SPICE simulation is less than 2 %. Furthermore, also the energetic behavior was investigated, and it is shown that the proposed model provides good results for a wide operating area.

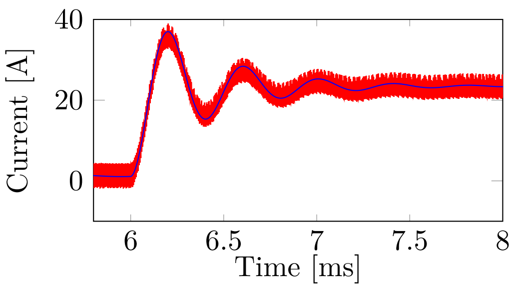

Figure 1. Inductor current step response of the Modelica(blue) and the SPICE model(red) to a step in the load

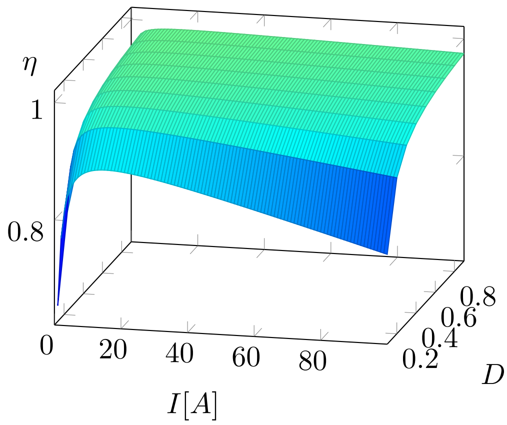

Figure 2. Efficiency map of the proposed Modelica model in buck mode as a function of D and I

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Modeling and Simulation of Liquid Propellant Rocket Engine Transient Performance Using Modelica

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Liquid propellant rocket engines are widely used and play a very important role in aerospace. This paper presents a liquid propellant rocket engine model library in Modelica language, which contains component models such as pipes, valves, tanks, turbo-pumps, combustion chambers, nozzles, injectors, gas generators, etc. The control equations of some most important components are given. We present the general method for applying the characteristics of Modelica to modeling procedure of LPRE. These component models can be applied to establish a variety of liquid rocket engine systems with the capability of predicting engine transient performance during startup, shutdown and regulation processes. Typical gas-pressurized liquid propellant engine system and turbo-pump liquid propellant engine system are modeled in the paper. Some simulations and analyses are performed to validate models qualitatively. All work is implemented in MWorks, which is a modeling and simulation platform that fully supports Modelica.

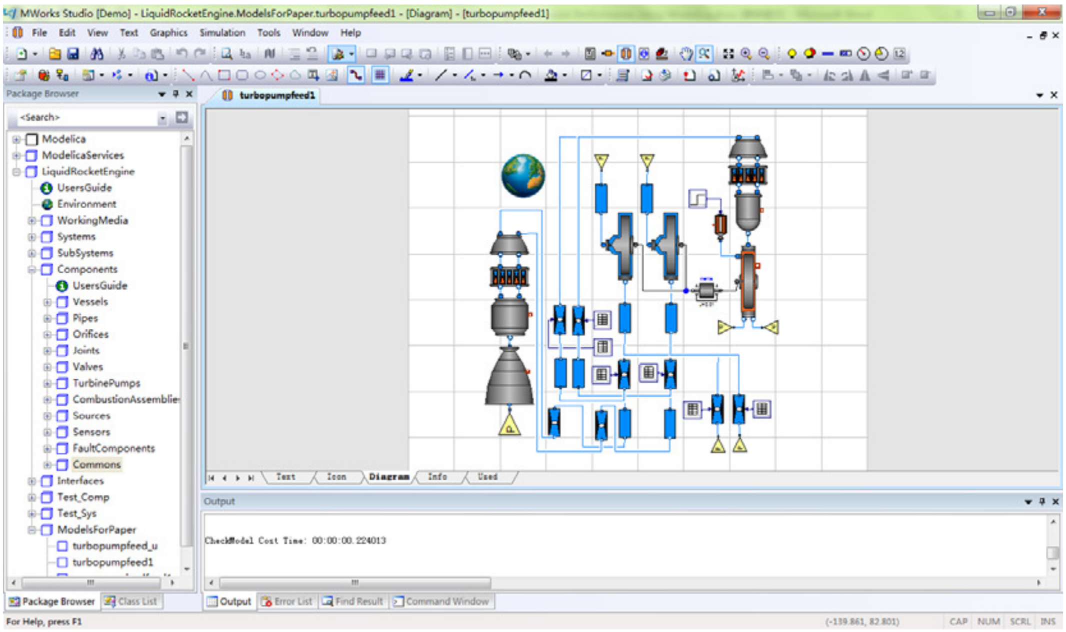

Figure 1. Example of MWorks and liquid propellant rocket engine model

Model Based Specifications in Aircraft Systems Design

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Executable specifications are computer algorithms written in an appropriate specification language with the purpose of demonstrating and verifying the compliance of the input-output behaviour of the model subject to the model specifications. Similarly, requirement modelling allows the specification and testing of demands on signals which are generated by a system or the model of a system. Together, executable specifications and requirement models enable a well-defined specification of a system.

While the traditional aircraft design process is based on document based specifications only, a model supported design process based on executable specifications and requirement models is thought to improve the process in terms of quality and time. In contrast to the traditional, more software oriented usage of executable specifications, we use them in a more general way also for specification of physical models and behavior.

In a former publication, MathWorks based tools were mainly used. In order to have a one-tool solution which allows better coupling of the physical models to requirement blocks, we show how it can be realized with Modelica based tools and libraries, especially with the new Modelica Requirements library.

For some requirements no ready to use requirement blocks were available. These were blocks for a funnel like constraint in time domain and blocks for constraints in frequency domain. The implementation of the FFT for frequency domain property monitors is non-trivial and often parameterization is implemented user-unfriendly. In the last part of the paper we present a user-friendly and numeric efficient implementation and give some overview on the implementation.

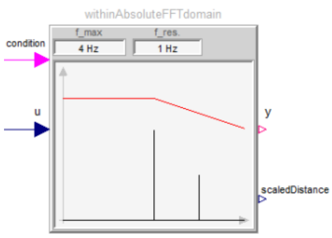

Figure 1: WithinAbsoluteFFTdomain FFT based property monitor for constraints in frequency domain

Multi Electrical Machine Pre-Design tool with error handling and machine specific advanced graphical design aid features based on Modelica

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This paper presents a design tool for Induction Machines, Permanent Magnet Synchronous Machines, Externally Excited Synchronous Machines and Switched Reluctance Machines. The sizing software is done in Modelica language. Is able to provide full dimensioning i.e.: cross and axial section measures (See Figure 1, right), and operation characteristics. The design is restricted by mechanical and electrical requirements (inputs) such as Rated Power, Rated Torque, Rated Speed, desired phase voltage, number of phases, pole pairs, angle of the V-shape (for IPM), etc..

Not all sets of inputs may be feasible. To help the designer reduce the number of iterations, the tool performs error handling during sizing (console messages) and after it via several tools (some are machine specific) and graphical aids. These tools are aimed to give clues about the possible design errors.

The tool is composed by two main layers: GUI and Sizing scripts (See Figure 1, left). GUI is made in MATLAB® GUIDE and does not involve any sizing operation only input and output handling. Sizing scripts are fully implemented in Modelica scripting allowing implementation in other libraries. Both are provided with help files and code explanation in order to re-use the tool and improve library's functionalities.

This pre-design tool is part of Modelica Library of Detailed Magnetic Effects in Rotating Machinery (MAGMOLIB) project managed by the German Aerospace Center (DLR) and developed by MCIA research center as part of the CLEANSKY partnership.

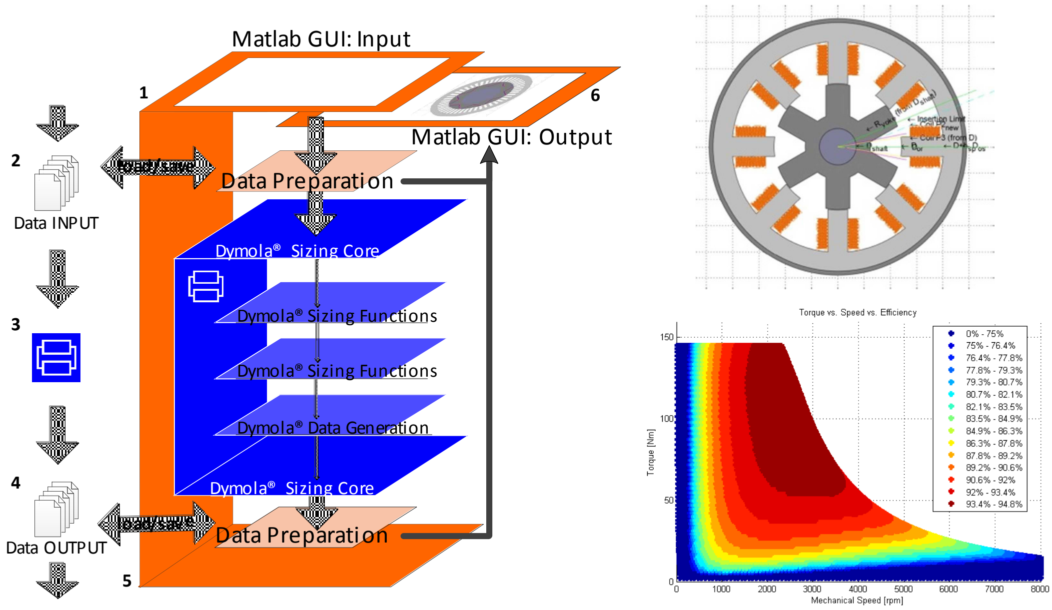

Figure 1. Left: Layer representation of the tool. Right-Top: Graphical representation of output cross section of SRM. Right-Bottom: Efficiency map (Torque vs. Speed) for IPM machine based on inductances and resistance values of the pre-designed Machine.

Enhancements of Electric Machine Models: The EMachines Library

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The MSL already contains transient models of multi phase electric machines: `Modelica.Electrical.Machines` and `Modelica.Magnetic.FundamentalWave`. For the next release of the MSL, quasi static machine models are planned to be included. These models neglect electric transients for performance reasons (Kral, Haumer, 2014): `Modelica.Magnetic.QuasiStaticFundamentalWave`.

Both the transient and the quasi static models consider Joule, friction, core and stray load losses. However, more advanced effects like saturation and skin effect are not taken into account.The new EMachines Library deals with these advanced effects. First, the deep bar effect is implemented, followed by further effects. Furthermore, the new machine models are based on a parameter record to overcome the drawback of parameterization by multiple parameters.

The deep bar effect (Toliyat, Kliman, 2004) increases the effective resistance and decreases the effective stray inductance of the rotor bars. This effect strongly depends on the electrical rotor frequency. Therefore the stator current and torque of induction machines at stand still, i.e. slip = 1, is strongly affected. Furthermore, the additional losses caused by higher harmonics of non-sinusoidal currents due to inverter operation are increased. Modeling the deep bar effect allows the investigation of the starting behavior of induction machines fed by the grid in a more realistic way (Figure 1).

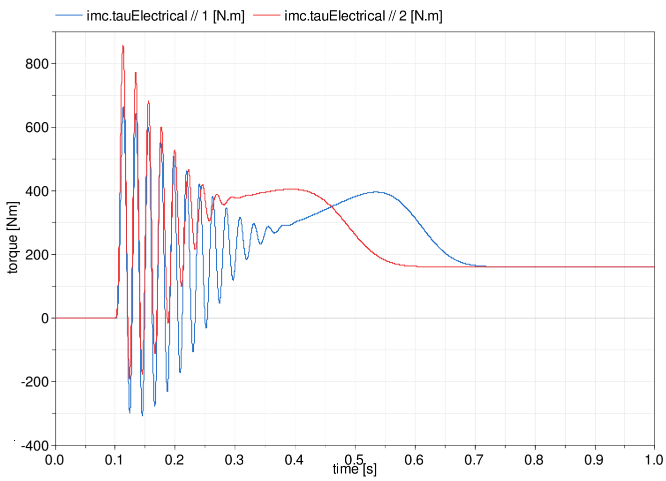

Figure 1. Transient torque w/o (blue) and with (red) skin effect

The EMachines library will be released as a supplemental library to the commercial EDrives library (Haumer, Kral, 2014).

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Simulation of Piping 3D Designs Powered by Modelica

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Traditionally, piping systems have been defined in Modelica by connecting components in a model diagram. Additionally, the systems engineer must enter values for parameters such as pipes diameter and length, volume of vessels, etc. Those values are often also defined in CAD piping 3D designs, for example in CATIA by Dassault Systèmes. A more convenient definition of the piping system can be made by using the data from the CAD environment.

A tool has been developed to extract data from CATIA piping 3D designs. This information is used to generate the corresponding Modelica representation.

Methodology based on the use of Modelica extends (inheritance) is applied to add controllers and other features to the generated model for dynamic simulation. Simulation results can be visualized directly in the 3D view of the piping design.

With the proposed approach of generative Modelica representation of piping 3D designs, the collaboration between CAD designers and system engineers will become easier. The automated exchange of data improves efficiency and reduces the risk of errors.

Figure 1. Animated piping 3D design

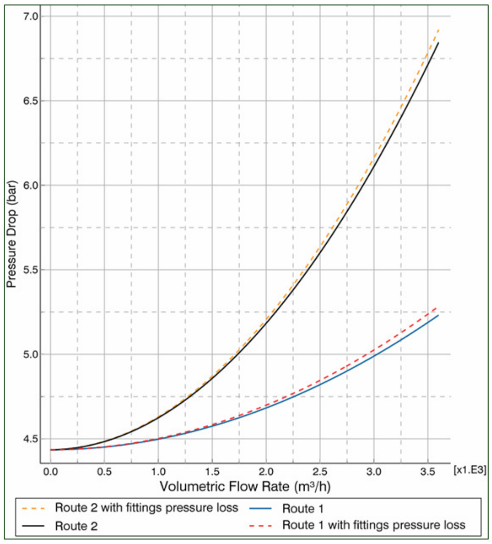

Figure 2. Computed pressure drop

Keywords: CAD, 3D, Piping, simulation, Modelica code generation

3D Schematics of Modelica Models and Gamification

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Block diagrams have been used for a long time to express data flow in dynamic models, i.e. the input output relations between calculation blocks. SysML diagrams are also used to express other relations such as component hierarchy and inheritance. Modelica uses object diagrams, a generalization of block diagrams since acausal connections are allowed. CAD uses a 3D representation to represent the assembly of a mechanism, i.e. how bodies are coupled with joints. This paper describes a generalization of object diagrams, called *3D Schematics*, to utilize 3D representations of the icons/shapes and unification with assembly diagrams and exploded views.

The ideas have been prototyped in a program called Playmola which is inspired by computer games. The goal is to make a model authoring environment that is much more intuitive and fun than existing ones. The hope is that such a tool would be used to promote science for students already in high-school.

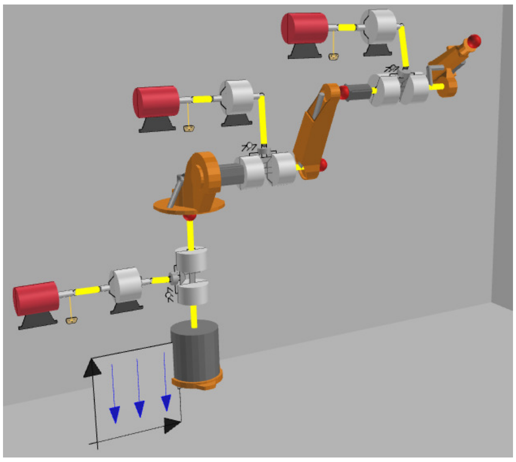

Figure 1. Exploded view of Robot model with motors and gearboxes in Playmola

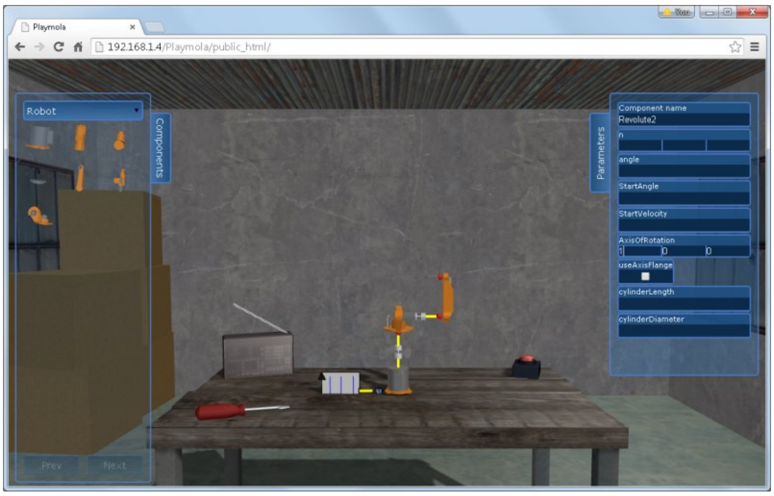

Figure 2. Garage environment for visual experiments in Playmola

Holistic Virtual Testing and Analysis of a Concept Hybrid Electric Vehicle Model

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The electrification of automotive powertrains is one of the key factors in meeting the development targets for fuel consumption and emissions. Both with and without the use of plug-in technology, powertrain hybridization assists the internal combustion engine in operating in optimal conditions and enables the recuperation of kinetic energy during braking. It also helps to increase fuel efficiency and reduce exhaust gas emissions.

Given the wide range of hybrid electric vehicle variants, finding optimized setups often poses a challenge due to the varying boundary conditions, different cases of application, as well as interdependent vehicle subsystems. In this case, optimization processes and tools assist in finding the best compromise, taking into account all the various constraints.

In this paper; the development, integration, and analysis of a hybrid electric vehicle (HEV) using system-level virtual testing will be presented.

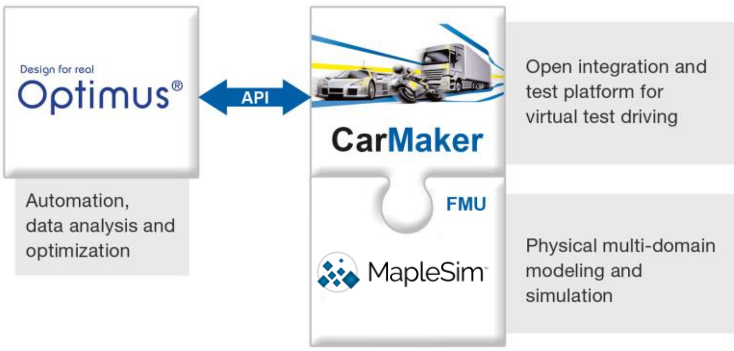

Figure 1. Modeling, Simulation and Optimization Environment

The work will discuss how a Modelica-based Parallel HEV powertrain model developed using MapleSim™ is integrated into an industrial vehicle modeling software tool (IPG CarMaker®) using the Functional Mockup Interface (FMI) standard; and how virtual testing and analysis was performed with an optimization tool (Noesis Optimus®).

The acausal modeling of the HEV powertrain was done using Modelica 3.2.1, allowing the flow of energy to be inferred from the operating characteristics and controller design. The multidomain model uses components from the electrical and mechanical libraries, and commercialized library components from MapleSim's Driveline Component Library and Battery Component Library.

Modeling of an Automatic Transmission for the Evaluation of Test Procedures in a Virtual End-of-Line Test Bench

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End-of-line tests for automatic transmissions are mandatory to ensure quality and safety. The interaction of unit under test, test bench and test automation leads to a high complexity in the development of test automation and test procedures. Validation of test automation and test procedures requires access to the test bench and the unit under test, both of which are only available close to startup of production. Therefore, virtualization of test bench and unit under test can be used to ease the bottleneck.

Virtualization is a common tool in the development of electronic control units for automotive applications using SIL and HIL technologies. The properties of simulation models for a virtual end-of-line test bench differ from those for classical SIL and HIL environments. In this paper, an automatic transmission model suitable for a virtual end-of-line test bench is presented. The characteristics of an extended *kpki friction model* based on the implementation of (Bai et al., 2013) are discussed in detail. Hydraulics are modeled using a Moore machine to enable simulation of the pressure build-up characteristics during shift operation.

With the resulting model, the influence of the key parameter of a test procedure actuating an overlapping gearshift is investigated in a virtual test system. Figure 1 shows the simulation results of the parameter study with varied sleep time between clutch actuation. The characteristics of the variable clutch pressure p, rotational speed ω and shaft torque T are discussed in detail.

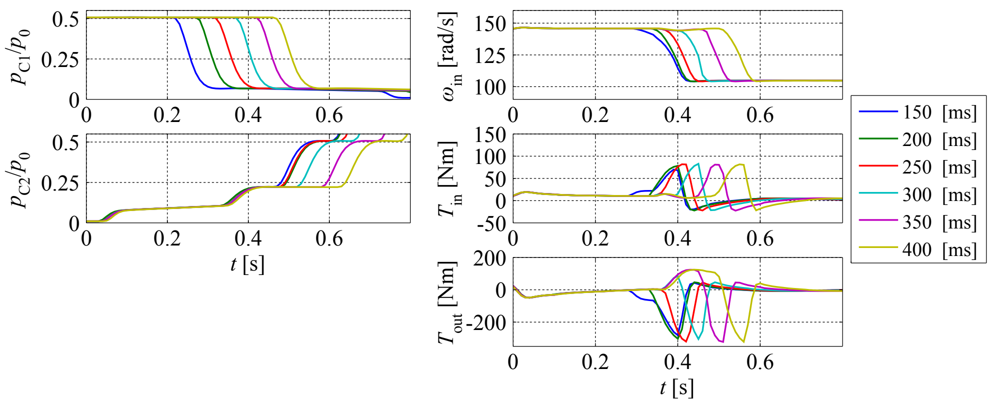

Figure 1. Simulation results of hydraulic pressure, rotational speed and torque

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A New Fault Injection Method for Liquid Rocket Pressurization and Feed Systems

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In the design of liquid rocket pressurization and feed systems, ground tests are the most widely used method for fault diagnoses. However, it is really hard or impossible to reappear some fault modes because of equipment restrictions, let alone covering all possible flight conditions. Fault simulation based on numerical method is an ideal way to overcome the shortage of ground tests. It relies on a detailed model of system behavior under nominal and faulty conditions (Daigle, 2011).

In this paper, we present a new fault injection method for liquid rocket pressurization and feed systems (PFS) without modifying the system structure. In particular, we develop a physics-based model of pressurization and feed systems based on Modelica, which describes both nominal and faulty behaviors in a unified way. To handle a large number of fault modes in PFS, we develop a configuration XML file containing all kinds of fault modes in a unified way. The XML file could be easily modified from GUI. In fact, the Modelica model and the fault mode are implicitly connected via the fault parameter, which lies in both the Modelica model and the fault mode. To realize the mapping between them, we introduce a mechanism that associates the Modelica model with specific fault modes based on customized Modelica annotation in MWorks®. The detailed process is given as below.

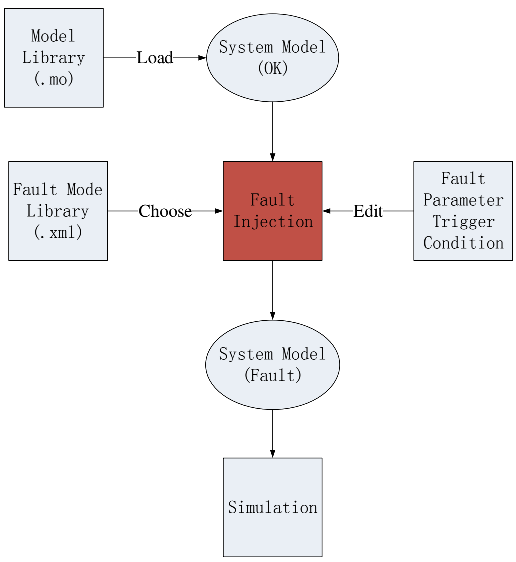

Figure 1 Fault Simulation Process

To prove the correctness of the system model and usefulness of the proposed method, we simulate several typical fault modes such as leakage and clogging and investigated their effects on the system performance.

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Automated Safety Analysis by Minimal Path Set Detection for Multi-Domain Object-Oriented Models

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The presentation and corresponding paper describe a method called DMP that integrates safety or reliability analysis with multi-domain object-oriented modelling. In essence, the method automatically Detects the Minimal Path (DMP) set of any fault-tolerant technical system. DMP is based on the simulation of normal behaviour, degradation and failure of a system. Thus, modelling of failures has to be supplemented to component models from generic libraries, e.g. the Modelica Standard Library, that typically represent only normal, intact behaviour. Minimal path set analysis generally assumes that a system and its components are two-state, i.e. intact or failed.

The DMP method is a state space simulation. In this context, the state space denotes the set of all combinations of intact and failed components of a system to be examined for detection of its minimal path set. The object structure of the system model is represented as a graph, in which nodes correspond to components, and edges correspond to connections. Evaluation of the graph reduces the size of the state space and hence the number of simulations required.

DMP starts with all components (nodes) of a system being intact. Nodes are then successively removed from the system graph, which corresponds to component failures. The model is simulated to identify if the system still operates or fails. Articulations can occur in the graph that, if removed, cause disconnection of the graph into several subgraphs. Since only a coherent set of intact nodes can be a minimal path, splitting up the graph at articulations reduces the state space. The lower the density of a graph is, the more articulations occur within it and thus fewer simulations are required. For completeness, method DMP allows that articulations can also belong to a minimal path.

DMP enhances the scope of application of a model while permitting all other simulation studies that originally motivated implementation of the model to be conducted. The method can be employed throughout the system development process to keep the safety analysis up-to-date with design iterations.

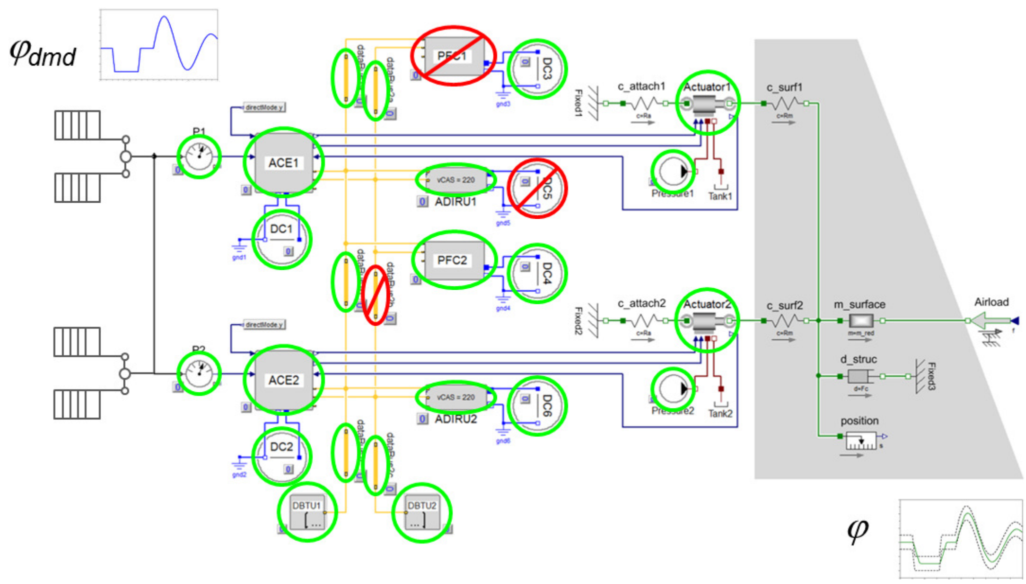

Figure 1. Safety analysis by state space simulation of an aircraft's rudder control system

High-fidelity Modelling of Self-regulating Pneumatic Valves

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In conventional aircraft energy systems, self-regulating pneumatic valves (SRPVs) are used to control the pressure and mass flow of the bleed air. The dynamic behavior of these valves is complex and dependent on several physical phenomena. In some cases, limit cycles can occur, deteriorating performance.

This paper presents a complex multiphysical model of SRPVs implemented in Modelica. First, the working-principle is explained, and common challenges in control-system design-problems related to these valves are illustrated. Then, a Modelica-model is presented in detail, taking into account several physical domains. It is shown, how limit cycle oscillations occurring in aircraft energy systems can be represented with this model. Finally, some multi-domain interactive effects are described.

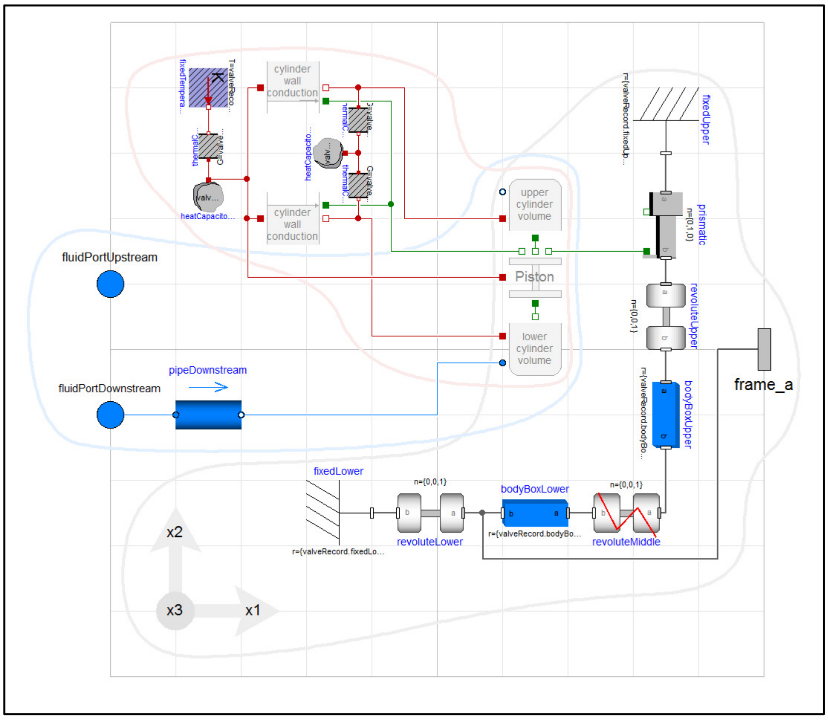

Figure 1. Modelica component layer of the valve-actuator base model

Dynamic Modeling of a Central Receiver CSP system in Modelica

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A dynamic model of a Central Receiver type CSP plant (CRS) was implemented in Modelica. The model consists of a set of CRS specific components, along with a Rankine cycle to form a complete system. Main components include models of a sun, heliostat field, receiver, storage tank and a Rankine cycle including a steam generator. The system uses a molten nitrate solution, called Solar Salt, as heat transfer fluid.

The components were modelled and configured after a reference system – the Solar Two test facility in CA, USA, operational in the late 1990's – but are generic and rescalable. A graphical view of the combined system model is illustrated in Figure 1.

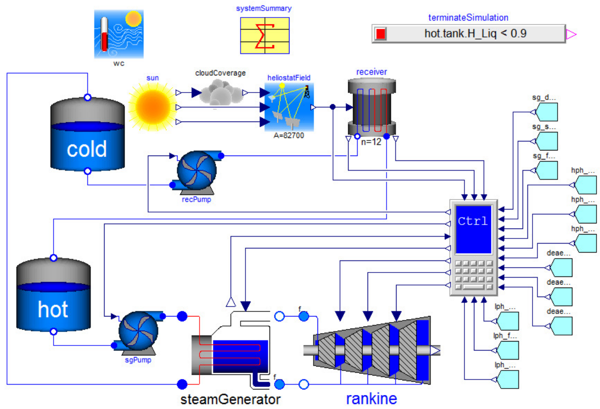

Figure 1. Combined system model.

The components and the full system were tested in a series of simulations – both dynamically and during steady state conditions – and the results were compared to data from the reference system. The dynamic behavior of the models aligned with expectations, although time constants could not be evaluated due to lack of dynamic reference data. The steady state characteristics were adequate for most models, although some complementary work needs to be done on the Receiver model.

This work is the result of a Master Thesis project at Lund University in collaboration with Modelon AB, Lund, Sweden (Edman, 2014). The models developed are largely based on the various model libraries in Modelons portfolio, especially the ThermalPower library, the LiquidCooling library and the Modelon Base library.

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Modeling of Linear Concentrating Solar Power using Direct Steam Generation with Parabolic-Trough

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Concentrating Solar Power (CSP) is a renewable electricity generation technology that uses sun's Direct Normal Irradiation (DNI) to generate electricity through a conversion from thermal energy to mechanical work with the help of a thermodynamic cycle. In its latest Technology Roadmap report (OECD/IEA 2014), the International Energy Agency estimates that with appropriate R&D support, the contribution of CSP to the global electricity production could reach 11% in 2050.

Among the several CSP technologies, parabolic-trough uses linear concentration to collect heat with a fluid flowing inside an absorber tube located at the focal line of a parabolic mirror. The process of using water as the heat transfer fluid in the tubes and generating steam for a direct use as the working fluid of the thermodynamic cycle is referred as Direct Steam Generation (DSG). It offers several advantages and has potential cost reductions effects, compared to technologies using other heat transfer fluids and heat exchangers (Eck et al. 2008; Feldhoff et al. 2009). The combination of the natural transient condition of solar irradiation and the dynamics induced by the presence of a two-phase flow inside the absorber tubes results in a behavior of the steam generation system that is strongly dynamic. Modeling this behavior at the system scale is useful for the sizing and design of both the solar field and its control system.

This papers deals with the Modelica /Dymola modeling of linear Concentrating Solar Power in a parabolic-trough experimental loop using direct steam generation. An extensive description of the parabolic collector and the absorber tube models is proposed. First results of the simulation of a clear sky day, with the aim of validating the models, is proposed. Experimental data from the CIEMAT-PSA DISS loop in Almeria, Spain, is used. Good behavior agreement is found between experiment and model, although adjustments to the model need to be done to make its accuracy satisfactory.

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Transient Simulation of the Power Block in a Parabolic Trough Power Plant

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Abstract

In the field of concentrated solar power (CSP) plants, parabolic trough systems with thermal oil as heat transfer fluid represent the technically and economically most mature technology. Due to storage systems these plants produce electricity on demand. However, a considerable portion of the annually collected thermal energy is consumed for the start-up procedure. In fact, after shut-down periods thermal masses must be reheated and additionally further energy losses due to imperfect start-up procedures occur. The present work has been carried out within the TURIKON project. The main goal is to evaluate and to optimize the transient behavior, namely the start-up of parabolic trough plants with thermal oil. For this purpose, a dynamic model was developed. An internal DLR solar library was used for the modelling of the solar field while the power block is modelled with the publically available ThermoPower library where some components had to be adapted for the needs of CSP plants. In the present publication first results are shown in order to demonstrate the capabilities of the plant model. The dynamic behavior of the power plant during normal operating mode and during a warm and a hot start-up procedure is evaluated and the warm start-up procedure energetically optimized.

Keywords: transient power block simulation, parabolic trough, concentrated solar power

Fault Detection and Diagnosis with Modelica Language using Deep Belief Network

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The air handling unit (AHU) is the main component of heating, ventilation and air-conditioning (HVAC) systems, and irregular faults in AHUs are major sources of energy consumption. Most researches accomplished FDD through simple amounts of sensors or regardless of real control logic of AHU in HVAC system. However, Modelica can make the AHU and HVAC system like as a real system. Modelica carried out the modeling for AHU in HVAC system of a building as shown in Figure 1.

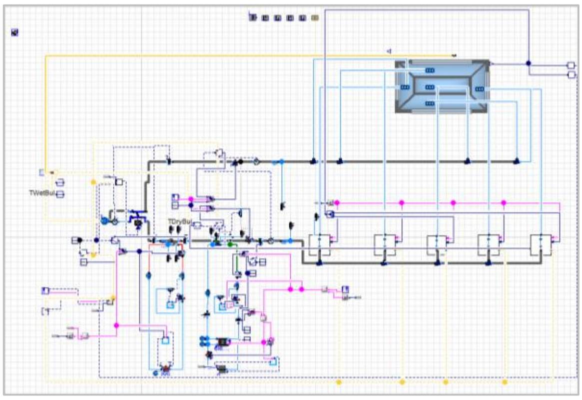

Figure 1. AHU system accomplished by Modelica

For energy efficient operation of HVAC, this paper aims to detect and diagnose three abnormal states in the AHU. After the application of results with Modelica as the normal and abnormal data, the fault detection and diagnosis process using machine learning is achieved as shown below. Data are filtered through the pre-process procedure, machine learning with a classifier procedure, and fault detection and diagnosis accomplished by the post-process procedure. In this research achieve with the popular deep learning model, called Deep Belief Network (DBN), where we train it using various data generated by Modelica.

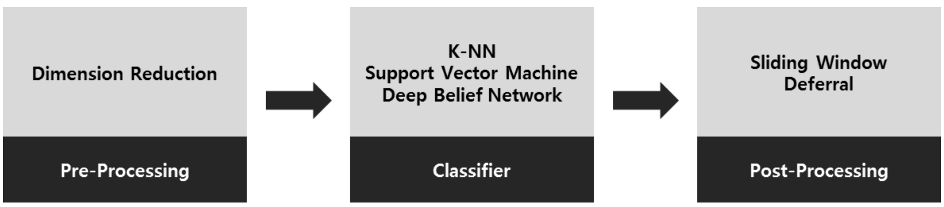

Figure 2. Process of FDD

References

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Formal Requirements Modeling for Simulation-Based Verification

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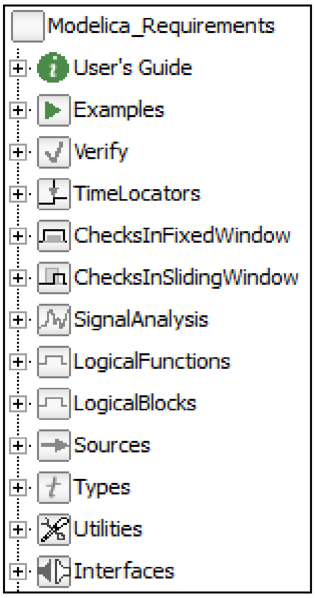


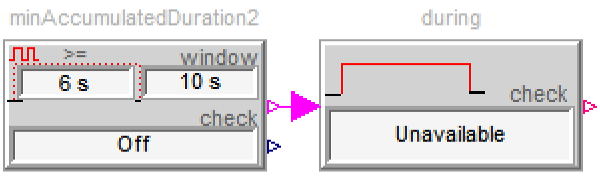
This paper describes a proposal on how to model formal requirements in Modelica for simulation-based verification. The approach is implemented in the open source Modelica_Requirements library (see figure to the left). It requires extensions to the Modelica language, that have been prototypically implemented in the Dymola and Open-Modelica software. The design of the library is based on the FOrmal Requirement Modeling Language (FORM-L) defined by EDF, and on industrial use cases from EDF and Dassault Aviation.

The approach is to (a) provide the open source library Modelica_Requirements to define and model requirements in a formal way using 2- and 3-valued linear temporal logic and other description forms; (b) associating requirement models with behavioral models; (c) testing whether the defined requirements are violated by the system design currently studied when the underlying behavioral models are simulated.

For example the textually described requirement (from an EDF use case)

> *When the MPS (Main Power Supply system) is switched off, signaled by Boolean Off, then the MPS must be declared Unavailable when it has been off for more than 6 accumulated seconds during any 10 seconds time window.*

can be modelled in the following, formal way with the Modelica_Requirements library:



Component `minAccumulatedDuration2` outputs `true`, if in any time window of length 10 s variable `Off` was accumulated `true` for at least 6 s. This signal is the input to component `during` which requires that whenever the input is `true`, variable `Unavailable` must be `true` as well. In that case the block outputs `Satisfied`. If the input of `during` is `true` and `Unavailable = false`, the requirement is clearly violated and the `during` block outputs `Violated` (if the input is `false`, the block outputs `Undecided`).

Towards a Formalized Modelica Subset

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Originally designed to address multi-physics simulation, Modelica integrates constructions to describe discrete system controllers since its specification version 3.3. I makes it possible to describe the physical environment as well as the system controllers within the same model. The ability to write controllers directly in Modelica makes it tempting to directly generate the actual embedded code from the model coupled with its simulation. Once this has been stated, there is only one small step that leads to considering embedding the generated code in safety-critical environments, such as airplanes.

Software that is embedded into such critical systems must respect qualification activities. Among them, we can find processes that must be followed for embedded code. These processes state requirements expecting strong guarantees on the language and tools that are used during developement. In particular essential guarantees are *determinism* and *absence of ambiguities*. One of this process is the DO-178C (2011) normative text used in aeronautics.

In this paper, we develop a formalization framework for a practical Modelica subset based in Thiele et al. (2012). The goal of this formalization is to provide a comprehensive and consistent description of the available constructs and how they interact. This approach has the advantage of being non ambiguous, in comparison to natural language formulation which cannot exhibit evidence that it cannot be interpreted in various contradictory ways. Furthermore, based on this formalism, it is straight forward to write an implementation that respects it.

This paper focuses on the static name resolution problem, and shows how it can be described within our framework. This example shall emphasize the advantages of such a formalization and illustrate how it can be used to solve ambiguities in the language design to meet the need of precise requirements in a qualified development process.

Even if this formalization is intereseting *per se*, it is also a first step that is necessary to define a complete modeling language that can be used to design safety critical applications. Our approach takes its origins from our previous experience on the Scade 6 language, the industrial dialect of the Lustre dataflow language, introduced in Halbwachs et al. (1991), used to produce qualifiable code to embed.

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Fundamental EoS Implementation for {Water+Ammonia} in Modelica

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The implementation of a library for the calculation of thermodynamic properties for the mixture {water + ammonia} based on a fundamental equation of state (EoS) for the Helmholtz free energy is developed and presented. The model uses the formulation of Tillner-Roth and Friend (1998) in order to provide the best available single state thermodynamic data. The calculation of the vapour-liquid equilibrium (VLE) with the aid of the fundamental equation of state is examined. However due to difficulties found under certain pressure and temperature conditions (see Figure 1), another method for calculating the VLE had to be used. The problems found included unreliable results and difficulties setting the initial values. Saturation temperature polynomials by Johnson et al. (2001) have been found to be faster and more reliable and have been implemented instead. It's possible to calculate thermophysical properties in single and two-phase region at pressures from the melting point up to 40 MPa.

In this paper the problems found to solve a VLE set of equations using an EoS of Helmholtz energy for two phase mixtures with Modelica are identified and discussed. An alternative and simpler solution for the VLE is presented and implemented in a fully working media library for the for the mixture {water + ammonia}.

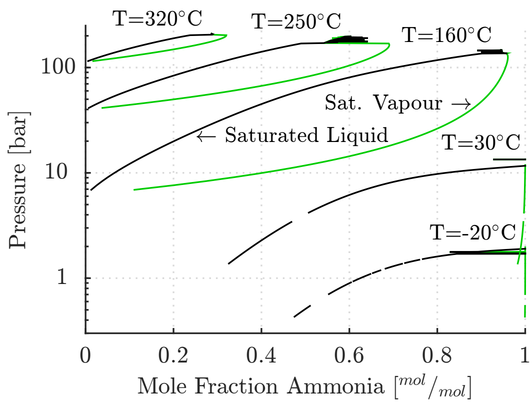

Figure 1. VLE Solution for different temperatures

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MultiComponentMultiPhase – a framework for thermodynamic properties in Modelica

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This paper describes the development and requirement specification of an open-source framework for multi-phase multi-component thermo properties in Modelica. The goal is to have a standardized interface to multi-component multi-phase fluids with access to external property packages in Modelica. This will make it easier to develop models for e.g. the process industry. The library uses a model based interface and implications of such a design are analyzed and compared with the traditional function based interface.

The availability of properties for steam and flue gases initiated the use of Modelica in the power industry, where it today is a well-established technology with several commercial and open source libraries available. High quality fluid properties are laborious to produce and their non-availability is therefore a typical blocking argument for the use of a certain tool or technology.

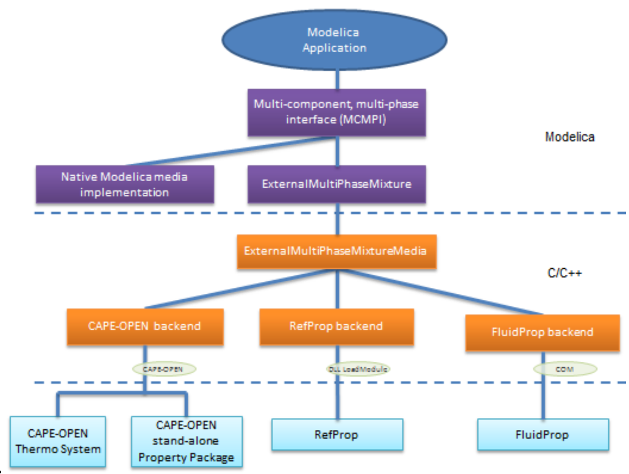

Figure 1. Overview of external framework structure.

In this project a Modelica library for multi-phase multi-component fluids has been developed together with an external C/C++ Modelica property interface with back ends to CAPE-OPEN, RefProp and FluidProp. The framework also contains a Modelica library for distillation processes for verification and testing of the media interface design.

Modeling of the German National Standard for High Pressure Natural Gas Flow Metering in Modelica®

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The German national primary standard for high pressure natural gas flow metering is a High Pressure Piston Prover (HPPP). It is used to calibrate transfer or working standards for high pressure natural gas flow metering and is traceable to the standards of length and time. The HPPP is operated and owned by the German national metrological institute Physikalisch-Technische Bundesanstalt (PTB) and currently installed on the calibration site for gas flow meters pigsar™ in Dorsten, Germany. The uncertainty of high pressure natural gas flow meters and therefore also the uncertainty of the HPPP as their primary standard in Germany is of major importance for the trade with natural gas. Figure 1 shows a picture of the HPPP.

Figure 1. Picture of the High Pressure Piston Prover (PTB , 2009)

The HPPP consists basically of a piston in a cylinder. The gas flow rate is measured using the time the piston needs to displace a defined enclosed volume of gas. Fluctuating piston velocity during measurement can be a significant source of uncertainty if not considered in an appropriate way (Mickan et al., 2010). A computational model was developed to investigate measures for the reduction of this uncertainty. It is written in Modelica®. The model validation shows good accordance of the piston velocity fluctuations in the model with measurement data for certain volume flow rates. Three independent ways to reduce the piston velocity fluctuations were demonstrated using the developed model. A significant reduction of the piston velocity fluctuations was achieved in the model by lowering the piston weight, controlling the start valve switching time and integrating a flow straightener.

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Automatic Regression Testing of Simulation Models and Concept for Simulation of Connected FMUs in PySimulator

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Alachew Mengist[1] Martin Sjölund[1] Adrian Pop[1] Peter Fritzson[1]

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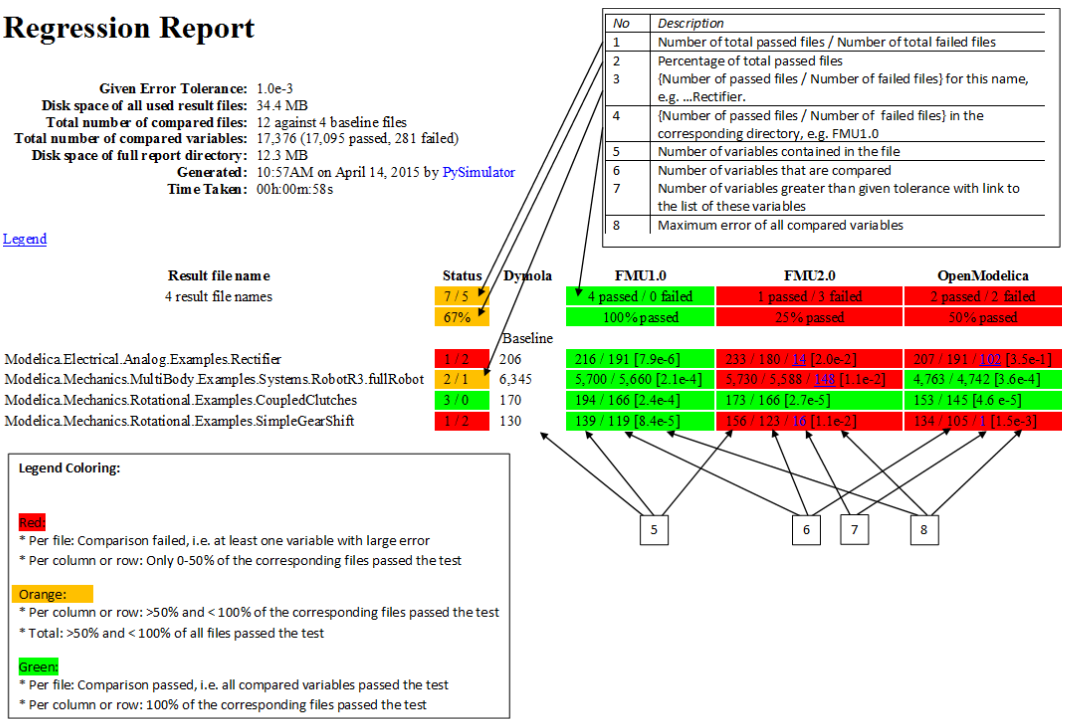
The Modelica and FMI tool ecosystem is growing each year with new tools and methods becoming available. The open Modelica standard promises portability but it is important to ensure that a certain model behaves the same in different Modelica tools or in a different version of the same tool. It is also very important (for model evolution) to check that a new version of the same model produces comparable results. Finally, it is desirable to verify that a model exported in FMU form from a Modelica tool gives exactly the same results as the original model. This paper presents a framework for automatic regression testing as part of PySimulator which provides an efficient and concise way of testing if a model or a range of models behaves in the same way in several tools or versions of a tool by checking that the results produced are essentially identical. The following regression report summarizes the comparing of different result files.



The FMI standard has been adopted by many tool vendors and is growing in popularity each year. This paper proposes a concept for building and simulating a system made from connected FMUs generated by different tools. The FMUs for Co-Simulation can be connected together using a GUI. The system model built graphically in this way can be saved for later use or simulated directly inside PySimulator. Active development is going on to also support simulation of connected FMUs for Model Exchange.

Abrasive waterjet intensifier model for machine diagnostics

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Waterjet/abrasive waterjet (AWJ) cutting machines are used for several industrial applications thanks to the great flexibility of the technology, which is suitable for cutting a wide range of materials [1]. This kind of machine tools includes an Ultra High Pressure (UHP) pump to generate the necessary pressure energy that is then converted into kinetic energy by the orifice into the cutting head. Different components, either belonging to the UHP pump or the cutting head, are subject to different kinds of faults and performance degradation, due to the challenging pressure conditions and the aggressiveness of abrasive particles.

The reliability of AWJ cutting machines is therefore a topic of major concern in industry. A fast detection of a faulty state and the automatic identification of the root cause for observed symptoms are expected to provide several benefits, including the reduction of unexpected machine stops, a quick leakage recovery, the minimization of wastes, the enhancement of maintenance operations, etc.

There are several studies in the literature devoted to AWJ process monitoring [2-4], mainly related to the determination and possible improvement of the cut quality. Nevertheless, very few authors investigated the development of automated tools for in-process monitoring and diagnosis of machine tool health conditions [5-7]. One of major challenge consists of characterizing the AWJ plant behavior under both healthy and faulty conditions, in order to train fault classifiers. Real data under faulty states are always difficult and expensive to collect, which makes purely data-driven diagnostic methods poorly attractive for a practical use. Model-based methods are expected to yield more effective diagnostics capabilities, thanks to the possibility of simulating the plant behavior under different operating conditions. This paper investigates the dynamics of an AWJ plant with multiple phased single-acting plungers, and it represents a first attempt to design an object-oriented dynamic model for such a kind of system. The model may be tuned to generate simulated signal patterns under different health conditions in order to train multi-fault diagnosis tools. The proposed model generates simulated water pressure and plunger displacement patterns, which can be used to characterize the AWJ working cycle. The injections of degraded states and faulty conditions into the model allows one to characterize the pattern deviations from the natural state, and hence to develop novel model-based fault detection and classification toolkits. The dynamic model is validated with respect to real-industrial data, acquired in reference cutting scenarios. Those data includes signals under healthy states and in the presence of faults affecting either the UHP pump components (cracked cylinders) or the cutting head components (broken orifices).

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Optimica Testing Toolkit: a Tool-Agnostic Testing Framework for Modelica Models

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The need for regression testing increases as the size and complexity of software project grows. This is no different from a Modelica library or tool. Large Modelica projects often involves several Modelica tools and libraries which are under development. In those situations, with several orthogonal code bases, the need for systematic regression testing is needed. To address this, Optimica Testing Toolkit (OTT) was developed. OTT is a framework for performing automatic testing on Modelica models.

OTT also provides a testing pipeline that is tool agnostic, meaning it provides the same testing pipeline regardless of what compiler and simulator performs the actual model compilation and simulation. Tool agnosticism is provided by means of an abstraction layer between OTT and the actual tools. Each tool is hooked into the abstraction layer via a plugin tailored specifically to that tool.

As part of the development cycle a Graphical User Interface (GUI), seen in figure 1, was developed. The GUI can be used for test authoring, test configuration and test execution. One important aspect considered during development was to ensure that the GUI had good usability. We used a number of different user studies together with the users in order to discover usability problems, and then used iterative development to address and fix those issues.

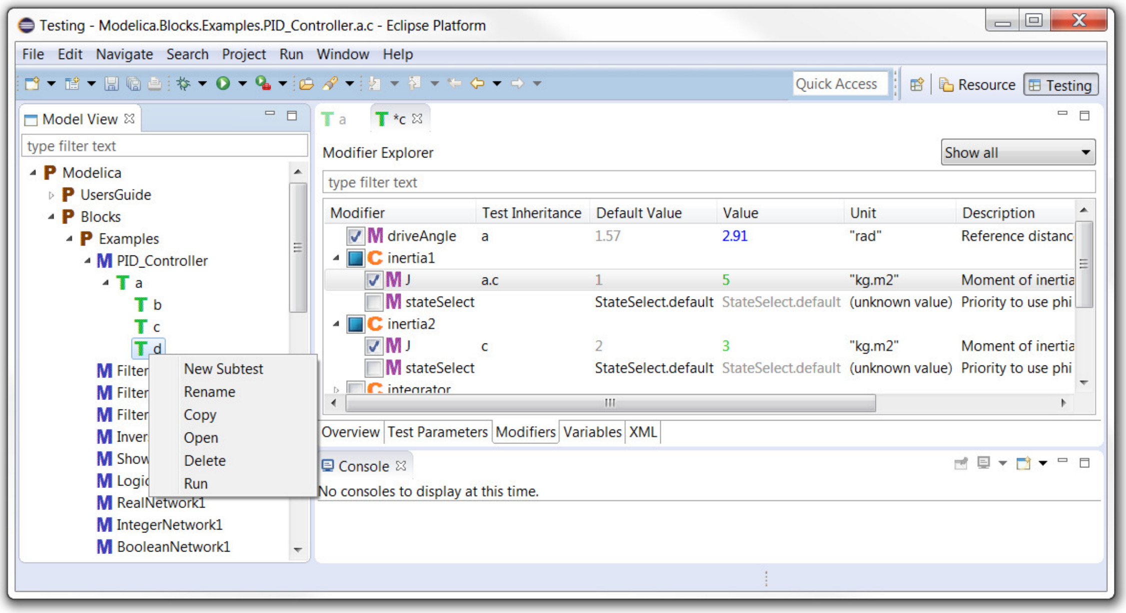

Figure 1. The OTT GUI.

Status of the TransiEnt Library: Transient simulation of coupled energy networks with high share of renewable energy

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Growing shares of fluctuating renewable energy generation technologies in power systems lead to temporal and regional imbalances between electricity supply and demand. Technologies that increase the operation flexibility of the grid (such as demand side management, power-to-heat, power-to-gas or flexible combined heat and power plants) are therefore gaining on importance. Simulation platforms enabling the coupled simulation of electricity, district heating and gas grids are needed to evaluate renewable energy integration strategies in urban energy systems. This is the goal of the `TransiEnt` model library which is being developed within the *TransiEnt.EE*[1] research project. This paper presents the current status of model library and outlines its structure and modeling concept. After completion, the library will be freely available and will provide a framework to model coupled energy grids, i.e. electricity, district heating and gas grids, including their corresponding producers, consumers and storage (see Figure 1). The usage of the library is illustrated in this paper by modeling and simulating an urban energy system based on the city of Hamburg. The impact of a high share of fluctuating renewable energy generation in the electric grid and the integration of excess electricity in the district heating network is presented.

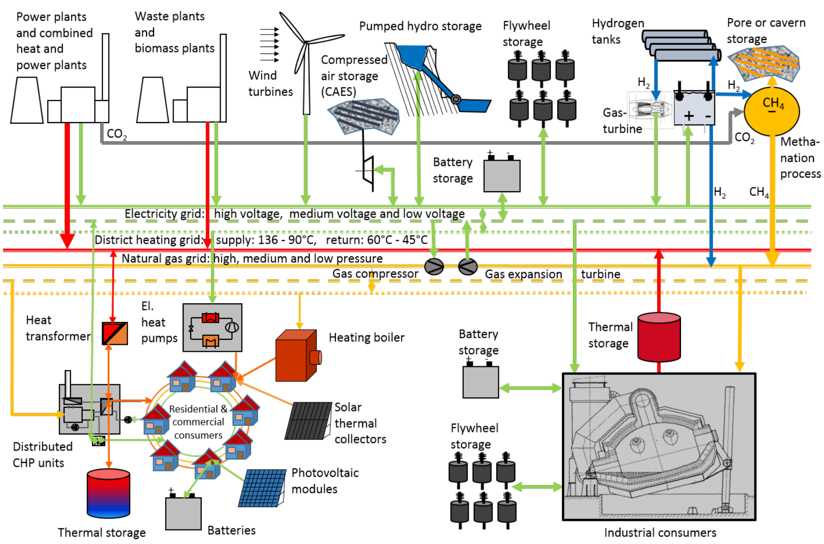

Figure 1. Scheme of coupled electricity, district heating and gas energy supply systems including their corresponding small- and large-scale producers, consumers, and storage systems.

[1] http://www.tuhh.de/transient-ee/

Mathematical Model of Soot Blowing Influences in Dynamic Power Plant Modelling

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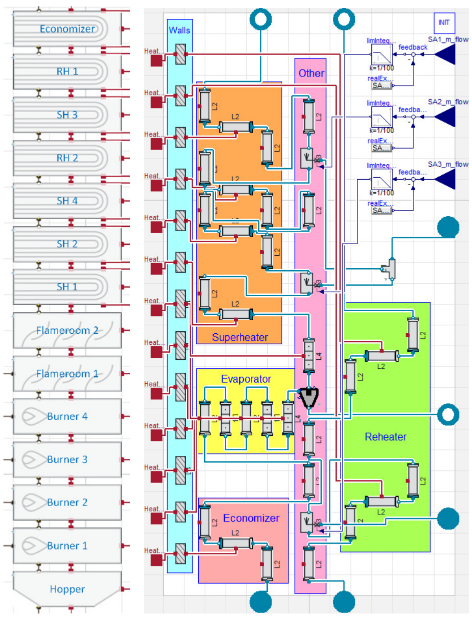
Due to the increasing integration of renewable energy sources in the existing power grid the conventional power plants have to set their focus more on flexibility and grid stabilization than supplying the base load. Since this task was not foreseeable when designing the currently existing power plants, they will have to suffer completely different load scenarios than expected. Dynamic modelling of complete steam cycles is a promising way to study the power plant operation of various future scenarios.

To adapt the model to real power plant behaviour, especially with a focus on control events, the implementation of effects due to steam blown into the gasside part of the boiler in order to detach soot from the heating surfaces (soot blowing) seem to bring great efforts concerning model validity. Furthermore special control optimizations can be done, for example on spray injection at soot blowing events. In this study temperature measurement data is used in combination with a highly detailed boiler model of the 550 MW hard coal fired power plant Rostock to build a mathematical model of soot blowing influence on the different heat exchangers.

The physical model, see Figure 1, has been made using the new open-source library ClaRa.



(a) Gas Side **(b)** Water Side

Figure 1. Gasside and Waterside parts of the developed boiler model

The validity of the mathematical model is tested using a real steady load scenario as inputs for the hybrid model containing both, the physical boiler model and the developed mathematical model for the soot blowing influence.

Flexibilization of coal-fired power plants by Dynamic Simulation

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Due to the strong expansion of the fluctuating renewable energies (wind and photovoltaic), the boundary conditions for coal-fired steam power plants are changing significantly. The residual load will be much more volatile than in the past. From this development, a trend towards a highly flexible operation of conventional steam power plants can be derived. Key challenges for a highly flexible power plant operation are the reduction of the minimum load and the increase of the load change rate. Dynamic simulation models play a central role for the improvement of the transient operation as they provide a "tool" for the evaluation of flexibility measures.

This paper presents the dynamic modeling of a coal-fired power plant in Modelica/Dymola using the power plant library ClaRa (Clausius-Rankine). The focus is on the detailed non-steady-state modeling of the steam generator and the validation of the dynamic simulation model. Additionally, first results of simulation studies about the integration of a thermal energy storage and the increase of the load change rate are presented.

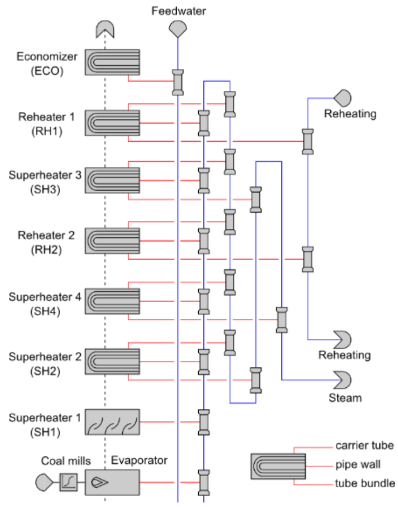

Figure 1. Modular structure of the steam generator model

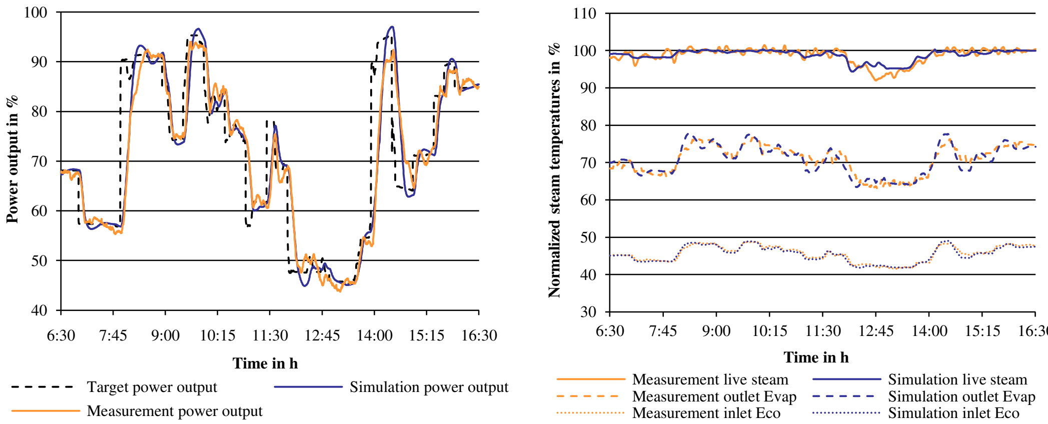

Figure 2. Comparison of the simulation (blue) and measurement values (orange) for power output (left diagram) and water-steam temperatures (right diagram)

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Where `impact` got *Go*ing

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This paper discusses the `impact` package manager. The primary goal of this project is to support the development of a healthy eco-system around Modelica. For many other languages, the existence of an easy to use package manager has made it easier for people to explore and adopt those languages. We seek to bring that same kind of capability to the Modelica community by incorporating useful features from other package managers like `bower`, `npm`, *etc.*

This paper is an update on the status of the `impact` package manager which was discussed previously in (Tiller and Winkler 2014). This latest version of `impact` involves a complete rewrite that incorporates a more advanced dependency resolution algorithm. That dependency resolution will be discussed in depth along with many of the subtle issues that arose during the development of this latest version of `impact`. Along with a superior dependency resolution scheme, the new version of `impact` is much easier to install and use. Furthermore, it includes many useful new features as well.

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Visualizing Simulation Results from Modelica Fluid Models Using Graph Drawing in Python

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Models of large thermo-fluid networks can be useful to better understand the dynamic behavior of complex systems. Yet, numerical outputs and line plots of individual variables may not be sufficient ways of processing the simulation results for the user. Thus, the aim of this paper is to present a visualization approach by means of graph drawing. To demonstrate the approach, we use an example from the Modelica Standard Library and the use case of a district heating system model. We parse the Modelica model code to generate a `System` graph that represents the model structure and its graphical layout. The graph drawing subsequently visualizes the results for every time-step. In the examples, we vary line thickness to visualize mass flow rates between two nodes and line color to show temperatures of the medium. We argue, that this approach can be a useful tool for modeling and analysis.

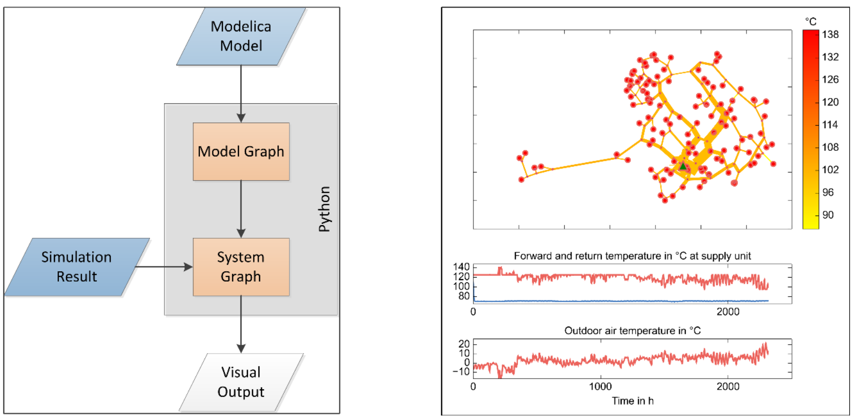

Figure 1. Process scheme and example of visual output for a district heating network simulation

The left of Fig. 1 shows a process scheme, illustrating how a Modelica model is represented in the form of a `Model` graph in Python and subsequently converted to a `System` graph. The `System` graph is designed to give a clear representation of the system layout, add data from simulation results, and provide a visual output according to the specifications of the user. One example of such visual output is given on the right of Fig. 1, generated from a district heating network model and its simulation result file. In a next step, such visualization output images are be combined into a video animation in order to present the dynamic behavior of the system. In addition to the visualization functionalities, we plan to use the Python graph structure as a foundation for automated generation of Modelica models, thus providing an integrated workflow to handle the complexity of input and output data for large thermo-fluid network modeling.

Reuse of Physical System Models by means of Semantic Knowledge Representation: A Case Study applied to Modelica

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Abstract

The emerged knowledge from a system's study shall be persistent and shared to increase the possibilities of improvement and apply it to other similar systems or situations. It is possible to design models that show the real conditions of the represented system by describing it conceptually, in a universal and normalized language that any domain expert could understand.

This paper presents the design and development of a solution to store and reuse physical system models (PSM) by indexing and retrieving their content and metadata. To do so, a mapping between the representation modelling language, Modelica, and a semantic-based representation schema, Relationship-RSHP, is defined as Modelica2RSHP (M2R). The use of Modelica, as a highly used language within the industry domain for modelling physical systems and the RSHP schema and used for years in systems engineering for knowledge management, enhances the strategy to map Modelica physical system models to RSHP as a direct link to perform simple transformations and to provide the basis to define and compare complex transformations. More specifically, the goal of the M2R approach is to establish the needed interconnection between the PSM domain and the knowledge field, by importing PSM, as electrical circuits designed under Modelica language into system repositories where their semantic information is kept for their persistency.

In order to design the interconnection between Modelica language and RSHP model, there have been specified the regular tree grammars that can be used for a transformation between both Modelica and RSHP grammars. The M2R has been implemented using the .NET framework. For that, it was required to build the Java JModelica sources to parse Modelica v3.2 and to extract the Java libraries dependencies to generate a script that transform the required Java libraries into .NET DLLs interpreted in .NET through the IKVM, an implementation of Java interpreter for .NET framework.

The M2R tool is also designed to be added in the knowledge management tool knowledgeMANAGER (kM), which supports the RSHP model to represent the information. The use of kM makes it possible to index and retrieve physical systems models, enabling the possibility to find similar PSM to a given query, with the capability to retrieve the model information and the similarity percentage with the query.

To prove the capabilities of M2R, a case study has been conducted to compare text vs. concept based information retrieval processes. A dataset of 25 electrical circuits and a set of 30 queries have been designed to extract precision and recall metrics assessing that the presented approach improves the retrieval of Modelica artifacts.

The results of the study show that by using M2R, a Modelica designed model could be reused by the proper mechanisms to represent the elements and relationships within the electrical circuit, to store such elements into a repository, to define a retrieval algorithm that would allow the identification of PSM by content and to retrieve the model according to different queries. For instance, a user should be able to express the next query based on natural language text: *Electrical circuits that contain a sine voltage source directly connected to an operational amplifier by a 20kΩ resistor*. In current Modelica environments, those tasks are hard to accomplish since they were not designed for these purposes. Advanced regular expressions could be a solution, but an approach taking advantage of describing elements and relationships can really improve the retrieval of Modelica artifacts, enhancing the reusability factor of existing PSM.

The main conclusion is that it is possible to state that a domain specific technology such as RSHP for knowledge representation can help the management of physical system artifacts, modelled in Modelica language, as knowledge assets. This gives the possibility to share and reuse physical system models by selecting a collection of them, from a wide physical system type's application as Modelica allows, in a standard format of representation, enhancing a methodology to reuse PSM, traceability actions or quality analysis of the models.

Keywords: Information Representation, Physical System Models, Modelica Language, Model Reuse, Knowledge Reuse

Mass Conserving Models of Vapor Compression Cycles

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Dynamic models of vapor compression cycles are becoming increasingly common due to their capabilities for system design, specification, and control. Because of the complexity of these models, their calibration to measured experimental data is an essential step in developing models that have predictive capabilities. One variable that can easily be compared between simulation and experiment is the the cycle's refrigerant mass inventory, or charge, which is usually known to a fairly high degree of precision and is constant over extended time intervals.

Unfortunately, many common model formulations for vapor compression cycles demonstrate significant variation in the total system charge that do not correspond to observed experimental behavior. Such variation can be seen in the output of a representative cycle simulation in Figure 1; in this simulation, the total cycle charge drops to 20% of its initial value due to numerical artifacts and errors. These variations in the total refrigerant inventory can be problematic because the dynamics associated with the variations in the cycle charge will be coupled to other system dynamics, causing erroneous system behavior.

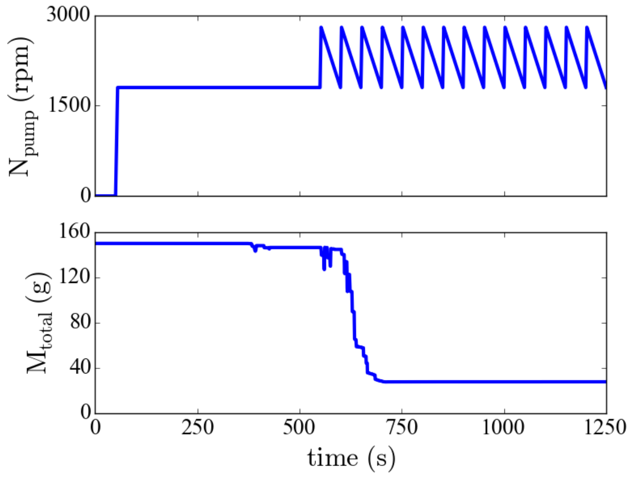

Figure 1. Observed variations in total cycle mass caused by numerical artifacts.

This paper presents an analysis of these models of vapor compression cycles to explain the causes of these variations in the system charge, as well as the development of alternative modeling approaches that eliminate this behavior and successfully conserve refrigerant mass in the cycle. An implementation of these alternative models in Modelica is also presented which demonstrates that these new modeling strategies are both effective at conserving refrigerant mass and are computationally efficient.

EPSILON Modelica library for thermal applications

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This paper presents the Modelica library built by the French company "Epsilon Ingénierie" in order to provide system models of several technologies for thermal applications. The Epsilon library has its own structure for media definition, allowing simulation of two-phase phenomena in the library models. This library also includes several heat transfer technologies models such as heat exchangers, thermo-electric generators, heat pipes, loop heat pipes, etc… This paper presents two examples of system modeling with the Epsilon library using OpenModelica: a capillary pumped loop and a Fresnel solar plant.

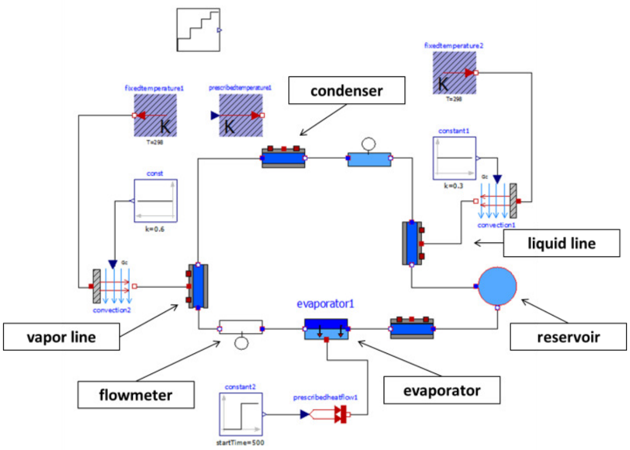

Figure 1. Epsilon OpenModelica model of a capillary pumped loop (CPL).

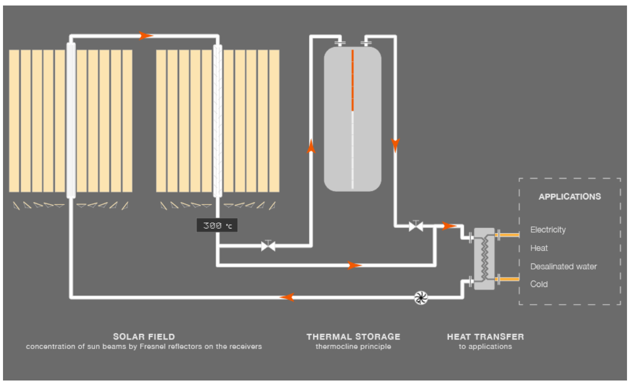

Figure 2. Linear Fresnel solar power plant of Alsolen company.

Multi-objective optimization of dynamic systems combining genetic algorithms and Modelica: Application to adsorption air-conditioning systems

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The Modelica language enables the fast and convenient development of physical simulation models. These models are often used for simulation studies. The re-use of simulation models for optimizations requires model adaption, additional tools or libraries. In this paper, we present a framework to connect Modelica models developed in Dymola to MATLAB's optimization toolbox. As optimization algorithm, we use a multi-objective genetic algorithm. With such a black-box approach, the user only has to define the design parameters and their corresponding bounds, as well as the objective functions. The optimization procedure and the implemented link between Dymola and MATLAB are displayed in Figure 1. Modelica script files execute the Dymola simulations and MATLAB's *gamultiobj* function evaluates the design parameters and objectives. The optimization procedure is tested for the design of an adsorption air-conditioning system. The two key performance indicators of this case study are the mobile coefficient of performance COP_{mobile} and the specific cooling power SCP. Both of these indicators are objectives to be maximized. In order to properly assess the benefit of a genetic optimization algorithm, we compare the resulting solutions (Figure 2, shades of blue) to those of a simple full factorial design (red). 40 iterations (generations) of the genetic algorithm correspond to the number of simulations of the full factorial design. The optimization procedure outperforms the full factorial design regarding solution diversity, objective quantity and objective quality. Thus, the necessary computation time can be significantly reduced to obtain comparable results. The presented framework provides convenient access to optimization methods leading to improved solutions for engineering practice.

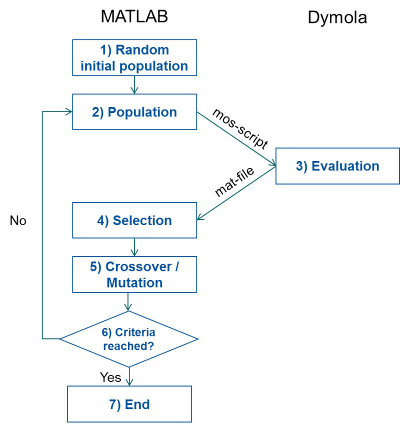

Figure 1. Procedure of black-box optimization linking Dymola with MATLAB.

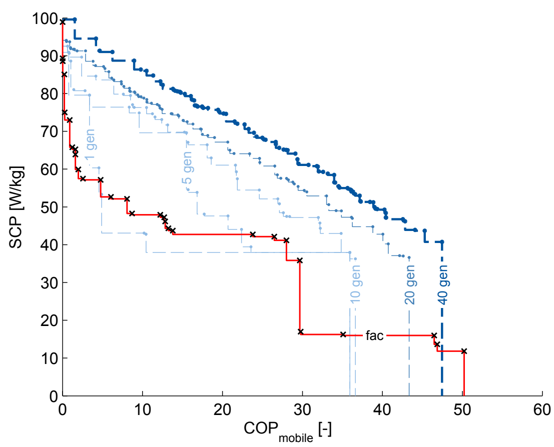

Figure 2. Pareto solutions of genetic algorithm (blue) and full factorial design (red).

A new Modelica
Electric and Hybrid Power Trains library

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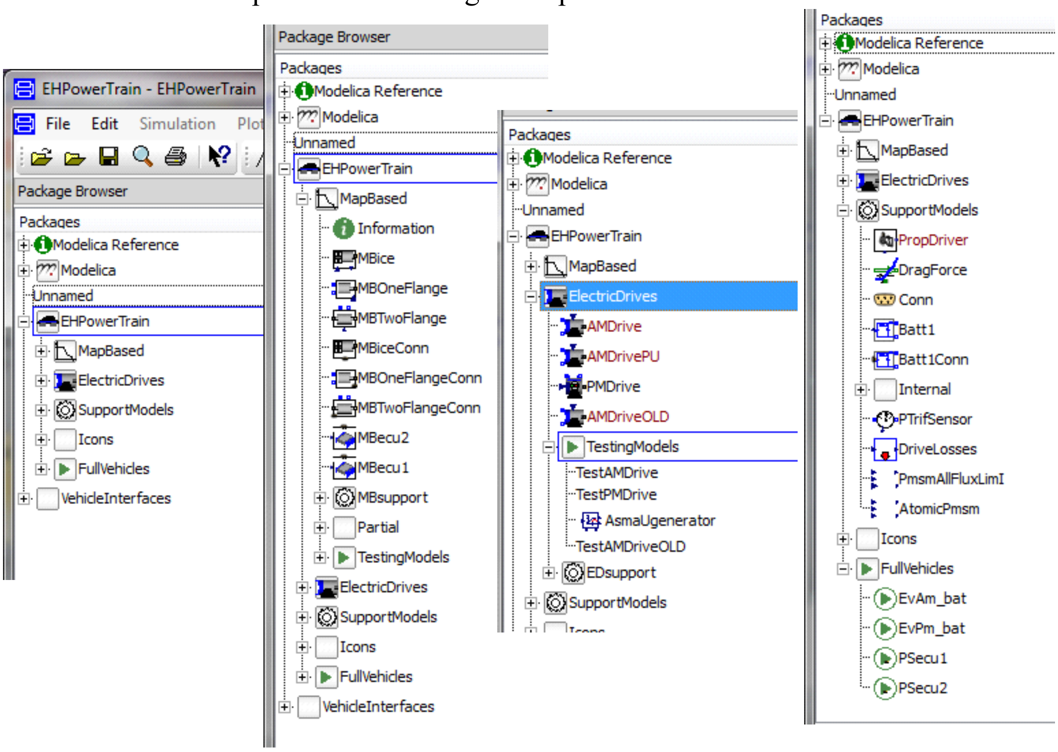
The paper describes a new library, devoted to simulation of electric and drive vehicle power trains.

This library is fully compatible with both Dymola 2015 and OpenModelica 1.9.2. It is available under the Modelica License 2, and presented at the 11th Modelica International Conference.

The library is a collection of models whose level of detail is adequate for electric and hybrid vehicle power trains simulations. In particular:

- the AC sinusoidal variation of voltages and currents is not followed, but substituted by RMS equivalents;
- in case of brushless motors the optimal choice of direct and quadrature-axis currents (Id and Iq) is directly implemented in the code, both at low speeds and in the flux weakening region;
- a collection of even simpler models (map based) is supplied as well. These models have as the unique dynamics the one induced by the mechanical inertia, but implement efficiency maps and torque and power limits.

The paper shows that the simplifications introduced do not produce too large errors, but allow fast and effective simulations in large timespans.
The library contains testing models to show how individual models operate, and some full vehicles examples.
It is made available open-source to the general public.



Initiatives for acausal model connection using FMI in JSAE (Society of Automotive Engineers of Japan)

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Autors initiated trial and evaluation of a new method to interconnect acausal physical ports and causal signal ports using FMI in a technical committee of JSAE (Society of Automotive Engineers of Japan). We introduced special ‘adapter’ models to interface between acausal physical port and causal signal ports as shown in Figure 1. For a benchmark model of the acausal system model shown in Figure 2, we applied the proposed method to generate and connect three FMUs and got good results about consistency. Also a guide-line about using FMI for acausal physical ports connection was made in JSAE and is distributed to general users of Japanese automotive industries. Finally expectation about future enhancement of FMI for model circulation between companies is presented.

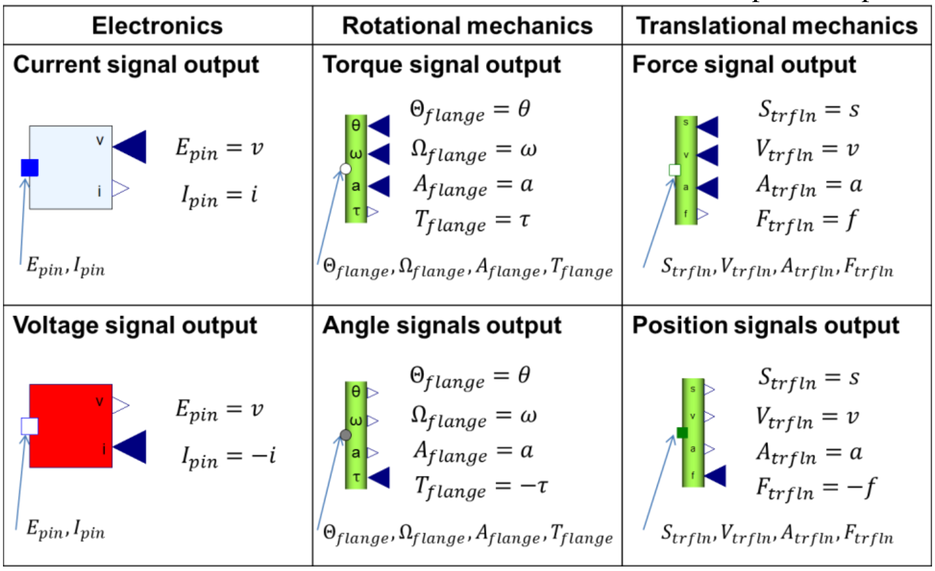

Figure 1: Adapter models between acausal physical port and causal signal ports

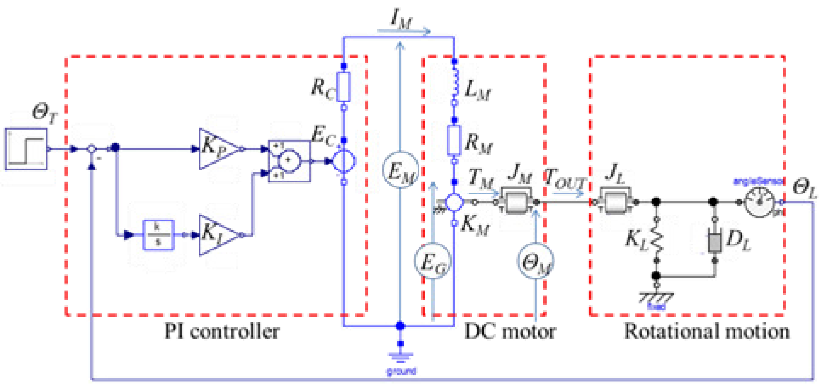

Figure 2: Benchmark model (Simple control system)

Dynamical Model of a Vehicle with Omni Wheels: Improved and Generalized Contact Tracking Algorithm

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A model of the multibody dynamics for an omni wheel assuming embedded in a frame of wider dynamical environment of the whole vehicle. Modelica primitives developed earlier (Kosenko, 2005; Kosenko et al, 2006) for the multibody applications with contacts involving friction are used. Generalization of (Kosenko and Gerasimov, 2014) has been performed for the model of contact tracking algorithm between roller and horizontal floor. Generalization includes non-zero angle between the roller axis of rotation and plane of the omni wheel. Contact tracking algorithm is implemented in two cases: (a) implicit and (b) explicit.

A comparison has been performed for these cases in frame of the omni wheel dynamics. A verification of the whole omni vehicle dynamics has been performed earlier (Kosenko and Gerasimov, 2014) but for the simpler case: for zero value of the angle of roller axis of rotation with respect to the omni wheel plane. Models for these cases (a) and (b) are currently "embedded" into the omni vehicle model earlier verified. Such a construct has been implemented by means of the object-oriented modeling. For simplicity we analyze currently a multibody system comprising the wheel plus set of rollers being mounted along the wheel circumference. A remainder of the vehicle is replaced by the wrench properly arranged in a way such that the wheel keeps its vertical orientation permanently. Really, the wrench mentioned is an implementation of a virtual dynamical testbench.

The performed computations have shown that two algorithms of the contact tracking generate completely identical dynamics of the whole multibody system. In addition, class hierarchy is considered for the behavioural inheritance in a model of the roller and the floor contacting involving the Coulomb friction.

The investigation was performed under financial support provided by RSF, project 14-21-00068.

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Kansei Modeling for Delight Design based on 1DCAE Concept

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It is crucial to produce emotional products (delight design) in addition to must design and better design in the future industry as shown in Figure 1. Conventional design tools like CAD systems lack functionalities to support the design of such products.

Though such support tools as Kansei design methodologies are available to some extent, they are still too specific to be applied to common design processes. Thus there are strong demands for the development of technologies for supporting upstream design work flow dealing with delight aspects based on Kansei and seamlessly integrating it to the downstream embodiment design processes.

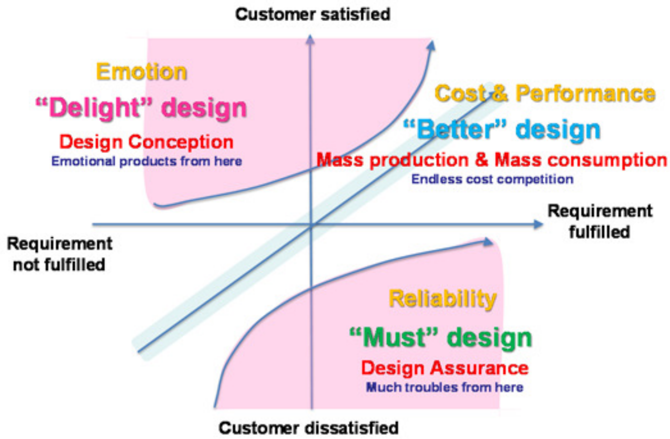

Figure 1. Three kinds of design

As a solution to the above issue, we are proposing the development of a design framework called "1DCAE", which can be applied to the early design stage of product development including the conceptual design and functional design. The 1DCAE concept can be applied not only better design, must design, but delight design. Here we introduce how 1DCAE concept applies to delight design and its core technology of kansei modeling.

We introduce the kansei modeling based on 1DCAE concept to realize delight design. The technology to capture the kansei is defined as the kansei modeling and the resulting model as the kansei model. 1DCAE is done by using the so-called 1D tool based on Modelica language. Kansei modeling is applied to the hair dryer which includes the physical part and the kansei part. Kansei model is built by using the kansei database. In case of dryer, air flow, sound, and handling are related to kansei.

Designers perform the delight design by using 1D tool with kansei model. They can check the degree of attainment for their ideas by calculating the attractive metric on 1D tool. Results of delight design obtained in this process is sent to the mechanical design and circuit design to perform the tangible design.

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A Modelica Library Organization Method Supporting Online Modeling and Simulation

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Today, the trend of achieving networked collaborative innovation and design of complex product based on Modelica is predictable in the industrial field. However, the existing file-based Modelica library organization method designed for single-machine environment does not satisfy the model management requirements for dynamic collaborative modeling and sharing under the network environment. Aiming at this problem, a new organization method of Modelica library based on database is proposed. The main principle of this method is that the organization objects are models rather than files. Through interacting with database storing metadata describing models, it is available to achieve model management based on the granularity of single model.

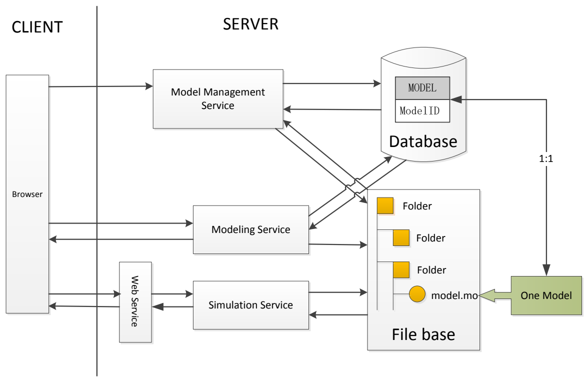

Figure 1. Model management framework.

As shown in Figure 1, in the B / S architecture, we use a combination of model database and model file base to provide data support for modeling and simulation, users can interact with the browser to execute modeling and simulation and get model management service.

Database is used to store the basic properties (metadata) of model and the information of relationships (reference, inheritance, etc.) between the models. And file base is organized by *mo* files based on file directory to support online compiling and simulating service using the existing compiler. The model management service can be implemented on the basis of attributes of models in the database. For example, the display and renting authority of model could be accessed via simply changing publishing state. If this model has been published, it can be rented and referenced by other users to acquire re-use. Instead, others cannot search it on the Internet. The modeling service saves the models' mo file in the file base and the models' metadata in the database. Besides, solving results can be stored in the file base by simulation service. In this framework, one model's descriptive information (metadata) in the database corresponds to one mo file in the file base. So, the management of model resources based on the granularity of single model can be reached conveniently.

Finally, an online service platform supporting multi-domain physical modeling and simulation in the web environment - CoModel (http://www.comodel.net.), has been researched and built based on this organization method of Modelica library. The fact that at present the platform shows good performance, proves that this data supporting method is advanced and effective to achieve online modeling and simulation.

CONTROL DEVELOPMENT AND MODELING FOR FLEXIBLE DC GRIDS IN MODELICA

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Abstract

This article will show a way of implementing different control strategies for power electronic converters in the Modelica modeling language. The different control modes were fitted into flexible models that could be interconnected in various power grid topologies. The power grid examples were controlled and kept stable during various load scenarios, using the developed controlled converter models. The work was performed using the Modelica tool Dymola. Modelica is an equation-based object-oriented modeling language. Electrical components in the Electric power library (EPL) from Modelon were used to model power electronic units, grids and other electrical infrastructure. The outcome of this effort was simulation results which clearly demonstrate that the developed controllers enables scalable and controllable DC power grids.

Towards Enhanced Process and Tools for Aircraft Systems Assessments during very Early Design Phases

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The paper deals with an improved process for early to detailed design phases of complex Aircraft systems. It is based on experience of Dassault Aviation (DASSAV) and Liebherr Aerospace Toulouse (LTS) in aircraft system design, and on works carried out within several R&D projects, in particular within current FP7 TOICA project (Thermal Overall Integrated Conception of Aircraft [1]), where new process are developed to tackle assessments of architectures composed of many heterogeneous and interconnected sub-systems using simulation. This new process described in the paper involves open standards like Modelica and FMI.

Architectures trade-offs require different kinds of analysis, in particular behavioral assessments. The purpose of this paper is to define vehicle system architectures, investigate the current performance assessment process and propose an improved process based on models exchanges and simulations, applicable during preliminary design phases like RFI (Request For Information) or RFP (Request for Proposal)

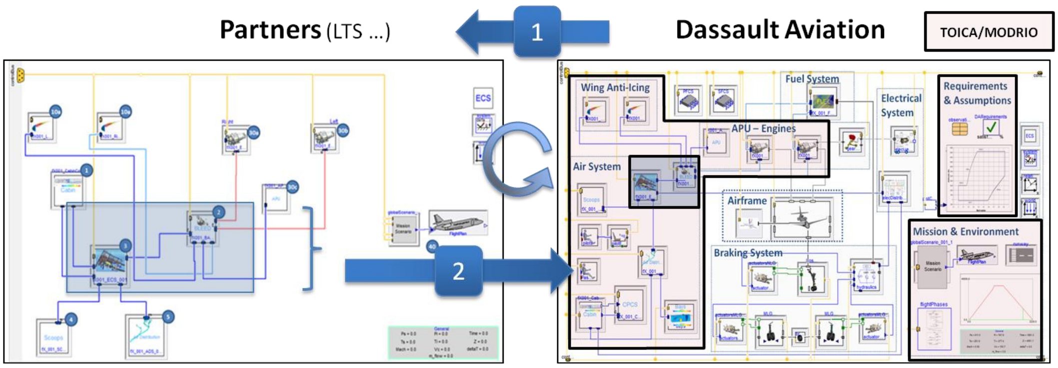

Figure 1. Exchange of models for Architectures Trade-offs.

In the current process, the aircraft architects ask suppliers to provide models for multi-systems assessments into Aircraft integrator office. This process has two drawbacks. It is difficult to assure that models will run in integrator's facility, and this request can't be currently handled efficiently during very early phases like RFI or RFP phases.

The new process, based on model exchanges using a Modelica framework, allows more efficiency and flexibility. As demonstrated, the workflow for architecture and sub-system assessment is straightforward compared to current one. It may more deeply imply partners/suppliers in assessment success, and may allow finding more innovative solutions by opening up aircraft requirements.

The process and associated tools are based on current powerful capabilities of Modelica and FMI which continue to improve to be able to manage heterogeneous models required for Aircraft systems assessment; in particular within current ITEA2 MODRIO project [2], which brings new capabilities that will be used within TOICA.

References

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Using FMI in a cloud-based Web Application for System Simulation

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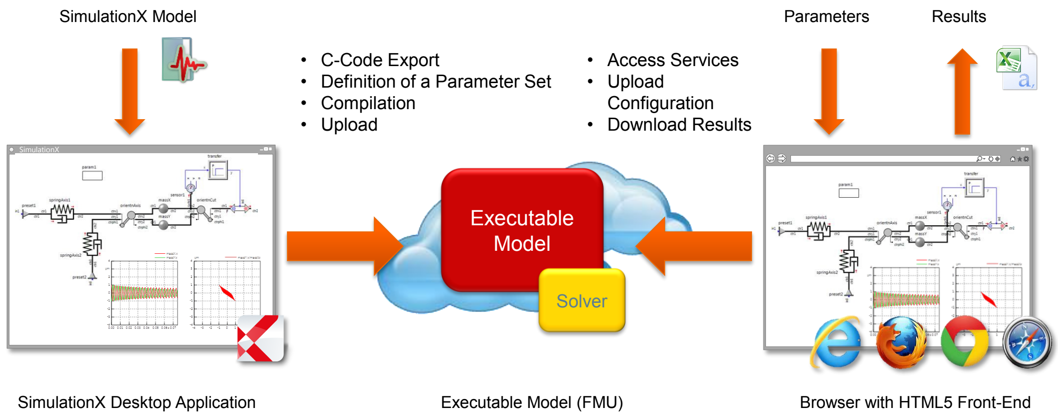
This paper presents a generic approach to combine cloud computing and system simulation. It shows the benefits of using FMI to deploy self-executing simulation units on multiple machines. Besides managing the calculation itself, we also present a web interface for uploading, managing and analyzing simulation models. To benefit from available hardware resources in the cloud, an engine is integrated which allows the definition of multiple simulations with different parameter sets in a single step.



Anticipatory Shifting – Optimization of a Transmission Control Unit for an 8HP Automatic Transmission through Advanced Driver Assistance Systems

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By integrating system simulation with vehicle dynamics into real-time environments, it is possible to simulate the physically correct behavior of vehicle components and also adjust it to the required operating strategies depending on external factors. Multi-physics system simulation for realistic representations of powertrains and their behavior combined with dynamic driving simulation allows for optimizations of the transmission control unit for an 8HP automatic transmission by employing advanced driver assistance systems for an increased efficiency through anticipatory shifting.

Realistic load cases that are based on measured data help optimize fuel consumption and driveline dynamics with respect to the control algorithms by using variation calculations with variable transmission parameters. This works also the other way around when control algorithms are validated and optimized quickly and free of risk as part of rapid prototyping.

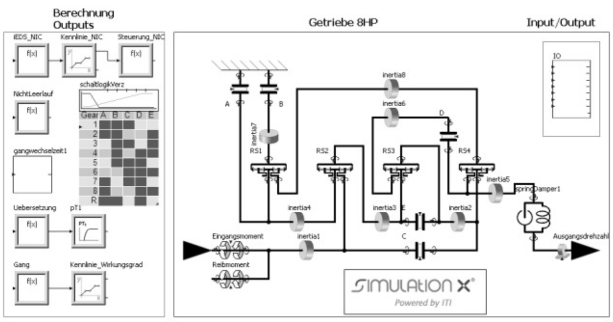

Figure 1. SimulationX model of ZF's 8HP automatic transmission.

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Simulation of distributed energy storage in the residential sector and potential integration of gas based renewable energy technologies using Modelica

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In-order to analyse the distributed production and storage of energy in de-centralised clusters, Modelica has been used to model buildings with micro Combined Heat and Power (μ-CHP) systems as their primary heat energy source. The classification of the buildings involve generalising their size based attributes and using experimental overall convective heat transfer coefficients (Defraeye et al., 2011). The output power of μ-CHP systems and the dimensions of the storage units are chosen corresponding to the building size to account for space heating, warm water demand and power storage requirements. To store the power locally, battery models are integrated and a power interface system has also been developed. Decentralised storage potential is modelled using distributed Power-to-Heat (PtH) as a storage strategy. As an initial part of analysing distributed storage potential, various house types with μ-CHP units are simulated with measured weather dependent boundary conditions. Subsequently, potential integration of distributed storage into a larger storage strategy involving the electrical grid and the gas grid is discussed where the μ-CHP units could act as an interface enabling a symbiotic relationship between the power grid and the gas grid.

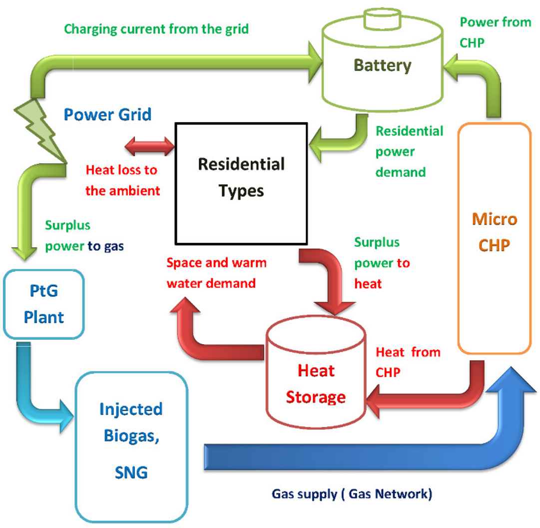

Figure 1. Concept diagram of distributed storage strategy

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Test of Basic Co-Simulation Algorithms Using FMI

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Since the FMI technology gains ground in industrial environment, the demand for robust co-simulation increases. In a master-slave concept the master algorithms define the quality of a co-simulation whereas the properties of the coupled FMUs for co-simulation restrict the variety of possible master algorithms.

At first a notation to describe coupling algorithms is introduced. Based on this notation basic coupling algorithms are described. These algorithms can be a starting point for developing further coupling algorithms.

In addition an existing experimental master tool with three basic master algorithms was improved to support FMI 2.0 as well as 1.0. For testing more than 20 Modelica examples were developed from which FMUs for co-simulation were generated by established simulation tools (e.g., Dymola, SimulationX). The examples demonstrate differences of the three master algorithms Gauss-Seidel method, Gauss-Seidel method with one iteration step, and Newton-Raphson method. Four of the 20 examples are described more detailed and the numerical results are discussed.

The experience collected with the test examples so far is summarized in recommendations for tearing as well as improving the master algorithms.

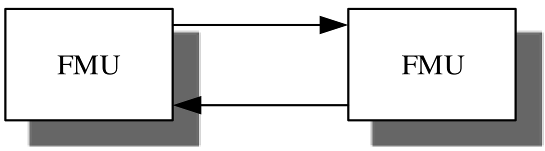

Figure 1. Coupling with feedback between two FMUs

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Experimental Calibration of Heat Transfer and Thermal Losses in a Shell-and-Tube Heat Exchanger

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Many factors such as, environmental issues, concern about sustainability and rising cost of fossil fuels are presently encouraging research and investment into renewable resources. Renewable energy power plants face the main problem of dispatchability of demand due to the variability of their power sources. Nevertheless, solar thermal power plants are appropriate for large-scale energy production since they efficiently store heat in Thermal Energy Storage (TES) systems. Thus, many commercial solar thermal power plants rely on this technology (Herrmann and Kearney, 2002).

The performance of solar thermal power plants with TES systems is highly influenced by the heat exchanger control strategies applied in the charging and discharging processes (Zaversky et al., 2013). Therefore, advanced control strategies may improve the performance of the whole plant. For this reason, a dynamic heat exchanger model is being developed. This heat exchanger is part of the CIEMAT-PSA molten salt testing facility. This multipurpose molten salt testing facility is devoted to evaluate and control the heat exchanged between molten salt and different kinds of heat transfer fluids.

Figure 1. Shell-and-tube heat exchanger

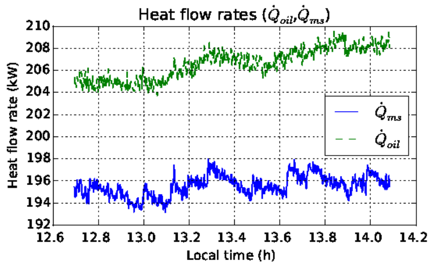

Figure 2. Heat flow rates

During experimental campaigns, it was noticed a performance loss in the heat exchanger (see figure 1) with respect to design performance. A dynamic heat exchanger model is being developed in order to evaluate this performance loss. This paper shows the followed procedure to calibrate heat exchanger thermal losses, which are shown in figure 2, as well as heat transfer correlations for both fluid sides.

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Suitability of Different Real-Time Solvers for a Model-Based Engineering Toolchain using Industrial Rexroth Controllers

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Due to the increasing complexity of technical systems, model-based engineering is getting more and more important during the development process of new products. The code generation from models and the usage of this code on hardware targets is one important feature of model-based development. To execute this code on the hardware device, a simulation runtime is additionally required, which offers numerical methods to solve the model equations. To use generated code on a controller, the simulation has to be executed in real-time, which is a huge requirement for the solver. A real-time solver has to guarantee that one time step is finished in a limited time, i.e. the real time cycle. In this context, linear-implicit Runge-Kutta methods, also known as Rosenbrock methods, are introduced.

In this work, a Modelica-based open source toolchain for model-based engineering with Rexroth controller is presented. This toolchain allows to generate C++-Code from Modelica models, which can be executed directly on industrial PLCs. Using this toolchain, a virtual commissioning can be easily performed. Therefore, the former described toolchain is used to execute both the plant model and the controller model on the hardware controller. In this contribution, a virtual commissioning of a single hydraulic axis, a typical hydro-mechanical system, on a standard Rexroth PLC is shown. Therefore, instead of parameterizing the controller directly on the real system, the controller model running on the PLC is connected to the system model, which is additionally executed on the PLC in parallel to the controller model. By doing so, the commissioning times can be reduced significantly, as the commissioning process can already be started during the build-up of the system using a simulation model of the system.

As hydro-mechanical systems are in general mathematically stiff, the choice of the solver for the system model equations is not arbitrary. In this work, five different real-time solvers, beginning with a simple explicit Euler through to more complex linearly implicit methods, are tested the hydro-mechanical example system. Furthermore, typical issues like time and state events as well as algebraic loops are discussed in context of real-time simulation requirements.

Integrated Engineering based on Modelica

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The academic society claims the use of virtual engineering (i.e. simulation) since many years. Nevertheless, it is de facto rarely ever used in the automation industry. This paper presents an approach and a toolchain for an integrated, digital engineering workflow including virtual commissioning, shown at a real industrial example. In particular, a new method for virtual commissioning that allows to drop all real-time requirements is presented.

Cyber-physical production systems rising with the concepts of industry 4.0 have a complexity that conventional engineering methods cannot bear. Therefore, the time has come to finally use model-based systems engineering methodologies that were proposed years ago, e.g. (VDI2206, 2004). Nevertheless, the automation industry acts very conservative towards new technology. This is mainly due to the distrust that model-based methods can be used in an economic manner. Within the development cycle in the automation industry CAD models are used, since they save costs compared to construction by hand. During other stages of the development cycle, virtual models are considered to be of little or no use, since the effort for modeling those images of real systems is assumed to excel the benefits. This prejudice can only be overcome by lowering the effort for modeling or increasing the value of generated models.

In this paper models generated in early development phases are re-utilized within later stages of the development cycle, like application engineering and commissioning. The re-use of models for virtual commissioning is in particular possible due to coupling of a Rexroth PLC and a (possibly non real-time) Modelica simulation using a new Modelica library. In order to obtain an development cycle that is as integrated as possible, transitions between different phases in the development cycle are tackled. First, starting with CAD data it is shown how to automatically generate a physical representation of a machinery in Modelica. Using the physical interfaces of Modelica the model can easily be extended by drive models from component manufacturers. In combination with Bosch Rexroth PLCs, a transition towards the commissioning phase without further adaptions (e.g. complexity reduction for real-time application) is possible employing a new Modelica library. To show the entire potential of an integrated engineering workflow based on Modelica, an approach for creating control code based on a Modelica model of the control algorithm is given. By demonstrating those methods in the industrial application example of a bottling machine, it is disclosed that the assumptions of a high effort for creating simulation models, as mentioned introductory, can be disproved.

References

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Coupling Model Exchange FMUs for Aggregated Simulation by Open Source Tools

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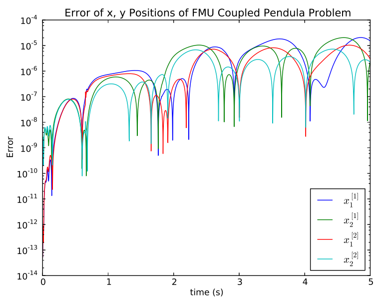
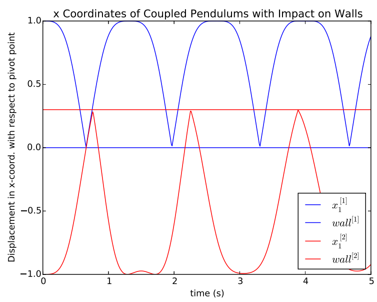
With the Functional Mock-Up Interface standalone sub-systems can be modelled to be part of larger systems that needs a framework for coupled integration. This paper suggest one way of solving the issue by aggregating sub-systems to one unified system that internally handles sub-system communication by coupling. The aggregated system can then be solved by applying a single solver with the benefit of using an aggregated Jacobian and the ability to monitor all sub-system events.

Figure 1a shows proof of concept where two FMUs, each modelling a pendulum with an external force acting on the pivot, are coupled together with a spring and simulated as an aggregated system using the `CVode` solver in Assimulo. As reference a monolithic model of the coupled system was made as an FMU and integrated using `CVode`.

The framework is not limited to coupling of FMUs but can be used to couple Python based problem classes defined by Assimulo. It can also add events to the aggregated system externally. The latter is demonstrated in Figure 1b where walls are added to the aggregated system of two pendulums coupled with a spring to block each pendulums motion. The figure shows displacement in x-coordinate with respect to the pendulums pivot.



(a) Error of aggregated system of coupled pendulums with a spring modelled with FMUs.



(b) Externally added events representing walls blocking coupled pendulum motion.

An Aeronautic Case Study for Requirement Formalization and Automated Model Composition in Modelica

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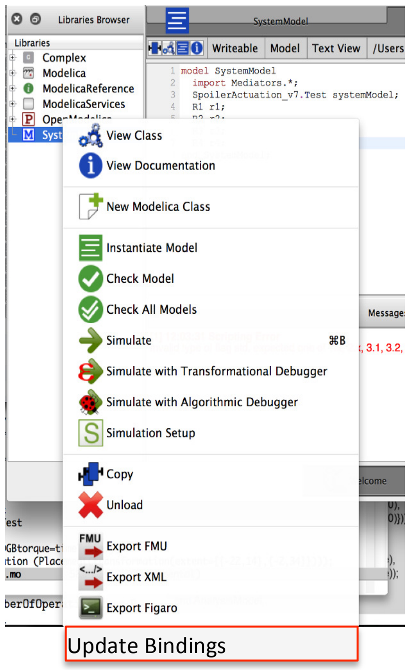
Building complex systems from models that have been developed separately without modifying existing code is a challenging task faced on a regular basis in multiple contexts including design verification. To address this issue an approach has been developed for automating dynamic system model composition by defining the minimum set of information that is necessary to the composition process. A design and implementation of this approach for standard Modelica is presented in the context of an application case study – the verification of a new design for spoiler activation against requirements.

The binding approach does not assume prior knowledge of each other by the respective models and therefore increases decoupling and allows reuse of existing models and libraries. As mediators can be defined in several steps this means that different people can provide the information necessary to connect the models at different stages in the design process. Furthermore, it enables a formal traceability between client and provider models. For example, determining which requirements are implemented in the system design model at hand can be achieved by looking at the bindings for mandatory requirement clients.

In this paper we describe:

- A new application of requirement verification on an industrial case study in the field of aeronautics
- The use of the new Requirement Modeling library for modeling the requirements of the case study.
- A modified version of the syntax for representing mediators that is fully compliant with standard Modelica syntax, meaning that the bindings can be edited and visualized in any Modelica tool.
- An implementation of the algorithm for binding generation described in *(Schamai, 2014)* in OpenModelica.



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FastHVAC - A library for fast composition and simulation of building energy systems

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The dynamic simulation of building energy systems, including heating, ventilation and air conditioning (HVAC) technologies, is gaining importance in recent years. Today, the simulation of building energy systems has broadened to analyze entire city districts [1]. This is especially important when considering the interconnection of buildings, which can be in terms of district heating networks or the electrical grid. In this field, measures like Demand Side Management [1] are meant to become more important in the future. The simulative analysis of these (large) energy systems with implemented thermal storages as well as heat generators, e.g. heat pumps and combined heat and power plants, requires the calculation of large equation systems and might lead to unreasonable computational effort.

Further, the simulation of (especially closed) hydraulic circuits, whose models are based on the package Modelica.Fluid of the Modelica Standard Library shows considerable difficulties. In particular, the steady-state initialization of these systems can be a critical issue [2]. Especially in cases where the thermal investigation of energy systems is focused, it requires additional expenditure without benefit. Further, the computational effort can be a critical factor, depending on the size of the observed system. The number of initialization variables can grow very fast [3]. In case of a city district analysis, this becomes a very critical issue, as the building energy systems should probably be parameterized automatically with little manual input.

This paper describes the implementation of a Modelica library that is designed to enable fast composition and simulation of building HVAC systems. The library is based on an approach which is focusing the thermal behavior of the components, while reducing the information about the hydraulic circuit to the mass flow rate. This approach limits the applicability of the library, but decreases the computational effort as well as the time to set up a model. Particularly, it is suitable for applications such as rapid prototyping of innovative energy systems and the development of advanced control systems for heat generators.

As stated in the case study, the simulation speed can be increased noticeably following the new approach. Nevertheless, the results are almost identical to more complex approaches, with coefficients of determination of approximately 1 for individual components as well as on system level. The modelling principle can be transferred to additional components.

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Open Source Library for the Simulation of Wind Power Plants

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This paper presents the new open source Modelica library WindPowerPlants. For the economic assessment of either a wind power plant or an entire wind park, the accurate prediction of the energy output is essential. Such prediction is usually performed by means of calculations based on statistical wind data. The proposed WindPowerPlants library is capable of assessing the energy output both for statistical and real wind data based on time domain simulations.

In the presented version of the library wind turbine models are modeled with pitch control. The generator models have variable speed and an optional connector to the mains. The entire library is based on power balance conditions and losses are fully neglected. Yet, the library can be extended towards more detailed models considering different types of losses.

The structure and components of the library are presented. Simulations examples are shown and compared with reference data. The applicability of the proposed WindPowerPlants library is demonstrated and possible enhancements are discussed.

The WindPowerPlants library was developed during a Diploma project at the Technical Engineering College, TGM. For the development of the library OpenModelica was used. The library is published under the Modelica2 license and available through the Modelica homepage. The main motivations for developing the presented library were:

- Investigate control mechanisms of wind power plants
- Support teaching activities in simulation
- Provide an open source library that may initiate further developments

Due to the openness of Modelica, wind power plant simulation can also be combined with electrical network aspects such as dynamics, stability, etc.

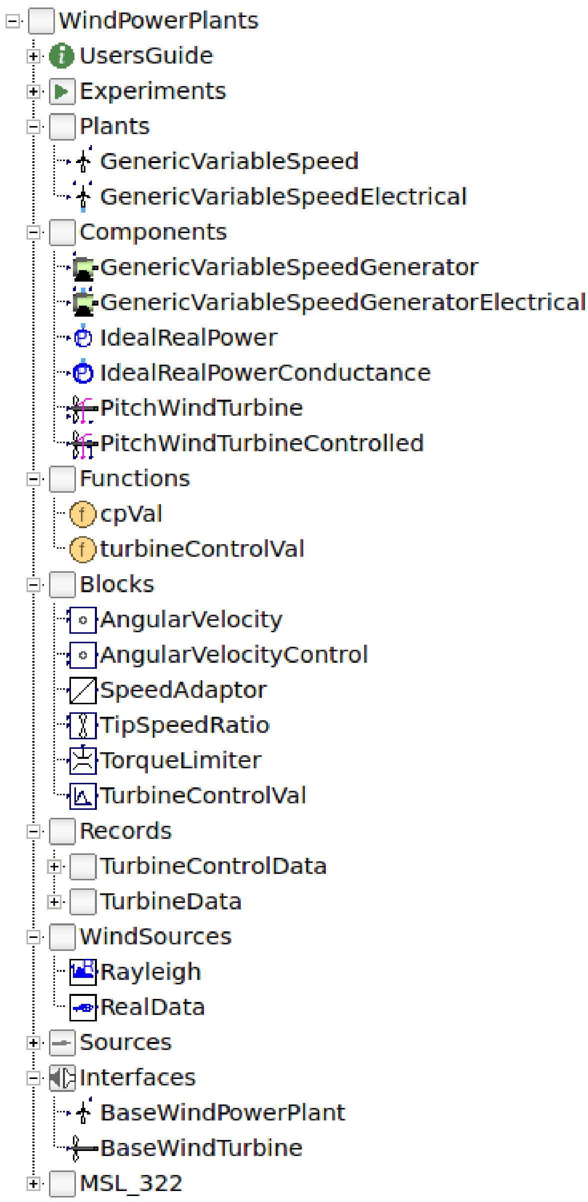

Figure 1. Library structure