Controls

Electrical

Systems

Tools

# BOOK OF ABSTRACTS

# 9th INTERNATIONAL MODELICA CONFERENCE

September 3-5, 2012
Munich, Germany
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**Editors:**
Martin Otter
Dirk Zimmer


MODELICA


DLR
Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft
Robotics and Mechatronics Center


Fluids

Mechanical

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# Content

# Fundamentals of Synchronous Control in Modelica

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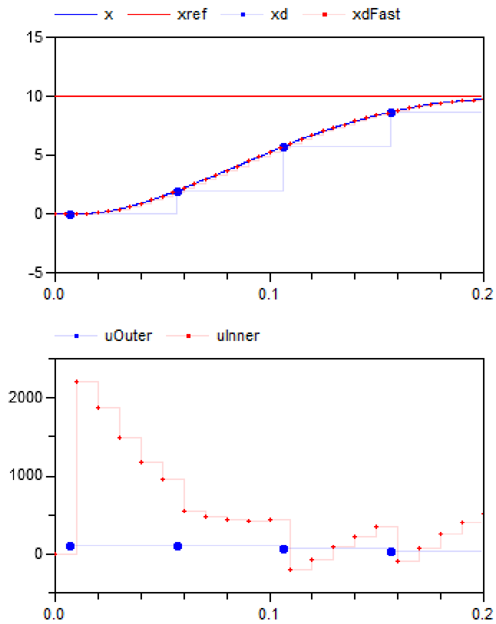
The scope of Modelica has been extended from a language primarily intended for physical systems modeling to modeling of complete systems by allowing the modeling of control systems and by enabling automatic code generation for embedded systems.




This paper describes the fundamental synchronous language primitives introduced for increased correctness of control systems implementation. The approach is based on associating clocks to the variable types. Special operators are needed when accessing variables of another clock. This enables clock inference and increased correctness of the code since many more checks can be done during translation. Furthermore, the sampling period of a clocked partition needs to be defined only at one place (either in absolute time or relatively to other clocked partitions), general equations can be used in a clocked partition, and in particular continuous-time equations that are automatically discretized.

In the paper a rational is given why the new language elements have been introduced by comparing the new possibilities with the features of Modelica 3.2 to model sampled data systems. A companion paper (*Elmqvist, et.al, 2012*) describes the state machine features of Modelica 3.3. Yet another companion paper (*Otter*, *et.al*, *2012*) describes a Modelica library, Modelica_Synchronous, which supports a graphically oriented approach to synchronous control systems implementation.

The new language elements follow the synchronous approach. They are based on the clock calculus and inference system of Lucid Synchrone version 2 and 3 (*Pouzet 2006*). However, the Modelica approach also uses multi-rate periodic clocks based on rational arithmetic and also non-periodic and event based clocks are supported.

In the text box to the right, a very simple system consisting of a continuous-time plant and a sampled data P controller is shown using the new language elements. In the figure above, simulation results of a system with different sampling periods are shown.

```
// Continuous system
der(x) = v;
m*der(v) = f - k*x - d*v;

// Controller with period of 0.01 s
vd = sample(v, Clock(0.01));
u = K*(vref-vd);
f = hold(u);
```

## References

Elmqvist H., Gaucher F., Mattsson S.E, and Dupont F. (2012): **State Machines in Modelica**. Proceedings of 9th Int. Modelica Conference, Munich, Germany, Sept. 3-5.

Otter M., Thiele B., and Elmqvist H. (2012): **A Library for Synchronous Control Systems in Modelica**. Proceedings of 9th Int. Modelica Conference, Munich, Germany, Sept. 3-5.

Pouzet M. (2006): **Lucid Synchrone, Version 3.0, Tutorial and Reference Manual**. http://www.di.ens.fr/~pouzet/lucid-synchrone/

# A Library for Synchronous Control Systems in Modelica

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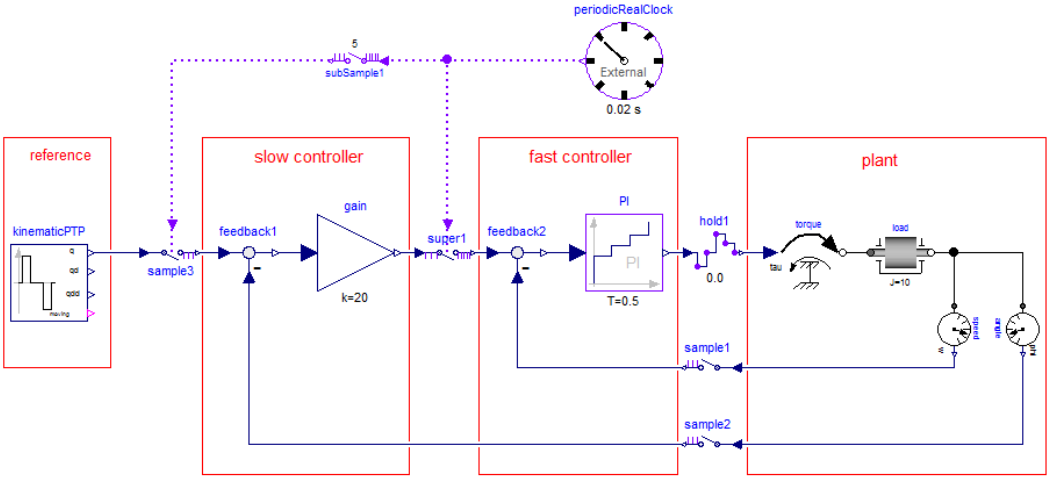
In the Modelica language version 3.3 synchronous language features have been introduced to precisely define and synchronize sampled data systems with different sampling rates. This article is a companion paper to (*Elmqvist et.al. 2012*) which should be first inspected to understand why new language elements have been introduced, as well as the syntax and semantics of them.

In order to utilize these language elements in an actual model in a *convenient way*, a free library “Modelica_Synchronous” has been developed using a prototype of Dymola for the new language elements. This library is in a prototype status. After an evaluation period it is planned to include this library into the Modelica Standard Library. Note, all Modelica libraries designed so far for sampled systems, such as Modelica.Blocks.Discrete, Modelica_LinearSystems2.Controller and Modelica_EmbeddedSystems are becoming obsolete and should be replaced by this new library.

A typical, simple example to define sampled data systems with this library is shown in the screen shot below, consisting of a continuous-time load inertia, and a position and speed controller with two sample rates that are precisely time synchronized to each other. The blocks `sample1`, `sample2`, and `sample3` sample a continuous time signal and provide them as clocked, discrete-time signals. The block `hold1` is a zero-order hold and transforms a clocked signal to a continuous time signal. The block `super1` defines that its input is super-sampled and provided as output. All equations in a partition marked by `sample`, `hold`, `superSample` (and blocks `subSample`, `shiftSample`, `backSample`) form a partition that is associated exactly to one clock (e.g. a clock with a periodic sample rate). The equations of a clocked partition are automatically deduced by clock inference using the simple rule that all variables used in an equation (with exception of the first arguments of the above operators that mark the boundaries of a partition) must belong to the same clock. Clocks can then be associated to partitions as optional inputs to the boundary marking blocks. Below, the fast controller has a sample rate of 0.02 s and the slow controller of 5*0.02 = 0.1 s.




## References

Elmqvist H., Otter M., and Mattsson S.E. (2012): **Fundamentals of Synchronous Control in Modelica**. Proceedings of 9th Int. Modelica Conference, Munich, Germany, Sept. 3-5.

# State Machines in Modelica

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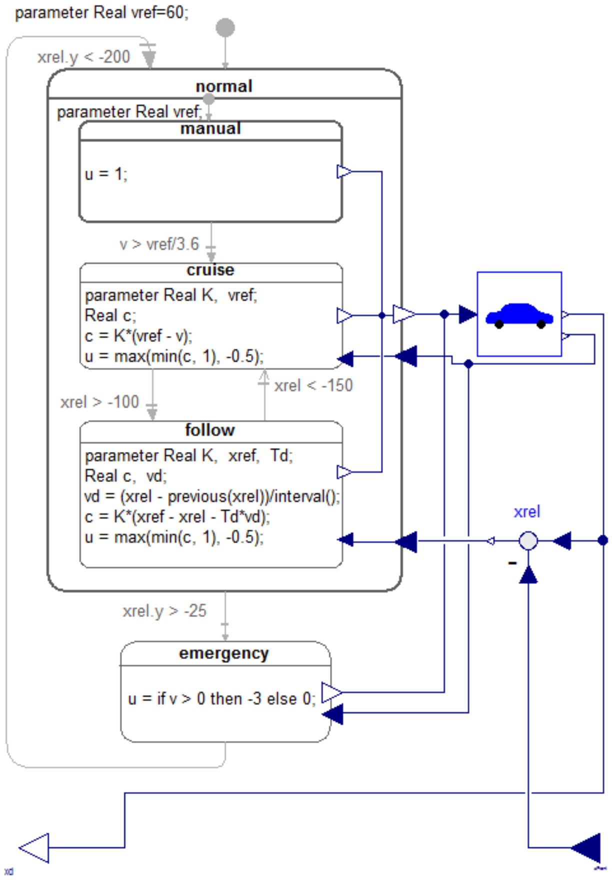
The scope of Modelica [2] has been extended from a language primarily intended for physical systems modeling to modeling of complete systems by allowing the modeling of control systems including state machines and enabling automatic code generation for embedded systems.

This paper presents state machines in Modelica. A companion paper [1] describes the fundamental synchronous language primitives introduced for increased correctness of control systems implementation since many more checks can be done at compile time.

The paper describes language elements to define state machines. Any block without continuous-time equations or algorithms can be a state of a state machine. Transitions between such blocks are represented by a new kind of connections associated with transition conditions.

The semantics of the state machines in Modelica is inspired by mode automata and basically the same as Lucid Synchrone 3.0 [3].

The paper gives the details for building state machines and includes several examples, such as a simple adaptive cruise controller shown to the right. In addition, the complete semantics is described using only 13 Modelica equations.




## References

[1] Elmqvist H., Otter M., and Mattsson S.E. (2012): **Fundamentals of Synchronous Control in Modelica**. Proceedings of 9th International Modelica Conference, Munich, Germany, September 3-5.

[2] Modelica Association (2012): **Modelica Language Specification Version 3.3**. https://www.modelica.org/documents/ModelicaSpec33.pdf.

[3] Pouzet M. (2006): **Lucid Synchrone, Version 3.0, Tutorial and Reference Manual**. http://www.di.ens.fr/~pouzet/lucid-synchrone/

# PNlib - An Advanced Petri Net Library for Hybrid Process Modeling

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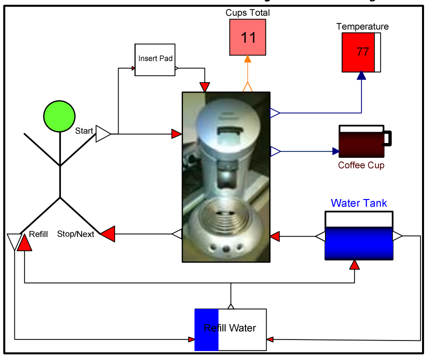
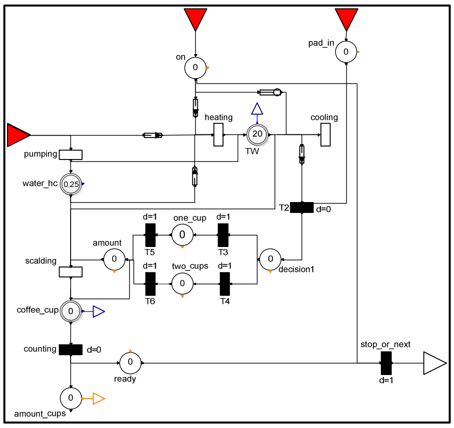
We present a new Petri net library, called PNlib, to enable graphical hierarchical modeling, hybrid simulation, and animation of processes in life sciences, technical applications, among others. In order to model these most different processes, a new powerful and universally usable mathematical modeling concept – xHPN (extended Hybrid Petri Net) – has been established. This specification is used for the PNlib realized by the object-oriented modeling language Modelica.




The xHPN modeling concept provides an intuitive and generally comprehensible way to represent and communicate processes in nearly all degrees of abstraction and it is easy to understand for researchers from different disciplines. It supports the qualitative modeling approach as well as the quantitative one. Furthermore, the processes can be modeled discretely as well as continuously and, in addition, discrete and continuous processes can also be combined within a hybrid Petri net model [1]. Furthermore, Petri nets allow hierarchical structuring of models and, therefore, offer the possibility of different detailed views for every observer of the model.




The PNlib is an ideal all-round-tool for modeling and simulation of nearly all kinds of processes, such as business processes, production processes, logistic processes, work flows, traffic flows, data flows, multi-processor systems, communication protocols, and functional principals. The present paper serves as guide for using the PNlib. The huge application field of the new library is shown by three selected examples. The first example demonstrates the representation of functional principles by a model of a Senseo coffee machine and the second one is a model of a printing production process. The third example presents the applicability of modeling business processes. All models are provided as application cases in the library. Additionally, the application of the PNlib for modeling biological processes has been already shown, for example, in [2].

## References

[1] David R., Alla H. On Hybrid Petri Nets. Discrete Event Dynamic Systems: Theory and Applications(11): 9–40, 2001.

[2] Proß S., Bachmann B. Hybrid Modelling and Process Optimization of Biological Systems, MATHMOD Conference, Wien, Austria, 2012.

# Simulation of Non-Newtonian Fluids using Modelica

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Nowadays, many different fluids in different applications such as in food industries and energy distribution systems show a non-Newtonian behavior. In order to simulate this behavior, various approaches exist but are not fully implemented in a simulation program. One of the problems with these kinds of simulations is the lack of compatibility with existing models. This makes the modeling very time consuming.

Non-Newtonian fluids are fluids in which the viscosity changes with respect to the applied stress. Many available fluids can fully or partly be described by Ostwald-de Waele relationship. In this paper, a simple approach is shown that provides a general set of equations which can then be used to model both Newtonian as well as non-Newtonian behavior of fluids according to this relationship. Since the implementation is in the base models, existing components can be easily used to simulate non Newtonian fluids without sacrificing the simulation times.

This is done by adding a new function to describe the flow behavior index which represents the degree of non-Newtonian behavior in each fluid in the base medium model in Media library in the standard library. The equations for the calculation of pressure drop in the flow model are adapted to use the new flow behavior index function for calculation of pressure drop for both Newtonian as well as non-Newtonian fluids in the same model according to [1] (see Figure 1).

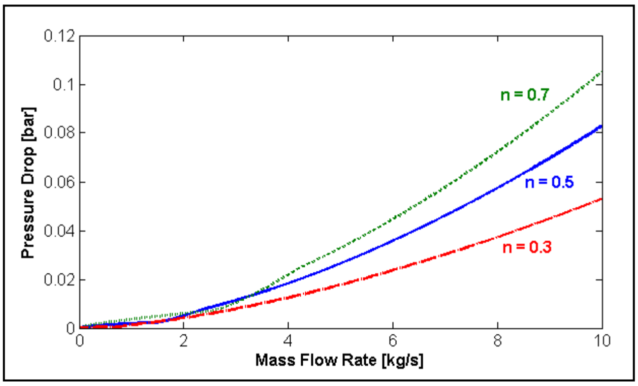


Figure 1: Comparison between different pressure-drops in fluids with different flow behavior indices

Grateful acknowledgement is made for the financial support by BMWi (Federal Ministry of Economics and Technology), promotional reference 032747B.

## References

[1] Metzner, A.B. und Reed, J.C.; Flow of Non-Newtonian Fluids - Correlation of the Laminar, Transition, and Turbulent-flow Regions; A.I.Ch.E. Journal. December 1955, pp. 434-440.

# HelmholtzMedia — A Fluid Properties Library

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For the simulation and design of power or refrigeration cycles, accurate properties of the working fluid are indispensable. All thermodynamic state properties, like pressure p or specific entropy s, as well as all partial derivatives of thermodynamic state properties can be calculated from fundamental equations of state. The most accurate equations of state available today for a variety of working fluids are fundamental equations of state in terms of Helmholtz energy [3]. Further properties of interest are surface tension or transport properties like viscosity and thermal conductivity. For each of these properties an independent correlation is necessary.

Both the Helmholtz energy equation of state as well as correlations for additional properties have been implemented as Modelica code in the *HelmholtzMedia* library. The library is compatible to and based on `Modelica.Media` [1]. The algorithms are written in a generalized form similar to the algorithms in RefProp [2].

## References

[1] H. Elmqvist, H. Tummescheit, and M. Otter. "Object-oriented modeling of thermo-fluid systems". In: *Proceedings of the 3rd International Modelica Conference*. 2003, pp. 269–286.

[2] E. W. Lemmon, M. L. Huber, and M. O. McLinden. *NIST Standard Reference Database 23: Reference Fluid Thermodynamic and Transport Properties - REFPROP*. 9.0. National Institute of Standards and Technology, Standard Reference Data Program. Gaithersburg, 2010.

[3] R. Span, W. Wagner, E. W. Lemmon, and R. T. Jacobsen. "Multiparameter equations of state — recent trends and future challenges". In: *Fluid Phase Equilibria* 183-184.1-2 (2001), pp. 1–20. DOI: `10.1016/S0378-3812(01)00416-2`.

# Object-Oriented Library of Switching Moving Boundary Models for Two-phase Flow Evaporators and Condensers

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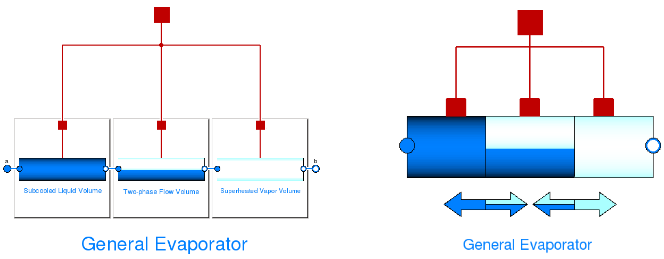
Heat exchangers play a very important role in industry; the modeling and control of these elements is a key part in the process plant control. Dynamic modeling is always a challenging task in which the trade-off between accuracy and speed must be evaluated. Moving Boundary Models (MBMs) are low-order and faster models than finite volume models; additionally they can describe the dynamic behavior of evaporators and condensers with high accuracy [1]. In the context of real-time simulation, dynamic system optimization and model-based control, where fast computation is required, the moving boundary method seems to be appropriate. The moving boundary method divides the evaporator/condenser in different regions depending on the fluid phase (subcooled liquid (SC), two-phase flow (TP) and superheated vapor (SH)). In each region, the lumped thermodynamic properties are averaged; the barrier is not fixed and it may move between adjacent CVs.




(a) Component diagram (b) Icon

Figure 1: General evaporator component

This paper discusses a new Modelica library of switching MBMs for two-phase flow heat exchangers, called the MBMs library. The novelty in this library is that the implementation strictly follows an object-oriented approach, because basic models considers the mass and energy balance equation, and compound models are developed interconnecting the basic models and adding switching support. All the evaporators and condensers are developed reusing the three basic models: SC, TP and SH models (cf. Fig. 1). An integrity test which compared the MBM results with the finite volume model implemented in the Modelica Fluid library as well as a stability test of the switching criteria are also presented.

## References

[1] S. Bendapudi, J. Braun, and E. Groll. A comparison of moving-boundary and finite-volume formulations for transients in centrifugal chillers. *International*

# High-Speed Compressible Flow and Gas Dynamics

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Discretization schemes suitable for gas dynamics are reviewed and applied to the declarative concepts of Modelica. Here, a suitable connector definition is introduced to enable both robust simulation and higher-order schemes, which require larger stencils than typically available on established thermo-fluid dynamics connectors.

## Summary

Certain applications involve a *high-speed compressible flow* (also called "gas dynamics"). Kinetic terms and dynamic pressure may not be neglected and have to be included in compressible formulations. Density variation is encountered with respect to flow phenomena, in particular dynamic conservation of momentum is relevant and also shock waves may be part of the solution. The Mach number may be larger than 0.3 (including the supersonic regime).

The key theoretical area to enable applications involving high-speed compressible flow is the discretization method for the governing equations. The foundations of numerical solution methods in thermo-fluid dynamics are well understood [3, 2]. However, in the framework of equation-based, object-oriented modeling languages, mostly methods suitable for low-speed compressible flow only have been applied. An exception is the work of López [1], who proposed an approach to model and simulate gas dynamics. Due to robustness issues, which are certainly linked to deficiencies in the connector definition used in [1], the approach was not widely adopted. In an attempt to finally extend the applicability of Modelica also to high-speed compressible flow and gas dynamics, this paper makes the following contributions.

- Relevant concepts of the theory in numerical solution methods for high-speed compressible flow are reviewed and translated from the algorithmic perspective taken in literature to the acausal concepts of Modelica.
- The elements of discretization schemes are decomposed in an object-oriented fashion and implemented in a generic library.

## References

[1] J. Díaz López. Shock wave modeling for Modelica.Fluid library using oscillation-free logarithmic reconstruction. In *Proceedings of the Fifth International Modelica Conference*, pages 641–649, 2006.

[2] C.-W. Shu. Essentially non-oscillatory and weighted essentially non-oscillatory schemes for hyperbolic conservation laws. *Advanced numerical approximation of nonlinear hyperbolic equations*, 1697:325–432, 1998.

[3] E. F. Toro. *Riemann Solvers and Numerical Methods for Fluid Dynamics: A Practical Introduction*. Springer, 1997.

# Gas Exchange and Exhaust Condition Modeling of a Diesel Engine using the Engine Dynamics Library

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In this paper the newly developed Engine Dynamics Library is presented. Ever increasing consumer and regulatory demand for improved fuel economy and lower emissions forces the engines and Engine After-Treatment Systems (EATS) to be improved continuously. Since the complete system is very complex, models are useful in cost effectively developing new control strategies and select hardware. The library is based on a mean-value combustion model and the focus lies on modeling the gas exchange with real-time like simulation times, useful for engine optimization and for evaluation of control strategies. The library contains models of the standard engine components such as manifolds, pipe, turbines, compressors, valves, mechanics, etc.

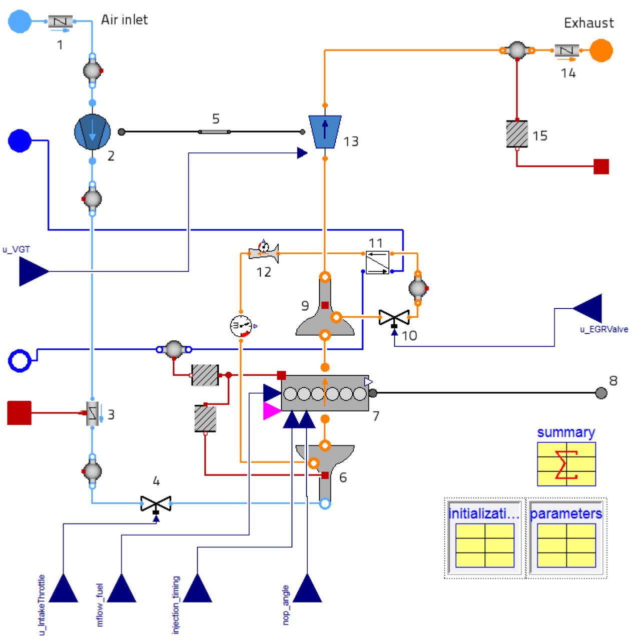


Figure 1: Diagram layer of the presented engine model

Simulation results from Dymola for a 13 L Volvo truck engine demonstrate that the model captures the transient flow and temperatures and emission trends, and has sufficient accuracy to be useful in engine optimization. The physical modeling approach allows for virtual prototyping by replacing individual components, which is an important advantage over black-box modeling. It is shown that the model captures essential system properties in the gas exchange, such as non-minimum phase behavior and sign reversal for VGT and EGR valve actuation. The model has been calibrated using surface fitting of maps and least-squares estimation of parameters in Matlab, as well as parameter optimization using JModelica and FMI.

# Library for First-Principle Models of Proton Exchange Membrane Fuel Cells in Modelica

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This paper describes the architecture and key equations of `FCSys`, a library to model proton exchange membrane fuel cells (PEMFCs) in Modelica. The motivating goal of this work is to reconcile many of the published models of PEMFCs and combine them in a reconfigurable PEMFC model that is effective for a variety of uses. It is necessary to distill equations from fuel cell literature into forms that at once capture the essence of the physical interactions, are conducive to the physical modularity of the device, and work within the constraints and take full advantage of the Modelica language.

Since the behavior of PEMFCs depends on both advection and diffusion, a suitable alternative to the Modelica Fluid library and the stream concept is necessary. The proposed solution uses a “mixing” scheme based on the exponential of the Péclet numbers for each transport process. Storage and transport processes are co-located in each subregion of a rectilinear grid—all in the same base model. The Onsager formulation is used, whereby the effort and flow rate are conjugates of the entropy flow rate associated with energy transfer.

The implementation is modular. It allows species to be enabled indendently for each region. In addition, the geometric axes may be independently enabled (up to 3D) and shearing (transverse momentum) may be optionally included. Chemical/electrochemical inteactions are communicated in a fully acausal manner through expandable connectors.

This paper focuses on the motivation, background, and approach. Future publications will describe the ongoing work to calibrate, validate, and utilize the model for particular case studies. The library is made available as open source.

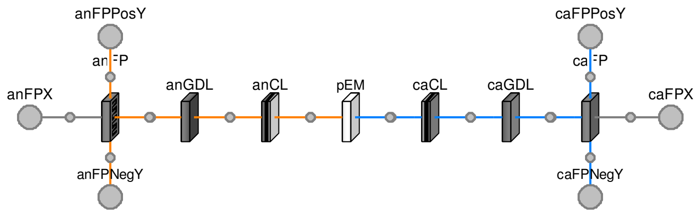


Diagram of a quasi-2D single-cell PEMFC

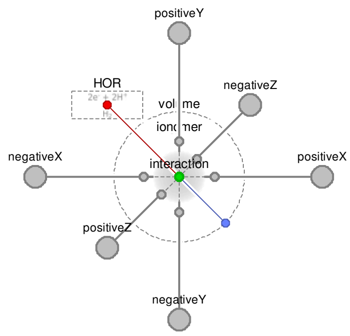


Diagram of a subregion

# The Modelling of Energy Flows in Railway Networks using XML-Infrastructure Data

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The paper reports on an activity of the DLR project Next Generation Train that led to the implementation of the Modelica RailwaySystem Library. This package provides the capabilities to simulate the energy flow in electrical railway networks on which railway vehicles are running. In particular the interaction of vehicle and its energy infrastructure is considered.

From the modeling point of view two specific problems had to be taken into account. Railway vehicles may be interpreted as energy sources or sinks that are moving in an inhomogeneous network. The network consists of catenaries or conductor lines that are supplied by power stations and may of may not be separated in isolated sections. Depending on the number and the instantaneous position and running state of the vehicles different types of flows may occur in parallel: energy may flow from power station to vehicle, or vice versa or from one vehicle to another vehicle.

As a second important aspect, the evaluation of the energy consumption of a vehicle is of course a function of the track characteristics such as length, slope, radius, positions of power station etc. so that data on the infrastructure topology and properties are required [1]. To this purpose, the library provides access to external infrastructure data, that are filed using the railway markup language RailML. This is a XML-based data format, advanced by the non-profit RailML initiative, see `http://www.railml.org/web/`.

In order to give a first impression, the example model in Fig. 1 presents a trivial network with 6 tracks, where 2 vehicle are running on. 6 power stations supply the DC-urban-train-network. Energy consumption due to conduction losses and traction is considered in this initial implementation. However the simulation framework of the RailwaySystem library does not introduce any restrictions on the modeling of the energy subsystems and is open for further extensions.

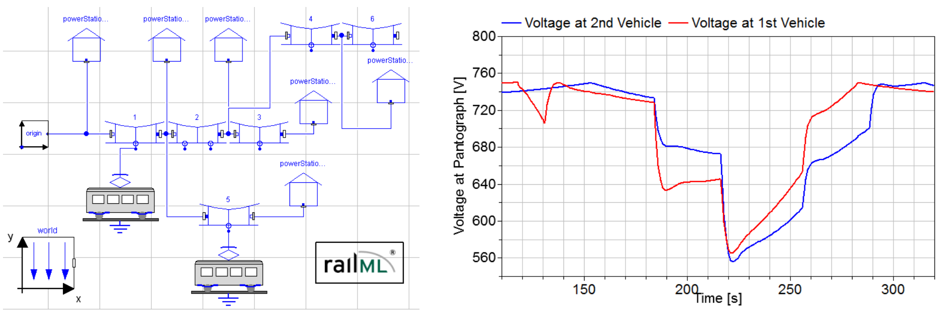


Figure 1: Diagram layer with a trivial network with 6 tracks and 2 vehicles and simulation result of the voltages of both vehicles as a function of time.

## References

[1] D. Hürlimann. *Objektorientierte Modellierung von Infrastrukturelementen und Betriebsvorgängen im Eisenbahnwesen.* Zürich, 2001. PhD thesis ETH Zürich.

# Implementation of a Modelica Library for Energy Management based on Economic Models

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The use of modeling paradigms for physical systems can in some instances be expanded to include other domains [1]. This paper presents one such example: it describes the implementation of economic models to be used for the purpose of energy management [2].

In this approach, each provider of energy and each consumer is characterized by a specific cost function. A global market or a set of local markets then decide about the distribution of energy flow.

To this end, a new Modelica library has been developed. The library is currently split into two sub-libraries that are geared towards different application domains: source management and load management. In source management, the consumer demand shall be fulfilled with the best possible efficiency. The target for load management is to identify the most important consumers that can be supplied under limited power availability.

The library is not coupled to any specific physical domain. All its components concern energy in its most abstract form. In fact, many energy management tasks involve multiple physical domains and therefore a domain-specific approach would be of limited value. The figure below depicts the Modelica model of a combined generator for electricity and thermal energy (heating) with two separate consumer profiles.

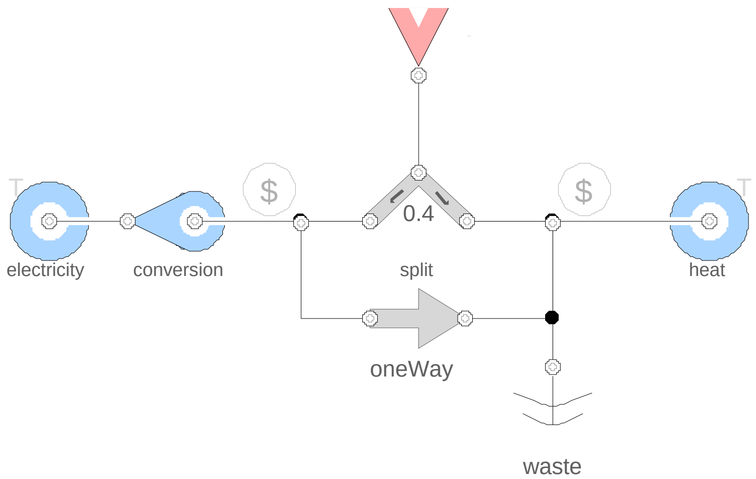


**Figure 1:** Model diagram of a combined power generator.

## References

[1] Brewer, J. W. and P. C. Craig. Bilinear, Dynamic Single-ports and Bond Graphs of Economic Systems. *Journal of The Franklin Institute*, No 185, 1991

[2] Schlabe, D., and J. Lienig, "Energy Management of Aircraft Electrical Systems - State of the Art and Further Directions," *International Conference on Electrical Systems for Aircraft, Railway and Ship Propulsion* (ESARS), Italy, October 2012.

# Modeling and Simulation of a Linear Piezoelectric Stepper Motor in MapleSim

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Devices based on piezoelectric materials have traditionally been modeled in PDE simulation software. These simulations are expensive to create and run. In this paper it is shown that lumped-parameter models of such devices can provide good fidelity with low computational cost.

In this research, Modelica components implementing piezoelectric material properties, electrostatic forces, and time-varying frictions were developed and integrated into a device-level model of a linear piezoelectric stepper motor. The model is parametric and extensible: the parameters can be changed to suit application-specific requirements, and nonlinear effects can be easily included. It was modeled in MapleSim, which is a Modelica-based system-level modeling and simulation platform provided by Maplesoft [1].

MapleSim simulation results matched those in [2][2] when similar values were implemented. Most importantly, the relative execution speed of the model permits multi-parameter optimizations not possible in full PDE simulations. This is demonstrated via the investigation of the effects of the motor clamp voltage on velocity using a compiled MapleSim procedure in Maple. Figure 1 shows an example of the model output.

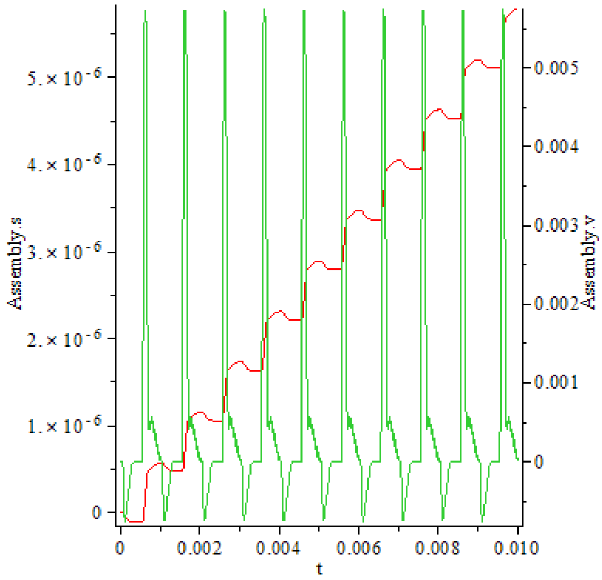


Figure 1: Plots of the position (red) and velocity (green) versus time of the linear motor.

## References

[1] www.maplesim.com

[2] Judy J W, Polla D L, and Robbins W P. A Linear Piezoelectric Stepper Motor With Submicrometer Step Size and Centimeter Travel Range. IEEE Trans. UFFC, Vol. 37, No. 5, 1990.

# Magnetic Hysteresis Models for Modelica

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Modelica models for transient simulation of magnetic hysteresis are currently being developed at Technische Universität Dresden. This paper gives an overview over the present progress of work. Two hysteresis models have been implemented so far in Modelica and are currently optimised and tested: the rather simple but efficient Tellinen model [1] and the more complex and accurate Preisach model [2]. Utilisation of the Tellinen model in combination with components of the Modelica.Magnetic.FluxTubes library [3] is exemplarily shown by transient simulation of a three-phase autotransformer. Additionally, an efficient implementation of the Preisach model is described and a comparison between the Tellinen and the classical Preisach hystesis model is presented (Figure 1).

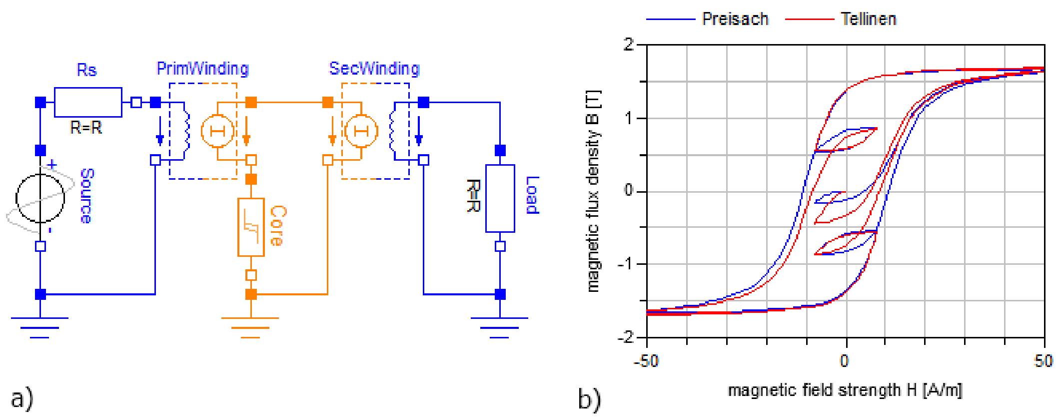


Figure 1: Simple electromagnetic network model of a single-phase transformer with closed ferromagnetic core including hysteresis effects (a) and a comparison between the implemented classical Preisach and the Tellinen hysteresis model.

It is planned to include the developed hysteresis models into the above-mentioned FluxTubes library after their further optimisation and validation with own measurements. These models will especially allow for the estimation of iron losses and for accurate computation of saturation behaviour during Modelica-based design of electromagnetic components and systems. This becomes increasingly important with the growing requirements regarding energy efficiency and mass power densities of such systems.

## References

[1] J. Tellinen: A Simple Scalar Model for Magnetic Hysteresis, IEEE Transactions on Magnetics, vol. 24, no. 4, pp. 2200 – 2206, July 1998

[2] F. Preisach: Über die magnetische Nachwirkung, Zeitschrift für Physik A Hadrons and Nuclei, vol. 94, pp. 277–302, 1935

[3] T. Bödrich: Electromagnetic Actuator Modelling with the Extended Modelica Magnetic Library, Proc. of 6th Int. Modelica Conf., Bielefeld, Germany, March 3-4, pp. 221–227, 2008

# Motor Management of Permanent Magnet Synchronous Machines

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Due to rising demand for mobility together with contradictions as climate change and scarce resources a rising variety of solutions for electric and hybrid electric vehicles gets offered. The same facts drive the need for optimizing already existing solutions to achieve higher torque density, better efficiency with respect to a given load cycle and lower losses to achieve increased cruising range with the same or even reduced energy storage. For the electric drive, there are mainly two state-of-the-art designs:

- Induction machine with squirrel cage
- Permanent magnet synchronous machine

Due to the machine design, the asynchronous induction machine with squirrel cage is a robust solution, but with the disadvantage that the electric field has to be excited by stator currents which cause additional ohmic losses.

The permanent magnet synchronous machine uses components that are more sensitive with respect to temperature and mechanical stress, but on the other hand the magnets offer a source of magnetization without additional losses.

For both machine topologies the induced voltage depends on the magnetic field and the speed. If speed gets high enough, the magnetic field has to be reduced in order to keep the induced voltage under a level that is available from the battery. In case of an asynchronous induction machine, the field current is just reduced. In case of a permanent magnet synchronous machine, the field current has to weaken the field excited by the permanent magnets to meet the voltage requirements. For the latter, the question investigated in this paper can be formulated as follows: Is it possible to determine an optimal field current, to minimize either total current consumption or losses? Current consumption is a limiting factor for designing the power electronics, whereas losses influence efficiency and cruising range.

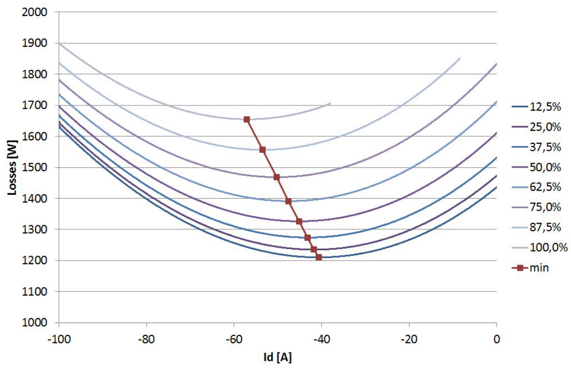

**Figure 1 Losses at nominal torque and var. speed**

## References

[1] Kleinrath, H.: Stromrichtergespeiste Drehfeldmaschinen, Springer 1980

[2] Kral, C., Haumer, A.: Object Oriented Modeling of Rotating Electrical Machines, Advances in Computer Science and Engineering, Chapter 8, INTECH 2011. http://www.intechopen.com/books/advances-in-computer-science-and-engineering/object-oriented-modeling-of-rotating-electrical-machines

[3] Vollmer, U., Schäfer, U., Taus-Beti, L.: Minimization of losses of PMSM for HEV, EVS24 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium 2009.

# An approach for modelling quasi-stationary magnetic circuits

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For the design of electrical machines the magnetic circuit has to be modeled. If only the winding layout or the stack length of the motor is changed a complete FEA analysis mostly is not necessary. In this case Modelica is well suited to model the magnetic circuit for quasi-stationary simulations. A new library `MagneticQS` based on existing standard libraries is presented. It is based on existing libraries but introduces complex variables. An induction motor example [1] (figure 1) under no-load conditions shows the basic concept of this library. The simulation results show that the new library is well suited to assist the design process for electrical machines.

The next step for developing the library is to test different types of machines under load conditions and compare the results with analytical algorithms and FEA. Once this goal is achieved an integral electrical machine magnetic circuit model can be implemented that can be used independently from the state of the machine (no-load, load) which is a great advantage in comparison with existing analytical models.

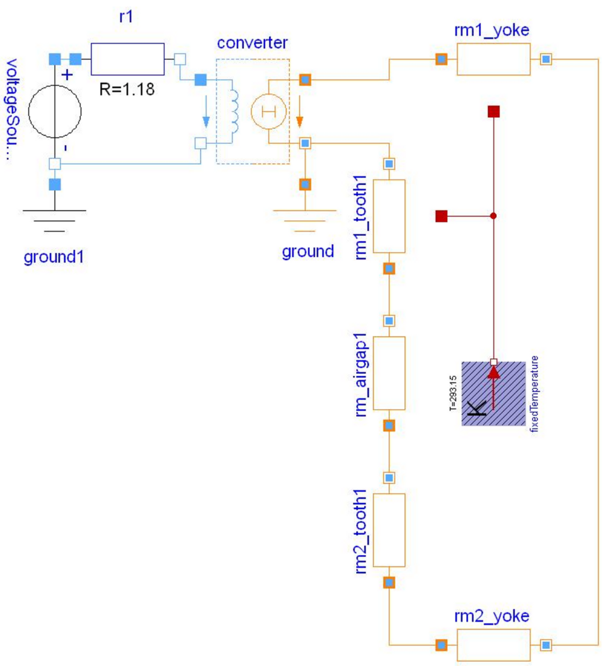


Figure 1: Induction machine no-load example

## References

[1] Vaske P, Riggert J-H. Elektrische Maschinen und Umformer Teil 2: Berechnung elektrischer Maschinen (*Calculation of electrical machines*). 1974.

# Functional Mockup Interface 2.0: The Standard for Tool independent Exchange of Simulation Models

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The Functional Mockup Interface (FMI) standard version 1.0 (see [1]) was published in 2010 as one result of the ITEA2 project MODELISAR, see [1]. In a short time after this first release several modeling and simulation tools started to support FMI. Today, more than 30 tools support FMI 1.0, and it is heavily used in industrial and scientific projects, not only in the automotive sector.

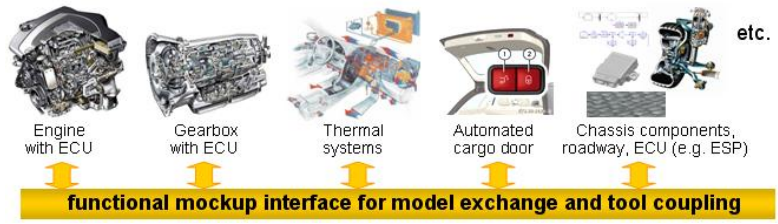


Figure 1: Improving model-based design between OEM and supplier with FMI.

After ending of the MODELISAR project in Dec. 2011, maintenance and further development is now performed by the Modelica Association in form of the Modelica Association Project FMI (see www.fmi-standard.org). FMI was initiated and organized by Daimler AG with the goal to improve the exchange of simulation models between suppliers and OEMs. The further FMI development is performed by 16 companies and research institutes. The FMI project is open for FMI interested persons and for (Modelica and non-Modelica) tool vendors supporting FMI. In this article an overview about the upcoming version 2.0 of FMI is given. This new version combines the formerly separated interfaces for Model Exchange and Co-Simulation in one standard. The specification document was clarified which increases the compatibility of implementations. New features ease the use and increase the performance especially for larger models.

## References

[1] T. Blochwitz, M. Otter, M. Arnold, C. Bausch, C. Clauß, H.Elmqvist, A. Junghanns, J. Mauss, M. Monteiro, T. Neidhold, D. Neumerkel, H. Olsson, J.-V. Peetz, S. Wolf: **The Functional Mockup Interface for Tool independent Exchange of Simulation Models.** 8th International Modelica Conference. Dresden 2011.
Download: http://www.ep.liu.se/ecp/063/013/ecp11063013.pdf

# Generation of Sparse Jacobians for the Function Mock-Up Interface 2.0

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Derivatives, or Jacobians, are commonly required by numerical algorithms. Access to accurate Jacobians often improves the performance and robustness of algorithms, and in addition, efficient implementation of Jacobian computations can reduce the over-all execution time. In this paper, we present methods for computing Jacobians in the context of the Functional Mock-up Interface (FMI), and Modelica. The algorithmic machinery employed consists of known methods and algorithms, such as numerical, symbolic, and automatic differentiation, as well as graph theoretic methods such as the BLT transformation. Two prototype implementations, sharing similarities as well as differences have been presented. One of the methods is a straight forward application of forward automatic differentiation and generation of C code, which results in functions for evaluation of directional derivatives, which in turn are used to compute Jacobians. The other method relies mainly on symbolic differentiation and makes use of symbolic simplification algorithms in a Modelica compiler to generate directional derivative functions. Both methods provide sparsity patterns for the ODE Jacobians, and and they both make efficient use of sparsity in order to reduce the number of directional derivative evaluations, a techinque referred to as compression.

The two approaches are implemented in JModelica.org and OpenModelica, respectivly, and compared in an industrial benchmark as well as in several synthetic benchmarks. Both implementations show linear growth in key measures such as model compilation time, generated code size and execution time, under realistic assumptions on model structure. In terms of execution speed, the method relying on symbolic differentiation and symbolic processing, as implemented in OpenModelica, performed faster.

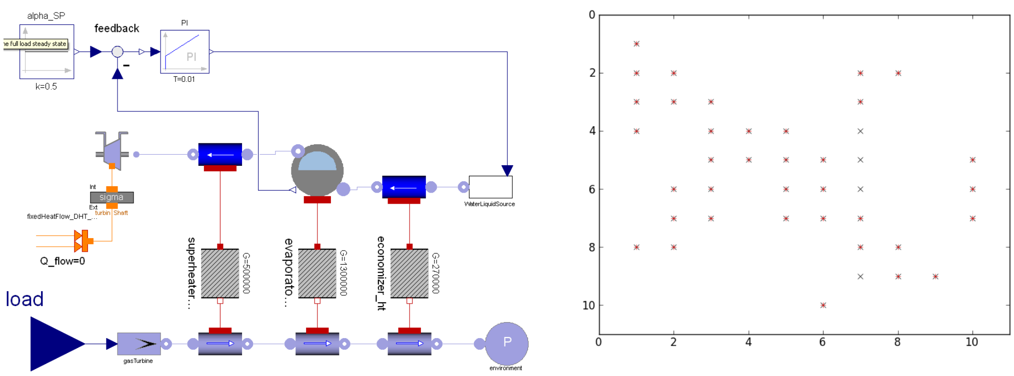


Figure 1: A power plant model used as benchmark in the papers, and the corresponding sparsity pattern.

# Designing models for online use with Modelica and FMI

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Model-based online applications such as soft-sensing, fault detection or model predictive control require representative models. Basing models on physics has the advantage of naturally describing nonlinear processes and potentially describing a wide range of operating conditions. Implementing adaptivity is essential for online use to avoid model performance degradation over time and to compensate for model imperfection. Requirements for identifiability and observability, numerical robustness and computational speed place an upper limit on model complexity. These considerations motivate that models for online use should be balanced-complexity, physically based with online adaption possible.

Despite potential benefits, the effort required to implement balanced-complexity models, particularly at large scales, may deter their use. This paper presents techniques used in the design of balanced-complexity models. A Modelica-based approach is chosen to reduce implementation effort by interfacing exported Modelica models with application code by means of the generic interface FMI. The suggested approach is demonstrated by parameter estimation for a process of offshore oil production: a subsea well-manifold-pipeline production system as illustrated in Figure 1.

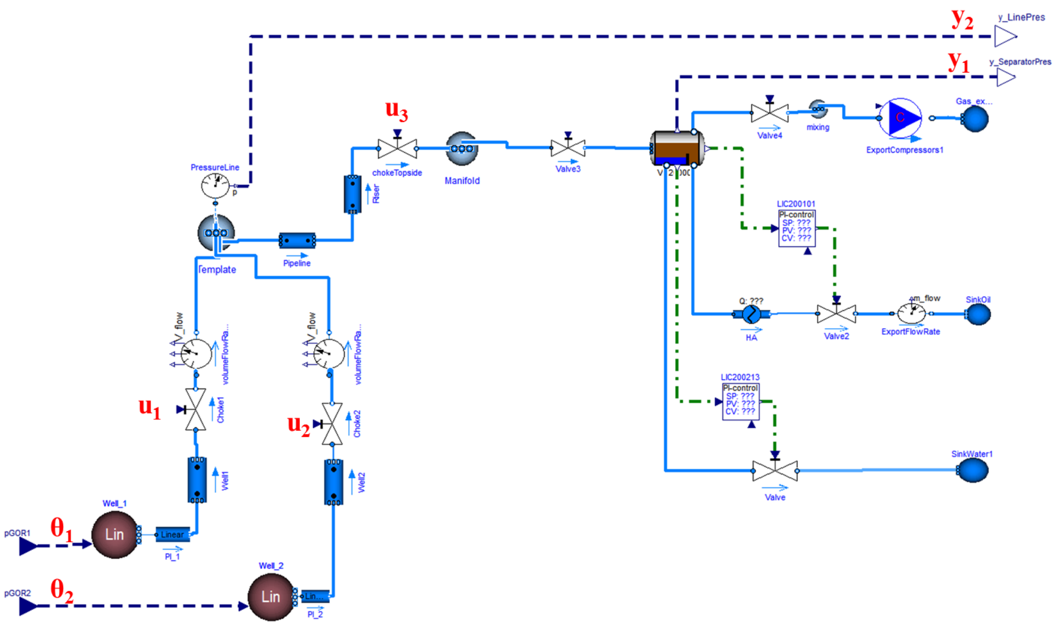


Figure 1: Overview subsea-pipeline-riser-separator system as implemented in DYMOLA, with piping (solid), handles to the estimator via FMI (dashed), and PI-control (dashdot).

# Co-simulation with communication step size control in an FMI compatible master algorithm

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Complex multi-disciplinary models in system dynamics are typically composed of subsystems. This modular structure of the model reflects the modular structure of complex engineering systems. In industrial applications, the individual subsystems are often modeled separately in different mono-disciplinary simulation tools. The Functional Mock-Up Interface (FMI) provides an interface standard for coupling physical models from different domains and addresses problems like export and import of model components in industrial simulation tools (FMI for Model Exchange) and the standardization of co-simulation interfaces in nonlinear system dynamics (FMI for Co-Simulation), see [2]. In November 2011, the third $\beta$-version of FMI for Model Exchange and Co-Simulation v2.0 was released [3] that supports advanced numerical techniques in co-simulation like higher order extrapolation and interpolation of subsystem inputs, step size control including step rejection and Jacobian based linearly implicit stabilization techniques. Well known industrial simulation tools for applied dynamics support Version 1.0 of this standard and plan to support the forthcoming Version 2.0 in the near future, see the "Tools" tab of website [2] for up-to-date information. The renewed interest in algorithmic and numerical aspects of co-simulation inspired some new investigations on error estimation and stabilization techniques in FMI for Model Exchange and Co-Simulation v2.0 compatible co-simulation environments. The present paper extends recent results from [1] on reliable error estimation and communication step size control in the framework of FMI for Model Exchange and Co-Simulation v2.0. Based on a strict mathematical analysis, we study the asymptotic behaviour of the local error and two error estimates that may be used to adapt the communication step size automatically to the changing solution behaviour during time integration. These theoretical results are illustrated by numerical tests for a (linear) quarter car model and provide a basis for future investigations with more complex coupled engineering systems.

## References

[1] M. Arnold, C. Clauß, and T. Schierz. Numerical aspects of FMI for Model Exchange and Co-Simulation v2.0. In P. Eberhard and P. Ziegler, editors, *Proc. of The 2nd Joint International Conference on Multibody System Dynamics, Stuttgart, Germany, May 29 - June 1, 2012*, ISBN 978-3-927618-32-9, 2012.

[2] FMI. The functional mockup interface. `http://www.functional-mockup-interface.org/`.

[3] Modelisar. Functional Mock-up Interface for Model Exchange and Co-Simulation v2.0 Beta 3. `http://www.functional-mockup-interface.org/specifications/FMI_for_ModelExchange_and_CoSimulation_v2.0_Beta3.pdf`, November 2011.

# On the Formulation of Steady-State Initialization Problems in Object-Oriented Models of Closed Thermo-Hydraulic Systems

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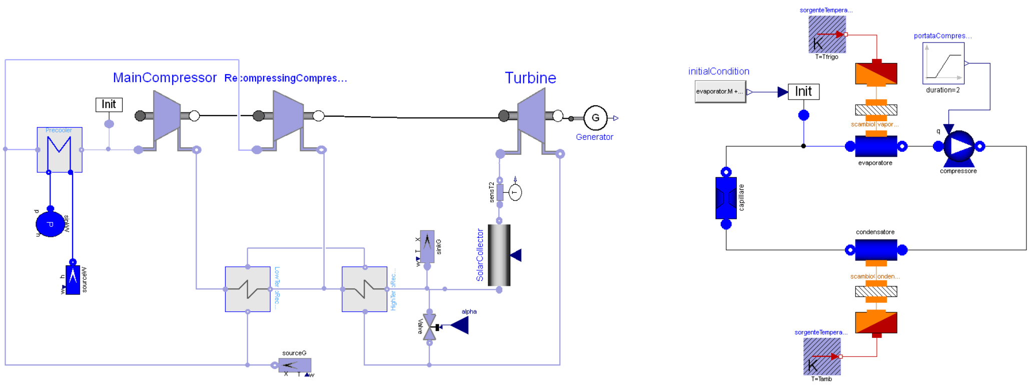
The object-oriented formulation of steady-state initialization for models of closed thermo-hydraulic systems yields singular problems, due to system-wide structural issues. The first contribution of the paper, based on a formal analysis of the problem, is a modular, object-oriented solution, taking the form of an additional component that allows to uniquely determine the initial conditions of the system. The solution has been successfully tested in two application cases: a closed, supercritical $CO_2$ Brayton cycle plant, Fig. 1(a), and a refrigeration system, Fig. 1(b).

Such singular initialization systems can arise without the end user being aware of the problem (and of its solution). When the solver is started, the singular Jacobian of the initialization problem leads to numerical errors, whose diagnostic messages hardly convey any useful information to the user. The second contribution of the paper is a method based on the analysis of the null space of the Jacobian of the initialization problem and on suitable annotations, providing the end user with meaningful, high-level, context-relevant diagnostic messages in this case.

This diagnostic method can also be applied to other well-known cases of models with system-level singularities, such as closed systems with constant density fluid or electrical circuits lacking a ground connection.




(a) Brayton Cycle (b) Refrigeration System

Figure 1: Example models

# Probability-One Homotopy for Robust Initialization of Differential-Algebraic Equations

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An evolution of the recently introduced operator `homotopy()` is proposed, which further improves the solution of difficult initialization problems. The background and motivation for this approach are discussed and it is demonstrated how to apply it for electrical and fluid systems. The key difference to the earlier approach is the supporting theory, which guarantees that the method converges globally with probability one.

## Summary

Previously [3], we introduced a homotopy operator. It maps `homotopy(actual = ..., simplified = ...)` to $\lambda \cdot actual + (1-\lambda) \cdot simplified$. The advantage of this approach is that the concept is simple and easy to understand. Also, it was successfully tested on relevant test cases [3, 1]. It has certain limitations however, in particular that the homotopy map is hard-wired into the language specification, that convergence is based on heuristics, and that a naive application can lead to singular problems (e.g., with a singular Jacobian at $\lambda = 0$).

The objective of this contribution is thus to propose a more powerful homotopy operator, which can be used as the original one, enables a declarative definition of arbitrary homotopy maps, and allows global convergence via probability-one homotopy [2, 4], an established method from topology.

Informally, the key elements of probability-one homotopy are a well-defined random element to guarantee the full rank of the Jacobian matrix, a boundedness argument, and an embedding, which essentially corresponds to the simplifications of component governing equations applied in [3, 1].

In the paper, a key theorem is reviewed to summarize the supporting theory. Additionally, implementation aspects in Modelica tools are discussed and a number of application examples are given.

## References

[1] F. Casella, L. Savoldelli, and M. Sielemann. Steady-state initialization of object-oriented thermo-fluid models by homotopy methods. In *Proceedings of Eighth International Modelica Conference*, Dresden, Germany, March 2011.

[2] S.-N. Chow, J. Mallet-Paret, and J. A. Yorke. Finding zeroes of maps: Homotopy methods that are constructive with probability one. *Math. Comput.*, 32(143):887–899, July 1978.

[3] M. Sielemann, F. Casella, M. Otter, C. Clauss, J. Eborn, S. Mattsson, and H. Olsson. Robust initialization of differential-algebraic equations using homotopy. In *Proceedings of Eighth International Modelica Conference*, Dresden, Germany, March 2011.

[4] L. T. Watson. Globally convergent homotopy methods: A tutorial. *Appl. Math. Comput.*, 31:369–396, May 1989.

# Simulating Modelica models with a Stand–Alone Quantized State Systems Solver

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This article describes an extension of the OpenModelica Compiler that translates regular Modelica models into a simpler language, called Micro–Modelica ($\mu$–Modelica), that can be understood by the recently developed stand–alone **Quantized State Systems (QSS) solvers**. These solvers are very efficient when simulating systems with frequent discontinuities. Thus, strongly discontinuous Modelica models can be simulated noticeably faster than with the standard discrete time solvers. In Fig. 1 we can see the complete proposed implementation of the model transformation, compilation and simulation process.

Extended simulations on two example models were performed, demonstrating the increased efficiency of the stiff LIQSS solvers over the default DASSL solver of OpenModelica. **Consistent speedups were achieved and the required CPU time was reduced up to 40 times**. Furthermore, for the two systems simulated we observed that the default DASSL solver failed to generate the correct results if we didn't force many output points. On the other hand, not only the **QSS solvers simulated correctly** the models at all setups but, because of the **dense output** they inherently generate, the number of steps taken remains constant regardless of how many output points are requested.

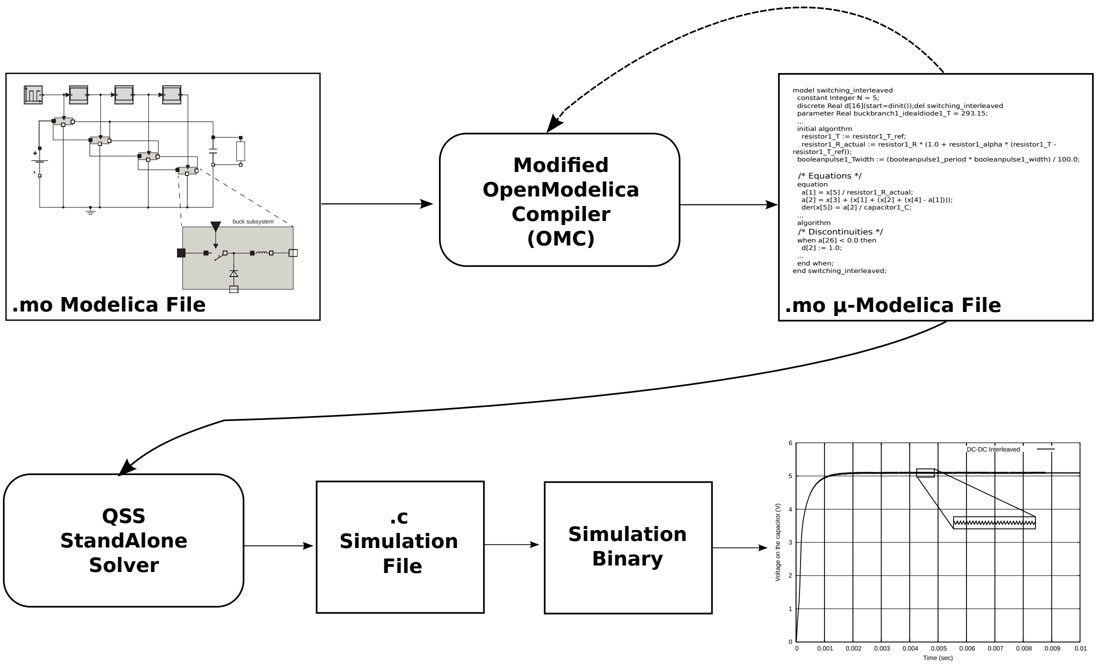


Figure 1: Pipeline of the implemented compilation/QSS simulation process

# Fast Simulation of Fluid Models with Colored Jacobians

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The industrial usage of the open-source Modelica tool OpenModelica was limited so far for power plant applications, due to performance of the large fluid systems. This paper presents some efforts to improve the simulation time on benchmark fluid models proposed by Siemens Energy.

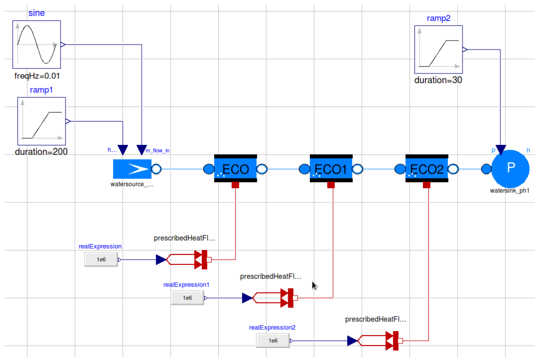


Figure 1: Pipes benchmark model

The main aspects presented here to achieve a faster simulation are an efficient evaluation of the jacobian matrix. This is done by extracting efficent the sparsity pattern of the jacobian matrix from the original model during the compile process. The information about the sparsity pattern make an compression of the jacobian matrix possible. The compression means that columns of the jacobians are combined and could calculated at once. The decision which is columns could be combined is determined by a coloring technique which is resultung a an colored jacobian matrix. Therefore the techniques are scratched, applied and shown that the effect is significant, moreover this feature pushes OpenModelica further to an efficient simulation environment for relevant industrial problems.

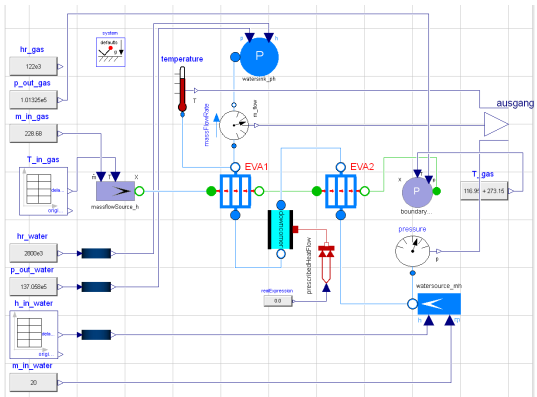


Figure 2: Heat exchanger benchmark model

# Modelling and Calibration of a Thermal Model for an Automotive Cabin using HumanComfort Library

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This article aims to describe a modular system level modeling approach for the thermal behavior of an automotive cabin. The model is parameterized with geometric and physical data. At the end a set of 6 parameters is used to calibrate the model with two measurement data sets: one for a passive heat up and active pull down and one for a cold heat up. The procedure can be used as a recipe for developing own models of the same kind which may be used in integrated thermal management studies.

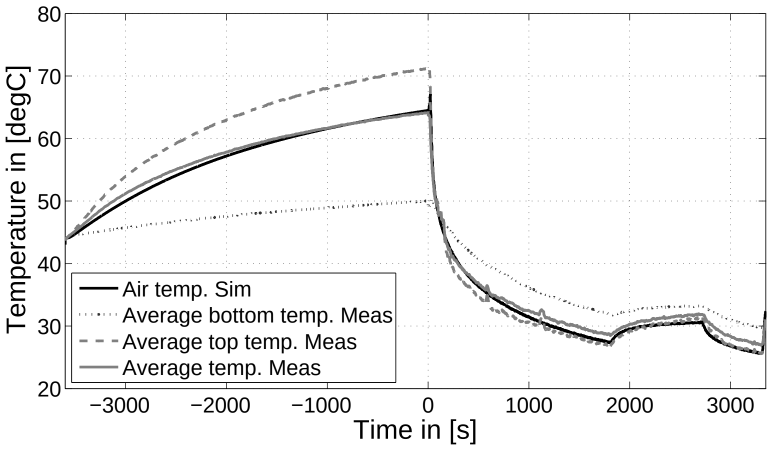


**Fig. 1 Calibration result for passive heat up and active pull down of a sedan car – comparison of simulation result with average air temperature measurement**

## References

[1] Michaelsen B., Eiden J.: HumanComfort in Buildings and Mobile Applications: In proceedings of the 7th Modelica Conference, Como, Italy, 2009, pp. 403-412.

[2] Neacsu C.-A., Ivanescu M., Tabacu I.: The influence of the solar radiation on the interior temperature of the car, http://www.theseus-fe.com/downloads, 2009.

[3] Kaiser C., Försterling S., Tegethoff W., Köhler J.: Untersuchungen von Regelstrategien für die Omnibusklimatisierung mit Hilfe einer Gesamtfahrzeugsimulation, In proceedings of ASIM GI Workshop, Wolfenbüttel (Germany), Feb. 2012.

[4] Baumgart R., Tenberge P., Urbaneck T.: Senkung des Kraftstoffverbrauchs durch Optimierung der Klimaanlage: In proceedings of 14th international congress and exhibition SIMVEC – Numerical Analysis and Simulation in Vehicle Engineering 2008, Baden-Baden (Germany), 2008.

[5] Mezrhab A., Bouzidi M.: Computation of thermal comfort inside a passenger car compartment, Journal of Applied Thermal Engineering, Elsevier, Volume 26, 2006, pp. 1697–1704.

[6] Grossmann, H.: PKW-Klimatisierung, Springer Verlag, Berlin, 2010.

# Holistic Vehicle Simulation using Modelica – An Application on Thermal Management and Operation Strategy for Electrified Vehicles

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The increasing electrification of the drive train in the automotive environment leads to higher requirements for automotive systems and their design. Furthermore, with the increased electrification of future car architectures the complexity and the interaction between the different physical levels (mechanical, electrical, thermal and chemical) will clearly be increased. Therefore, a computer based methodology to support the engineer in the design phase of car concepts, components and control algorithms is desirable. All relevant sections of a vehicle development process, e.g. longitudinal and lateral dynamics, thermal management or the power supply should be considered. Due to this necessity a new holistic vehicle library based on the modeling language Modelica is being developed at the Forschungsgesellschaft Kraftfahrwesen mbH Aachen (fka) and the Institute of Automotive Engineering (ika) of RWTH Aachen University.

The model library takes into consideration all energetic (mechanical, electrical, thermal and chemical) and logical (sensors, actors and control units) flows including dynamic boundary conditions (e.g. drive cycles, ambient conditions) of automotive concerns. It follows a layer based level approach and has four levels. At the lowest level (base level) generalized elements are implemented which can easily be adapted due to the object oriented modeling property of inheritance or instantiation. The second level, the components level combines a variable number of base elements to generate models to a chosen level of design. At the system level (third level) the interactions of energy and signal flow between all components are implemented. The top level, i.e. the vehicle level combines all vehicle sub models such as the power train, the respective cooling circuits, the power supply and the passenger cabin. Beside the global boundary conditions, such as the driving cycle, the route profile, ambient conditions or initial conditions a control block which consists of the driver and the ECU manages all concerns of control.

The introduced holistic method is applied exemplarily on an architecture with the traction battery used as a thermal storage to determine the potential of such a design on the overall efficiency and to analyse different operational strategies.

# Modelling of Radiative Heat Transfer in Modelica with a Mobile Solar Radiation Model and a View Factor Model

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This paper presents a model to estimate the solar radiation under clear sky conditions over stationary surfaces like building façades or parked automobiles, moving surfaces like vehicles following a predefined path, as well as flying surfaces like aircraft during climb, cruise and descent. For the latter it is important to predict the peak solar irradiance under clear sky condition to calculate maximum possible solar thermal loading. Solar heating can contribute significantly to thermal loads of an aircraft, especially when flying at high altitudes. Solar radiation affects e.g. aircraft cockpits directly through the windshield and cabins through windows. Heat dissipated by internal heat sources and heating by direct solar radiation has an adverse effect on thermal comfort of passengers, cabin crew and pilots which requires considerable amount of cooling air in the cabin and in the cockpit. In this paper results of irradiation over surface on ground and over aircraft windows and windshields at cruise altitude are presented.

Another model implemented, calculates the view factor between two or more surfaces. Determination of the long-wave radiant heat exchange between two or more surfaces or heat exchange with a surface itself requires a view factor matrix. There are several analytical solutions available to calculate view factors for simple and known configurations. Many building simulation programs estimate the view factors in a simplified way, especially when complex geometries are involved. The simplified approach may result in high errors of surface temperatures, which can further cause error in energy balance and estimation of comfort level. The purpose of creating this model is to calculate view factors between complex geometries. The view factor matrices of an enclosed space and of a geometry with openings on its surfaces are presented in this paper. A sensitivity analysis of a view factor matrix is also presented.

# VEPZO – Velocity Propagating Zonal Model for the prediction of air-flow pattern and temperature distribution in enclosed spaces

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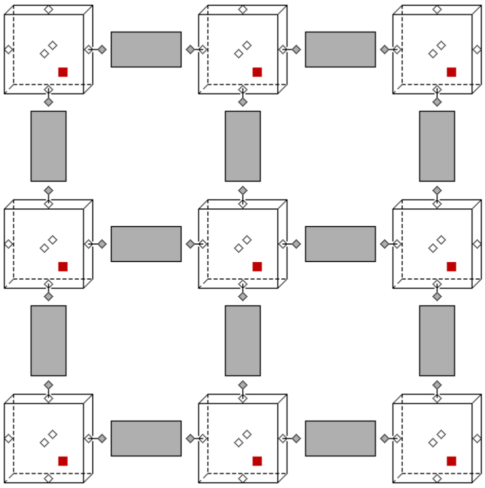

This paper presents the VEPZO-model (VElocity Propagating ZOnal model), the first three dimensional airflow model for indoor spaces that has been implemented in Modelica. It is developed from the idea of zonal models. A zonal model divides a room into typically 10 to 100 zones exchanging air through flow paths. Zonal models are a compromise between the computational speed provided by the assumption of a perfectly mixed air volume and the high local resolution provided by computational fluid dynamics.

The model predicts airflow and temperature distribution in a room. Former zonal models incorporate the assumption that air rests in the zones and only moves in the flow paths. Therefore, driving airflows resulting from a jet or plume need to be described by special correlations instead of the zonal model. Once the velocity in the correlation is dissipated below a certain threshold, the zonal model is used again. A Modelica implementation of this suggestion would require the model to change its set of equations during runtime to be able to switch from the zonal model to a correlation model where needed. However, this structural dynamics is currently not foreseen in Modelica.

The VEPZO model considers the airflow velocity as a further property of the zone which results from the incoming and leaving airflows. This property is propagated to the flow models. By this procedure, driving airflows are carried into space. Furthermore, the acceleration of airflow is computed in the flow models. This acceleration results from forces acting on the flow path. Losses of the airflow are modeled by an increased viscosity (0.001 Pa·s) similar to the idea of turbulent viscosity.

The VEPZO model uses components like the air models from the Modelica.Standard library. Furthermore, it allows interfacing to components by e.g. using the standardized heat connector.

In an application example a displacement ventilation of a twin-aisle aircraft cabin is investigated. The VEPZO model shows a quick prediction of the temperature distribution in the cabin. With the displacement ventilation a comfortable thermal environment can be achieved.

The use of Modelica to solve this problem showed to be advantageous as many of the auxiliary components (walls, air in other compartments, air properties in zones) are represented with predefined models allowing the research engineer to concentrate on the core of the development, in this case the VEPZO model.

# Modeling and Testing of the Hydro-Mechanical Synchronization System for a Double Clutch Transmission

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Synchronization is a core component in the automotive powertrain. It uses friction and locking elements to synchronize the occurring speed difference during gear shifting. The optimization of this shifting process is of high interest in respect to fuel consumption and comfort considerations. Moreover, for the model-based calibration of automated transmissions, detailed simulation models of the synchronization system are also necessary. Highly accurate models allow simulation of nonlinear effects having a major influence on the shifting process, it can supply more realistic reflects during synchronization and give a more exact guidance for the calibration. Currently, with less detailed models only rough estimations of the shifting process are possible, but it has a reduced meaning for the precise calibration.

This paper uses a 7-speed double clutch transmission (DCT) as the research object and presents the detailed hydro-mechanical synchronization model with 5 stages (pre-sync, locking, unlocking, turning hub and engagement) instead of 3 stages (neutral position, friction phase and engaged position). Firstly, an introduction about the theory of the synchronization system is given. This supplies a detailed understanding of its working principle. Subsequently, a Modelica® based synchronization model consisting of hydraulic system, hydro-mechanic actuators and gear shifting synchronizers is presented and discussed in detail. Finally, these modules are respectively evaluated based on different test cases (such as mechanical module testing in Figure 1). A comparison with test bench measurement data from an automated manual transmission (AMT) system is also included in the end (see Figure 2).

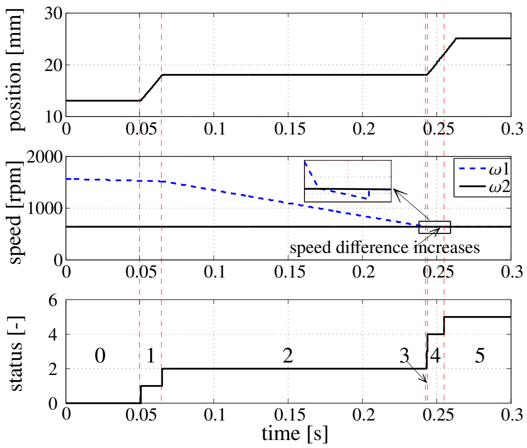


Fig. 1: Simulation results of mechanical module

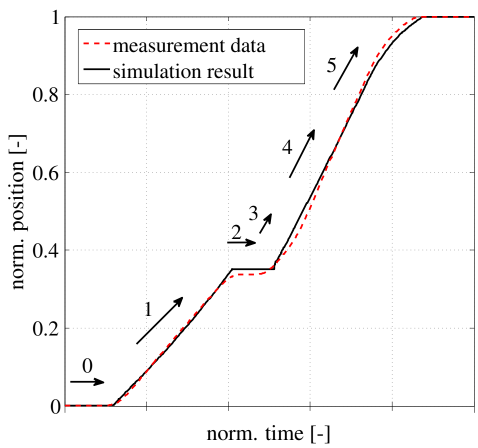


Fig. 2: Synchronization: Comparison of simulation results with measurements

# Predicting the launch feel of automatic and dual clutch transmissions

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Recent developments of the Powertrain Dynamics (PTDynamics) Library [1] are presented and these are used to model the initial launch response of two vehicles. The developments discussed are the introduction of a dynamic torque converter model, the addition of a new wet clutch model that accounts for temperature effects and aggregated shafts.

In automatic transmissions the engine and gearbox are coupled by a torque converter. This is typically modelled using the steady state performance curves for the torque converter that relate speed ratio, torque ratio and capacity factor (k-factor, MPC2000, or c-factor). The problem is that models based on these curves cannot capture the transient behaviour of the torque converter. During large transient events such as initial launch, gear shifting and driver tip-in and tip-out events the transient response of the torque converter has an impact on the vehicle response and the perception of performance experienced by the driver.

A dynamic torque converter model has been implemented to overcome this problem and enable the torque converters fluid inertia and stator dynamic behaviour to be included in simulations. The model is based on the nonlinear lumped parameter model derived in Hrovat and Tobler [2] that describes the converter dynamics. An example vehicle model is used to illustrate the different results achieved during the initial launch of a car using the steady state and dynamic torque converter models.

Wet clutches are key components in both automatic and dual-clutch transmissions and a new model for predicting the torque response of a wet clutch pack has been developed. The torque across a wet clutch is a direct function of automatic transmission fluid (ATF) film thickness, pressure distribution and asperity pressure at the interface. The model calculates the total torque across the wet clutch as the sum of the hydrodynamic torque and asperity torque.

Initial torque generation is known to be heavily influenced by the presence of the lubricating oil and its properties [3] requiring accurate clutch pressure control for smooth engagement. By accounting for the hydrodynamic and friction torque from asperity contact separately, the Wet Clutch models within the PTDynamics library were used to study the torque engagement profile under cold and warm conditions. Results show a need for controller calibration during cold starting conditions to achieve a smooth pull-away from standstill.

## References

[1] Dempsey M., and Picarelli A. Investigating the MultiBody Dynamics of the Complete Powertrain System. Como, Italy: Proceedings 7th Modelica Conference, 2009.

[2] Hrovat D., and Tobler W.E., Bond-graph modelling and computer simulation of automotive torque converters. Journal of the Franklin Institute 319,93-114, 1985

[3] Yang, Y., Lam, R., and Fujii, T.: Prediction of Torque Response During the Engagement of Wet Friction Clutch, SAE Technical Paper, 981097, 1998.

# Modelling of Elastic Gearboxes Using a Generalized Gear Contact Model

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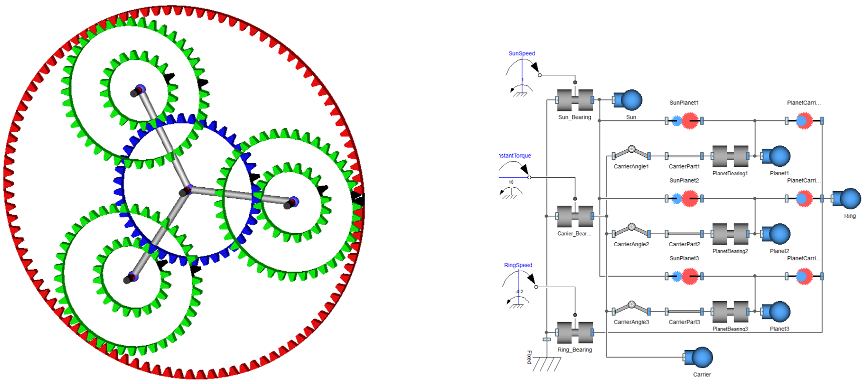
In this paper an elastic gear contact model is presented. Using an external planar library [1], it is possible to model arbitrary gear configurations ranging from simple spur gears up to complex epicyclic gear configurations (see Figure 1(a)). In Figure 1(b) the Modelica graphical interface of the epicyclic gear from Figure 1(a) is shown.



(a) Graphical representation (b) Modelica model

Figure 1: Model of an epicyclic elastic gear

Moreover the presented gear model can simulate a constant- or varying gear tooth elasticity (simulating internal excitations of the gearbox). An example of a simple spur gear with varying tooth stiffness is given (see Figure 2).

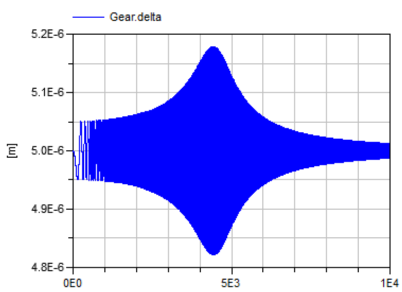



Figure 2: Simulation of the deformation of an elastic spur gear with increasing velocity.

## References

[1] ZIMMER, D. A planar mechanical library for teaching modelica. In *review for the Proceedings of the 9th International Modelica Conference* (2012).

# Revised and Improved Implementation of the Spur Involute Gear Dynamical Model

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An improved model having new, more realistic, properties is constructed with use of previously implemented approach for building up a model of the spur involute gear dynamics. First of all, an algorithm for contact tracking of cylindrical surfaces directed by involutes was rearranged. This algorithm is “simply” reduced to tracking the two involutes. A result is that common line normal to these contact curves always coincides with the line of action. This property permits obtaining direct simple formulae for contact computations.

A backlash in gearbox is also taken into account in the model under consideration. This means that a loss of contact between the teeth is possible as gearwheels rotate. This may then cause an appearance of a contact patch during the reversal. Furthermore, a dynamical reasons may force the mesh process to return to the former mode of the forward stroke and so fourth. All such scenarios for switching modes are implemented in the model in a unified way.

A time overlapping of contacts between teeth pairs is used to ensure the mesh reliability. This property is also implemented in the described dynamical model. New contact of the next pair of teeth arises and starts its motion along the line of action before the old contact leaves this line at the point of teeth disengagement.

The project under presentation is based on the original development of the multibody dynamics simulation class library [2]. Modelica templates being applied to the teeth contact model implementation initially were developed in [3].

This work was performed with partial support of Russian Foundation for Basic Research, projects: 11-01-00354-a, 12-01-00536-a, 12-08-00637-a.

## References

[1] Kosenko, I., Gusev I. Implementation of the spur involute gear model on Modelica. In: Proceedings of the 8th International Modelica Conference, Auditorium Centre of the Technische Universitat Dresden, Germany, March 20–22, 2011, pp. 315–328.

[2] Kosenko, I. I., Loginova, M. S., Obraztsov, Ya. P., Stavrovskaya, M. S. Multibody Systems Dynamics: Modelica Implementation and Bond Graph Representation. In: Proceedings of the 5th International Modelica Conference, arsenal research, Vienna, Austria, September 4–5, 2006, pp. 213–223.

[3] Kosenko, I., Aleksandrov, E., Implementation of the Contensou–Erismann Model of Friction in Frame of the Hertz Contact Problem on Modelica. In: Proceedings of the 7th International Modelica Conference, Como, Italy, 20–22 September 2009. Francesco Casella, editor. Linköping University Electronic Press, 2009. ISBN 978-91-7393-513-5. Linköping Electronic Conference Proceedings, ISSN:1650-3740. DOI: 10.3384/ecp0943, pp. 288–298.

# Accessing External Data on Local Media and Remote Servers Using a Highly Optimized File Reader Library

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ncDataReader2 [1] is an open-source solution for the efficient interpolating access to external data sets. The library of C-functions can be used with different applications and works well with Modelica. Data sets can be easily accessed as continuous functions using different interpolation and extrapolation methods. The application range covers reading generated or measured data, the integration of simulation results from Modelica or other systems and the validation, parametrization and optimization of models using external data. Data sources may be local files or remote servers. Using the netCDF file format, the DAP network protocol and different optimization approaches the data access can be surprisingly fast, even for large remote files with many variables containing millions of values.

Two different APIs (application programmers interfaces) are available to the Modelica user, accompanied by some wrapper functions and classes written in Modelica.

The most used application today is reading weather data in Modelica simulations of buildings and solar systems. But it is easy to use the library for other purposes and with different software packages.

A server run by the authors provides different data to the research group. This includes weather files generated with METEONORM, the monitoring of a solar plant and the results of different simulations. Using the DAP protocol these data sets can be accessed in simulations like local files using ncDataReader2.

In a research project covering the co-simulation of a solar thermal system the library was used to read the results of a Modelica simulation into the boundary conditions of a CFD simulation with ANSYS CFX. This made it possible to study and adjust the complex CFD model of the thermal storage under realistic conditions, but with reasonable calculation effort. The optimized model was then used in a second step in a real co-simulation of the system.

Another application is the parametrization of a model by the integration of measured data from a real photovoltaic (PV) system located at the UdK into a simulation model of the system. Besides the performance values some environmental conditions of the plant are measured and archived. The *BuildingSystems* library [2] includes a one-diode model of a PV module which contains a constant correction parameter that needs to be adjusted for a real system. A simulation of the model reads the measured environmental conditions with the data reader library. By comparing the calculated and the measured performance the parameter can be adjusted to match the real system under the observed conditions.

## References

[1] ncDataReader2: http://www.j-raedler.de/projects/ncDataReader2
[2] BuildingSystems: http://www.modelica-buildingsystems.de

# Detailed geometrical information of aircraft fuel tanks incorporated into fuel system simulation models

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Fuel tanks in fighter aircraft have an irregular shape which is represented by a detailed CAD model. To simulate a fuel system with sufficient amount of detail to solve the design issues, necessary geometrical information need to be given in a compact and computationally fast form. A function approximation using radial basis functions is suggested, analyzed and compared to some other methods. The complete process from production scale CAD model to system simulation model is considered. The work has shown the following:
It is possible to achieve an appropriate level of accuracy for all intended design studies. It is important to get a sparse representation to keep the translation/compilation time down. Several different choices of radial basis functions are usable and the Gaussian is comparable to the others with respect to simulation time, but gives more sparse representations. Care is needed to avoid the Runge phenomenon, which may slow down simulations considerably when the fuel level is close to a pipe end. Finally, using RBF as function approximation keeps simulation times in the same level of magnitude as the simple and much less accurate 2D square box approximation previously used.

*Keywords: aircraft design; fuel systems simulation; geometrical representation; surrogate model; radial basis functions.*

## References

[1] Gavel. H. (2007) *On Aircraft Fuel Systems – Conceptual Design and Modeling.* Dissertation No.1067, Division of Machine Design, Department of Mechanical Engineering, Linköpings University. ISBN 978-91-85643-04-2

[2] Lind. I. & Andersson. H. (2011) *Model Based Systems Engineering for Aircraft Systems – How does Modelica Based Tools Fit?* In proceedings of the 8th International Modelica Conference, Dresden, 2011

[3] Steinkellner S., Andersson H., Gavel H. and Krus P. *Modeling and simulation of Saab Gripen's vehicle systems*, AIAA Modeling and Simulation Technologies Conference, Chicago, USA, AIAA 2009-6134, 2009

[4] Wikström J., 3D *Model of Fuel Tank for System Simulation: A methodology for combining CAD models with simulation tools*, Masters thesis LIU-IEI-TEK-A—11/01201—SE, Linköpings University, 2011, http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-71370

[5] Buhmann, M. D. *Radial Basis Functions*, Acta Numerica (2000) 1—38.

[6] Chen. S., Billings. S.A. & Lou. W. (1989) *Orthogonal least squares methods and their application to non-linear system identification*. Internal Journal of Control, 50:5, 1873 -1896

[7] Chen. S., Billings. S.A., Cowan. C.F.N. & Grant. P.M. (1990) *Practical identification of NARMAX models using radial basis functions*. Internal Journal of Control, 52:6, 1327 -1350

[8] Boyd, J.P., *Six strategies for defeating the Runge Phenomenon in Gaussian radial basis functions on a finite interval*. Computers and Mathematics with Applications, 60 (2010), 3108-3122.

# Simulation of Artificial Intelligence Agents using Modelica and the DLR Visualization Library

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This paper introduces a scheme for testing artificial intelligence algorithms of autonomous systems using Modelica and the DLR Visualization Library [1]. The simulation concept follows the 'Software-in-the-loop' principle. No adaptations are made to the tested algorithms. The environment is replaced by an artificial world generated by the Visualization Library and the rest of the autonomous system is modeled in Modelica. The scheme is introduced and explained by using the example of the ROboMObil [2], which is a robotic electric vehicle developed by the DLR's Robotics and Mechatronics Center.

The variety of autonomous systems, or also known as artificial intelligence agents (AIA), can range from small toys like Lego mindstorms to full-sized robotic cars like the ROboMObil (ROMO). In all cases an agent consists of three essential parts: sensors, the core artificial intelligence for the agent's functionality, and actuators. The agent perceives its current environment through its sensors, interprets it and plans the next actions to reach its goal before acting upon the environment through its actuators. For a sufficient simulation of an autonomous system the bidirectional connection of an agent to its environment must be considered.

The combination of Modelica with the DLR Visualization Library creates a powerful tool for an efficient development of complex physical agent and environment models.

Our motivation for the presented scheme is a bidirectional autonomous systems simulation, which combines extensive Modelica models of the ROMO with the artificial intelligence system used in the real vehicle.

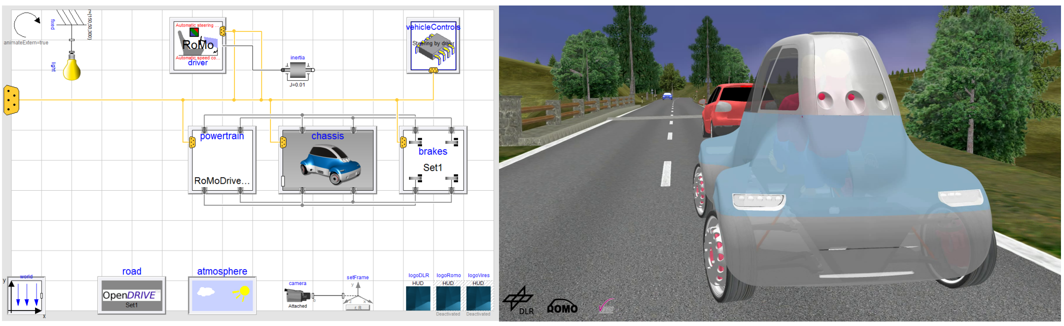


Figure 1: A Modelica model of the ROMO using the DLR Visualization Library and the corresponding visualization

## References

[1] Tobias Bellmann. Interactive simulations and advanced visualization with modelica. In *Proceedings 7th Modelica Conference, Como, Italy*, 2009.

[2] Jonathan Brembeck, Lok Man Ho, Alexander Schaub, Clemens Satzger, and Gerhard Hirzinger. Romo - the robotic electric vehicle. In *22nd International Symposium on Dynamics of Vehicle on Roads and Tracks*. IAVSD, 2011.

# Functional Development with Modelica: A Use-Case Analysis

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The paper deals about the development steps of an embedded controller. The activities of the role function developer are explained for the simple example traffic light controller. The method of virtual integration is explained to establish short feedback loops.

The behavior of a dynamic system is in general too complex to treat by theory or formulas. Several simulation methods have been established for analyzing such systems. The virtual integration method is conducted on a model to gain knowledge about the (intended) real system behavior. This abstraction typically allows to focus on the main properties of the studied multi-domain system and their effects. These components require specific domain solvers for mechanical, electrical, etc. components. In this context, the term co-simulation has been established. The virtual integration is based on co-simulation and described in [3, 4]. There is a rather huge literature on the Vee-Model and systems engineering, see e.g. [1]. For more general introduction see, e.g. [2]. In the following, we demonstrate how to develop a control algorithm for an embedded controller designing the entire system - both the plant and the control components - with the modeling language Modelica.

This approach allows us the modeling and simulation of the entire system, and thus the validation of the design decisions in an early phase of the development.

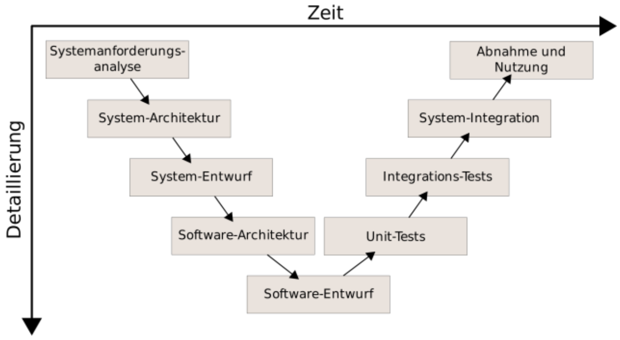


Figure 1: The development phases of the Vee-model that are considered in this paper are, see Figure 4, [17]: system level requirements, system design, module design, module implementation, module integration and test and finally system integration and test on an embedded controller.

*Keywords: embedded systems; simulation; modeling; short feedback loops; co-simulation; virtual integration; Vee-Model; systems engineering*

## References

[1] A.-P. Bröhl and W. Dröschel. Das V- Modell. Der Standard in der Softwareentwicklung mit Praxisleitfaden. Oldenbourg R. Verlag, September 1995. ISBN 978-3-348622-207-4

[2] T. Huckle and S.-A. Schneider. Numerische Methoden: Eine Einführung für Informatiker, Naturwissenschaftler, Ingenieure und Mathematiker. Springer, 2006. ISBN 978-3-54030-316-9

[3] A. Maier and S.-A. Schneider. Analyse des Einflusses der Co-Simulation bei der Modellintegration. Tagungsband ASIM 2011, 2011. ISBN 978-3-89967-733-1

[4] S.-A. Schneider, B. Schick and H. Palm. Virtualization, Integration and Simulation in the Context of Vehicle Systems Engineering. In Embedded World 2012 Exhibition & Conference Proceedings. Weka Fachmedien, 2012. ISBN 978-3-64550-072-2

# Translating Modelica to HDL: An Automated Design Flow for FPGA-based Real-Time Hardware-in-the-Loop Simulations


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Recent movement towards electric vehicles imposes new challenges on the development of drivetrains. Especially the verification of electric motor controllers (EMCs) using the hardware-in-the-loop (HiL) test methodology requires real-time simulation of the functional environment with low latencies. An electric motor emulator (EME) emulates an electrical motor under real conditions, including position feedback and other sensor signals. If needed, a power stage recreates the original currents and voltages. Due to the dynamic electric behavior of the motor, the model iteration rate has to be in the order of one microsecond. Since such real-time requirements are hard to meet using software solutions, HiL emulators of electric machines typically involve a field-programmable gate array (FPGA) which carries out time-critical computations. Although Modelica has proven to be an effective language for describing electric hybrid drivetrains [1], there is currently no tool support for compiling Modelica to FPGAs.

We present an integrated methodology which translates Modelica models to VHDL hardware designs. The implementation is realized and validated using SimulationX. Our approach combines well-known methodologies from both differential-algebraic equation (DAE) processing and high-level synthesis (HLS) [2]. We employ inline integration [3] to obtain a compact calculation rule which can be efficiently mapped to hardware. Moreover, we incorporate parametrizable circuit templates (so-called IP cores) to solve common subproblems during the mapping process. The combined model of motor and drivetrain is built using an FPGA-aware Modelica library. The resulting model is automatically transformed to an FPGA design, traversing a sequence of transformation steps, such as compilation, assignment of operations to FPGA clock steps (scheduling), assignment of operations to hardware resources (allocation and binding), interconnect and control path construction. We demonstrate the methodology using the example of a direct current (DC) motor. Our results show that the generated hardware design meets the given time and resource requirements.


## References


[1] Winkler D., Gühmann C. Hardware-in-the-Loop simulation of a hybrid electric vehicle using Modelica/Dymola. Yokohama, Japan: The 22nd International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium & Exposition, Japan Automobile Research Institute, 2006

[2] Coussy P., Morawiec A. High-Level Synthesis: from Algorithm to Digital Circuit. Springer Netherlands, 2010.

[3] Elmqvist H., Otter M. and Cellier F.E.: Inline Integration: A New Mixed Symbolic/Numeric Approach for Solving DAE Systems. Proc. ESM'95, European Simulation Multiconf., 1995.

# A Modelica Library for Real-Time Coordination Modeling

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Embedded software is an important part of today's life. One reason for the increasing trend of embedded systems is the introduction of coordination between previously autonomous systems resulting in complex systems of systems in order to realize functionality which cannot be achieved by each system alone [2]. The car industry is an example where vehicles communicate with other vehicles in order to extend the car's vision to areas obstructed by other vehicles. This coordination requires an intensive communication between the systems under real-time constraints.

Modelica in version 3.2 and the StateGraph2 library for state-based modeling lack appropriate support for the sketched case of modeling the real-time coordination between autonomous systems as this coordination is often realized by communication using asynchronous messages and complex state-based behavior.

In this paper, we present a Modelica library for modeling communication under hard real-time constraints. Our library extends the StateGraph2 library by providing support for (1) synchronous and asynchronous communication and (2) rich modeling of real-time behavior. These extensions are based on our previous work on the MECHATRONICUML modeling language [1]. We illustrate our extension using a robot platooning scenario.

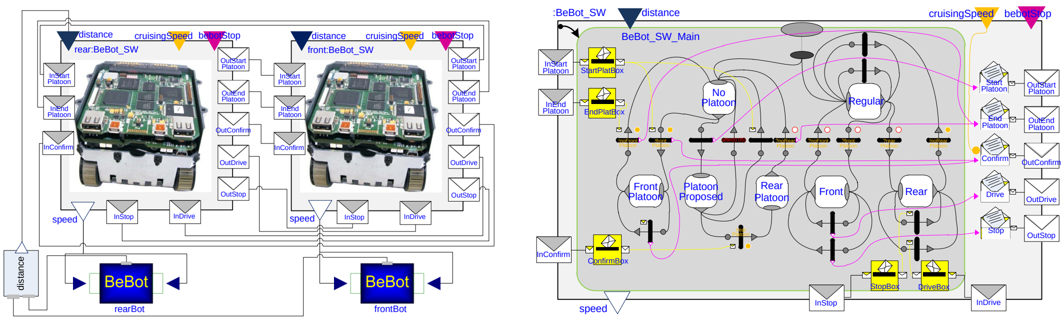


Figure 1: Platoon Scenario Instance and Behavior Model

This work was developed in the project ENTIME. The project ENTIME is funded by the state of NRW, Germany and the EUROPEAN UNION, European Regional Development Fund.

## References

[1] S. Becker, C. Brenner, S. Dziwok, T. Gewering, C. Heinzemann, U. Pohlmann, C. Priesterjahn, W. Schäfer, J. Suck, O. Sudmann, and M. Tichy. The mechatronicuml method - process, syntax, and semantics. Technical Report tr-ri-12-318, Software Engineering Group, Heinz Nixdorf Institute, University of Paderborn, 2012.

[2] W. Schäfer and H. Wehrheim. The Challenges of Building Advanced Mechatronic Systems. In Lionel C. Briand and Alexander L. Wolf, editors, *FOSE*, pages 72–84, 2007.

# Implementation of a Graphical Modelica Editor with Preserved Source Code Formatting

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When an Integrated Development Environment (IDE) is developed, the support for multiple views of the same document is often essential. An example of this is Modelica models, where it should be possible to view and edit the same model in both its textual and graphical representation.

One implementation of Modelica is the open-source platform JModelica.org. It contains the Eclipse-based JModelica.org IDE [1] which provides a text editor for Modelica code, implemented using the JModelica.org compilers and the JastAdd framework [2].

In this paper, we present an implementation of a graphical editor for the JModelica.org IDE. Several challenges arising when implementing a graphical editor for Modelica models are discussed. Amongst others, the difficulties in rendering Modelica diagrams and how to interact with existing frameworks in Eclipse are covered. Also, a method for preserving the formatting of a modified source code file is presented, which is essential when the model is altered in the graphical editor.

The presented implementation is compared to other open source software (OSS) implementations of Modelica editors.

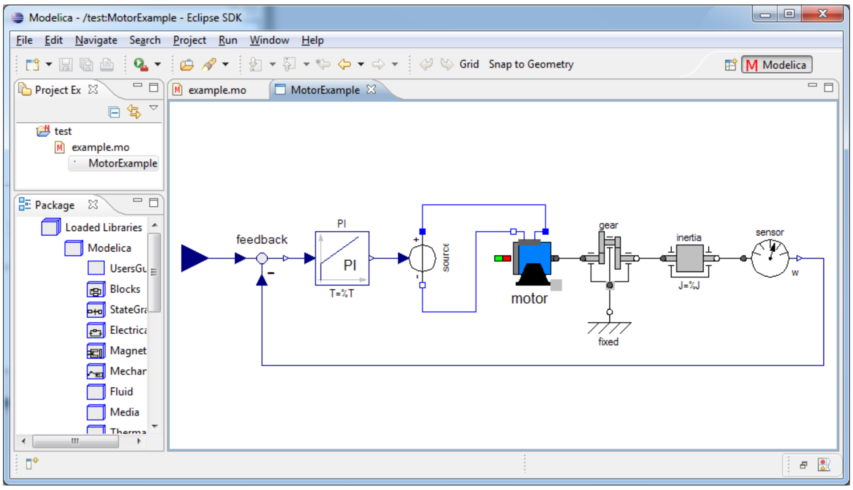


Figure 1: The graphical editor in JModelica.org.

## References

[1] J. Mattsson, The JModelica IDE: Developing an IDE by Reusing a JastAdd Compiler, Master's thesis, Department of Computer Science, Lund University, Sweden, 2009.

[2] G. Hedin, E. Magnusson, JastAdd: an aspect-oriented compiler construction system, *Science of Computer Programming* 47 (1) (2003) 37–58. doi:http://dx.doi.org/10.1016/S0167-6423(02)00109-0.

# Model-based Requirement Verification : A Case Study

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This paper presents a complete case study that takes a real Fuel Display System element used in Scania Trucks and applies an unified process for modelling system requirements together with the system itself and verifying these requirements in a structured manner. In order to achieve this process the system is modeled in Modelica, and requirement verification scenarios are specified in ModelicaML and verified with the vVDR (Virtual Verification of Designs against Requirements) approach [1].

As electronic systems become increasingly complex, so do the requirements that they must fulfill, both in terms of functionality and safety. Thus, maintaining the conformity between the system requirements and the system implementation manually becomes increasingly difficult and unproductive.

The reasons for choosing vVDR approach are its requirements formalization approach, its scalability and the level of possible automation. The way requirements are formalized detects inconsistencies or incompleteness of requirements, it allows expressing requirements monitors using the same formalisms that are used to formalize designs or scenarios, and it allows determining which requirements can be verified using simulations.

## References

[1] Wladimir Schamai, Peter Fritzson, Christiaan J. J. Paredis, and Philipp Helle. Modelicaml value bindings for automated model composition. In *Proc. of Symposium on Theory of Modeling and Simulation (TMS/DEVS 2012)*, 2012.

# ParModelica: Extending the Algorithmic Subset of Modelica with Explicit Parallel Language Constructs for Multi-core Simulation

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In today's world of high tech manufacturing and computer-aided design simulations of models is at the heart of the whole manufacturing process. Trying to represent and study the variables of real world models using simulation computer programs can turn out to be a very expensive and time consuming task. On the other hand advancements in modern multi-core CPUs and general purpose GPUs promise remarkable computational power.

Properly utilizing this computational power can provide reduced simulation time. To this end modern modeling environments provide different optimization and parallelization options to take advantage of the available computational power. Some of these parallelization approaches are based on automatically extracting parallelism with the help of a compiler [1] [2]. Another approach is to provide the model programmers with the necessary language constructs to express any potential parallelism in their models. This second approach is taken in this work.

The OpenModelica modeling and simulation environment for the Modelica language has been extended with new language constructs for explicitly stating parallelism in algorithms. This slightly extended algorithmic subset of Modelica is called ParModelica. The new extensions allow models written in ParModelica to be translated to optimized OpenCL[3] code which can take advantage of the computational power of available Multi-core CPUs and general purpose GPUs. This enables the Modelica modeler to express parallel algorithms directly at the Modelica language level. The generated code is portable between several multi-core architectures since it is based on the OpenCL programming model.

The implementation has been evaluated on a benchmark suite containing models with matrix multiplication, Eigen value computation, and stationary heat conduction. Good speedups were obtained for large problem sizes on both multi-core CPUs and GPUs. To our knowledge, this is the first high-performing portable explicit parallel programming extension to Modelica.

## References

[1] Peter Aronsson. *Automatic Parallelization of Equation-Based Simulation Programs*, PhD thesis, Dissertation No. 1022, Linköping University, 2006.

[2] Håkan Lundvall. *Automatic Parallelization using Pipelining for Equation-Based Simulation Languages*, Licentiate thesis No. 1381, Linköping University, 2008

[3] Khronos Group, Open Standards for Media Authoring and Acceleration, OpenCL 1.1, accessed Sept 15, 2011. http://www.khronos.org/opencl/

# Modelling and Simulation of the Coupled Rigid-flexible Multibody Systems in MWorks

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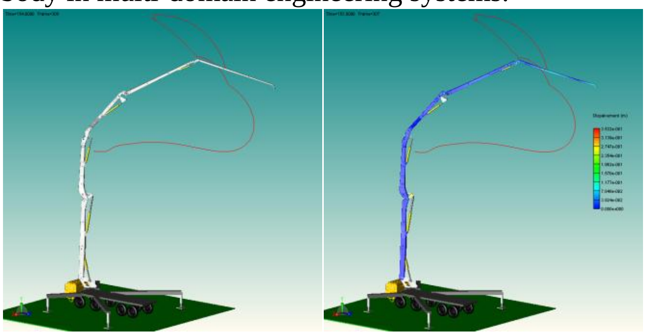
Aiming to the design challenge of modern mechatronic products, this paper presents a method to simulate the coupled rigid-flexible system in MWorks. The FlexibleBody model is designed to support the coupled rigid-flexible system, and a library of boom system of concrete pump truck is constructed base on the model. The simulations for both of rigid and coupled rigid-flexible boom system are carried out, and the comparison between their results is performed to testify the FlexibleBody model.

Firstly, the component mode synthesis technique[1] is introduced and the Craig-Bampton method[2] is adopted to build the flexible-body model. The general flexible-body model named FlexibleBody is developed based on the standard MultiBody library in Modelica, which describes the small and linear deformation behavior of a flexible-body that undergoes large and non-linear global motion. In the model, the modal neutral file is introduced as a standard interface to describe the constraint modes.

Secondly, the model is used to construct a library of boom system of concrete pump truck and the simulations covering the expanding and folding process are carried out based on both the rigid multibody and the coupled rigid-flexible system models. The results show that in each boom the value of mode coordinate q[1], corresponding to the $7^{th}$ mode, is the biggest. It indicates that the $7^{th}$ mode contributes most energy to the flexible-body. And the values of other modal coordinates are smaller and smaller, with less energy contribution. The variation tendency is complied with the modal superposition theorem and energy criterion. The force and the hydraulic flow change gently in the rigid boom system, but change dramatically in the coupled rigid-flexible boom system, due to the elastic deformation of flexible booms. Compared with the rigid system, the coupled rigid-flexible boom model has higher accuracy, and is more close to the actual system.

The method in this paper provides an effective approach to build unified model and simulate flexible-body in multi-domain engineering systems.



Rigid boom system　　Coupled rigid-flexible boom system

Figure 1: Comparation between rigid system and coupled rigid-flexible boom system

## References

[1] R. Craig, M. Bampton. Coupling of substructures for dynamic analysis. Amer. Inst. Aero. Astro. J. 1968, 6(7): 1313-1319.

[2] ADAMS. Theoretical Background. MSC Software Cor., 2003: 1-30. http://ti.mb.fh-osna-brueck.de/adamshelp/mergedProjects/flex/flex_gen/flextheory.pdf.

# A Modelica Library of Anisotropic Flexible Beam Structures for the Simulation of Composite Rotor Blades

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The non-linear static and dynamic analysis of bent and twisted beams is of major importance for many engineering disciplines. Especially for helicopter rotor applications beam models are used to simulate its dynamic behavior. Due to the predominant deployment of composite materials in rotor blade development the long and slender beam structure is subject to non-classical effects such as transverse shear deformation, geometrical nonlinearities, cross-sectional warping, and elastic coupling. Thus a sophisticated beam theory has been implemented to Modelica which is capable of simulating extensional, torsional and flexural deformation and the couplings between those degrees of freedom. The theory used has extensively been tested in practical applications such as the CAMRAD II rotorcraft analysis code and been proven to provide satisfactory results [2, 1]. It is based on cross-sectional modeling and thus allows the user to provide varying material parameters at any number of points along the beam principal axis. Hence the influence of anisotropy and inhomogeneity can be taken into account.

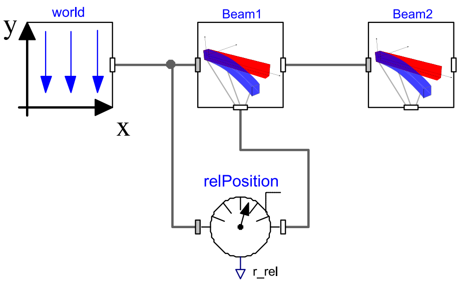


Figure 1: example beam setup

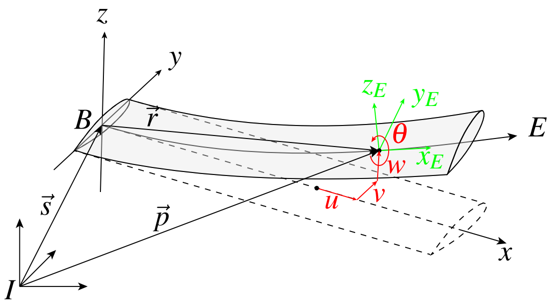


Figure 2: motion of the beam

The library presented describes the motion of the beam element by the rigid motion of a reference frame at one end of the beam and an elastic motion relative to this frame. The element can be attached to the standard Modelica multi-body environment using frame connectors. In addition to the connectors at each end of the beam an arbitrary number of frames can be defined to connect to other components such as joints, sensors, or force elements. Figure 1 shows an exemplary setup with two beam segments connected in series and Figure 2 depicts the reference frame and its elastic degrees of freedom.

## References

[1] HODGES, D. H.: *Nonlinear composite beam theory*. American Institute of Aeronautics and Astronautics, 2006.

[2] JOHNSON, W.: *Rotorcraft dynamics models for a comprehensive analysis*. 1998.

# Modeling and Simulation of a Fault-Tolerant Electromechanical Actuation System for Helicopter Swashplates in Modelica

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A general trend in aviation is to replace hydraulic subsystems like primary flight control actuators by electromechanical devices. However, substituting a hydraulic actuator by an electromechanical actuator (EMA) has the disadvantage of reduced component reliability. This accompanies two major challenges. First, in order to meet aircraft safety regulations higher degrees of redundancy are needed for the utilization of EMAs. Moreover, in the case a redundant actuator jams mechanically, it must be disconnected from the swashplate to maintain controllability of the remaining actuators and the ability to position the entire swashplate.

The system under investigation is therefore specified to provide fail-operative behavior for major mechanical failures and dual-fail-operative behavior for combinations of any other failures. This requires certain degrees of redundancy of all system parts and meaningful mapping of the components in order to allow for failures while maintaining function and performance. A special control approach is applied to cope with the redundant actuators. Furthermore, suitable means for failure detection, failure isolation and system reconfiguration are needed.

In specific failure cases the system must be reconfigured in order to maintain the specified performance level to meet aircraft safety regulations. The assessment of the system's reaction upon such kind of scenarios is however a complicated task and must be supported by modeling and simulation.

Therefore, modeling and simulation of such a fault-tolerant electromechanical system in Modelica is described in this paper. The most relevant Modelica features regarding the introduced system are discussed, such as base classes, inheritance, and parameterization. Finally, sample simulation results are shown and discussed.

# Survey of appropriate matching algorithms for large scale systems of differential algebraic equations

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This paper presents a survey on matching algorithms which are required to translate Modelica Models. Several implementations of matching algorithms are benchmarked on a set of physical models from mechanical systems in ODE and DAE representation. The major part of algorithms is based on the Augmenting Paths Method and one algorithm is based on the Push-Relabel Method. The algorithms are implemented in the programming language C and MetaModelica. In addition two cheap matching algorithms are used to jump-start the advanced matching process.

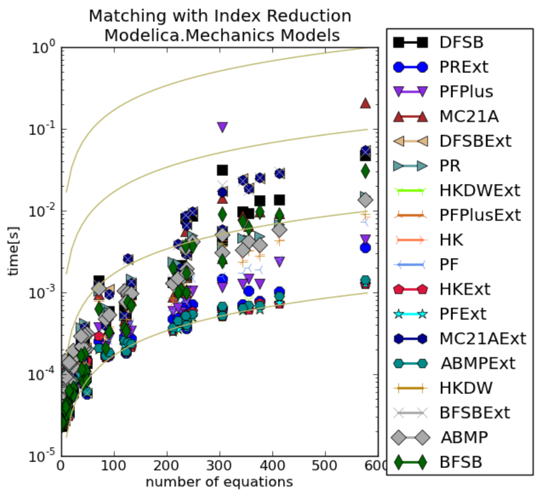


Figure 1: Results from Matching with Index Reduction for Modelica.Mechanics Example Models

# Static and Dynamic Debugging of Modelica Models


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Advanced development of today's complex products requires integrated environments and equation-based object-oriented declarative (EOO) languages such as Modelica for modeling and simulation. The increased ease of use, the high abstraction, and the expressivity of such languages are very attractive properties. However, these attractive properties come with the drawback that programming and modeling errors are often hard to find.

In this paper we present static and dynamic debugging methods for Modelica models and a debugger prototype that addresses several of those problems. The goal is an integrated debugging framework that combines classical debugging techniques with special techniques for equation-based languages partly based on graph visualization and interaction.

The static transformational debugging functionality addresses the problem that model compilers are optimized so heavily that it is hard to tell the origin of an equation during runtime. This work proposes and implements a prototype of a method that is efficient with less than one percent overhead, yet manages to keep track of all the transformations/operations that the compiler performs on the model.

Modelica models often contain functions and algorithm sections with algorithmic code. The fraction of algorithmic code is increasing since Modelica, in addition to equation-based modeling, is also used for embedded system control code as well as symbolic model transformations in applications using the MetaModelica language extension.

Our earlier work in debuggers for the algorithmic subset of Modelica used high-level code instrumentation techniques which are portable but turned out to have too much overhead for large applications. The new dynamic algorithmic code debugger is the first Modelica debugger that can operate without high-level code instrumentation. Instead, it communicates with a low-level C-language symbolic debugger to directly extract information from a running executable, set and remove breakpoints, etc. This is made possible by the new bootstrapped OpenModelica compiler which keeps track of a detailed mapping from the high level Modelica code down to the generated C code compiled to machine code.

The dynamic algorithmic code debugger is operational, supports both standard Modelica data structures and tree/list data structures, and operates efficiently on large applications such as the OpenModelica compiler with more than 100 000 lines of code. Moreover, an integrated debugging approach is proposed that combines static and dynamic debugging. To our knowledge, this is the first Modelica debugger that supports both transformational and algorithmic code debugging.

# A Modelica Sub- and Superset for Safety-Relevant Control Applications

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More and more embedded software components are specified in models representing the so-called high-level application that is then automatically transformed (usually via embedded C-code) into binary code that is executable on the embedded target. Despite Modelica's obvious suitability to efficiently create appropriate high fidelity system models, the utilization of Modelica for developing discrete control functions is not yet wide spread.

This can be attributed to: a) a somewhat too limited expressiveness in modeling discrete controller functions; b) the lack of a flexible, seamless development approach from the controller model comprising the *logical functions* to the *technical system architecture* (i.e., code running on the target platform) and last but not least c) because *safety-relevant software functions need means to achieve a high assurance level*, which is not supported with current Modelica (tools).

The aim of the paper is to study impacts of a safety-relevant development process (based on validated tools) to high-level, domain-oriented modeling languages (see Figure 1). In particular it proposes a sub- and superset of the modeling language Modelica suitable for safety-relevant software development, including tool validation. To illustrate the development using the proposed language elements an exemplary library (referred to as SAFEDISCRETECONTROL library) is presented and applied at an exemplary use case.

*Keywords: embedded systems; functional safety; simulation; code generation; compiler; formal methods; validation; verification*

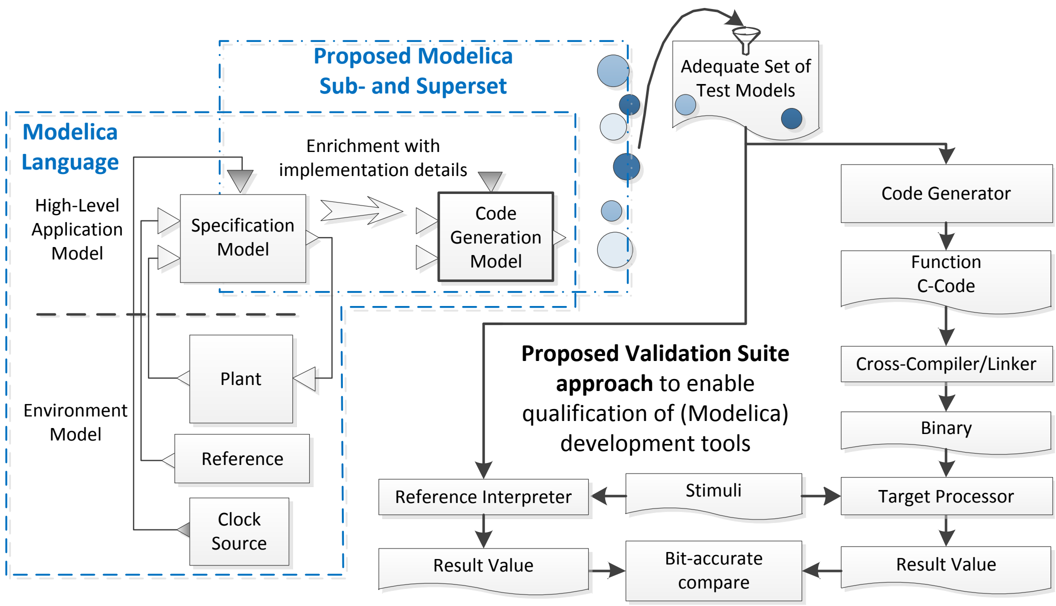


Figure 1: From High-Level Application Models (Specification Models) to code generation models utilizing a qualifiable sub- and superset of the Modelica language.

# A Modelica Library for Industrial Control Systems

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In many simulation studies, control plays a relevant role. Sometimes this is because the study is precisely aimed at setting up the control system for the plant at hand, but in many other situations, even if control synthesis is not the main goal of the study, the behaviour itself of the modelled object depends significantly on the operation of some controls. As such, quite often the representation of the control system deserves substantially the same accuracy as the representation of the physical plant (in the broad sense of the term).

At present, numerous Modelica libraries are available to represent plants with a virtually arbitrarily accuracy, but the same is not true – at least, to the best of the authors' knowledge – for controllers. To appreciate that, the interested reader could for example throw a glance at the PID block as provided by any control environment, be it targeted to a PLC, a DCS, or whatever. Apparently, such blocks are more articulated than for example the PID of the Modelica Standard Library (MSL)—as by the way real-life control systems do exhibit a number of peculiarities that are not accounted for in "textbook" representation, see e.g. [1].

The remarks just made are in no sense meant to be a criticism, it is worth stating; nonetheless they evidence that for the simple controller representations of the MSL (or analogous ones) to be adequate, some conditions are necessary. Summarising, and sticking to the PID example,

- the specific form of the controller (let alone the detailed operation of the control algorithm) must not be relevant for the problem,
- and the operation of typical elements of industrial controllers, such as tracking and locks, must not be of concern either.

If this is the case, MSL-like representations are perfectly adequate. If on the contrary either this is not the case in the simulation *scenarii* to be considered, or one wants to describe the control system so as to be capable of simulating the controlled plant in its entire set of operating modes, the same representations cannot serve the desired purpose.

For the reasons above, and after several years during which the authors and their group have been developing *ad hoc* solutions for individual cases, the decision was recently taken to put all of that knowledge and Modelica code together in a structured manner.

## References

[1] F.G. Shinskey. Process control: as tought versus as practiced. *Industrial & Engineering Chemistry Research*, 41(16):3745–3750, 2002.

# Modelica3D -
# Platform Independent Simulation Visualization

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**Abstract**

Modelica3D is a platform-independent, free Modelica library for 3D visualization. Its implementation is based on a message-passing architecture. Through its loosely-coupled architecture, Modelica3D can be combined with different rendering-tools. It is also highly extensible and scalable.

Visualisation of simulation results usually yields two-dimensional plots. For increased accessability (e.g. to easily identify critical patterns between multiple system-states), they might also be embedded into a three-dimensional scene. Modelica3D provides the means to do so in an innovative way:

Models visualised with Modelica3D have complete control over the animated scene. Visualisation is not done by post-processing the result data, but via the exchange of *messages*, which are directly composed during the simulation. This procedural design distinguishes Modelica3D from earlier declarative approaches as discussed in [1] or [2]. Messages are encoded and sent via dbus ([3]) and can thus be recieved on many different platforms and programming languages.

The loose coupling between simulation and visualisation backend yields several advantages:

- Backends can be implemented for different tools by providing a dbus-server object. We demonstrate this with a Blender-based ([5]) backend for high quality, but slow rendering and a real-time capable implementation based on OpenSceneGraph [4].
- Extension of the 3D-API is easy. New messages (and different parameters) can be added in pure Modelica.
- Simulation and visualisation might be computed on different physical hosts (or at different times) since dbus-messages can be sent over the network (or cached on disc).
- Even variable-structure systems can be visualised by simply keeping the rendering server running between different modes.

## References

[1] V. Engelson. 3D Graphics and Modelica-an integrated approach. *Linköping Electronic Articles in Computer and Information Science. Linköping universitet*, 2000.

[2] Thomas Hoeft and Christoph Nytsch-Geusen. Design and validation of an annotation-concept for the representation of 3d-geometries in modelica. In *Proceedings of the 6th International Modelica Conference*, 2008.

[3] R. Love. Get on the D-BUS. *Linux Journal*, 2005(130):3, 2005.

[4] Paul Martz. *OpenSceneGraph Quick Start Guide*, 2007.

[5] Ton Roosendaal and Stefano Selleri. *The Official Blender 2.3 Guide: Free 3D Creation Suite for Modeling, Animation, and Rendering*. No Starch Press, June 2004.

# Proposal for a
# Standard Time Series File Format in HDF5

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Many simulation programs store their simulation results in an own file format with different information, some store only the results, other more information as unit and name of the signals. However, information supplied in these files is mostly not complete, reading the files can be inefficient and storage of huge amounts of data is almost impossible.

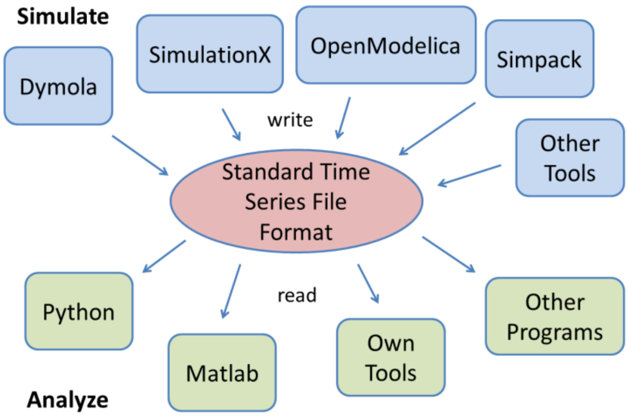


Figure 1: Standard time series file format and its interaction with tools.

These issues exist since decades for almost all simulators in many physical domains. Scripting tools such as Matlab, Scilab or Python are better suited to automate plotting of results with fine control of the layout, to generate standardized result evaluation reports, to perform signal processing (e.g. FFT), to compare with measurements, to run Monte Carlo simulations, or to perform optimization over many simulations etc.

The basic problem is then how to connect a simulation with a scripting environment. With a *standardized time series file format*, the approach from Figure 1 simplifies the task a lot, since simulation environments could generate files in this format and scripting tools may directly read files in this format.

The paper describes a proposal for a standard to store time series on file as they appear as results from dynamic model simulations (see Figure 2 for an example). We explain, why it is necessary to develop such a standard, which are the requirements to efficiently store simulation results and why we selected HDF5. The selected common basic data format, the information stored and data for time series are described in detail. At the end, we present first performance results in Python and Matlab. For example, a result file with more than 200 GBytes has been successfully generated.

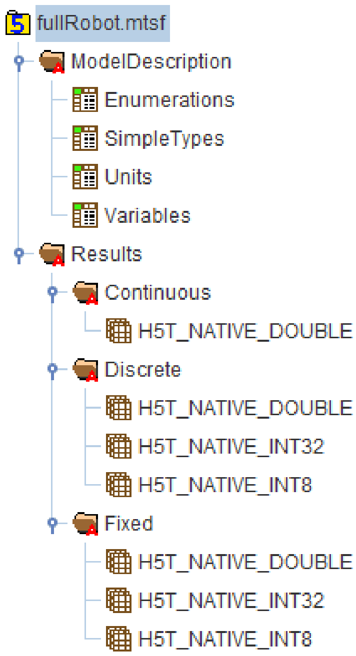


Figure 2: HDF5 hierarchy of the proposed file format.

# Towards a Memristor Model Library in Modelica

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The memristor (memory resistor) is a special kind of resistor with memory. It was predicted as the missing fourth circuit element by Chua [1] in 1971. Figure 1 shows the proposed graphical symbol.

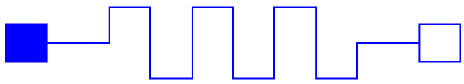

**Figure 1 Proposed graphical symbol of the memristor**

The advantage of memristors (or more general of memristive devices) is to store information without any power source to be needed. The interests in the memristor rose rapidly when in 2008 Williams from the HP laboratories presented a fabricated memristor [2]. Since then an intensive investigation started on both how a memristor works and how it can be utilized in electronic circuits. This paper deals with the adaption of two published memristor models to Modelica. The first one is called HP-model because it models the fabricated HP memristor. The memristance is built as two variable resistors connected in series. Two extensions, so called window functions, are presented to cover special effects in the HP model that occur in real memristor devices. The second model presented, can be better adapted to given memristor characteristics, e.g. measured data.

To verify the models different voltages were applied, a single voltage pulse, a sinusoidal voltage and multiple voltage pulses. Inasmuch as simulation results were given in the corresponding papers, our results were compared to them. Furthermore a Graetz rectifier circuit which uses memristors instead of diodes and its simulation results are presented.

The modeled memristors are the first step towards the general aim of a library for memristors, and memristive systems. By using the electrical connectors of the MSL the models can easily be applied into multi domain simulations.

## References

[1] Chua, L. O.: Memristor – the missing circuit element. IEEE Trans. Circuit Theory vol. 18, no. 5, pp. 507-519, 1971.

[2] Strukow, D.; Snider, D.; Stewart, D.; Williams, R.: The missing memristor found. Nature, vol. 453, pp. 80-83, Mai 2008.

# Fault Detection of Power Electronic Circuit using Wavelet Analysis in Modelica

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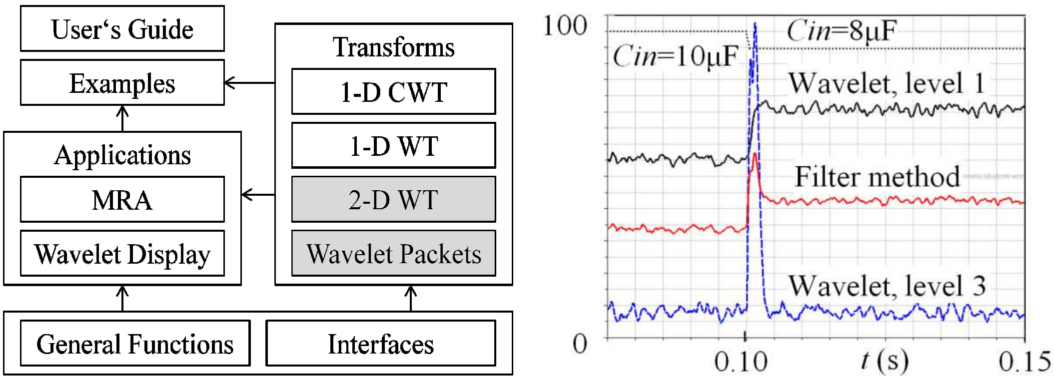
In more electric aircrafts (MEA) the electric power network is important for the reliability of the whole system [1]. To prevent the occurrence of severe faults it is the key to identify the faults in the early stage before a complete failure happens. In this study the fault detection of a buck converter for MEA was investigated. Specifically, the capacitance drop failure of the electrolyte capacitor in the input filter of the converter had to be detected.

For designing a feasible fault detection strategy Modelica simulation combined with wavelet transform was used in the reported study. By applying wavelet multi-resolution analysis to the inverter input current signals, which was obtained from the simulation results, clear fault features could be extracted from the noisy sensor signals.

In order to carry out wavelet transform in Modelica, a specific wavelet library is being developed and the preliminary library has been used to design the fault detection method. The structure of the library, which is still under construction, is shown in the figure (left side), whereas the right part of the figure gives the fault features obtained using wavelet analysis, with the comparison to the traditional filter method, as an example.




The results showed significant advantages of the wavelet method over filtering. As shown in the figure, the wavelet method obtained a much stronger pulse and a more significant magnitude change related to a fast drop of 20% capacitance.

This work not only proved the feasibility of the wavelet theory in early stage fault detection in MEA power electronics, but also showed the functionality of Modelica as a suitable tool for quick design of fault detection strategy.

## References

[1] Y. Ji and J. Bals. Multi-Model Based Fault Detection for the Power System of More Electric Aircraft. Proceedings of the 7th Asian Control Conference, Hong Kong, China, Aug. 27-29, 2009.

# PySimulator – A Simulation and Analysis Environment in Python with Plugin Infrastructure

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The open source environment *PySimulator* is introduced and its design is discussed. The central idea is to provide a generic framework to perform simulations with different simulation engines in a convenient way, to organize the persistent storage of results, to provide plotting and other post-processing feature such as signal processing or linear system analysis, and to export simulation and analysis results to other environments. PySimulator consists of a convenient graphical user interface (see Figure 1) similar to many other, usually commercial, simulation environments.


**Figure 1:** Main graphical user interface of PySimulator.

The major innovation of PySimulator is its *plugin system*: Nearly all operations are defined as plugins with defined interfaces. Several useful plugins are already provided, but anyone can extend this environment by his/her own plugins and there is no formal difference to plugins already provided by the authors of the paper. Introducing a new plugin means to copy a template and adapt it by writing Python code. Hereby it is possible to build upon the results of other plugins and provide own results to other plugins. All plugin functionality available via the graphical user interface shall also be easily accessible in Python scripts. This will allow a modeler to define and automatically execute Python scripts.

# An OpenModelica Python Interface and its use in PySimulator

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How can Python users be empowered with the robust simulation, compilation and scripting abilities of a non-proprietary object-oriented, equation based modeling language such as Modelica? The immediate objective of this work is to develop an application programming interface for the OpenModelica modeling and simulation environment that would bridge the gap between the two agile programming languages Python and Modelica.

The Python interface to OpenModelica – OMPython, is both a tool and a functional library that allows Python users to realize the full capabilities of OpenModelica's scripting and simulation environment requiring minimal setup actions. OMPython is designed to combine both the simulation and model building processes. Thus domain experts (people writing the models) and computational engineers (people writing the solver code) can work on one unified tool that is industrially viable for optimization of Modelica models, while offering a flexible platform for algorithm development and research.

Figure 1 presents an overview of the functions of the OMPython API together with its sub components.

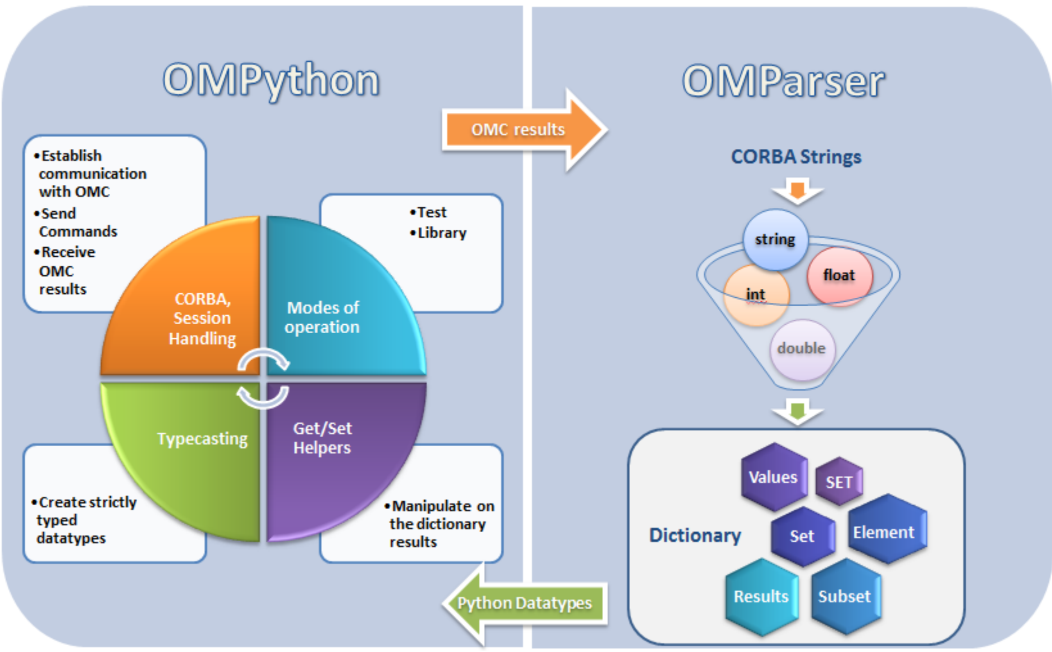


**Figure 1.** Fucntions of the OMPython API

# WebMWorks: A General Web-Based Modeling and Simulation Environment for Modelica

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In this paper we present a web-based general modeling and simulation environment: WebMWorks on which users can easily perform system design, simulation and analysis in the browser. There are two main roles in the modeling and simulation of multi-domain physical systems using Modelica, one is the model developer, and the other is the model user. The model users usually use the models or libraries provided by the model developers to carry on the system modeling and simulation. The environment is designed to make model developers' cooperation easier and to improve the efficiency of modeling and simulation for model users.

By application of RIA (*Rich Internet Application*) technologies, WebMWorks provides a web-based graphical editor allowing visual modeling of Modelica models. Model users can use the icon editor and diagram editor conveniently via internet. Based on MWorks platform [1], the environment adopts SOA-based architecture and effectively solves the problems of sharing of simulation resources and reuse of the models. It also supports multi-user, multi-task and model sharing. This paper introduces the main characteristics and architecture of WebMWorks, and presents the operational effect of the system. The system based on a layered architecture is shown in Fig.1

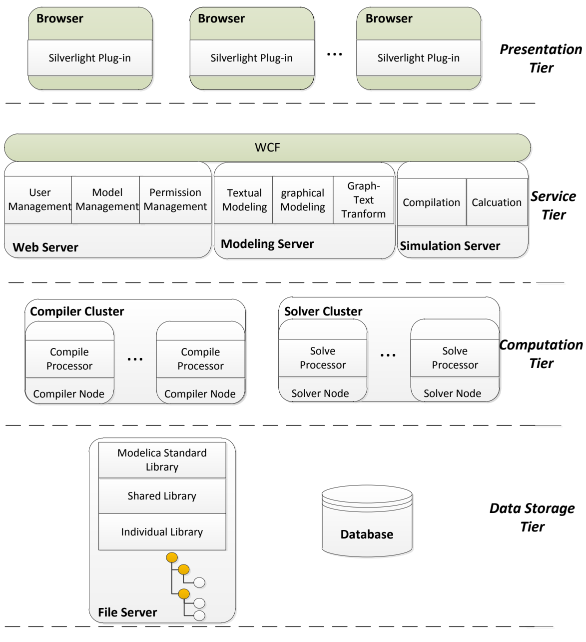

Figure 1: System architecture of WebMWorks

## References

[1] F.-L. Zhou, L.-P. Chen, Y.-Z. Wu, J.-W. Ding, J.-J. Zhao, Y.-Q. Zhang. MWorks: a Modern IDE for Modeling and Simulation of Multi-domain Physical Systems Based on Modelica. *Modelica 2006, Vienna Austria, September 2006.*

# Using BCVTB for Co-Simulation between Dymola and MATLAB for Multi-Domain Investigations of Production Plants

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Nowadays it has become more and more important to be able to simulate models with partial models of different complexity and differing requirements regarding solver algorithms, step sizes and other model-specific properties. To meet these requirements, models of such complexity are approached via co-simulation. Co-simulation stands for "Cooperative Simulation". One can tell from the name that its purpose is to simulate separate models and let them communicate and synchronize to certain points in time given by an overall simulation which lets all partial models cooperate.

The aim of this paper is to optimize the energy consumption in cutting factories. Therefore it's necessary to simulate the thermal processes in production halls. Since all different machines in one production hall require individual modelling approaches, certain solvers and even different software, this problem is approached with co-simulation. Via the Ptolemy-based co-simulation tool BCVTB (Building Controls Virtual Test Bed), a room model implemented in Modelica, machines implemented in Modelica, Simscape and Simulink as well as a MATLAB data model of the measured heat emission of a machine are co-simulated.

At the first impression, BCVTB seems like a quite advanced tool to enable cooperative simulation in a rather easy way. On the other hand it's not possible to let models communicate with BCVTB at variable time steps with the given BCVTB blocks. In Simulink the communication at time steps which aren't known before can be realized by activating a subsystem containing the BCVTB block. To also achieve this in Dymola, most parts of the given BCVTB block would have to be rewritten.

What's more is that between two synchronization time steps all values from BCVTB are extrapolated uniformly so depending on the actual graph and the synchronization step size, the single errors could sum up to an amount which causes the model to fail any validation. For the described use in thermal systems which react very slowly, co-simulation with BCVTB might be considered sufficiently accurate, but to achieve a valid co-simulation which requires precise or at least reliable approximations with arbitrarily small errors, other possibilities of co-simulation will have to be considered.

## References

[1] M. Wetter. Co-simulation of building energy and control systems with the building controls virtual test bed. In press: Journal of Building Perfor- mance Simulation, 2010.

# FEM models in System Simulations using Model Order Reduction and Functional Mockup Interface

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The integration of a three-dimensional FEM model (ANSYS) in a dynamic, component-based system simulation tool (CoSMOS) is described. In order to avoid high simulation times of a direct co-simulation while maintaining the relevant details of the FEM submodel at the same time, order reduction is applied to the FEM model. The reduced submodel is encapsulated in an FMU and finally imported in a system simulation. An example use case, which connects the thermal model of a C-arm to a temperature control model, is presented to demonstrate the workflow that is sketched in Fig. 1.

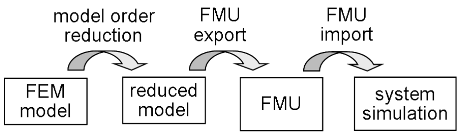


Figure 1: Workflow presented

# Using Modelica models for Driver-in-the-loop simulators

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Driver-in-the-loop simulators are increasingly used in Motorsport and Automotive companies to enable engineers and drivers to experience a new vehicle design in a realistic environment before it is built. The use of simulators enables drivers to test a new vehicle and/or control system without having to build a prototype and to carry out those tests in complete safety and in repeatable conditions.

As vehicle systems increase in complexity, the successful integration of all these systems becomes even more critical to achieve a correctly functioning package. The control of the powertrain systems coupled to the chassis model, for example, will define a large part of the driving experience. These systems must be designed to work in harmony and deliver the required driving experience.

The use of simulators enables engineers to test a new vehicle and/or control system without having to build a prototype. It also enables the tests to be carried out in complete safety and in 100% repeatable conditions.

Using Modelica as the development language for the vehicle model within these systems enables rapid model development and the fast evaluation of vehicle concepts. This enables more vehicle concepts to be tested before committing to a prototype build. The reduction in prototype builds translates into a cost reduction in the development stages of the vehicle and a broader range of solutions through model swapping and parameterisation changes can be explored within the same amount of time.

This paper presents an example of a Sports Saloon car with full multi-body double wishbone suspension chassis model coupled to a manual transmission 4-cylinder turbocharged direct injection gasoline powertrain. The vehicle model is created using the VDLMotorsports [1] and Engines [2] Libraries. Some of the key aspects of these libraries that enable them to achieve real-time simulation are described in the paper. For the suspension mechanism, the key is the development of highly optimised models that eliminate the nonlinear systems of equations found when modelling a double wishbone suspension. We also discuss other issues such as the tyre contact model.

The whole vehicle model is then exported as C-code and integrated into a driving simulator. The generic architecture of a driving simulator is introduced and a more detailed description of a test system is included. In this test system the model is running at 800Hz which is governed by rFactor Pro running at 400Hz and the need for the model to run at a multiple of this base frequency.

## References

[1] http://www.claytex.com/products/claytex-libraries/#vdlmotorsports-library

[2] Dempsey M. Picarelli A. Investigating the MultiBody Dynamics of the Complete Powertrain System. Como, Italy: Proceedings 7th Modelica Conference, 2009.

# Development of New Concept Vehicles Using Modelica and Expectation to Modelica from Automotive Industries

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To cope with future mobility society, development of many new concept vehicles is becoming increasingly active in recent years [1]. Those vehicles have characteristics of smaller size, lighter weight, less number of passengers than the conventional vehicles. Also those vehicles tend to be equipped with lower RRC (Rolling Resistance Coefficients) tires and new driving systems mainly using electric motors to achieve less emission and less energy consumption. Some of those future vehicles are equipped with IWM (In-Wheel-Motor) systems to achieve flexible layout of power-train and also advanced vehicle motion control [2]. Because such new-concept vehicles have different mechanical structure and control structure from those of conventional cars, it was necessary to make new models to estimate their motions by simulation. In this paper, development of the simulation models of those new vehicles by Modelica is described. Those models were developed based on Vehicle Dynamics Library (VDL) of Dymola. One example of applying simulation by Modelica to a future personal vehicle of Toyota is introduced. On the other hand, it became clear that future small vehicles tend to have reduced stability and handling ability than conventional vehicles because of the reasons shown in Figure 1. Figure 2 shows the result of an animation for the open-loop side wind test. It is evident that the future small vehicle is affected much than the conventional vehicle by side wind. To cope with the problem of reduced stability and handling ability, a benchmark problem of improving performance of such future small vehicles was settled by Japanese joint committee of automotive industries and academia. As a member of the committee, the author will introduce the benchmark problem in this paper.

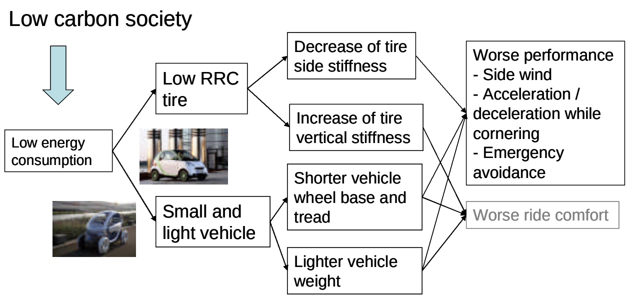


Figure 1: Problems for small vehicles

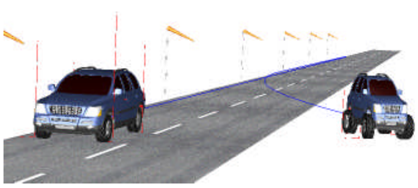

Figure 2: Result of side-wind test

## References

[1] Gombert B., "eCorner – the electric propul-sion system of the future", Proceeding of Chassis Tech Plus 2011, pp. 803-813, 2011.

[2] Katsuyama E., "Decoupled 3-D moment con-trol by an In-Wheel Motor vehicle" Proceed-ing of Chassis Tech Plus 2011, pp. 133-150, 2010.

# A Modular Technique for Automotive System Simulation

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Increasingly challenging requirements such as environmental legislation and costumer demands are leading to a need for more overall system understanding in the automotive sector. Modelica, as a suitable way for multi-physics modeling, is therefore applied by Bosch, e.g. to investigate energy flows amongst domains.

In this paper, we present a modular approach to an overall vehicle system simulation. It consists of two implementation parts: a vehicle component library which is adapted to handle modular interfaces and a co-simulation environment as shown in figure 1. This allows us, to decouple stiff hybrid DAE systems and run subsystems faster in parallel via solver coupling.

The library contains subsystems of the mechanical, thermal, hydraulic, electrical and control domain to configure different vehicles. The object-oriented nature of Modelica is used for the data handling or to replace subsystems by an interface to the co-simulation environment.

The latter, MDPCosim, was developed at TU München [1]. In the present paper, further work on MDPCosim, such as extrapolation methods and an adaptive macro step size are discussed. Such coupling aspects were and recently are under investigation, e.g. [2]. It is broadened in the present paper to the widespread use-case of drivecycle simulation.
Some results of a coupled vehicle simulation with adaptive communication stepsizes are given and analyzed having regard to error and performance aspects.

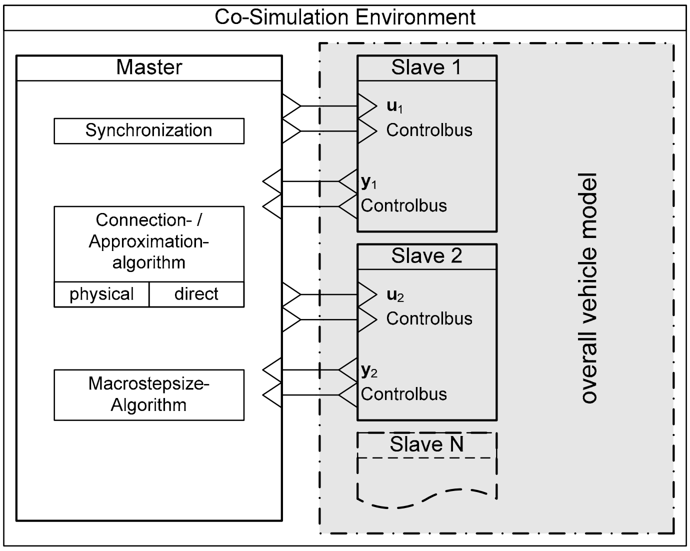


*Figure 1: modular vehicle simulation with master-slave architecture for co-simulation*

## References

[1] Friedrich, M., Schneider, M., Ulbrich, H. A Parallel Co-Simulation for Mechatronic Systems. The 1st Joint International Conference on Multibody System Dynamics, Lappeenranta, Finland, 2010.

[2] Clauß, C., Arnold, M., Schierz, T., Bastian, J. Master zur Simulatorkopplung via FMI. ASIM-Konferenz STS/GMMS 2012, ISBN 978-3-901608-39-1, Wolfenbüttel, 2012.

# Modeling Vehicle Drivability with Modelica and the Vehicle Dynamics Library

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This paper highlights the use of multi-domain physical models for simulation of vehicle drivability applications. The models are implemented using the Vehicle Dynamics Library and Engine Dynamics Library from Modelon. The application examples include vehicle launch, vehicle start-stop, and transmission shift events. The examples are structured to illustrate how increasingly sophisticated models provide additional model fidelity or increase the drivability phenomena observed. The applications also include different modeling approaches for the engine with both a conventional automatic and dual clutch transmission.

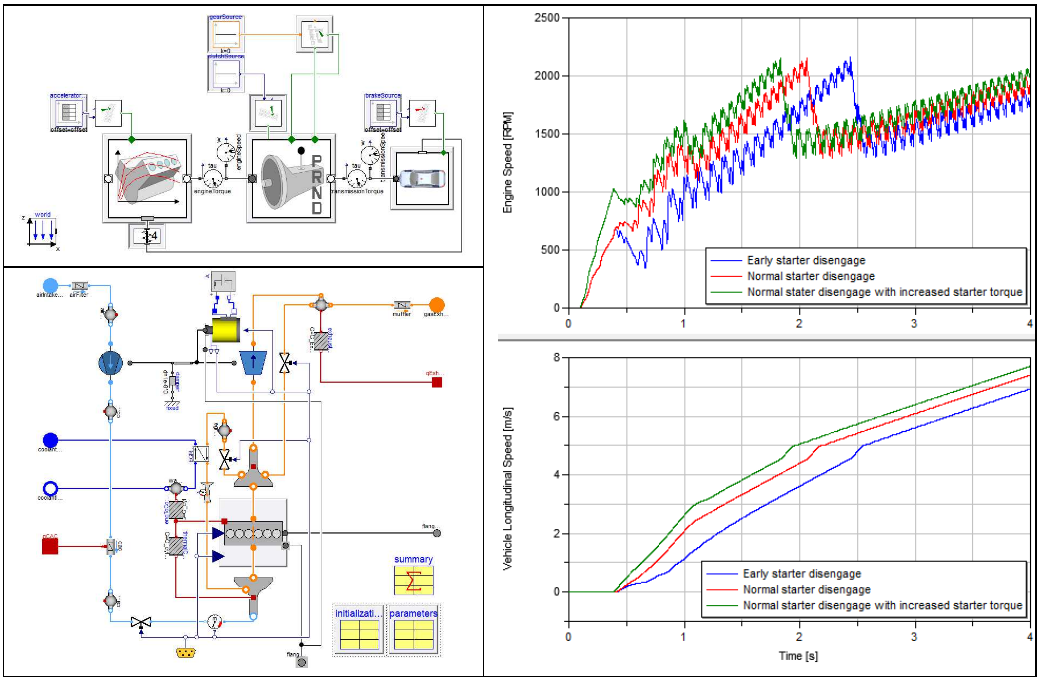


Figure 1. Launch model for drivability applications (upper left), start-stop launch results (right), and engine model from Engine Dynamics Library (bottom left)

## References

[1] Andreasson, J., “The Vehicle Dynamics Library: New Concepts and New Fields of Application”, *Proceedings of 8th International Modelica Conference*, 2011.

[2] Andersson, D., and Dahl, J., 2012, “Gas Exchange and Exhaust Condition Modeling of a Diesel Engine using the Engine Dynamics Library”, *Proceedings of 9th International Modelica Conference*, 2012.

# Status of ClaRaCCS: Modelling and Simulation of Coal-Fired Power Plants with $CO_2$ Capture

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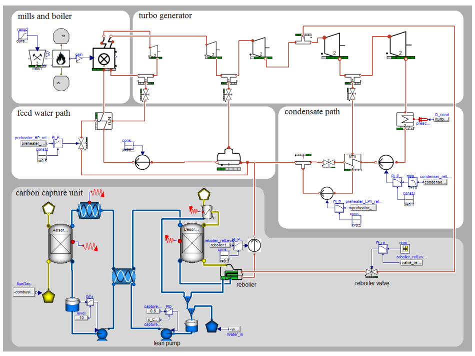
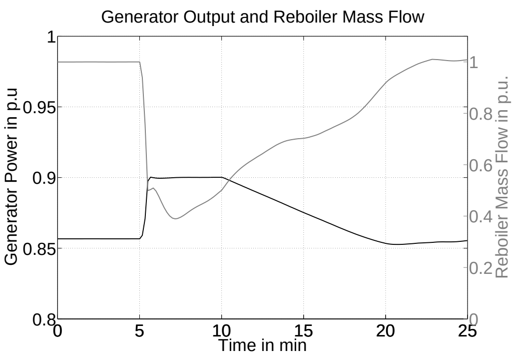
Within the DYNCAP project, the Modelica library `ClaRaCCS` is developed. The goal of the library is to provide models for the analysis of complex power plants with $CO_2$ capture in both static and dynamic operation mode. After completion of the DYNCAP project, the library will be freely available under the Modelica license. This paper gives an introduction to `ClaRaCCS` and presents the current status of development.The technical fundamentals of conventional steam power plants as well as carbon capture processes modelled in the library are outlined. General features of the library are introduced: Starting from the general library structure the guiding principles, that underlie the models in `ClaRaCCS`, are explained. The treatment of media data as well as validation of models is described. These properties are illustrated by a concrete modelling example, where the model of a furnace is described. The current status of `ClaRaCCS` is demonstrated by an example of use: the model of a coal-fired power plant with attached post combustion carbon capture unit is presented. The results of a simulation scenario are shown, where throttling of the carbon capture unit is used in order to meet the demand for a short term increase of the power plant's generator power. Future steps of development are outlined.



Model of a coal-fired power unit with attached $CO_2$ post combustion capture unit.



Power output during reduction of the steam tapping used for the $CO_2$ capture unit.

**Acknowledgements.** On behalf of the authors we would like to thank all members of the `ClaRaCCS` team. This research project is funded by the Federal Ministry of Economics and Technology (project number 03ET2009). For valuable data input and discussions the staff of KNG, EnBW, Vattenfall and E.ON are gratefully acknowledged.

Supported by: Federal Ministry of Economics and Technology on the basis of a decision by the German Bundestag

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# Start-up Optimization of a Combined Cycle Power Plant

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In the electricity market of today, with increasing demand for electricity production on short notice, the combined cycle power plant stands high regarding fast start-ups and efficiency. In this paper, it has been shown how the dynamic start-up procedure of a combined cycle power plant can be optimized using direct collocation methods, proposing a way to minimize the start-up time while maximizing the power production during start-up.

Physical models derived from first principles have been developed in Modelica specifically for optimization purposes, in that the models contain no discontinuities. Also, the models used for optimization are simpler than typical high-fidelity simulation models. Two different models used for optimization in four different start-up scenarios are presented in the paper.

A critically limiting factor during start-up is the stress of important components, e.g., the evaporator. In order to take this aspect into account, constraints on the stress levels of such components have been introduced in the optimization formulation. In particular, it is shown how a pressure dependent stress constraint, similar to what is used in actual operation, can be applied in optimization. Also, different assumptions about which control variables to optimize are explored.

Results are encouraging and show that energy production during start-up can be significantly increased by increasing the number of control inputs available to the optimizer, while maintaining desirable lifetime of critical components by introducing constrains on acceptable stress levels.

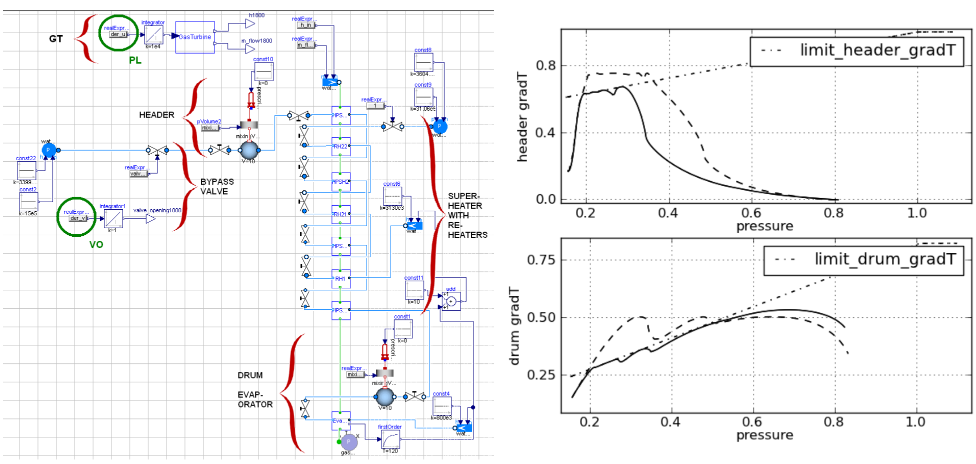


Figure 1: Left: a Modelica model for a combined cycle power plant optimized in the paper. Right: stress levels in a steam header and in the drum, respectively, constrained by constant bounds (dashed) and a pressure dependent constraint (solid).

# Modeling and Simulation of a Vertical Wind Power Plant in Dymola/Modelica

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A small wind power plant connected to the grid has been modeled in Modelica/Dymola and controlled using external controllers written in C++. The small wind power plant consists of three wind power units, with a nominal power of 3kW, and one grid connection interconnected with an internal DC-grid. All the controls needed for controlling and optimizing the operation of the individual parts in the plant were developed and implemented. Apart from this a managing control for the entire plant were developed and implemented.

The control was implemented using an external static library interconnected with Dymola. the External Object approach for implementing objects in Modelica was also tested. The optimization algorithms developed for the wind turbine was done in a way so that no measurements of the wind speed are needed. The controls were developed so that they can achieve a number of different tasks such as Reactive Power Compensation and Island Control.

Models were implemented in Modelica using Dymola as tool. In order to model the power electronics involved in the system the Electric Power library (EPL) has been utilized. Models for the wind turbine were developed and tested.

The models were in the end tested and evaluated by running a number of different simulations. The Different test cases consists of optimizing the power output, controlling the power output to a desired level and island operation, that is to power up a small grid on its own.

*Keywords: wind power, power electronics, control, optimization, vertical wind power, Electrical Power library*

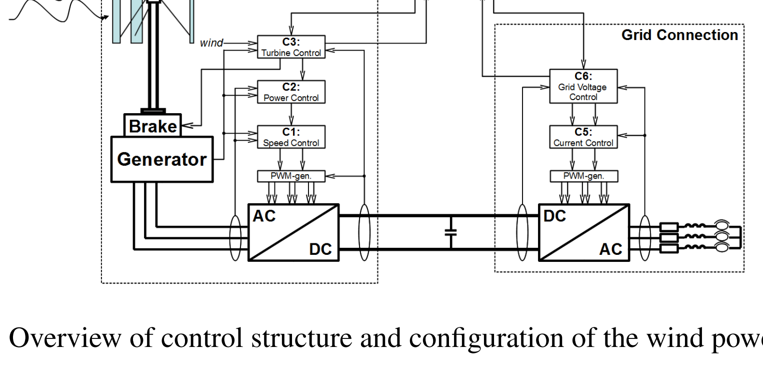


Figure 1: Overview of control structure and configuration of the wind power plant.

# First- and Second-Order Parameter Sensitivities of a Metabolically and Isotopically Non-Stationary Biochemical Network Model*

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The Jülich-Aachen Dynamic optimization Environment (JADE) is employed for computing first- and second-order parameter sensitivities of a metabolically and isotopically non-stationary biochemical network model. Based on a Modelica representation of the model, code generation, algorithmic differentiation and first- and second-order adjoint sensitivity analysis are employed for computing the gradient and the Hessian of a parameter estimation objective function. In particular, we use composite adjoints, an extension of the classical adjoint sensitivity analysis, and a numerical integrator based a modification of second-order discrete adjoints of the extrapolated linearly-implicit Euler method. Therewith, the $116 \times 116$-Hessian of the objective function with respect to 116 model parameters can be computed at the cost equivalent to only 18 objective function evaluations, while computing the same Hessian with the cheapest finite-difference formula would require 6845 evaluations of the objective function. These results make the JADE platform particularly attractive for large-scale applications with nonlinear numerical optimization solvers that require second-order derivatives.

*This work was carried out during the tenure of an ERCIM "Alain Bensoussan" fellowship program. This program is supported by the Marie Curie co-funding of regional, national and international programs (COFUND) of the European Commission.

# Collocation Methods for Optimization in a Modelica Environment

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Optimization of large-scale dynamic systems is becoming a standard industrial technology. Applications include minimization of material and energy consumption during set-point transitions in power plants and chemical processes, minimizing lap times for vehicle systems or trajectory optimization in robotics.

There are different kinds of dynamic optimization problems and in this paper we consider two categories. The first is optimal control, where the aim is to find control variable trajectories (and possibly parameters) that minimize, for example, the amount of resources spent to perform a specified action. The second category is parameter estimation, where the problem is to find the values of unknown model parameters that allow the model to behave according to given measurement data.

There are many approaches to solving dynamic optimization problems. In this paper, an algorithm based on direct collocation is developed and implemented. Details regarding the theory and implementation are presented. The algorithm is implemented in JModelica.org. Modelica is used to model the system dynamics, and the language extension Optimica is used to encode the optimization formulation.

JModelica.org is an open-source Modelica platform targeting large-scale dynamic optimization. It already has an old and well-tested collocation algorithm. The purpose of the newly developed algorithm is to offer improved flexibility and performance, through the use of the automatic differentiation tool CasADi. The new algorithm is compared to the previous one in two benchmarks. The first benchmark is optimal control of a small-scale but highly non-linear tank reactor. The second benchmark regards optimal start-up of a combined cycle power plant of larger scale. Below are the results from the second benchmark, where we see that the new algorithm is consistent with the old algorithm. In this case, the solution time of the new algorithm is 8 times shorter than that of the old algorithm.

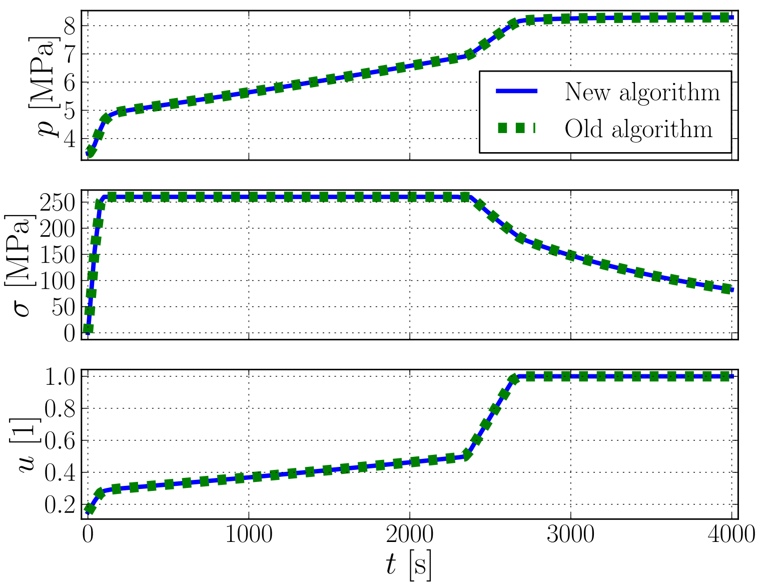


Figure 1: Comparison of the old and new algorithm on optimal start-up of a power plant

# Parallel Multiple-Shooting and Collocation Optimization with OpenModelica

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Mahder Gebremedhin[2], Peter Fritzson[2],
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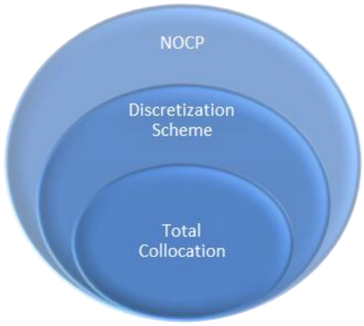
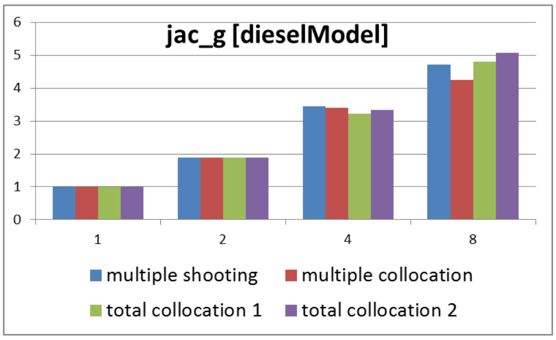



Nonlinear model predictive control (NMPC) has become increasingly important for today's control engineers during the last decade. In order to apply NMPC a nonlinear optimal control problem (NOCP) must be solved which in general needs high computational effort. State-of-the-art solution algorithms are based on multiple shooting or collocation algorithms, which are required to solve the underlying dynamic model formulation. This paper describes a general discretization scheme applied to the dynamic model description which can be further concretized to reproduce the well-known multiple shooting or collocation method (see also [1]). Furthermore, this approach can be refined to represent a total collocation algorithm [2] in order to solve the underlying NOCP much more efficiently. Further speedup of optimization has been achieved by parallelizing the calculation of model specific parts (e.g. constraints, Jacobians, etc.).

The corresponding discretized optimization problem has been solved by the interior optimizer Ipopt [3]. The proposed parallelized algorithms have been tested on different applications. As industrial relevant application an optimal control of a Diesel-Electric power train has been investigated. Speedup curves for parallel execution are presented.




## References

[1] Tamimi, Jasem. 2011. Development of Efficient Algorithms for Model Predictive Control of Fast Systems. Düsseldorf: VDI Verlag, 2011.

[2] Biegler, Lorenz T. 2010. Nonlinear Programming: Concepts, Algorithms, and Applications to Chemical Processes. s.l. : Society for Industrial Mathematics, 2010.

[3] Interior Point OPTimizer (Ipopt), https://projects.coin-or.org/Ipopt

# Optimization Library for Interactive Multi-Criteria Optimization Tasks

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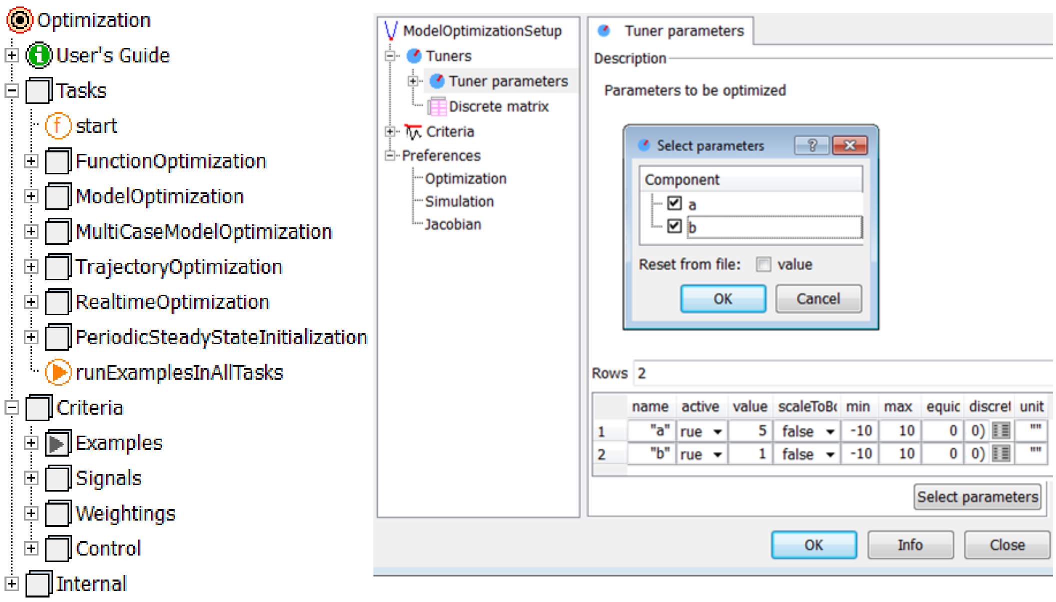
The commercial library Optimization 2.1 for interactive multi-criteria optimization tasks has been released along with Dymola 2013. The library offers several numerical optimization algorithms for solving different kinds of optimization tasks. User defined Modelica functions or models provide the basis for an interactive optimization process where the user keeps overview of complex multi-criteria optimization tasks that can take discrete parameters, several model operating points or trajectories into account. Computational performance of optimization runs can be significantly increased by parallel numerical integrations of the Modelica model on multi-core machines.




Final Solution (evaluation 10 of 10):

| Tuner parameters | name | value | difference to start | |
|---|---|---|---|---|
| | Kf | -5.5232595242712623 | -1.8701419383966962 | -10 |
| | Ki | -5.3042111393027085 | -1.2579880640408883 | -10 |
| | Kq | 0.9929150386583678 | 0.2040424595732118 | 0 |

| Criteria | name | scaled criteria | diff. to start | unscaled criteria |
|---|---|---|---|---|
| 0 1 2 3 | overshoot | 0.6179831900826351 | -15.2% | 0.0617983190082635 |
| | maxElevator | 0.9999999998785056 | 37.2% | 2.9999999996355169 |
| | riseTime | 0.6179833954077121 | -15.2% | 0.308991697703856 |
| | settlingTime | 0.6179845192191472 | -15.2% | 1.544961298047868 |
| 0 1 2 3 | **Maximum of criteria** | 0.6179845192191472 | -15.2% | |

# A Planar Mechanical Library for Teaching Modelica

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This paper presents a planar mechanical library that has been primarily designed for didactical purposes. The idea of such a library is that it is simple and easy to understand. In this way, the students can focus on learning the principles of equation-based modeling and they can avoid the lot of peculiar particularities that have meanwhile become part of the Modelica language.

We have used this library in the Modelica course at the technical university in Munich The course is enlisted in the computer science department. Planar mechanical systems are ideally suited for teaching equation-based modeling, because their components are easy to model and to understand but the resulting systems are often complex in behavior and demanding in their computational aspects. Or to put it in short terms: you can do a lot of cool stuff by simple means.

Consequently, the paper presents also valuable examples for teaching: the chaotic motion of a double pendulum, a kinematic loop represented by a piston engine, and an inverse pendulum as example for control. Figure 1 presents the highlight for the students of the course: a planar two-track car model that can be visualized in 3D and steered by the keyboard input in real-time.

The planar mechanical library is freely available under the Modelica 2 license [1].

**Figure 1:** 3D-Realtime visualization of the two track vehicle

## References

[1] Zimmer D. Virtual Physics. Lecture Notes available at: www.robotic.dlr.de/dirk.zimmer

# DyMoRail: A Modelica Library for modelling railway buffers

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This paper gives an overview of the DyMoRail library.The aim of this Modelica library is the simulation of longitudinal dynamics of entire railway trains. In our presentation, we will illustrate the functionality of the DyMoRail library, shown in Figure 1, by the example of Flirt multiple units.

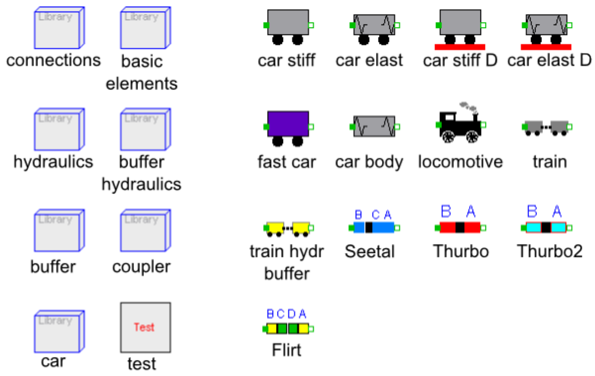


Figure 1: DyMoRail library structure

Buffers and couplers are an essential part of the railway wagon. They have to be optimized for new wagon types to work for different train compositions. They have to absorb minor impacts, take up slack between locomotive and wagons and bear the load of preceding wagons when pushing. Years ago it was good enough for couplers and buffers to fulfil UIC (International Union of Railways) standards. But nowadays manufacturers only survive in this competitive market if they are able to offer optimized solutions regarding force, energy absorption, and driving comfort. Modelling plays an important role in this optimization process. One of the main requirements to this rail model are that it should allow easy substitution of components and handling of different combinations of subsystem parts.

DyMoRail allows to model longitudinal of complete train compositions in various configurations. The library contains a number of different car models, buffers, couplers equipped with both friction and elastomer springs, as well as the center-buffers for multiple units (such as Seetalbahn, Thurbo, Flirt). Furthermore we are able to simulate the entire motion cycle during a collision (retraction of the buffer, force increase with stroke of the buffer, extension of the buffer, and finally the separation of the wagons).

## References

[1] Maurer W. Puffer nach Mass. Eisenbahn Revue 3, 2003, p.118-119.

[2] Maurer W. Simulationsgestütze Entwicklung von Puffern und Dämpfern für Eisenbahnzüge. Proceedings of the 18th Symposium on Simulationtechnique ASIM 2005, Erlangen, Germany, ASIM September 12-15 2005.

# Natural frequency analysis of Modelica powertrain models

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The natural frequency analysis of complex powertrain models created in Modelica presents a number of problems.  This paper presents the basic principles and some of the problems associated with carrying out this kind of analysis.  As a result of this work, a new feature in the Powertrain Dynamics Library has been developed to automate these methods and provide the end-user with a simple set of functions to perform natural frequency analysis.  Simple examples are used to illustrate the problems and solutions and a complex powertrain model is then analysed using the library.

Using Dymola it is possible to linearize models automatically but the results of this present a number of issues when linearizing complex models.  Two issues are described in detail in the paper: the first is the handling of relative states; and the second relates to components that use the standard Modelica stick/slip friction model.

In the first case, the use of relative states rather than positional states makes the interpretation of the modal response more difficult.  It is generally easier to understand how to interpret the magnitude and phase diagrams when the states represented are the ends of the shaft rather than a plot based on relative states. A method is described to convert the relative states to absolute states.

The behaviour of the standard Modelica stick/slip friction models is also not linearized in the expected manner and modifications to the analysis have to be made around these components.

Simple examples are used to describe and illustrate these problems and the solutions developed.  An example of a complex powertrain model is then analysed using automatic functions that implement these methods in the Powertrain Dynamics library and it's natural frequencies and modal response discussed.  The modal response for the shuffle frequency is in Figure 1 and the bode diagram for the complete powertrain model is also generated.

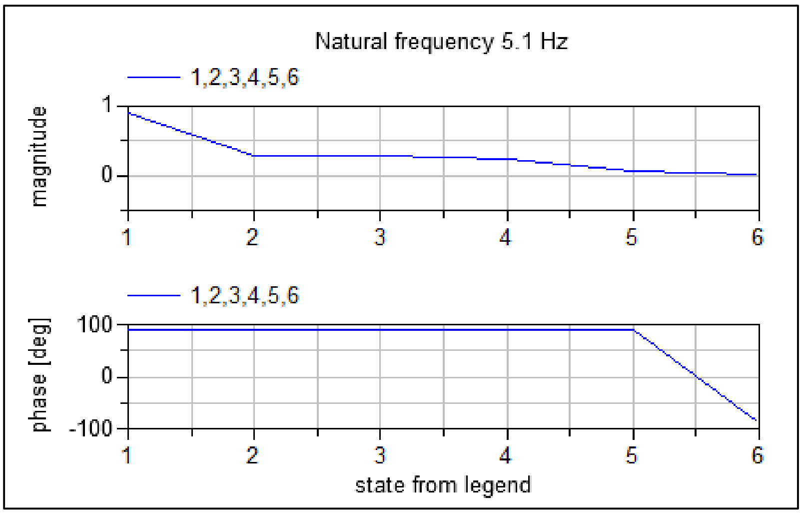


Figure 1.  Modal response of the Simple vehicle model at 5.1Hz. The magnitude and phase of the different states are plotted.

# Achieving O(n) Complexity for Models from Modelica.Mechanics.MultiBody

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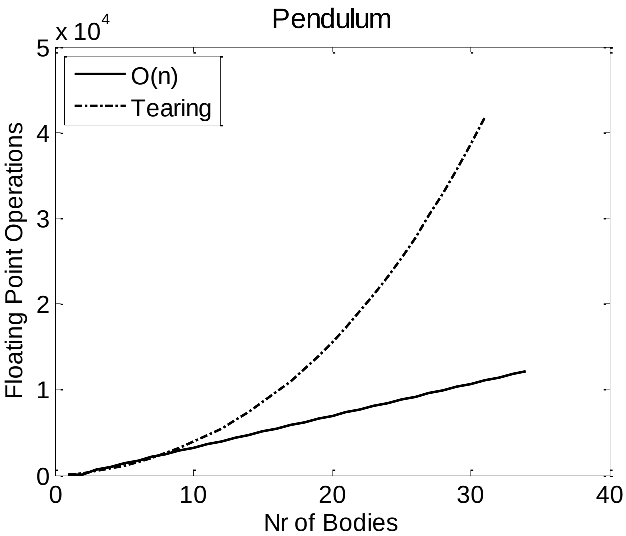
When translating a model that uses elements from Modelica.Mechanics.MultiBody the Modelica Compiler has to deal with a large sparse linear system of equations. The application of *Tearing* [1] yields a dense linear system usually of size equal to the number of degrees of freedom. Solving such a system for the unknowns requires $O(n^3)$ operations.

From literature [2], [3] algorithms can be found that are able to solve a mechanical system in only O(n) operations. The way those algorithms have been formulated inhibited the application in a general equation based framework like Modelica.

This paper presents a graph theoretical generalization of those O(n) algorithms which has been implemented into the OpenModelica Compiler (OMC). The performance of the new algorithm has been compared to Tearing by looking at several test models. The figure below shows the operation count for simulation of a pendulum consisting of N bodies.




## References

[1] H. Elmqvist and M. Otter: Methods for Tearing Systems of Equations in Object Oriented Modeling, Proc. ESM'94, European Simulation Multiconference, Barcelona, Spain, June 13, 1994, pp. 326-332.

[2] H. Brandl, R. Johanni and M. Otter: A very efficient algorithm for the simulation of robots and similar multibody systems without inversion of the mass matrix, In Kopacek, P., Troth, I. and Desoyer, K. (Eds.), Theory of Robots, Oxford, Pergamon Press, 1988, pp. 95- 100

[3] R. Featherstone: Rigid Body Dynamics Algorithms. Springer, New York, 2008

# Modeling the discontinuous individual channel injection into fin-and-tube evaporators for residential air-conditioning

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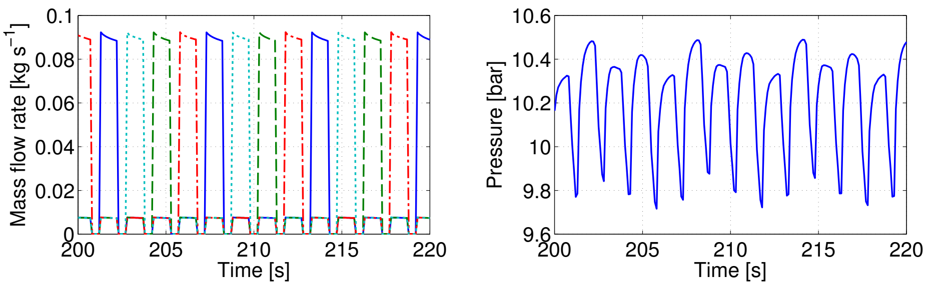
In this paper a working principle based upon the novel expansion and distributor device EcoFlow™ is analyzed. The device enables compensation of flow maldistribution by control of individual channel superheat. The working principle is discontinuous liquid injection (pulsating flow) into each individual channels during a specified cycle time. Moreover, the influence of the injection cycle time is investigated together with an optional secondary flow into the other channels with regards to cooling capacity, overall UA-value and COP.

The results showed spurious fluctuations in pressure when simulating the pulsating flow, thus the dynamic behavior in the mixture two-phase flow model is insufficient to model the discontinuous liquid injection principle. Despite, the fluctuations and imperfections of the model we found that the cycle time should be kept as low as possible and that the optional secondary flow increases performance. Moreover, the paper reports on the applicability of Modelica developed models to analyze and optimize the working principle and design of expansion devices such that Modelica may be used in future development of novel discontinuous expansion devices.




The spurious fluctuations in pressure have not been observed as high in any similar experiments carried out at Danfoss. The current analysis should therefore be seen as a first study of the injection dynamics with the current model approach and limitations. When simulating the injection dynamics, we must keep in mind that the correlations for heat transfer, friction and void may become invalid at large transients in mass flow, since they are developed from steady state experiments. Furthermore, the discontinuous refrigerant injection is essentially pulsating two-phase flow, and the significance of the liquid/vapor interfacial dynamics may become important such as interfacial friction and drag and/or thermodynamic non-equilibrium effects. These phenomenons are not included in the typical mixture two-phase flow model used in many Modelica libraries.

# Validation and Application of the Room Model of the Modelica *Buildings* Library

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To support the design and operation of low energy buildings, the Lawrence Berkeley National Laboratory has been developing a free and open source Modelica *Buildings* library for building energy and control systems [1]. Version 1.1 Build1 of the library contains about 200 component models for building energy and control systems. These component models can be used for (1) rapid prototyping of innovative building systems, (2) design of building energy systems, (3) performance analysis of existing building systems, (4) development, specification and optimization of building control sequences, and (5) model-based operation for controls, fault detection and diagnostics.

Recently, we implemented window and room models into the *Buildings* library to extend its capability to whole building energy simulation [2]. However, the models were not systematically validated against reference data in [2]. In [3], we presented the validation of the window model which is an important part of the room model. This paper is to validate the room model and to show an application where the model is used as part of a controls framework of a window shading device of a building. After the introduction, we will briefly describe the physics and implementation of the room model. Then we will validate the room model using a subset of ANSI/ASHRAE Standard 140 [4], which is a standard test suite for evaluating building energy simulation tools. After validating the room model, we will describe an application where the room model is part of a simulation-based controls framework used to control a window shading device of a test cell for reducing building energy consumption.

## References

[1] M. Wetter, W. Zuo and T. S. Nouidui, "Recent developments of the Modelica buildings library for building energy and control systems," in *Proceedings of the 8th International Modelica Conference. Dresden, Germany, March 2011*, 2011.

[2] M. Wetter, W. Zuo and T. S. Nouidui, "Modeling of Heat Transfer in Rooms in the Modelica "Buildings" Library," in *Proceedings of Building Simulation 2011*, Sydney, 2011.

[3] T. S. Nouidui, M. Wetter and W. Zuo, "Validation of the window model of the Modelica Buildings library," in *Proceedings of SimBuild2012*, Madison, 2012.

[4] ANSI/ASHRAE, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs (ANSI/ASHRAE Standard 140-2007), Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2007.

# The Indoor Climate Library and its Application to Heat and Moisture Transfer in a Vehicle Cabin

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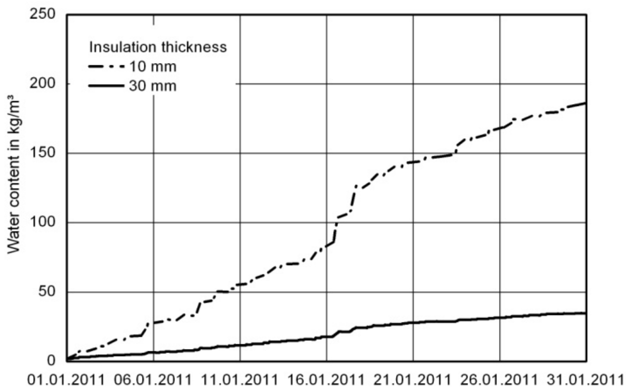
This paper presents the newly developed Indoor Climate Library. The library facilitates simulation of the coupled heat and moisture transfer through envelopes and the interaction of envelopes with the interior air. The computation of coupled heat and moisture transfer becomes more and more important for the development of electric vehicles. Due to the lack of waste heat from the combustion engine the heating of a vehicle cabin during winter time becomes a challenge. One way to reduce heat losses through the envelope is to add insulation. However, insulation bears the risk of water accumulation and its performance usually decreases with increased water content. The Indoor Climate Library helps the user to detect such problems early in the product development process and to find remedies.

The user can build the whole model from predefined parameterized templates: Wall and window templates allow quick creation of models of different enclosures. The domain model contains the air in a room and is connected to the walls and windows. Outside surfaces are the interface between wall templates and the environment. The environment provides the boundary conditions of the simulation.

An insulated car cabin is considered as application example. Four passengers are supposed to travel one hour in the morning and one hour in the evening from Monday to Friday in winter conditions. During weekend the car is not used. Passengers emit heat and moisture according to sedentary work. Cabin enclosures are assumed to consist of three layers: 1 mm aluminium, 10 mm mineral wool and 1.2 mm cloth. Fenestration is assumed to be a one-pane window. Leakages are supposed to lead to one air change per hour (ACH) in the cabin. A ventilation system delivers 50 ACH during occupation of the vehicle. The supply temperature is controlled to result in a cabin air temperature of 22 °C.

With the Indoor Climate Library it could be shown that this wall design leads to considerable accumulation of water in the insulation. The model allows assessing remedies to this problem. In this example, the insulation thickness was increased. This results in considerably lower water accumulation which is beneficial for the performance of insulation and for the risk of mold growth.



# Dynamic modelling of a Condenser/Water Heater with the ThermoSysPro Library

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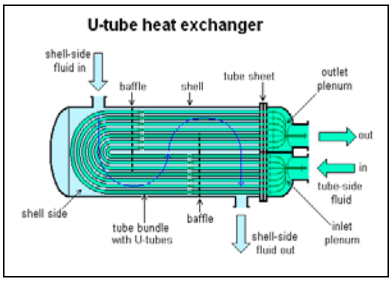
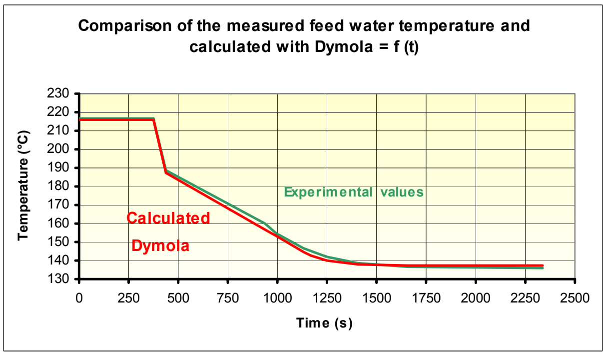
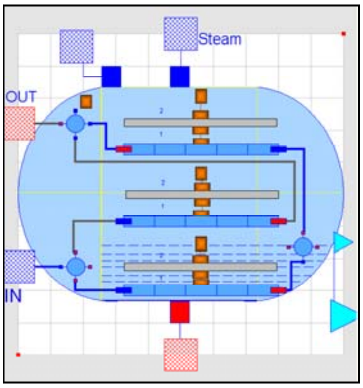
A new dynamic model of a water heater has been developed. The component model is meant to be used for power plant modeling and simulation with the ThermoSysPro library developed by EDF and released under open source license.
The model and the test conditions are fully described: modeling hypothesis, governing equations, parameter values and test transients.
To validate the model, three difficult transients were simulated: the islanding (sudden plant disconnection from the grid), flow reversal and zero-flow conditions inside the water heater.
Regarding the islanding scenario, the simulation results are very close to the experimental values measured on site. This transient demonstrates the physical validity of the model at it is fast and challenges the model equations in all operating conditions of the exchanger.

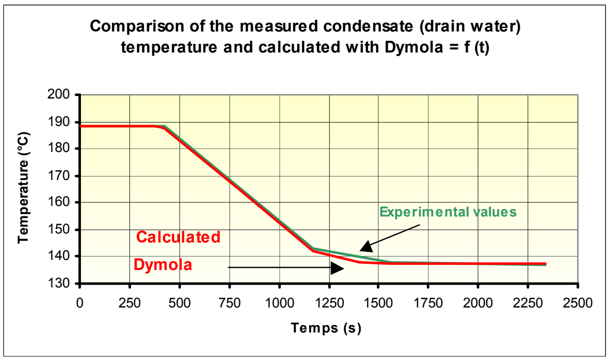



**Shell-and-tube heat exchanger**




**Model of the condenser/water heater**




**Simulation results of the islanding scenario, and comparison with experiment**

# FMI implementation in LMS Virtual.Lab Motion and application to a vehicle dynamics case

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The aim of this paper is to present the implementation of the Modelisar Functional Mock-up Interface (FMI) [1] in LMS Virtual.Lab Motion, a multi-purpose simulation software for mechanical systems [2]. LMS Virtual.Lab Motion is used as a simulation platform into which one or several FMUs can be linked in order to perform co-simulation for analyzing complex multidisciplinary systems. In co-simulation, the overall system is split into different subsystems, which are treated by different optimized simulation tools, coupled by input and output variables, thus creating a coupling loop [3]. For the two distinct standards, FMI for Model Exchange and FMI for Co-Simulation, the different approaches are described in detail in the paper.

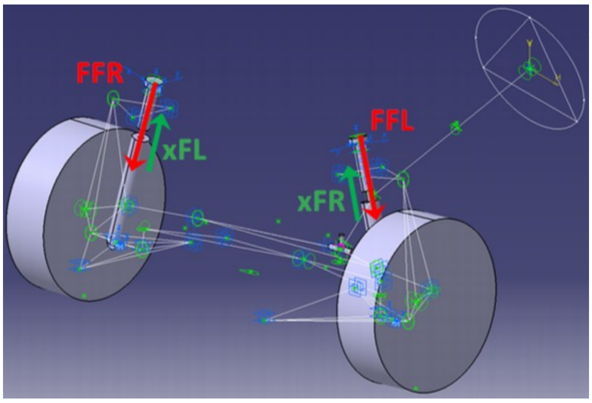


Figure 1: Vehicle front suspension model in LMS Virtual.Lab Motion (air-spring FMU inputs are highlighted in green and outputs in red)

For demonstrating the implementation of the FMI interface and industrial applicability, an application case is presented from automotive industry, with an Opposite Wheel Travel scenario using a half vehicle model in LMS Virtual.Lab Motion (as presented in Figure 1) and an Air-spring FMU based on Modelica code. For simplicity, the air-spring is modeled with an isothermal process, considering a closed system and ideal gas. The chamber of the gas is considered as rigid, thus neglecting the elasticity of the bellow. The Modelica model of the air-spring and obtained results are presented in detail in the paper.

## References

[1] Functional Mock-up Interface: http://www.functional-mockup-interface.org/

[2] LMS International, LMS Virtual.Lab Rev. 11, http://www.lmsintl.com/virtuallab, May 2011.

[3] Busch M. and Schweizer B. Numerical Stability and Accuracy of Different Co-Simulation Techniques: Analytical Investigations Based on a 2-DOF Test Model, 1st Joint International Conference on Multibody System Dynamics, Lappeenranta, Finland, May 25–27, 2010.

# Generating Functional Mockup Units from Software Specifications

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This paper presents how we employed the *Functional Mockup Interface* (FMI) in order to integrate discrete model-based real time protocol specification with controller design and appropriated simulation facilities using Modelica/Dymola. The specification language which we use is called MechatronicUML. In MechatronicUML, the system model is structured hierarchically and consists of components. The component model differs from other component-based approaches, as MechatronicUML employs active components, i.e. the behaviour of each component is specified by a real-time statechart. Figure 1 shows the provided tool support with editors for real-time statecharts and structured component diagrams.

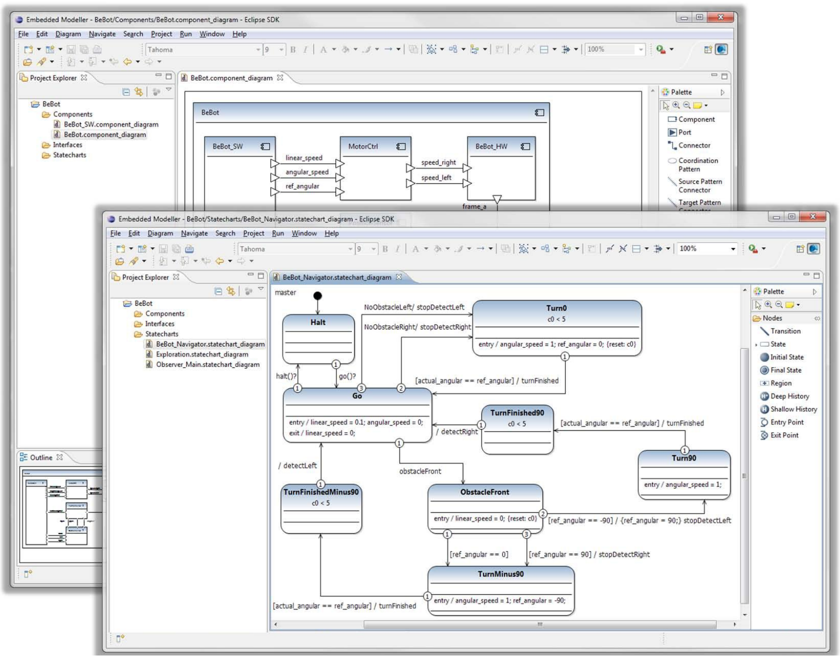


Figure 1: EMBEDDEDMODELLER

The approach has been developed as part of the ENTIME project (ENTIME is the German acronym for 'Design Methods for Intelligent Mechatronics'). The project aims at the development of a seamless methodology reaching from conceptual design to concrete implementation of mechatronic systems. It is carried out in close cooperation with nine industrial partners. To support simulation of the physical models and corresponding feedback loops together with specifications of real-time protocols, the main challenge was to provide the needed tool support, because the project collaborators use different modeling and simulation tools in their industrial practice.

# Functional Mock-up Interface in Mechatronic Gearshift Simulation for Commercial Vehicles

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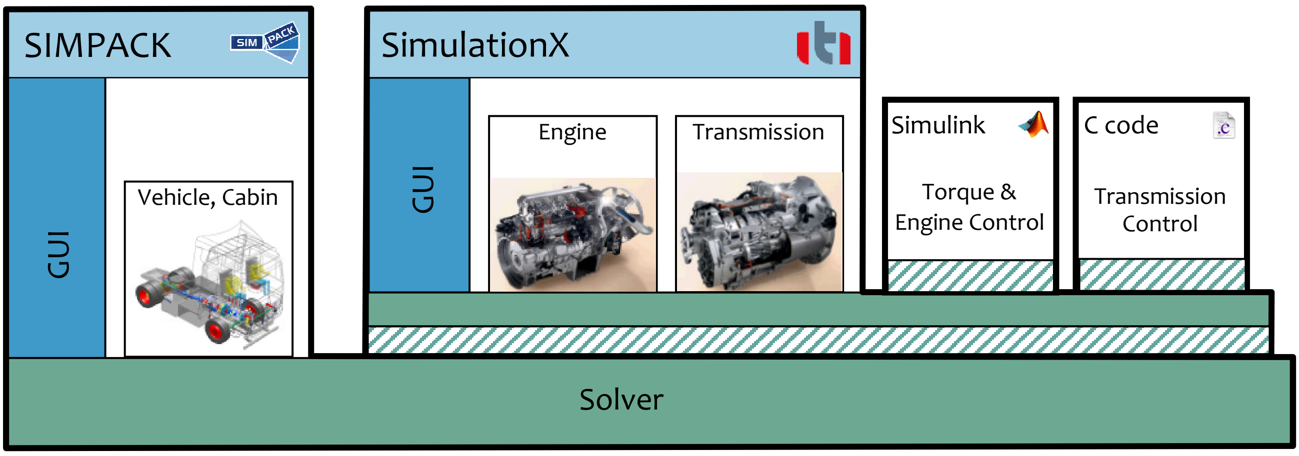
## Abstract

Mechatronic gearshift simulation of automated transmissions in commercial vehicles is used for optimization and development in today's truck engineering departments at Daimler.

Within the ITEA2 project Modelisar in cooperation with ITI GmbH and SIMPACK AG this application served as a usecase for proof of concept of the newly developed Functional Mock-Up interfaces (FMI). This paper presents the results of this usecase. Utilizing these standardized interfaces, models from different tools are coupled to build up the overall system for the mechatronic gearshift simulation.




**Prototype Mechatronic Gearshift Simulation utilizing FMI for Model Exchange**

The coupling via FMI for Model Exchange was achieved for control modules from MATLAB/Simulink into the SimulationX powertrain model and secondly for the 1D-multiphysics powertrain from SimulationX into the multibody vehicle in SIMPACK.

Furthermore FMI for Co-Simulation was investigated in a pure SimulationX framework for the powertrain model.

Very promising results have been achieved for modeling as well as for simulation processes and the FMI technology has clearly shown its capability to be applied in the productive simulation process.

*Keywords: FMI, Modelisar, multibody system, automated gear shifting, mechatronics, co-simulation, model exchange*

# Using Functional Mock-up Units for Nonlinear Model Predictive Control

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A software framework for prototyping of Nonlinear Model Predictive Control (NMPC) loops is presented that is based on the standardized model exchange format FMI (Functional Mock-up Interface). Arising optimal control problems are solved by an efficient implementation of the direct multiple shooting method, which is especially suitable for nonlinear and stiff system models. Using co-simulation, an optimizer, plant, and estimator can be coupled to a closed NMPC loop. Several stages of a typical control design process are supported, ranging from virtual simulation experiments to real plants with prototype NMPC controllers. Energy efficient control of vapor compression cycles is presented as example application of the proposed methods.

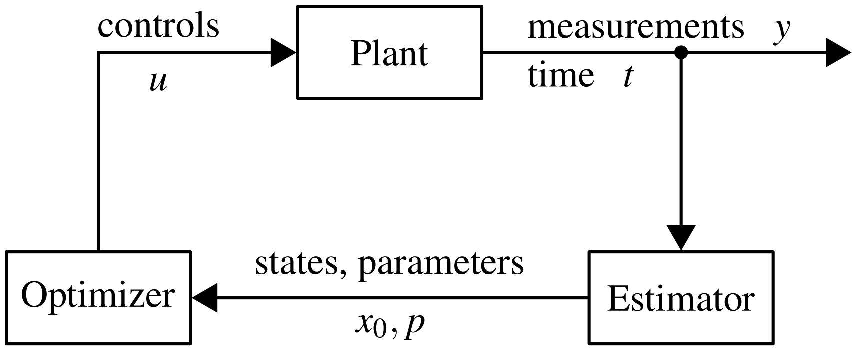


Figure 1: Signal flow diagram of closed NMPC loop.

# Modeling a Low-temperature Compressed Air Energy Storage with Modelica

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The usage of compressed air in order to store electricity has been applied already in the 1970ies. Recently, the concept again gains a lot of attention due to it's ability to balance out the power output of intermittent renewable energies such as wind power or photovoltaics. The basic idea of compressed air energy storage (CAES) is to absorb electricity by compressing ambient air by an electrically driven compressor in times of surplus electricity in the grid and store it in a pressurized containment of any kind. During discharge the compressed air is released and heated up with fossil fuel to drive an expansion turbine. The turbine is connected to a generator supplying electric power to the grid. Nowadays, CAES approaches aim on cycle operation without the need of fossil fuels to heat up the compressed air during expansion. Therefore, a thermal energy storage (TES) is applied. It captures the heat of compression during the charging process and allows to use it to heat up the air in the discharging process [1]. The main challenges are the demand for a compressor redesign to face temperatures of up to 650°C and the development of a large packed bed TES.

In order to avoid the challenges associated to high temperature TES Fraunhofer UMSICHT investigates the possibility to design A-CAES plants for lower TES temperatures. Interesting results for a two-stage A-CAES at 350°C [2] and the fact that the cycle efficiency of A-CAES is not governed by the Carnot efficiency led to the current 100-200°C LTA-CAES concept [3]. One part of the development process is the dynamic simulation of the plant to examine the thermodynamic behavior of the system. Here, off-design behavior regarding turbomachinery output temperatures, pressure losses and heat flows are of particular interest.

## References

[1] Marquardt R., Hoffmann S., Pazzi S., Klafki M., Zunft S.: AA-CAES – Opportunities and challenges of advanced adiabatic compressed air energy storage technology as a balancing tool in interconnected grids. In: 40. Kraftwerkstechnisches Kolloquium 2008, Vol. 2, Technische Universität Dresden (Ed.), 2008.

[2] Wolf D.: Methods for Design and Application of Adiabatic Compressed Air Energy Storage Based on Dynamic Modeling. Bochum, Germany: PhD thesis, faculty of mechanical engineering, Ruhr-University Bochum, 2010.

[3] Budt M., Wolf D., Prümper H.-J.: A Low-temperature approach to Adiabatic Compressed Air Energy Storage. Proceedings of 12th International Conference on Energy Storage, Lleida, Spain, 2012.

# Natural Unit Representation in Modelica

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A method is presented by which alternative systems of physical units may be represented and utilized in Modelica. The method may be useful in simulating models of physical systems where the base units of the International System of Units (Système international d'unités, SI)—the standard unit system in Modelica—are poorly scaled. It also provides a convenient means to express the values of physical quantities in fields of science and engineering where data is typically represented in other systems of units or where the rank of the system of units is less than that of SI (i.e., natural units). By explicitly expressing the value of a physical quantity as the product of a number and a unit (where the unit is an algebraic variable), the method uses variables that are unit-neutral. Unfortunately, workarounds are necessary in order to implement the method in the current version of the Modelica language. Nonetheless, it may be useful in special applications, and the related discussion may provide valuable insight. In particular, it is shown that there is an apparent conflict in the interpretation of "number" and "value" between Modelica and the International Bureau of Weights and Measures (Bureau International des Poids et Mesures, BIPM).

# Modelica Code Generation with Polymorphic Arrays and Records Used in Wind Turbine Modeling

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At Fraunhofer Institute for Wind Energy and Energy System Technology IWES a simulation software for offshore wind farms is being developed, concentrating on the ability to define physical models at different levels of detail. Therefore parameterizable models representing parts of wind turbines are defined that can be transformed for various purposes like simulation with Finite Element Method (FEM) tools or Modelica solvers.

This paper describes the concepts of purely parametric physical models and code generation. It is elucidated how models of different complexity can be transformed into each other by model driven development techniques. Thereby the focus is set on the generation of Modelica code and it is explained how the use of Modelica libraries simplifies the generation of simulatable code.

During the development of generators for Modelica, issues arose regarding type compatibility of arrays with different sizes when using polymorphism. These issues are explained by an example and possible enhancements for the Modelica language are suggested.

*Keywords: model transformation; polymorphism; code generation; wind turbine modeling*

# Derivative-free Parameter Optimization of Functional Mock-up Units

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Representing a physical system with a mathematical model requires knowledge not only about the physical laws governing the dynamics but also about the parameter values of the system. The parameters can sometimes be measured or calculated, however some of them are often difficult or impossible to compute directly. Finding accurate parameter values is crucial for the accuracy of the mathematical model.

In this paper, we present applications of derivative-free optimization algorithms to parameter estimation in the JModelica.org platform. The implementation allows the underlying dynamic system to be represented as a *Functional Mock-up Unit (FMU)*, thus enables parameter estimation of models exported from modeling tools compliant with the *Functional Mock-up Interface (FMI)*.

Examples are provided in order to demonstrate the implemented functionality. In Figure 1, the Nelder-Mead simplex method [1] has been applied to a Furuta pendulum system where friction coefficients have been optimized in order to minimize the difference between measurements and the simulated response from the mathematical model of the system. In addition, an industrial benchmark where the algorithm is used to calibrate a model based on the Engine Dynamics Library (EDL) for a 13 liters Volvo truck engine is presented [2].

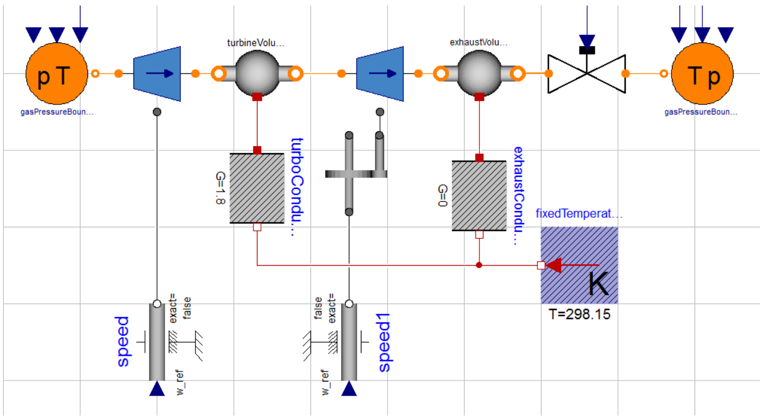


Figure 1: Component diagram of the Volvo truck engine calibrated in the paper.

## References

[1] A.R. Conn, K. Scheinberg, and L.N. Vicente. *Introduction to Derivative-Free Optimization*. Mps-siam Series on Optimization. Society for Industrial and Applied Mathematics/Mathematical Programming Society, 2009.

[2] J. Dahl and D. Andersson. Gas exchange and exhaust condition modeling of a diesel engine using the Engine Dynamics Library. In *In 9th International Modelica Conference 2012*. Modelica Association, 2012.

# Stochastic Simulation and Inference using Modelica

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Physical-model simulation using Modelica has traditionally been viewed as a deterministic problem, despite major sources of uncertainty. This uncertainty mainly concerns initial conditions, as well as accuracy and fidelity, of a model.

At present, Modelica tools (e.g., Dymola) enable variability of initial conditions by different instantiations of model parameters $\Theta$ or by assigning values to internal model variables. However, this assignment can be done only once for each simulation. For simulations in which stochastic variables exist or there are external processes providing data (e.g., sensor/actuator data) to the model on a regular basis, the simulation must be re-started for each new input. This limits the scope of using Modelica for use with certain feedback control systems (e.g., Model-Predictive control) or in embedded systems.

In this article, we propose a framework for stochastic optimisation that uses Modelica as a deterministic modeling language and simulation methodology (figure 1). The key idea of this framework is to couple a (deterministic) Modelica model with exogenous stochastic models, e.g. weather and occupancy forecast models. These stochastic models generate an ensemble of input trajectories, e.g., by using Monte Carlo sampling on a probability distribution function. Each input trajectory is given as input to a Modelica simulation. Finally, the ensemble of simulation outputs is analysed using statistical methods, in order to obtain useful information, depending on the chosen application domain.

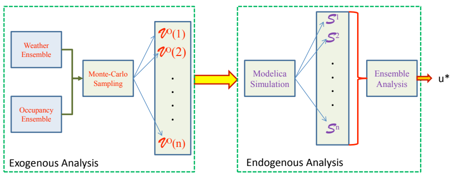


Figure 1: Architecture of our framework for stochastic optimisation.

We apply this approach to the domain of buildings and energy management, in terms of under-floor heating control optimisation. We define this control task as the optimisation of a cost function $J$ that accounts for users' comfort and energy efficiency in a building. In this context, the main sources of uncertainty are weather and occupancy predictions, and we discuss how to model these inputs as exogenous stochastic models. Finally, we discuss our implementation and show preliminary results that indicate improvements with respect to the chosen metric.

Our approach shows how one can extend the existing Modelica language and toolset for such tasks. However, it also highlights deficiencies in Modelica for stochastic representation, as well as deficiencies in the Modelica tools to incorporate stochastic inference *within* a simulation, as well as the inability to accept exogenous inputs during a simulation.

# A Toolchain for Real-Time Simulation using the OpenModelica Compiler

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Simulation is always based on models. These models can be mind-models, scaled physical models or mathematical models. No matter what kind of model is used, the purpose of simulation is mostly the validation of characteristics of physical systems. Nowadays, even detailed mathematical models can be simulated in relatively short time. Hence, computer-simulation is an important tool in the mechatronic development cycle and helps to reduce costs by shorten the development process.
Clearly, the level of detail of the employed model plays a very important role. To obtain a model with a higher level of detail, more modeling effort has to be invested and one has to expect longer simulation times. A proper model is as simple as possible, but still complex enough to reproduce the physical effects under consideration [1]. However, there exist tasks that can not be fulfilled satisfactorily with the help of non-real-time simulations regardless of which level of detail is used. These are among others:

- Setting up Simulators (e.g. driving simulator),
- Controller testing,
- Physical Component testing.

Real-time simulation refers to a mathematical model of a physical system including a numerical integration method that can execute at the same rate as actual "wall clock" time. Hence, using real-time simulation, the real system can be replaced by a virtual system which makes real-time simulation suitable for the applications mentioned above. Due to this possibility and the increased available computing power, real-time simulation became very popular in the recent years.
Consequently, many commercial simulation tools offer a complete toolchain for real-time simulation. Such a toolchain consists of a modeling environment, a simulation-runtime and a compiler which can compile the model for a real-time-target. Simulink together with the Real-time Workshop form the toolchain offered by The MathWorks. Some other tools do not offer an own compiler, but an export to Simulink, so that the real-time Workshop can be used. There are also tools which offer an integrated solution. However, currently the OMC lacks such an automated toolchain at all. In this paper a C++ Simulation-Runtime is presented which forms the basis for a toolchain for real-time simulation. This modular C++ Simulation-Runtime contains a numerical integration method suitable for real-time simulations of hydraulic systems and can also be used for co-simulation.

## References

[1] T. Ersal, H.K. Fathy, D.G. Rideout, L.S. Louca, and J.L. Stein. A review of proper modeling techniques. *Journal of Dynamic Systems, Measurement, and Control*, 130:061008, 2008.

# Time varying mass and inertia in paper winding multibody simulation

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## Abstract

This paper will discuss Modelica's unprecedented flexibility for multi-body simulations. Classical multi-body simulation has as a prerequisite constant mass and inertia for deriving the equations of motion for rigid bodies. However, there are industry applications, like the control development of paper winding, that require time dependency of mass and inertia. In these applications mass and inertia cannot be assumed constant and will thus constitute part of the differential equations system by means of introducing mass and inertia as states.

Introducing mass and inertia as states, rather than parameters, requires reformulation of the Newton/Euler formulation of the body model component in the Modelica mechanics multi-body library.

A successful new body model formulation has been created and is applied in an industrial example system model.

*Keywords: dynamic mass, dynamic inertia, multi-body, mechanics, paper winding, vibration, FMI*

## Introduction

In the paper industry winding machines are used to reduce the inconveniently large paper roll into smaller paper rolls of just a few tons. The dynamic properties of these machines are heavily influenced by the change in mass and inertia of the paper rolls while winding and unwinding [1, 2]. The time varying resonance frequencies of the system will put limits on the machines throughput.

The paper industry has an interest to investigate the dynamic machine properties by simulation as the references are proof of. This publication will deal with one of the key aspects of a simulation package to handle; the mass and inertia time (revolution) dependency.

Mastering this topic of dynamic mass and inertia properties may not only allow for system controllers' validation in the time domain with Dymola's[1] real time capabilities, but also support algorithm development with FMI technology exporting models to control development environments. This publication shows Modelica's capabilities in to this specific topic of paper winding.

## References

1. Virtanen T, *Fault Diagnostics and Vibration Control of Paper Winders,* Ph D dissertation Helsinki University of Technology, Espoo, Finland, 2006
2. Zwart, J., Tarnowski, W., *Winder Vibration Related to Set Throw-outs*, PAPTAC 89th Annual Meeting, Montreal, Canada, 2003

[1] Dymola is a registered trademark of Dassault Systèmes

# Collaborative complex system design applied to an aircraft system

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Aircraft systems have evolved dramatically since the beginning of aviation. Many improvements of performance and safety have been made. Now each sub-system has optimized performance and it is thus difficult to find gains without breakthroughs in architectures or technologies; and this is the objective of the R & D studies towards a more electric aircraft.

Simulations are widely used to explore and justify aircraft architectures [1], but system simulations currently suffer from limitations which make them difficult to use for complex multi-systems analysis. Therefore tools and processes must evolve to accompany these major changes in order to support the designers in their quest of optimized design.

This article deals with new processes and tools which will take part, in a close future, in the determination, the verification and validation of systems architectures (fig. 1)

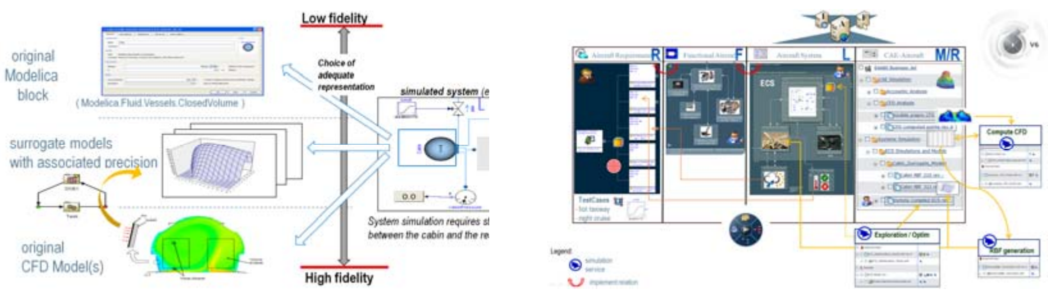


**Figure 1: Use of CFD surrogate models in Modelica behavioral system, within V6 PLM framework**

It sums up what should be a truly efficient tool for aircrafts systems design, and illustrate how it can be managed using Modelica within a collaborative V6 PLM framework.

The results presented here were obtained during the CSDL project (Complex Systems Design Lab), partly funded by the French government.

## References

[1] Advances in Product Modelling and Simulation at Dassault Aviation; Lionel de la Sayette; RTO AVT Symposium, April 2002

# Backward simulation - A tool for designing more efficient mechatronic systems

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This paper uses the method of backward simulation or inverse system simulation as a tool to optimize system configurations or to size components for hydraulic drives. Backward simulation (understood as inverse system simulation) means that input and output of the simulation are switched. The direction of computation goes backward from the physical outputs to required control inputs. The main benefit of backward simulation is the fact that a control is not necessary. In fact, one can say that perfect control is assumed, because the required output is given as input to the simulation. Another benefit is, that implemented with Modelica, the backward simulation approach can be used with the same models and with the same simulation tool that is used for the forward simulation approach. This leads to a better communication between design and control engineers which can use the same simulation model in different stages of the product development process.

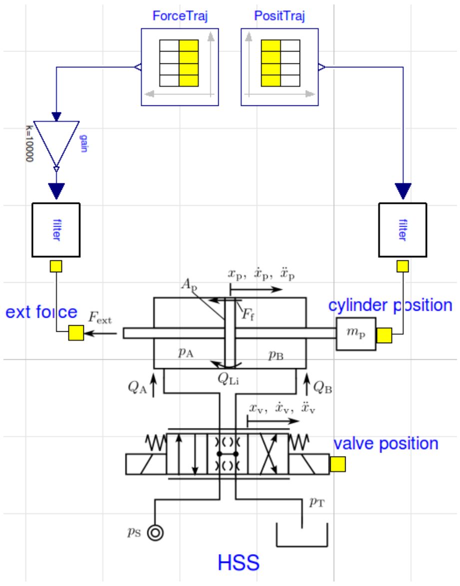


Figure 1: Dymola backward simulation of hydraulic servo system

**Figure 1** shows the simulation model of a simple hydraulic drive. For simulation of such a system, usually the valve input signal has to be provided by a control. Using the backward simulation approach with Modelica, the valve input can be calculated from boundary conditions, which are the cylinder motion and force inputs.

The paper explains the backward simulation approach using simple examples. The benefit for the product development process is explained and illustrated at the example of a hydraulic drive. Using the backward simulation approach, resizing of the components can be done without a need to change the control. Through resizing of the components the energy consumption of this drive can be reduced by nearly 40%.

# Modelling of new vehicle suspension concept with integrated electric drive

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In the last years, the electrification of the powertrain of passenger cars became one of the huge challenges for the vehicle developers. Several solutions for the mass-produced hybrid electric vehicles exist such as parallel or serial arrangement of internal combustion engine and electric drive. On the contrary, the pure electric vehicles are still designed in significantly lower series.

The presented paper introduces a new design of vehicle suspension which was developed in the joint research project of BMW Group Forschung und Technik, DLR and Schaeffler Group. In this suspension the wheel guidance and gearbox are highly integrated thus enabling to place the drive motor close to the wheel and consequently to minimise required space in the vehicle, see the overall design as shown in Figure 1. Therefore, the saved space can be utilized otherwise, e.g. for a battery or an electronics assembly.

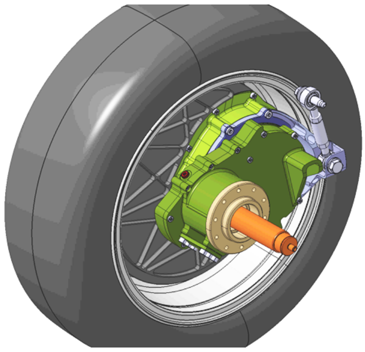

Figure 1: Overall view of the presented rear suspension (electric drive not displayed)

The paper focuses especially on different aspects of the modelling in the early design stage where the first estimations of suspension characteristics and vehicle handling were performed. This covers the coupling of multibody model of suspension with one-dimensional model of gearbox (based on the *PowerTrain* library [1] from DLR), spiral spring model or elastokinematic bushings. The created Modelica library was consequently based on the *VehicleInterfaces* standards, see [2], in order to promote easy interoperability with other automotive libraries.

Finally, the results of kinematics analysis of the suspension are discussed emphasising the support angle $\varepsilon_B$ at braking and its dependency on the gearbox ratio.

## References

[1] Schweiger Ch., Dempsey M. and Otter M.: The PowerTrain Library: New Concepts and New Fields of Application. In: Proceedings of the 4th International Modelica Conference. Hamburg–Harburg, 2005.

[2] Dempsey M., Gäfvert M., Harman P., Kral Ch., Otter M. and Treffinger P.: Coordinated automotive libraries for vehicle system modelling. In: Proceedings of the 5th International Modelica Conference. Vienna, 2006.

# Dynamic modeling and simulation of a multi-effect distillation plant

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Desalination processes provide an excellent way to tackle the water scarcity in places close to the sea. The use of desalination plants in these regions with plentiful seawater resources is becoming a technological way to produce freshwater. Since large-scale desalination typically requires large amounts of energy, a solution is coupling desalination plants with renewable energies [1]. This process can be performed in various ways, for instance, using solar energy in which the source that provides the heat for the desalination process is collected in a solar field.

Multi-effect distillation plants (MED) show a great interest in industry due to its efficiency when they are coupled with a solar thermal system. This kind of systems is gaining more acceptance as a result of their lower energy requirements, higher heat transfer coefficients, compactness, high product water quality and low pre-treatment [2].

The present paper shows a dynamic model for the multi-effect distillation unit included in the AQUASOL system [3] at CIEMAT-Plataforma Solar de Almería (PSA). This model has been developed with the object-oriented Modelica language using the Dymola tool and the *Modelica.Thermal* library. This framework has allowed us to develop new libraries to make simulations easier in different operating conditions. It has been designed to improve the operation of the process and develop a control strategy which optimizes the distillate production. The physical models are based on conservation equations of mass and energy. They also include experimental correlations for heat transfer coefficients [4]. Conservation laws are applied in the different components such as the heater, the effects and the preheaters. The results of the mathematical model simulation of the whole process show promising outcomes.

## References

[1] Mathioulakis, E, Belessiotis, V, Delyannis, E, Desalination by using alternative energy: Review and state-of-the-art, Desalination 203, 346-365, 2006.

[2] Ali, M.T, Fath, H.E.S, Armstrong, P.R, A comprehensive techno-economical review of indirect solar desalination, Renewable and Sustainable Energy Reviews 15, 4187-4199, 2011.

[3] Alarcón-Padilla, D, García-Rodríguez, L, Blanco-Gálvez,J, Assesment of an absorption heat pump coupled to a multi-effect distillation unit within AQUASOL project, Desalination 212, 303-310, 2007.

[4] Palenzuela, P, Alarcon, D, Blanco, J, Guillen, E, Ibarra, M, Zaragoza, G, Modeling of the heat transfer of a solar multi-effect distillation plant at the Plataforma Solar de Almeria, Desalination and water treatment 31, 257-268, 2011.

# Modeling a drum motor for illustrating wearout phenomena

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In this contribution, a model of a drum motor is presented. This model was designed for description of dynamic behaviour of the drum motor as well as for the possible implementation of several wearing phenomena. Using this model, a better understanding of wear and tear phenomena has been achieved by carrying out a considerable number of simulation runs using different operational and wearing conditions. Using this information, important knowledge about detection of wearout signs was able to be gained.

Mathematical models help to increase the understanding of physical properties of a system. Often, mathematical models with different levels of detail are used. In these cases, it may be a difficult task to obtain reliable parameters. In this paper, we present three different approaches for establishing a model structure and for the determination of needed parameters. Some of them we were able to calculate while other ones we were only be able measured. Calculation was performed analytically or by using a Finite Element model. This way, we were able to define every part of the model with an appropriate level of detail and equip them with adequate parameter values.

The main components under investigation are roller bearings, O-rings, and a one-stage gear. We integrated all three partial models into one Modelica model of the complete system. Using this model we carried out simulation investigations of wear and tear phenomena. Hence, get experiences in predicting the behaviour of a worn system within its usual environment. This opens the possibility to investigate some consequences of wearout effects in several simulation runs in order to establish design rules for condition monitoring algorithms and thus support the development of adapted condition monitoring systems.

## References

[1] Colbourne, J.R.: The geometric design of internal gear pairs, AGMA Technical Paper, 87 FTM 2, 1987

[2] Fritzson, P.: Principles of Object-Oriented Modeling and Simulation with Modelica 2.1, IEEE Press, 2004

[3] Herold, T.; Franck, D.; Lange, E.; Hameyer, K.: Extension of a d-q model of a permanent magnet excited synchronous machine by including saturation, cross-coupling and slotting effects. IEEE International Electric Machines Drives Conference (IEMDC), Niagara Falls, Ontario, Canada, 15-18 May, 2011, Proc. pp. 1363-1367

[4] Hertz, H.: Über die Berührung fester elastischer Körper. Journal für die reine und angewandte Mathematik, 92:156-171, 1881

[5] Paland, E.G.: Technisches Taschenbuch. INA Schaeffer KG, 2002

[6] Tan, X.; Modafe, A.; Ghodssi, R.: Measurement and modeling of dynamic rolling friction in linear microball bearings. Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME, 128 (4) , pp. 891-898, 2006

[7] Zhuravlev, G.A.; Ageev, A.I.: Gear Teeth Bending Strength Analysis. Izvestia vyssih ucebnyh zavedenij. Masinostroenie (11), pp. 44-48, 1978

# “Green Building” – Modelling renewable building energy systems and electric mobility concepts using Modelica

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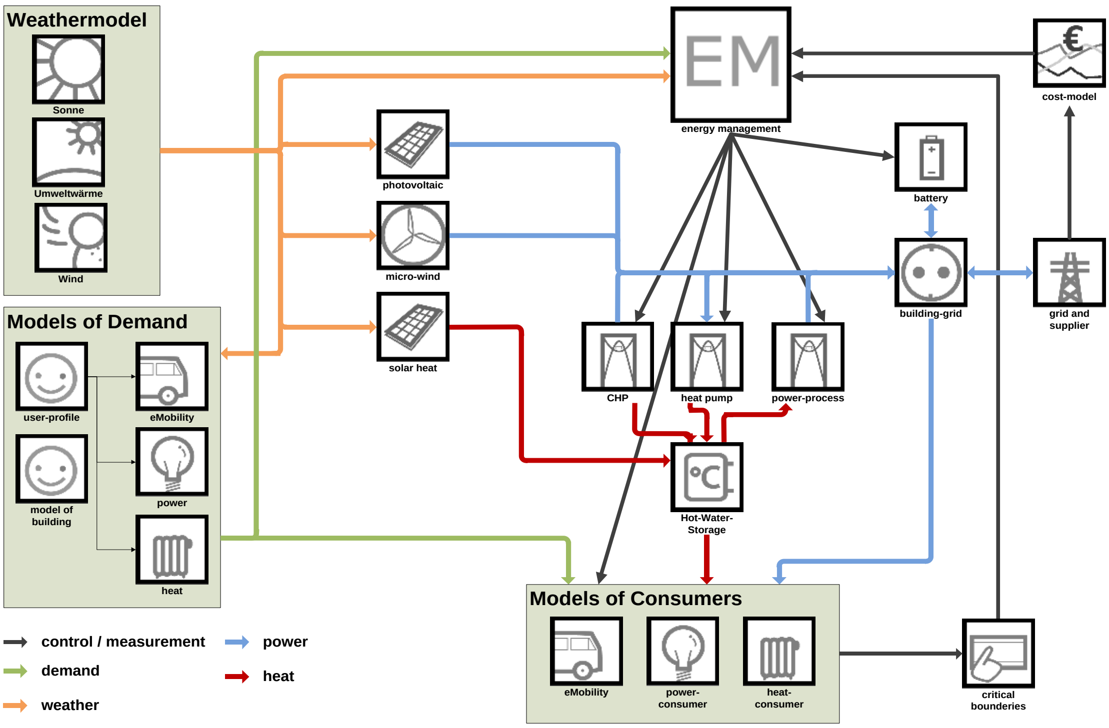
For most people, a comfortable living and mobility are basic needs. With the rising individual demand for energy as well as the diminishing fossil energy resources, new optimized concepts for energy supply and usage are required. To address these challenges, renewable energy sources, decentralized storage, and electric mobility concepts are matters of rapidly growing importance.

Future building energy systems have to successfully integrate user demands, local renewable energy, storage systems and charging infrastructure, a task requiring extensive scrutineering.

Typical questions to the engineer are to compare different system layouts with respect to sustainability, cost, and robustness, or to identify the right levers in an energy system to optimize components and control algorithms. To solve this task within an acceptable time frame, EA EnergieArchitektur GmbH and IAD TU Dresden together with ITI GmbH have developed the Modelica-based “Green-Building” library. The library offers compatible models of similar granularity in the renewable, thermal, electric, eMobility, cost and user behavior domains.




This paper describes the approaches and philosophy of the library by using a CHP powered building with stationary battery. One of the shown examples is the search for an optimal solution between stationary battery cost and renewable coverage of the vehicle mileage in a typical commuter driving cycle.

# High-Fidelity Transmission Simulation for Hardware-in-the-Loop Applications

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Model-based development plays a central part in optimizing existing transmission designs and exploring new system architectures. Design iterations and performance evaluations are done through virtual prototypes of the transmission systems, used in hardware-in-the-loop (HiL) simulations. In this paper, MapleSim's Driveline Component Library (Figure 1) is introduced. The combination of this Modelica library and Maple's core symbolic technology, enables engineers to include more detail into their models targeted for real-time simulation of transmission systems. The paper also includes some results from the work at Aisin AW in modeling transmissions and HiL testing.

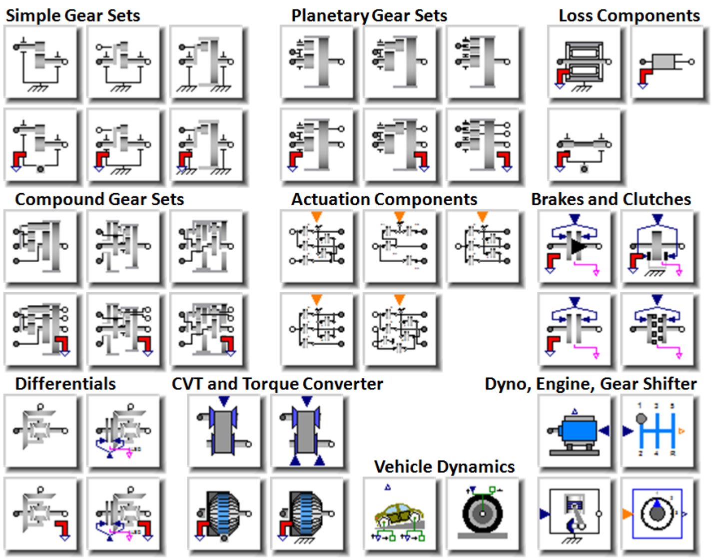


**Figure 1: Driveline Component Library**

## References

[1] *MapleSim User's Guide*, 2011, ISBN 978-1-926902-09-8.

[2] Pelchen C., Schweiger C., and Otter M., "Modeling and Simulating the Efficiency of Gearboxes and of Planetary Gearboxes," *2nd International Modelica Conference*, Proceedings, pp. 257-266.

[3] Bernadin L., Chin P., DeMarco P., Geddes K. O., Hare D. E. G., Heal K. M., Labahn G., May J. P., McCarron, Monagan M. B., Ohashi D., and Vorkoetter S. M., *Maple Programming Guide*, 2011, ISBN 1-926902-08-1.

[4] - , "Mean-Value Internal Combustion Engine Model", *Maplesoft, White Paper*, http://www.maplesoft.com/contact/webforms/whitepapers/enginemodel.aspx, (accessed: 2/4/2012).

# ADGenKinetics: An Algorithmically Differentiated Library for Biochemical Networks Modeling via Simplified Kinetics Formats

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This work demonstrates a comprehensive overview of a compact but powerful freely available Modelica library for descriptive modeling of biochemical reaction networks using a specific subset of enzyme kinetics referred to as simplified kinetics formats. These subsets of enzyme kinetics are represented by generalized structured kinetic formulas suitable for biochemical reactions with arbitrary number of substrates, products, inhibitors and activators [2]. While existing powerful works and guidelines for modeling biochemical reaction networks already exist [4], in this work a first attempt of utilizing the power of Modelica constructs for providing a compact implementation of such generalized structured formulas is presented. This gives the opportunity of realizing biochemical reaction networks using few number of reaction components, in contrast to libraries based on classical mechanistic kinetics which require hundreds of reactions components.

*ADGenKinetics*[1] is the first algorithmically differentiated library by which algorithmic differentiation (AD) techniques [3] are directly applied at the library level [1]. The resulting additional subpackage contains extended components with which parameter sensitivities, i.e. derivatives of model variables w.r.t. model parameters, are represented. By importing these types in base models, the dynamics of the underlying biochemical reaction network together with the parameter sensitivities, i.e. the derivatives of all variables w.r.t. the specified input parameters, are simulated. The underlying novel equation-based AD techniques which have been especially designed for *ADGenKinetics* have also the potentials to be employed by other Modelica libraries.

## References

[1] A. Elsheikh and W. Wiechert. Automatic sensitivity analysis of DAE-systems generated from equation-based modeling languages. In C. H. Bischof, H. M. Bücker, P. D. Hovland, U. Naumann, and J. Utke, editors, *Advances in Automatic Differentiation*, pages 235–246. Springer, 2008.

[2] W. Liebermeister and E. Klipp. Bringing metabolic networks to life: convenience rate law and thermodynamic constraints. *Theoretical Biology and Medical Modelling*, 2006.

[3] U. Naumann. *The art of Differentiating Computer Programs, an Introduction to Algorithmic Differentiation*. SIAM, 2012.

[4] E. L. Nilsson and P. Fritzson. A Metabolic Specialization of a General Purpose Modelica Library for Biological and Biochemical Systems. In *Proceeding of the 4th International Modelica Conference*, Hamburg, Germany, 2005.

[1] The open-source *ADGenKinetics* library is provided under the Modelica License 2

# Variable Structure Modeling for Vehicle Refrigeration Applications

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In this paper a variable-structure approach for Modelica models is presented. A variable-structure model is a model that can change its set of equations and variables during a simulation run. Common simulation environments like Dymola do not provide the means to model and simulate variable-structure models and therefore not many examples do exist right now. In this paper an approach is presented where Dymola is used to model the necessary models and Matlab is used to switch from one model (and therefore set of equations and variables) to another [1].

As a use case a simplified model of a thermal management system for Lithium ion batteries in a hybrid vehicle is introduced. This model consists of two parallel branches, where of the branches is not needed through the complete simulation time. This parallel branch can be removed from the model through the variable-structure approach when it is not needed. This has two main advantages. For once the simulation time can be reduced because no unnecessary calculations are done during the simulation phase. The needed simulation time of a simulation with only one model (with one set of equations) and from the model with the switch from one model to another is show in figure 1. It is apparent that the simulation time through this variable-structure approach was significantly reduced. Another advantage in this example is that the mass flow in the parallel branch can be set to exactly zero, which is not the case for the static structure model. This makes the simulations results more accurate. Therefore with this variable-structure approach it is possible to reduce simulation time and increase the simulation accuracy. Furthermore it will be presented how a model needs to be prepared for such an approach and which restrictions this approach has.

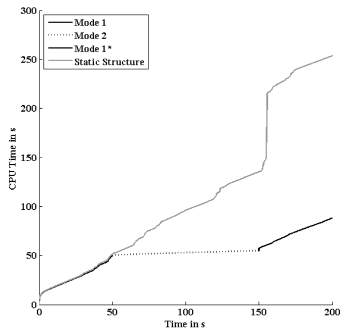


Figure 1: CPU time needed for simulation

## References

[1] Mehlhase A. Varying the level of detail during simulation. In: Proceedings of ASIM 2011, Symposium Simulationstechnik, Winterthur, Swiss, 7-9 September 2011.

# Thermal Simulation of Power-Controlled Micro-CHP Systems for Residential Buildings

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Future energy systems will include an increasing part of renewable energy sources. Nonetheless, due to the variable power that e.g. wind power and photovoltaics provide, flexible and efficient solutions are needed to close the gap between the loads and the profiles of the renewable energy sources. One of the most promising technologies for the future are combined heat and power (CHP) units which could provide electricity to stabilize the electrical grid and produce heat at the same time which can be used to supply buildings with space heating and domestic hot water.

This paper shows a modelling approach of whole-system simulations with Modelica. This includes models for a CHP plant, storages and the supplied building. Different control strategies can be used as it is shown in figure 1.

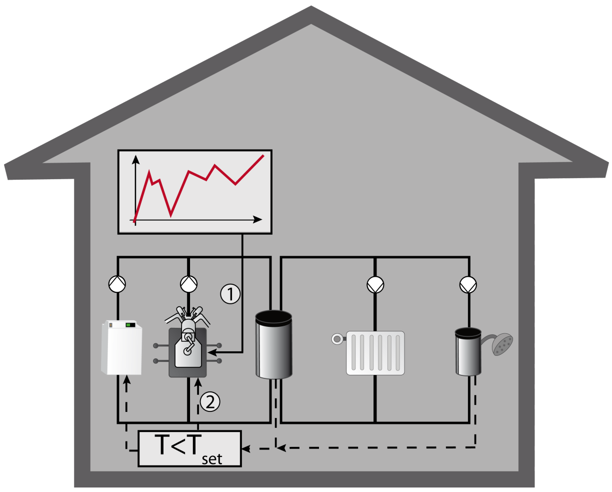


Figure 1: Analysed system with two different control strategies for the CHP plant

The strategies that are presented are the power-controlled mode (figure 1, control strategy 1)and the heat-controlled mode (figure 1, control strategy 2). In the power-controlled mode a pre-defined profile for the plant is set up and the plant runs as much as possible according to this profile. Just for security reasons (to high temperatures) it can be switched off. In the heat-controlled mode the plant always runs when a heat demand for space heating or domestic hot water is determined.

Both strategies are presented in an example to show the effects that occur in a coupled simulation of the CHP plants in interaction with storages and the heat sinks. This is for example the feedback of the actual storage temperature to the operation of the plant. Those effects have to be considered to analyse future energy systems in detail.

# Modeling of a falling film evaporator

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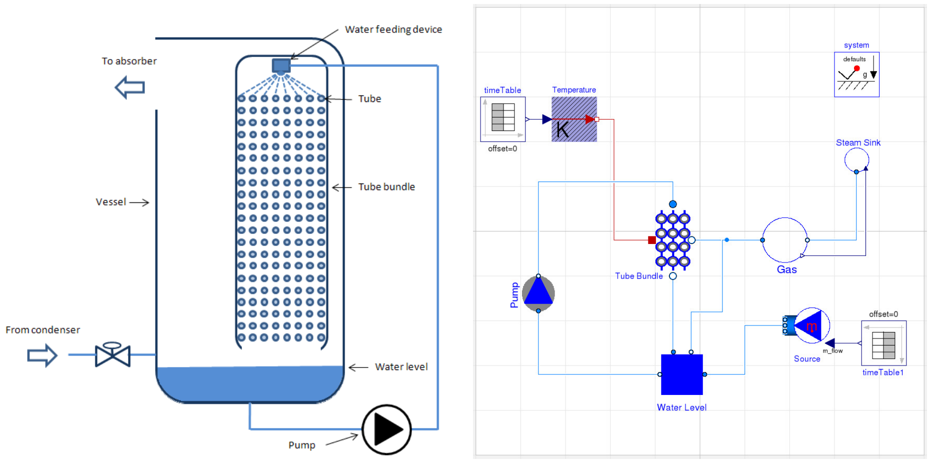
One of the difficulties of working with solar energy is its variability. Since this technology starts, researchers have studied how to avoid solar irradiance disturbances affect energy production. The proposed solutions range from thermal storage to auxiliary energy sources to make feasible facilities. At Plataforma Solar de Almería an experimental plant was set up to test and develop an hybrid solar-gas process that combines, a thermal desalination system and a solar field with a Double Effect Absorption Heat Pump (DEAHP) coupled with a gas boiler [1]. The DEAHP transfers heat from the last effect of the distillation plant (low temperature source) to the first effect (high temperature source) using the energy provided by the gas boiler.

This paper is focus on the evaporator of the DEATH. It is a horizontal-tubes-falling-film-type evaporator (a). Falling film evaporators have demonstrated better performance than flooded tubes evaporators in air conditioning and refrigeration applications due to its higher heat transfer coefficient and its smaller size [2].

The model presented in this paper is based on classical Newton's viscosity law and Nusselt falling film theory. A library of evaporator components compatible with Modelica.Fluid, Modelica.Thermal and Modelica.Media has been implemented (b). The simulations presented have the expected behaviour. These models will be used to a complete model of a heat pump.




(a) DEAHP evaporator scheme

(b) DEAHP evaporator in Modelica

## References

[1] D. C. Alarcón-Padilla, L. García-Rodríguez, and J. Blanco-Gálvez. Experimental assessment of connection of an absorption heat pump to a multi-effect distillation unit. *Desalination*, 250(2):500–505, 2010.

[2] G. Ribatski and A. M. Jacobi. Falling-film evaporation on horizontal tubes—a critical review. *International Journal of Refrigeration*, 28(5):635–653, 2005.

# Integration of Modelica models into an existing simulation software using FMI for Co-Simulation

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The Functional Mock-up Interface (FMI) opens new opportunities for the development and extension of existing non-Modelica simulation programs with Modelica models. For the developer, this is a productive way to design and validate new complex simulation models with multi-domain modeling languages such as Modelica [1]. With the standardized Functional Mock-up Interface and the Functional Mock-up Unit (FMU) export it is possible to execute these models within other software tools, including information exchange during the simulation. However, there are some design requirements in Modelica, which have to be taken into account. In this paper, models for different HVAC (Heating, Ventilation and Air Conditioning) equipment configurations are integrated into existing software using the FMI. An interface extension plug-in is developed to pick a specific FMU. The existing software [2] calculates the hygrothermal behavior of buildings iteratively. Two different coupling algorithms are investigated: an iterative and a co-simulation approach. The iterative approach requires the option to reject and repeat time steps of the FMU. This option is not supported by the simulation environment, which was used to export the FMU [3]. Therefore, the iterative approach is not feasible for the described application. In the co-simulation approach the FMU is executed alongside the existing simulation process. Hence, the building model and the HVAC model calculate the steps alternately with a *ping-pong* method. However, this requires a decreased time step size compared to the time step size of the existing software program.

The existing whole building simulation software and the Modelica HVAC models are complex models with many variables and their own specialized solvers. Separately they are proven, validated and stable for many kinds of simulations. The described co-simulation approach seems to be a reasonable way to integrate Modelica models into the existing simulation software.

## References

[1] Elmqvist, Hilding 1997. “Modelica – A unified object- oriented language for physical systems modeling.” Simulation Practice and Theory 5, no. 6., 1997.

[2] Lengsfeld, K.; Holm, A. 2007. „Entwicklung und Validierung einer hygrothermischen Raumklima-Simulationssoftware WUFI®-Plus“, Bauphysik 29 (2007), Heft 3, Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, Berlin.

[3] Dassault Sysèmes AB 2011. Dymola. Dynamic Modeling Laboratory. Dymola Release notes, Lund, Sweden.

# Chemical Process Modeling in Modelica

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**Structural information.** Chemical process models are typically large-scale but highly structured. Information on how the hierarchical components are connected can help to make the solution procedure more robust, reliable and orders of magnitude faster. Our ultimate goal is to develop structure-driven optimization methods for solving nonlinear programming problems (NLP). The structural information is programmatically accessible in JModelica *before flattening*.

**Connector class.** Creating a component-based framework for chemical process modeling is the first step towards our final goal. The most challenging step was to design the connector class. Our choice of the independent variables in the connector class guarantees the linearity of the material and heat balances. The linearity of these equations is important for efficiency reasons. The Modelica.Fluid library superficially resembles our library, however Modelica.Fluid does not allow our choice of the independent variables.

**Smallest subcomponents.** The smallest Modelica subcomponents of our library are referred to as atomic units. The set of atomic units has been determined by recursively decomposing a variety of chemical processes. As a result, these atomic units are sufficient for general-purpose chemical process modeling.

**High-level model building.** Once the component library is finished, software with a graphical user interface can be used to build chemical process models. The process model creation involves only high-level operations on a GUI; low-level coding is not required. This is the desired way of input and this is also how it is implemented in commercial chemical process simulators.

**Bridge towards the optimization community.** Typical optimization problems in chemical engineering arise in process design, process control, model development, process identification and real-time optimization. AMPL is the de facto standard for model representation and exchange in the optimization community. We are aiming to create a 'Modelica to AMPL' converter. One could use the Modelica toolchain to create the models conveniently on a GUI. After exporting the Modelica model in AMPL format, the readily available AMPL-based environments can be used. Such a code generator to AMPL already existed in 2007 but it is no longer supported, and not publicly available.

**Application.** The Modelica library serves as a common language between mathematicians and chemical engineers. The library was tested on the model of JACOBSEN & SKOGESTAD [1], an industrial distillation column of high practical relevance. The distillation column has 5 steady-states in a certain region of the bifurcation parameter. The fact that the Modelica implementation gives the expected steady-states suggests that the implementation of the involved Modelica components is correct.

**Acknowledgements.** The research was funded by the Austrian Science Fund (FWF): P23554.

## References

[1] E.W. Jacobsen and S. Skogestad. Multiple steady states in ideal two-product distillation. *AIChE Journal*, 37:499–511, 1991.

# FMI Add-on for NI VeriStand for HiL Simulation

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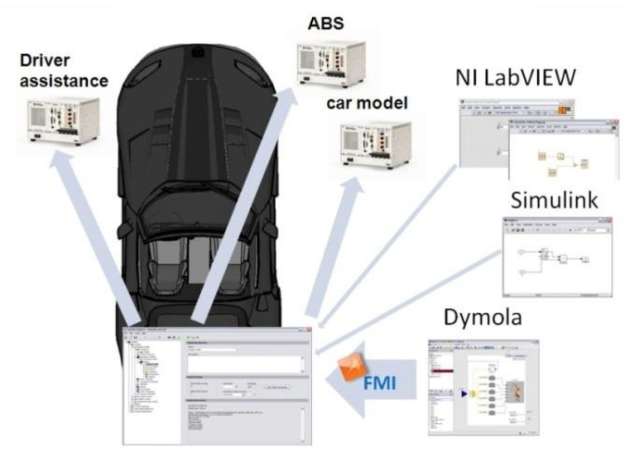
This paper describes the implementation of the Modelisar Functional Mock-up Interface (FMI) support in NI VeriStand, a commercial software environment suitable for real-time testing applications.

This paper presents the work conducted to implement the FMI Add-on for NI-VeriStand, which is available as a commercial product, and the process to make hardware in the loop simulation starting from a Model Based Development environment compliant with the FMI for Co-Simulation standard for model export and using it in NI VeriStand environment with National Instruments real-time hardware.

The aim of this work is to enable NI VeriStand to support the FMI standard for Co-Simulation. This in order to perform rapid-prototyping and hardware in the loop simulations using National Instruments hardware directly from Modelica models exported using the FMU standard. With the FMI Add-on it is possible to use FMU models in Windows and /or in National Instruments RT Targets like NI PXI and NI CompactRIO.

In this paper, we will present:

- A description of the activity carried out for the implementation of the FMI Add-on for NI-VeriStand.
- A detailed description of the steps that are to be performed in order to use FMUs in National Instruments PXI RT Targets.
- A validation test for the FMI Add-on performed with Dymola and National Instruments PXI RT Target based on the detailed model of a 6 dof manipulator.




## References

[1] Functional Mock-up Interface: http://www.functional-mockup-interface.org/index.html

[2] H. Hadj-Amor, C Faure, M. Ben Gaïd, N. Pernet, “Towards a Modelica Real-time co-simulation with FMI”, Multiphysics Simulation - Advanced Methods for Industrial Engineering Conference, Fraunhofer, 22-23 June 2010

# Using Static Parametric Design to Support Systems Engineering of Industrial Automation Systems

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This paper proposes a static parametric design methodology for application of the model based systems engineering (MBSE) paradigm in the world of Modelica. This methodology allows for parameter synthesis of the industrial automation systems under consideration of customer requirements. Furthermore, the parametrized system can be verified automatically. An integrated system model consisting of requirements, system design and verification models is created and can be used as a design template to generate a new parameter set according to the change of customer requirements. A case study from the practice is presented to proof the concept of this methodology.

The objective of the static parametric design methodology is to perform a parameter synthesis of a technical system according to the customer requirements automatically. The following diagram illustrates the main idea of this methodology. The starting point is a formalized requirements model which defines the requirement variables and performance variables. According to the selection variables calculated from the static calculation model, the proper components of the desired system can be selected iteratively from the product catalog. The optimal design can be verified by the means of simulation automatically.

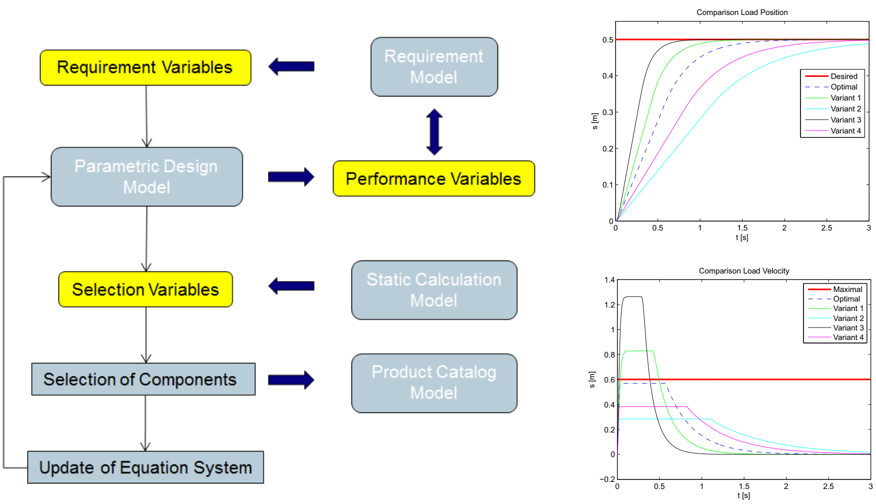


Figure 1: Static Parametric Design Methodology