HIL pilot project for exchanging submodels based on FMI

Always the Right Model

Realistic hardware-in-the-loop tests require real-time-capable models that can simulate the required system behavior with the right degree of accuracy. Together, BMW, ITI, and dSPACE test the transfer and use of a real-time-capable model part via an open, tool-independent interface.

For a joint project, BMW, dSPACE, and ITI used a model of an automatic transmission to analyze whether the Functional Mock-up Interface (FMI) standard (2.0) is suitable for use in real-time hardware-in-the-loop simulation. The companies also tested a process prototype for replacing submodels in an existing simulation model with FMI-based submodels.

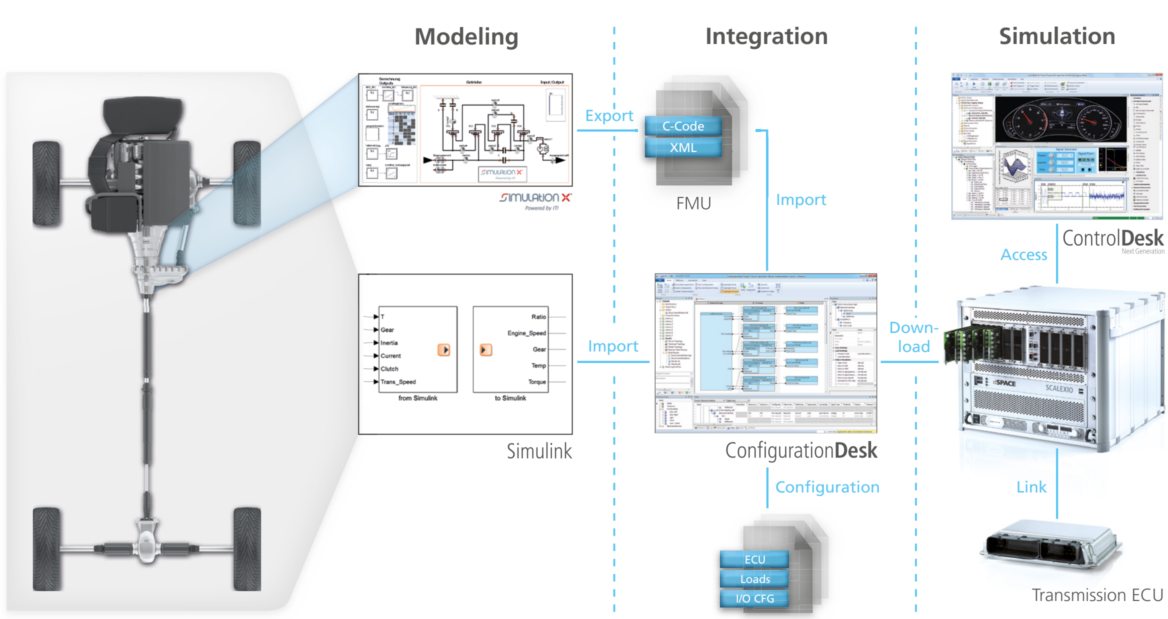
Test System Setup

To make the simulation realistic enough and prevent entries in the fault memory of the ECU when it is being tested with a HIL simulator, two things are needed: the correct interaction of the ECU interface with the HIL simulator and realistic simulation models. This is needed to test the behavior of an ECU realistically. Because the tests in the project were to be executed for realistic use cases, the project uses the electrical interface and environment simulation models of an existing HIL setup for the ECU of an 8-gear automatic transmission, adjusted for use in dSPACE's HIL simulator SCALEXIO®. In addition to MATLAB®/Simulink® and also SimulationX® from ITI for modeling, the project uses dSPACE's ConfigurationDesk® software for configuring the SCALEXIO system and dSPACE ControlDesk® Next Generation for controlling the HIL simulation (figure 1).

The Idea Behind FMI

The basic idea of FMI is to avoid redundant work: Its goal is to reuse existing simulation models, which can come from different suppliers, in different development phases and in different departments of a company. This requires a standard that makes it easier to transfer and integrate environment models that were developed with development tools from different providers. Functional Mock-up Interface (FMI) is such an open, tool-independent standard. It lets engineers use the perfect modeling approach for each submodel and easily combine these submodels in a project. The submodels are transferred via Functional Mock-up Units (FMUs). FMUs are compressed folder structures containing the model functionality and the required interface description as ANSI-C-compatible API and XML file. Users can also add documentation and other data that the model requires. The new functions of the FMI 2.0 standard are beneficial for HIL projects, such as the possibility to adjust parameter values during simulation run time and the direct definition of step sizes for real-time-optimized solvers. Therefore, FMI 2.0 for Co-Simulation is used in this project. In the FMI for Co-Simulation

Figure 1: Setup of the overall system. The Simulink model and the FMU from ITI are integrated to one overall model in ConfigurationDesk. The overall model is then configured and loaded to SCALEXIO for HIL simulation. The simulation is controlled via ControlDesk Next Generation.



variant, the suitable real-time-optimized solver is already included in the FMU.

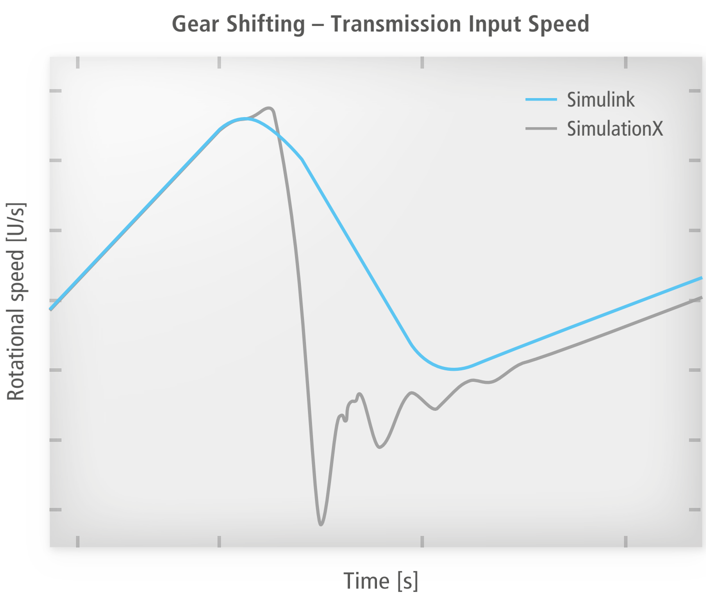
Benefits of the New Model

The project aims at using the described advantages of FMI to integrate a new, Modelica-based, acausal, dynamic transmission model in the Simulink-based overall drivetrain model. The goal is to better represent the elastic behavior of the transmission when simulating the overall behavior. To this end, ITI modeled four sets of planetary gears with variable gear ratios in SimulationX, including the associated inertias and elasticities, and the input, output and friction torques. The switchable clutches are modeled as friction surfaces with the appropriate physical friction behavior, including the alternation between the locked and unlocked states. The clutches are controlled by a gear shift logic with a speed- and torque-dependent gear shift diagram. Figure 2 highlights how different the simulation precision is for the dynamic transmission behavior when it is simulated with the simple Simulink model or with the SimulationX model. The environment model of the drivetrain is computed in real time with simulation steps of 1 ms. The new transmission submodel that is modeled in SimulationX and exported as an FMU has to meet these real-time requirements.

Integrating the New Model

At the start of the project, the model interface for integrating the transmission model was defined and then used by all project partners throughout the project (figure 3). To integrate the new transmission model into the existing, Simulink-based drivetrain environment model, the developers performed the following steps: >>

Figure 2: The blue curve (Simulink) indicates the idealized rev interval during a gear shift in the existing, signal-flow-oriented transmission model. The gray curve (SimulationX) indicates the transmission behavior in acausal modeling, which is more realistic because it considers vibrations.



About FMI

The FMI standard was first defined in the MODELISAR project in 2011 and is currently being developed further by the FMI project of the Modelica Association. The standard focuses on the exchange of models of dynamic systems: i.e., models that are defined by differential, algebraic, and discrete equations.
Its current version, 2.0., includes new functions that benefit HIL simulation. One major advantage is the possibility to define the step size for real-time-optimized solvers and tunable parameters that allow changing the parameter values during simulation run time. This is necessary for interactive experiments and HIL simulations that cannot simply be restarted because the control loop includes real hardware.
www.dspace.com/go/fmi

About ProSTEP

The ProSTEP iViP Association is an international association that is committed towards developing innovative approaches to solving problems and modern standards for product data management and virtual product creation.
www.prostep.org

Exchanging interface information between project partners

Creating the model interface in the modeling environment

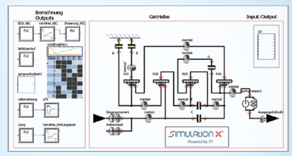
Importing and linking the model interface in ConfigurationDesk

Input

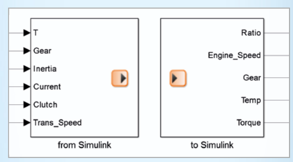
Name	Comment	Range	Unit	Initial value
IN.T	Transmission input torque	[0,x]	Nm	0
IN.Gear	Current gear	{1,2,3...}	-	0
IN.Inertia	Transmission input inertia	[0,∞]	Kg·m²	0
IN.Current	NIC control current	[0,i]	A	0
IN.Clutch	Clutch state	[0,100]	%	0
IN.Trans_Speed	Transmission output speed	[x,y]	rad/s	0

Output

Name	Comment	Range	Unit
OUT.Ratio	Current gear ratio	[a,b]	-
OUT.Engine_Speed	Transmission input speed	[0,x]	rad/s
OUT.Gear	Idling state	{0,1}	-
OUT.Temp	Transmission oil temperature	[Tmin, Tmax]	K
OUT.Torque	Transmission output torque	[x,y]	Nm



Gearbox SimulationX model exported as FMU



Powertrain Simulink model

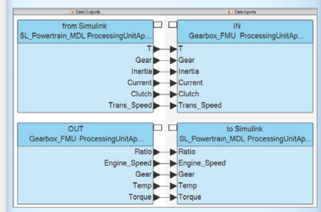


Figure 3: The predefined modeling interface is considered and implemented in each work step.

1. Cropping the existing, simple transmission from the Simulink model
2. Adding the necessary model interfaces to the Simulink model via dSPACE Model Port blocks
3. Forwarding the data required for creating the new transmission model to ITI. This data included:
   a. An interface description file
   b. The required model functionality
   c. The technological framework (C compiler, real-time requirements, etc.)
4. Based on this data, ITI developed a physical SimulationX model and provided an FMU and a Simulink-based S-function as a test benchmark.
5. First, the S-function was included in the model to test whether the SimulationX transmission model functions correctly (variant 1).

   Then, the FMU was integrated to test the interface's function (variant 2).

Tests and Results

The project partners used ControlDesk Next Generation to perform closed-loop tests on the dSPACE HIL simulator SCALEXIO for the two variants: i.e., for the integration via Simulink using an S-function (variant 1) and for the integration via an FMU, with ConfigurationDesk (variant 2). The computation times for the model under test were nearly identical in both cases and the test results were bit-identical. It was possible to compute the new transmission model variant, which considers vibration phenomena of up to 40 Hz, with numeric stability in real time at a step width of 1 ms. FMI 2.0 for Co-Simulation therefore shows that it is fit for the standardized, tool-independent transfer of real-time-capable models. This means that the FMI standard can help simplify exchanging environment models between departments.

Tool Chain Integration

But exchanging model parts is only a first step; it is also important to test how the exchanged element can be used in an existing tool chain. To make the adaptation process as fast and resource-saving as possible, major adjustments to the configuration and experiment tools must be avoided. Since the configuration software ConfigurationDesk supports both Simulink and FMI as import formats for environment models, exchanging the model part via the established model interface was quick and easy. ConfigurationDesk recognized the new model interface, making it possible to use the interface for forwarding the model signals. In ControlDesk Next Generation, the model parameters and variables of the FMU are available in the same way as in Simulink-based models. This made it easy to adjust and reuse the existing tests and the experiment layout for the transmission HIL system. Once the new, FMI-based transmission model was integrated in the overall project, the existing workflow and the associated HIL tests can be reused within the project without significant modifications.

Outlook

ProSTEP used the experience gained in this pilot project in their Smart Systems Engineering Project for the developed workflow describing the collaboration of various partners during FMI-based model exchange. It is planned to continue the project described in this article in order to analyze the workflow for exchanging intellectual-property-protected FMUs for HIL testing. ■

By kind permission of BMW AG

Summary

BMW, dSPACE, and ITI used a model of an automatic transmission in a pilot project to analyze whether the Functional Mock-up Interface (FMI) standard is suitable for use in real-time hardware-in-the-loop simulation. It was possible to compute the new FMI-based variant of the transmission model, modeled in SimulationX, with numeric stability in real time with a step size of 1 ms. FMI 2.0 for Co-Simulation therefore appears to be suitable for exchanging real-time-capable models. The easy integration of FMI-based models into the dSPACE tool chain made it possible to reuse existing tests and experiment layouts with little additional effort. Because the ECU of the automatic transmission runs on the SCALEXIO HIL system without entries in the fault memory, detailed tests that consider the dynamic effects of the transmission can now be performed in real time.

In the future, the FMI standard can be used to combine only the most suitable model elements, regardless of who manufactured them.