Powertrain System Simulation

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Powertrain System Simulation

1. Vision
2. Concept
3. Implementation
   - Virtual Control Modules
   - Plant Models
   - Use Cases & Testing
4. Conclusions on Business Model
5. Summary
Aim for completeness of the virtual approach for maximum impact!
To calibrate drivability (also) using a virtual vehicle the whole powertrain including all functional software and hardware components has to be digitalized.

* CPC = Central Powertrain Controller
SiL Platform for Powertrain System Simulation

Concept

Platform Functionality
- Access Rights Management
- Calibration Tool Interface
- Test Automation
- Auxiliary Code

Co-Simulation

ECU
TCU
CPC
BMS
Inverter ECU

Plant Models
Virtual xCUs

Engine
Transmission
Vehicle & Driveline
Battery
Electric Motor Inverter
Ingredients

Virtual Control Units (vXCUs)

Plant Models

Testing Use Cases
Completeness of powertrain software virtualization is crucial.
Creating Virtualized Control Units: Build Inhouse-SW for SiL (CPC, TCU)

Daimler / Inhouse

- Modelling / Programming / (C-) Code-generation
- Sil-Compiler
- Preprocessed items (object files, SiL-specific)
- “Linking” (SiL-specific)
- Virtual control unit

Inhouse Software: Direct usage on standard PC by tailored build process
Creating Virtualized Control Units: ChipSim for Multi-source xCU

ChipSim: technology with attractive „one-size-fits-all“ attributes. Detailed at instruction set level.
Same Difference – It Does Matter How Much of the xCU Is Included!
Same Difference – It Does Matter How Much of the xCU Is Included!
Completeness of powertrain software virtualization is crucial.
Ingredients

- Virtual Control Units (vXCUs)
- Plant Models
- Testing Use Cases
## Plant Models: Quality Levels – Example: Engine Model

<table>
<thead>
<tr>
<th>Quality level</th>
<th>Output e.g. engine</th>
<th>Characteristics</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced</td>
<td>torque, rpm</td>
<td>• Quality and accuracy comparable to production and vehicle-to-vehicle variation</td>
<td>DEM (discrete event models, crank-angle-based models)</td>
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<td></td>
<td></td>
<td>• Excellent transient response matching</td>
<td></td>
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<tr>
<td></td>
<td>CO₂</td>
<td></td>
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<tr>
<td></td>
<td>thermal properties</td>
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<tr>
<td>Functional</td>
<td>torque, rpm</td>
<td>• Physical phenomenology covered</td>
<td>MVM (mean value models)</td>
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<td></td>
<td></td>
<td>• Qualitative evaluation, accuracy sufficient</td>
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<tr>
<td></td>
<td></td>
<td>• Limited dynamic response (EUDC-dynamics)</td>
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<tr>
<td></td>
<td></td>
<td>• Physical, empirical or semi-physical models</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CO₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>thermal properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic</td>
<td>I/O supported, general</td>
<td>• I/O supported, general system-behavior</td>
<td>Look-Up-Tables</td>
</tr>
<tr>
<td></td>
<td>system-behavior</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Simple Look-up-models and physical approach</td>
<td></td>
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</tbody>
</table>

Functional model class (e.g. mean value models for engine) suitable for many applications
Ingredients

Virtual Control Units (vXCUs)

Plant Models

Testing Use Cases
Use Case Matrix
Example: Operating Strategy

Operating Strategy ICE/EM
- < 1 xCU / modules
- Look-up tables
- Update measurements

➤ Prediction
➤ Concept evaluation

Operating Strategy ICE/EM
- Multi-xCU (3+)
- MVM
- Measurements

➤ Simulation
➤ Optimization
➤ Calibration
➤ Testing

Development Phase
Example: Engine Speed Governor

**Software System Test**
- Multi-xCU (3+)
- Open loop
  - xCUs communicate

**Integration Test**
- 1 xCU
- Open loop
  - SW and Comstack according to spec

**Module Test**
- < 1 xCU / Module
- Open loop
  - Module according to spec

**Powertrain System Test**
- Multi-xCU (3+)
- MVM
- HW/Messungen
  - Concept validated
  - Response of engine and transmission

**Development Phase**
- Advanced
- Functional
- Basic

Mercedes-Benz
Ingredients

Virtual Control Units (vXCUs)

Plant Models

Testing Use Cases
In addition to unrestricted driving, various test types can be implemented which - when used repeatedly - can be triggered automatically.
Test Automation

Automated Tests, e.g.:
- Drivability
- Air path
- WLTC
- Durability

New Software (virtualized)
New Dataset
Test
dataset management
Trigger
SiL
Analyze
ok?
yes
Release
no
Test automation enables permanent evaluation of the development progress and supports continuous improvement of software and calibration.
Aspects for Assessing a Software-in-the-Loop Environment

**Completeness**
- Completeness is more important than specific level of detail
- No limitations, no pitfalls, interactive operation

**Open Models**
- Open models vs. blackbox
- One task → one tool for measurement, calibration and diagnosis

**Focus on Physics**
- Physical phenomena more important than accuracy
- Rights Management (DRM) – Content defines value

**Flexible Licensing**
- Royalty-free models
- Pure Software – always available & highly scalable

**Modularity and Extendability**
- Intuitive interfaces, standardized exchange formats
- A simple user interface increases acceptance

**Implementation**

- Unrestricted Driving
- Standard tools
- Access Rights
- “To-go”-Flexibility
- User-friendly
Conclusions on Business Model

**Control Modules**

- The vXCU is part of the delivery and part of the business model OEM - supplier
- Technology for XCUs with software from multiple sources available
- The virtual XCU must be available before the real one or the software

- If it has software, it has a virtual control module

**Plant Models**

- Supply of plant models which are required for the completeness of the SiL (e.g. battery, starter/alternator) or the required parameters
- The plant model must be available before the real component

- The plant model is the first development ressource
Conclusions on Business Model

Exchange Format

- Plant models and vXCUs should not be restricted to a tool-specific format
- Exchange between multiple model owners required
- Enabler for completeness of SiL

- Independence from target platforms by means of exchange formats

Standards

- Strong alignment to standards, both "external" (e. g. FMU) and "internal" (e. g. for open and standardized software architecture AutoSAR)

- "Comply on standards, compete on implementation"
Conclusions on Business Model

Skills

• Development on virtual vehicles becomes an integral part of every development discipline
• Simulation provides the modeling skills but not (all) the simulation results
• Skill set part of the training-on-the-job for professionals or the academic education

▷ Additional skills for virtual development

Engineering Tools

• Tools to analyze and post process test results to be activated by generic test automation and reporting

▷ Compatible with both, real and virtual test environment and process
Summary

- The goal is to use a virtual vehicle for development where it is suitable.
- For powertrain development, e.g. for drivability calibration, this requires that all control units and powertrain subsystems are virtualized. Completeness of the system is crucial - hence, powertrain system simulation.
- The key technology is the Software-in-the-Loop approach for digitalizing control systems.
- The virtualized control modules are integrated with powertrain plant models using a co-simulation tool.
- The SiL-platform provides engineers with the complete application software for the ECUs and all relevant powertrain models. It is used for software development, calibration and simulation tasks.
- The virtual platform catalyzes automated testing.
- The option of integrating powertrain system simulation into development project has an impact on the cooperation of OEMs, suppliers and engineering companies.
Thank You for Your Attention!