MBD solution covering from system design to verification by real-time simulation for automotive systems

Kosuke KONISHI, IDAJ Co., LTD.
Agenda

• System/Component model designs to validation
  – Needs of co-simulation platform supporting multi domains
  – Overview of MBSE
  – Co-simulation platform
• Use Case: Application to Hybrid Vehicle Design and Validation
• Conclusion
Needs of co-simulation platform supporting multi domains

• Model-Based Development (MBD) approach has been deployed to “control software” domain for more than 10 years.

• Today, simulation is a key factor for development costs reduction. 0D/1D simulation has been fully applied to several domains in automotive systems. That means modeling level is enough for collaborative development across domains.

• But, challenging issue is to have co-simulation platform supporting multi domains to enable “concurrent system development” in Model-Based Systems Engineering (MBSE).
  
  – Several models from the domains should be executed by a common solver when a simulation tool is configured for co-simulation platform.
  
  • It takes more execution time due to small time step required for the models.
  • Connecting models are not easy because the interface for integration depends on the co-simulation platform.

• Goal:
  
  – Provide co-simulation platform and integrate into MBSE process.
Overview of MBSE

1. System modeling: system descriptions using SysML
   - Use only some SysML constructs for components definition, functional decomposition, architecture definition
   - System models are traced with system requirements.
   - System models should be passed to component design process automatically if possible.

2. Design and validation of sub-systems and/or components
   - Based on system models with SysML notations, architecture and interface information are passed to the component design/simulation tools automatically or manually.
   - In each domain, those components are designed.

3. Do simulations at component level, sub-systems level, or vehicle system level on co-simulation platform.
   - Simulation platform satisfying independent from modeling tools and support of connections of multi-domain models
   - Several means to connect and execute models
     - Standalone and Tool-coupling, FMI1.0/2.0 standard
   - The simulation platform facilitates MILs/SILs to HILs within the same environment.
Overview of MBSE

Sub-system/Component level

Driver
Engine
Vehicle

V-process
Functional Models
Detailed Models
Tests

Tests/Validation

System Model
SCADE System

Co-Simulation Platform

Co-simulation at Sub-system or system level

System requirements/behavior
Traceability

Engine Control
Vehicle Control

Friday, October 03, 2014
2014 Automotive Simulation World Congress
October 9-10, Tokyo, Japan
System Modeling with SysML : SCADE System

• Describe system structure and functional definition in system model. (keep it simple)
  – Using only Block Definition Diagram (BDD), Internal Block Definition (IBD), Allocation table. These are minimum description of system in terms of structure.
  – System requirements and system behavior are described in natural language as before.
• However, system requirements and system behavior can be traced in SCADE System using requirement management feature.

Allocation tables for relationship between architecture and function

Functional view

Architecture view
System Modeling with SysML: SCADE System

- Manage “traceability” between requirements/behavior descriptions and system design simultaneously in the integrated tool.

System requirements/behavior descriptions written by Word

System model

Traceability management tool
Co-Simulation Platform : xMOD

• In this MBD flow, the most important piece is to provide co-simulation platform by “xMOD”.

• Requirements that xMOD satisfies:
  1. Executing models in “standalone” mode to ensure independence with modeling tools and reduce costs
  2. Coupling heterogeneous models
     • Open architecture facilitates easy integration of models
  3. **Optimizing** complex model execution
     • Multi-cores/Multi-thread execution with specific solvers
     • “Synchronous/Asynchronous algorithm” to manage data communication among models
  4. **Compatibility** with new simulation standard
     • FMI 1.0/2.0 for both Model Exchange and Co-Simulation types
  5. **Continuity from MILs to HILs**
     • The same PC can be configured for HILs with Real-time OS
     • “Standalone” models can be executed on xMOD HIL
Co-Simulation Platform: xMOD

- Mixing “standalone execution” and “tool-coupling” is required depending on situation.
  - For control engineers, they don’t want to operate plant models on other tools, but just changing values of parameters and look-up tables. For that, plant models may be provided as “standalone”.

![Diagram of xMOD Co-simulation Platform](image)
Use Case:
Application to Hybrid Vehicle Design and Validation

- Use case: design and validate hybrid vehicle and control algorithms
  - System model: SCADE System and traceability management tool
  - Engine, Hybrid system, T/M, Vehicle models: GT-SUITE
  - Control models: SCADE Suite, Simulink
  - Co-simulation platform: xMOD
    - SCADE Suite model: Export as FMU
    - Simulink model: Standalone executable
    - GT-SUITE model: Tool-coupling
Use Case:
Application to Hybrid Vehicle Design and Validation

- System modeling with SCADE System
  - Consider “granularity” in block definition because some components may be replaced by the ones with different specification.
  - For example, Engine is selected for gasoline or diesel.
Use Case:
Application to Hybrid Vehicle Design and Validation

- Traceability between textual requirements in Word and SysML designs is managed in SCADE System.
  - Functional blocks and Architectural blocks are traced to requirements fully.
Use Case:
Application to Hybrid Vehicle Design and Validation

- Design Engine, HEV, T/M and Vehicle models in GT-SUITE:
  - The block consists of Battery, Inverter, two Motor/Generators, Clutch, Engine, T/M and Vehicle.
  - IBD for Motor/Generator is designed and applied to GT-SUITE model.
  - In order for GT-SUITE model to communicate to control models via xMOD, an object for tool-coupling interface should be inserted into the model.
Use Case:
Application to Hybrid Vehicle Design and Validation

- Control model design with SCADE Suite and Simulink are separated by the characteristics of the requirements:
  - SCADE Suite is applied when the control is based on State-machine or mode and complex.
  - Simulink is applied when the control is based on pure mathematical equations and/or Look-up Tables.
Use Case: Application to Hybrid Vehicle Design and Validation

- Details of Mode control is designed based on State-machine in SCADE Suite.
  - Parallel Mode: Clutch (CL) is engaged and Engine power drives vehicle via T/M.
  - Series Mode: Clutch (CL) is dis-engaged and the power of MG2 drives vehicle via T/M while Engine is mainly used for charging battery via MG1.
Use Case: Application to Hybrid Vehicle Design and Validation

- A part of specifications for detailed control model design:
  1. In Series mode, if the current SOC is less than a threshold depending on maximum power of MG2 and power required for vehicle drive for a certain time, Rapid charge mode is active.
  2. In Parallel mode, if the power required for vehicle drive is greater than 0 for a certain time, Drive model is active to let Engine on.
Use Case:
Application to Hybrid Vehicle Design and Validation

1. Preparation for co-simulation on xMOD:
   1. Export SCADE Suite model as FMU
      • ***.fmu is generated.
   2. Build Simulink model for standalone executable via Simulink Coder.
      • ***.dll and ***.xmodel are generated.
   3. Generate *.dat file from GT-SUITE model to be coupled on xMOD.
      • ***.dat file is generated.

2. The generated files are stored in xMOD model library.
3. On xMOD Editor, they are connected.
Use Case: Application to Hybrid Vehicle Design and Validation

- Complete co-simulation model on xMOD

xMOD Editor

SCADE model

Simulink model

GT-SUITE model
Use Case:
Application to Hybrid Vehicle Design and Validation

• Execute the simulation on xMOD using GUIs.

Since GT-SUITE model is tool-coupled with xMOD, the execution of the GT-SUITE model is executed on GT-SUITE tool and the data of inputs and outputs are only communicated to xMOD.

xMOD Simulator controls simulation and access to data or parameters in the models.
Use Case:
Application to Hybrid Vehicle Design and Validation

- To validate the control design, several cases are tested on xMOD.
- Case1: Drive vehicle with different initial SOC on NEDC cycle
  - Initial SOC as 95%, 50%, 10%.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Initial SOC 10%</th>
<th>Initial SOC 50%</th>
<th>Initial SOC 95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Series</td>
<td>EV</td>
<td>EV</td>
</tr>
<tr>
<td>B</td>
<td>Series</td>
<td>Series</td>
<td>EV</td>
</tr>
<tr>
<td>C</td>
<td>Parallel</td>
<td>EV</td>
<td>EV</td>
</tr>
<tr>
<td>D</td>
<td>EV</td>
<td>EV</td>
<td>EV</td>
</tr>
<tr>
<td>E</td>
<td>EV</td>
<td>EV</td>
<td>EV</td>
</tr>
</tbody>
</table>

Zone A: At low vehicle speed range, because “parallel” mode is not activated, MG2 drives vehicle. In case that SOC is lower than 10%, Engine runs for charge. In case that SOC is higher than 10%, “EV” mode is activated.

Zone B: Same as Zone A, but because required vehicle power is larger than Zone A, engine power is used for the battery charge even for medium SOC.

Zone C: At medium vehicle speed range, engine power can be applied to driving vehicle. At low SOC, engine power drives vehicle at optimum fuel consumption.

Zone D: At medium vehicle speed range, because required vehicle power is low, EV mode is activated.

Zone E: Regenerate energy at deceleration.
Use Case:
Application to Hybrid Vehicle Design and Validation

- Case 2: To compare acceleration performance with the difference of battery.
  - Engine/Vehicle and Control specifications are same.
  - Number of Battery cells in series is changed.

<table>
<thead>
<tr>
<th>Zone</th>
<th>220V</th>
<th>440V</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Series</td>
<td>Series</td>
</tr>
<tr>
<td>B</td>
<td>Parallel</td>
<td>Parallel</td>
</tr>
</tbody>
</table>

Zone A: At very low vehicle speed range, because engine is not activated to drive vehicle, MG2 drives vehicle with maximum power while engine and MG1 generate powers and supply to the battery.
Zone B: Parallel mode is activated for engine, MG1 and MG2. Due to limitation of maximum battery power, MG1 and MG2 provide power to drive vehicle as much as possible.
Conclusion

• We presented Model-Based Systems Engineering enabling co-simulation across domains.
  
  – The approach starts with system designs by SysML(SCADE System) and requirements described by natural language. Both are linked in traceability management in the same tool.
  – System designs are passed to component design process automatically or manually.
  – At V&V phase, co-simulation platform xMOD provides several types of model exchange means for multi domains.
    • Standalone, Tool-coupling and FMI integration(ME/CS) can be mixed for model connections.
    • Independent from modeling tools, multi-core/multi-thread technique improves simulation performance.
  
  – We also showed use case of Hybrid Vehicle design and validation on xMOD based on the MBSE approach presented.