A multi-physical simulation architecture to support the development of hybrid electric vehicles

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LCVTP Systems Model Framework

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Introduction

LCVTP: Multi-partner collaborative project with an aim to progress the development of low carbon vehicle technology within the West Midlands.

Systems Modelling Activities:

- Vehicle systems simulation platform developed to support integrated model-based development activities across a range of different project workstreams.

- Objective to develop a single common simulation environment to promote collaborative development & dissemination of models among multiple project partners.

- Intended to accommodate a number of different use cases through the substitution of both plant & control subsystem components with varying degrees of functionality and fidelity.
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Project Scope

Example Use Cases:

- **Model based development of control systems for low carbon vehicles.**
  - VSC – Vehicle Supervisory Control
  - HVAC & Cooling – Advanced Thermal Energy Management Systems
  - BMS – Battery Management System (High Voltage)
  - Regenerative Braking & Stability Control

- **Study the impact of regenerative braking on vehicle dynamics.**

- **Performance & fuel economy predictions for competing HEV architectures.**
  - Incl. potential benefit from thermal energy recovery systems & minimisation of parasitic losses.

- **Component sizing: e.g. drive motor, APU & energy storage units.**

- **Optimisation of powertrain cooling systems.**
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Platform Requirements

- **Support a wide range of emerging hybrid electric vehicle architectures.**
  > Requires capability for multi-physical modelling of powertrain.

- **Development of high/low voltage electrical networks.**
  > Accommodate a range of different electrical architectures, subsystems & analysis.
  > Requires consideration of electrical dependency in model derivation & physical connections between HV/LV electrical subsystems.

- **Development of thermal network.**
  > Inclusion of thermal management system.
  > Requires inclusion of thermal dependency in subsystem models.
  > Support multiple interactions between thermally dependent subsystems.
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Platform Requirements

• Required to support MATLAB/Simulink derived controllers.

• To include an appropriate realisation of the full vehicle model for real time simulation within a HIL (Hardware-In-Loop) environment.

• Framework required to extend into existing IPG CarMaker model environment to study vehicle dynamics.

• Vehicle level models to be derived from standard libraries of subsystem models to promote parallel development & maximise reuse of core assets.

• Appropriate SVN version control & standardised signal naming convention for project-wide collaboration.
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Model Structure

MATLAB/Simulink

Controller

Vehicle Supervisory Control Unit (VSC)

Thermal Management Control
APU Controller
Battery Management System
Motor/Generator Control Unit
Transmission Control Unit
Braking Control System

Plant

Dymola

Auxiliaries
Engine
Motor/Generator
Battery
Motor/Generator
Transmission
Differential
Friction Braking

Thermal Management Components

CarMaker (Optional)

Driver
Environment

Vehicle
Suspension & Tyres

Bus message
Electrical connection
Signals (sensor, control)
Mechanical connection
Thermal connection
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Model Structure

Framework includes three top-level implementations constructed from a single library of subsystem components.

1. Simulink Longitudinal
   - Simulink based control models + embedded Dymola powertrain model.
   - Example use cases – fuel efficiency studies, controller development etc.

2. Dymola Standalone
   - Basic control functionality + drive cycle implemented in standalone Dymola model.
   - Example use cases – HV electrical transients, vehicle dynamics etc.

3. CarMaker
   - Example use cases – vehicle dynamics, HIL simulation + failsafe tester etc.
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Model Structure – Control Architecture

- Control architecture based on JLR Vehicle Model Architecture (VMA).
- Subsystems modularised according to workstream activities & vehicle ECU deployment.

- Dymola powertrain integrated using standard Simulink s-function interface.
- Plant subsystems lumped to maintain acausal interactions between components.
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Model Structure – Plant Architecture

- Dymola HEV vehicle model architecture.
  > High & low voltage electrical networks.
  > Thermal interactions between subsystems.
- Object orientated structure.
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Model Structure – IPG CarMaker Integration

Complete powertrain model including plant & control integrated into CarMaker vehicle dynamics model via Simulink interface using DVA (Direct Variable Access).
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Model Structure – HIL Real-Time Environment

- Real-time simulation of LCVTP full vehicle model implemented on CarMaker XPack4 HIL Platform

- HIL platform used to prove capability of control algorithms & diagnostics to run in real-time on 32bit processor platform.
- Also used to study the impact of signal propagation delays over CAN & Flexray networks, & robustness to fault injection.
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Model Structure – HIL Real-Time Environment

- Complete powertrain model, including plant & control, integrated into CarMaker HIL model.
- Executed on IPG XPack4 real-time computer.
- Specific controllers split out onto independent ECUs.
Objective: To support the evaluation & development of integrated control systems associated with advanced regenerative braking.

- Competing electro-hydraulic braking systems.
  - Impact of brake system configuration on potential energy recovery & overall braking performance.

- Control strategy (interaction with ABS).
  - Immediate vs. blended termination of regen in response to stability event.

- Control architecture.
  - Impact of specific ECU deployment & latency signal propagation delays.
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Example Use Cases – Regenerative Braking

Vehicle-level model based testing performed using medium fidelity powertrain subsystem models & CarMaker/Simulink interface.

- 1st order hydraulic brake models implemented in Dymola incl. Electro-hydraulic regen brakes & ABS modulation.
  - Neglection of 2nd order characteristics.
  - Incompressible hydraulic fluid.
  - Lumped compliance for pipes, pads & callipers.
  - Linearisation of discontinuities.
- Suitable for real time application.
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Example Use Cases – Regenerative Braking

Control Architecture Case Study:

• BTAC – Brake Torque Apportionment Controller responsible for arbitration of friction & e-machine braking torques for a given driver demand.
  
  • Design consideration: communication network & critical deployment of key functions onto vehicle ECUs.
Front axle regenerative braking with handover to friction braking at <35kph
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Example Use Cases – Regenerative Braking

Impact of signal propagation delays due to varying CAN message cycle times.
Standard foundation brake system response to high-low grip event with & without ABS.
Impact of regenerative braking with varying control architecture & transit delays.
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Conclusions

• Hybrid-electric vehicle systems are inherently multi-physical & require a more integrated systems approach to model based development.

• A vehicle systems simulation platform has been developed as part of the LCVTP to support integrated systems modelling activities across a range of different technology areas.

• Through the substitution of analogous library models with varying levels of functionality & fidelity, an array of diverse use cases may be addressed.

• IPG CarMaker & XPack4 have used in conjunction with MATLAB/Simulink & Dymola physical modelling package for HEV control development.

• For more information on the project see:
  http://www2.warwick.ac.uk/fac/sci/wmg/research/lcvtp