



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

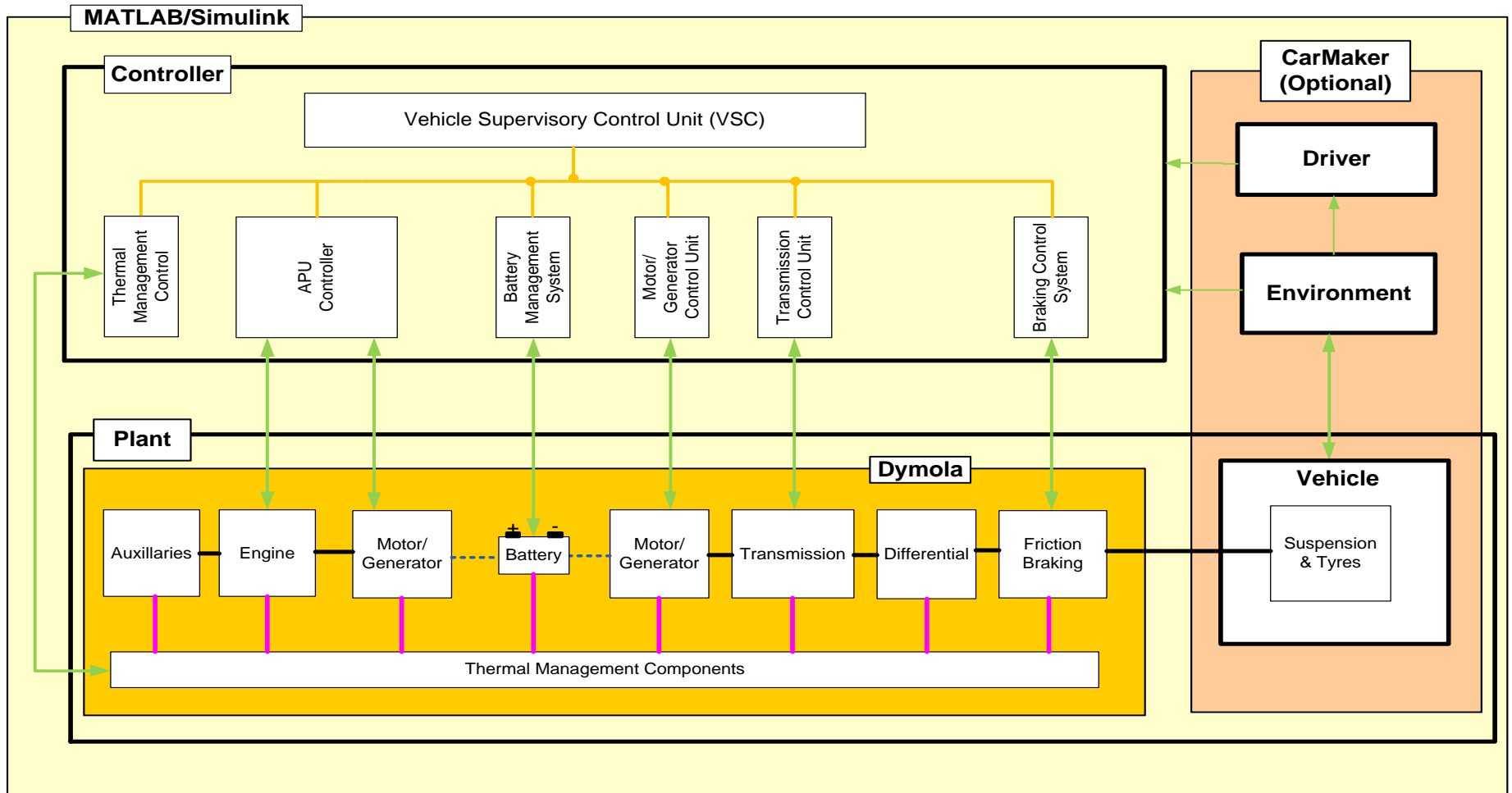
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LCVTP Systems Model Framework

- 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.

- LCVTP model framework extended from WARPSTAR 2+ longitudinal forward dynamic hybrid vehicle model framework.
- Vehicle level models to be derived from standard libraries of subsystem models to promote parallel development & maximise reuse of core functions.
- SVN version control & standardised signal naming convention for project-wide collaboration.
- 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.

Model Structure



Bus message



Electrical connection



Signals (sensor, control)



Mechanical connection



Thermal connection



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

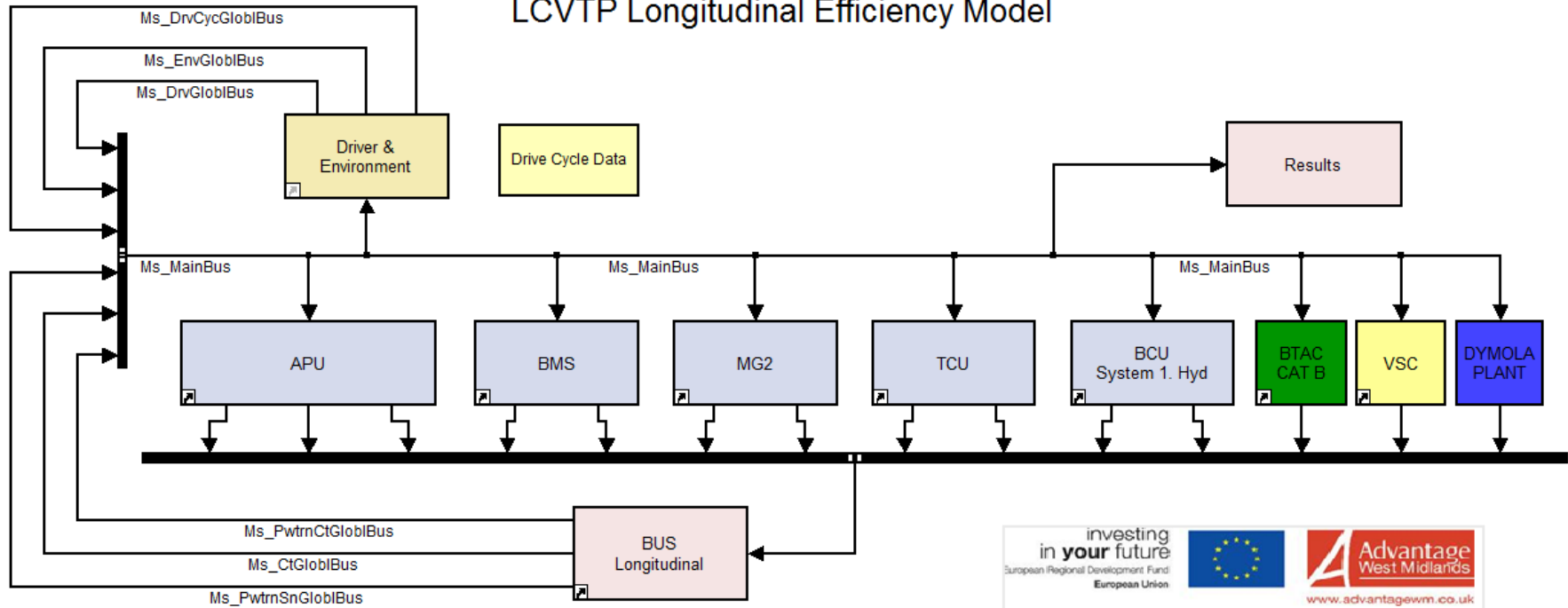
- CarMaker extension of Simulink longitudinal inc. CarMaker suspension & tyre models.
- Example use cases – vehicle dynamics, HIL simulation + failsafe tester etc.

- Platform primarily used for the development of vehicle control systems.
- Required to support MATLAB/Simulink derived controllers & appropriate translation for real-time simulation.
- Control signal architecture to support multi-level control hierarchy - i.e. interaction between vehicle supervisory & plant level control systems
 - > Communication signals representative of real world system for HIL/SIL analysis.
 - > Adoption of standardised naming convention - incl. clear differentiation of realistically measureable signals & additional model inputs/outputs required for analysis.

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Platform Requirements - Control

LCVTP Longitudinal Efficiency Model

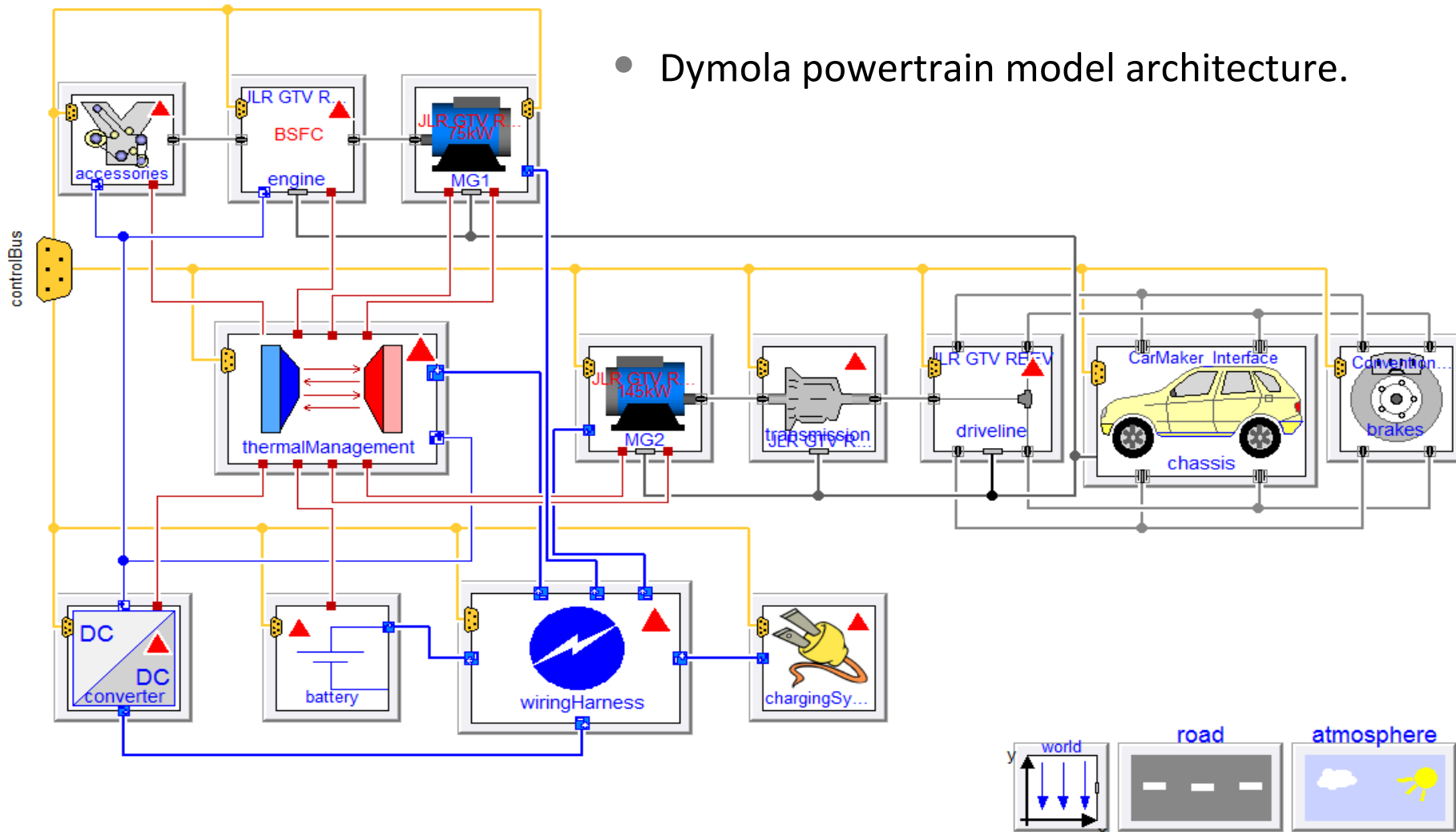


- Control architecture based on JLR Vehicle Model Architecture (VMA).
 - Plant subsystems lumped together to maintain acausal interactions between components.

- 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.

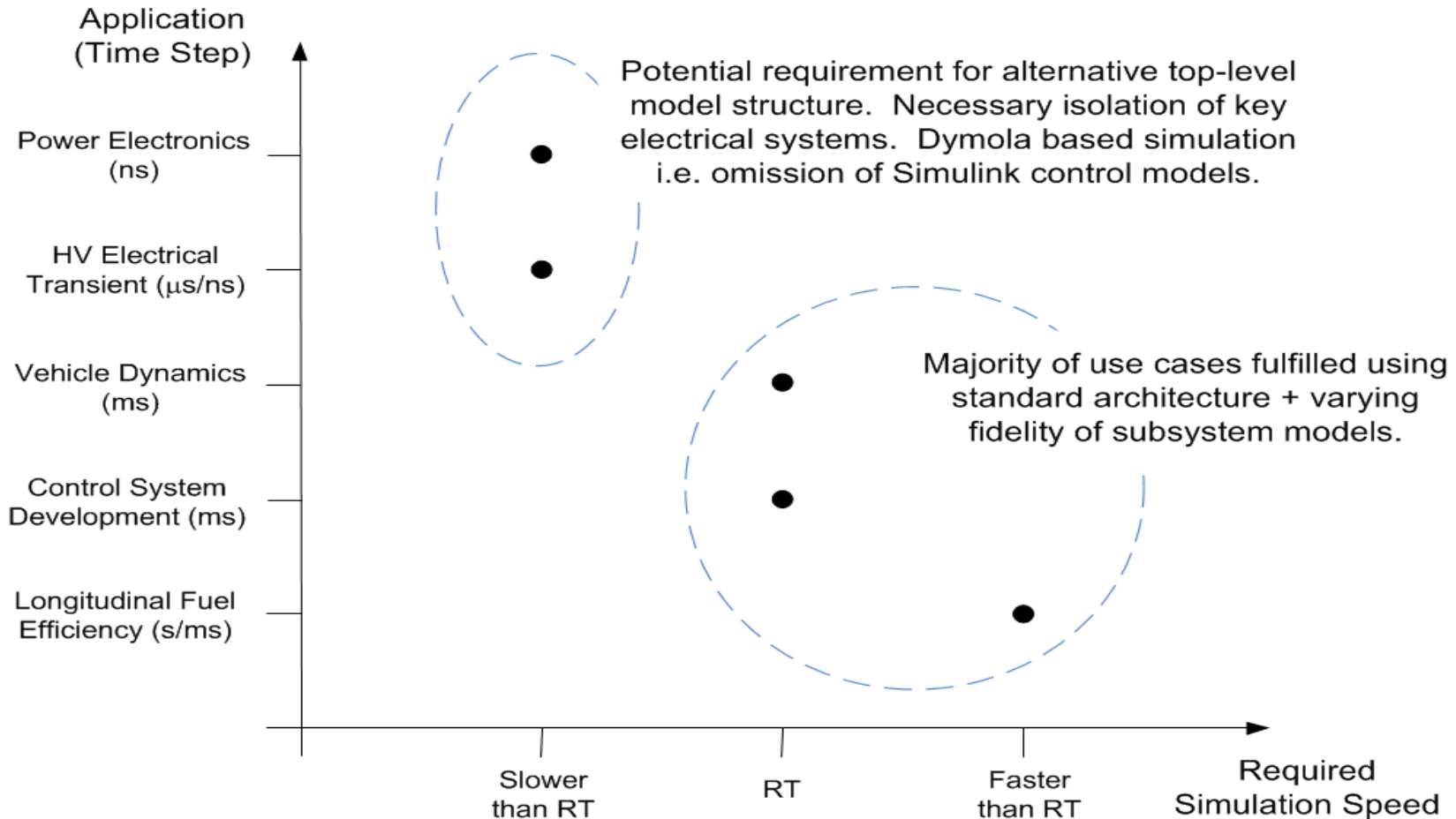
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Platform Requirements - Plant



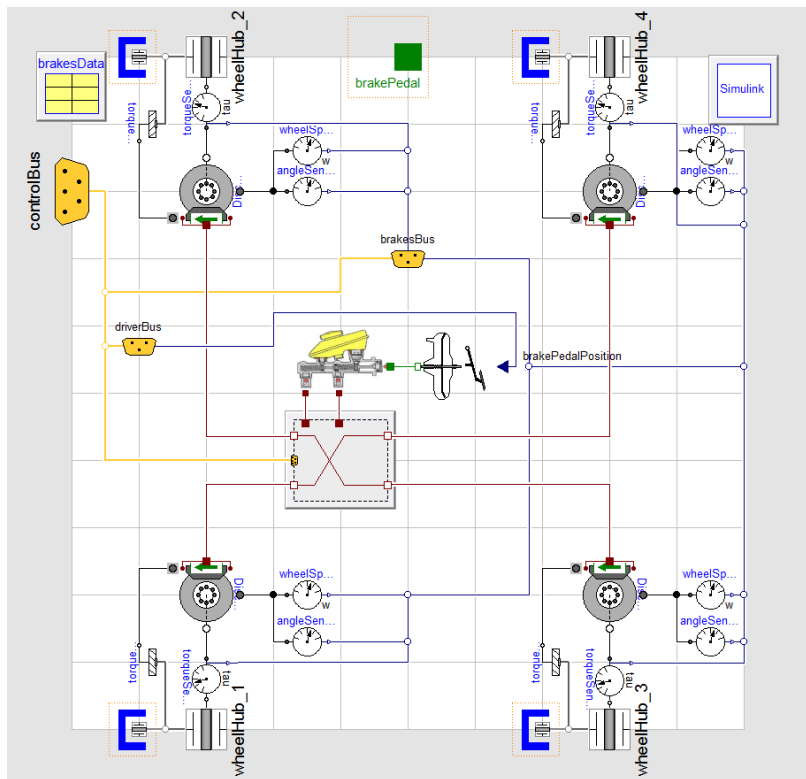
Platform Requirements - Subsystems

Model fidelity & simulation performance requirements



Example Use Cases – Regenerative Braking

- **Objective:** To support a comparative assessment of competing regenerative braking systems & corresponding control architecture.



- 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.
- Reduced models derived from more complex AmeSim hydraulic models.
- Suitable for real time application.


CarMaker

CarMaker 3.0.5

LCVTP - CarMaker Vehicle Dynamics JLR GTV REEV

Partial integration of WARPSTAR 2+ series electric hybrid architecture into CarMaker generic model.

CarMaker
Model
Configuration



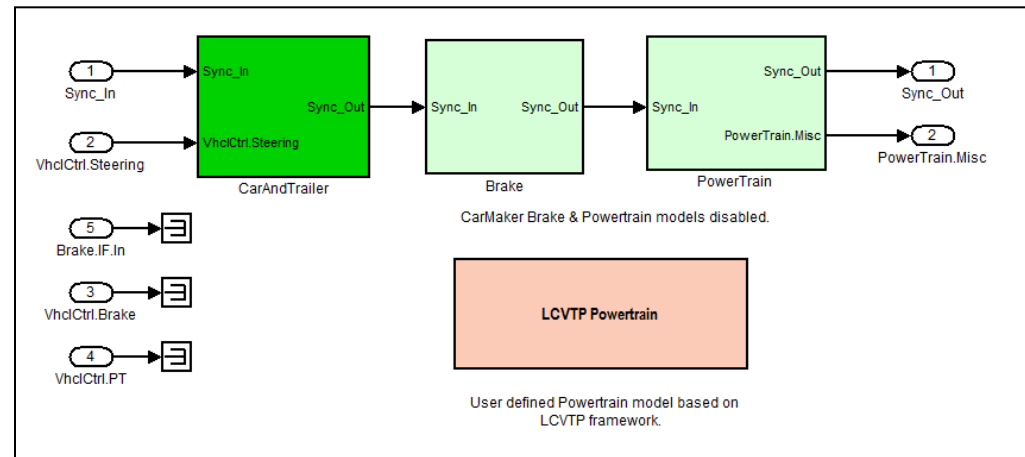
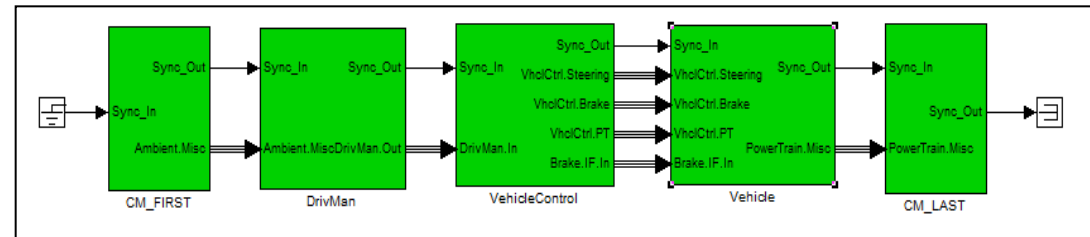
Simulation GUI

CarMaker

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- Complete powertrain model including plant & control integrated into parameterised CarMaker lateral vehicle dynamics model via Simulink interface.

Example Use Cases – Regenerative Braking

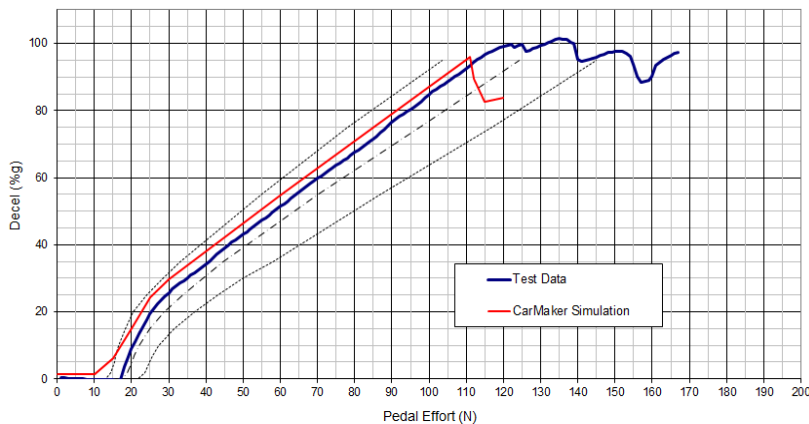
Application:

- To assess the efficacy of five competing EHB regenerative braking systems & corresponding control strategies on potential energy recovery & vehicle stability.



- To study the critical interactions between high & low level brakes control systems during ABS/ESP events.

Pedal Effort vs Deceleration



Example Use Cases – Control Development

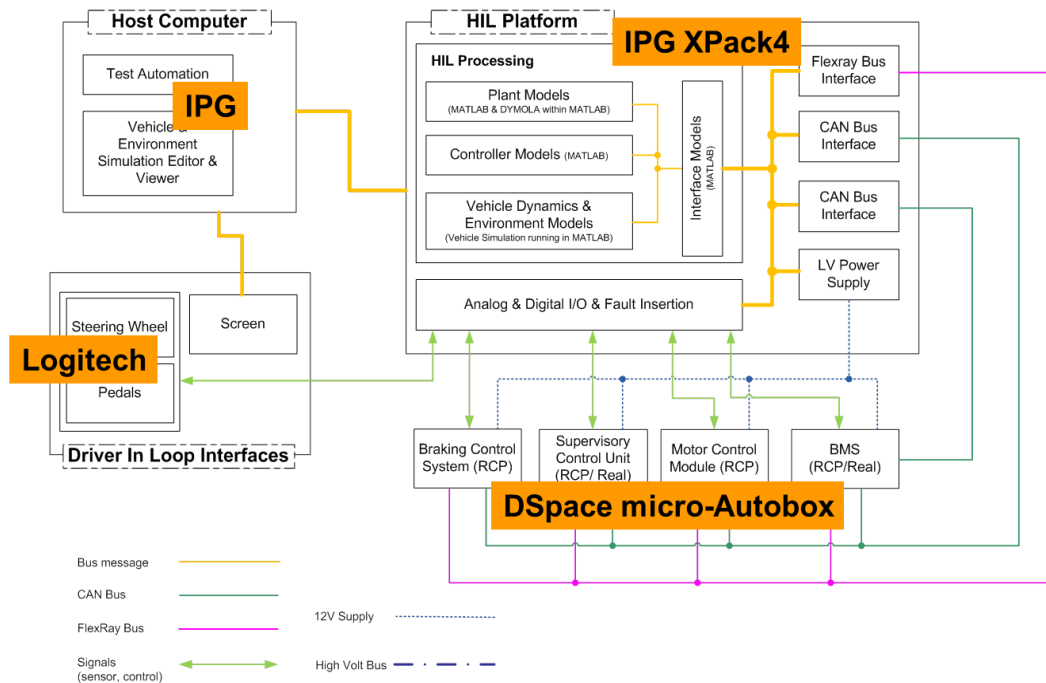
Objective: To support integrated development, optimisation & functional testing of vehicle supervisory control & thermal management systems in both office & HIL environments.

- Controllers integrated into longitudinal forward dynamic model based on low/medium fidelity, single-dimensional physical plant models.
- Comparative assessment of existing & novel control algorithms in terms of fuel consumption & CO₂ emissions etc. over extended drive cycles.
 - > Including quantitative evaluation of advanced functions such as predictive optimisation & on-board diagnostics.

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Example Use Cases – Control Development

- 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.
- Currently being used to study impact of signal propagation delay over CAN & Flexray networks, & robustness to fault injection.

Example Use Cases – HV Electrical Transients

Objective: To study HV electrical transient behaviour & the potential interactions between HV components such as cables, battery, drive motor & power electronics.

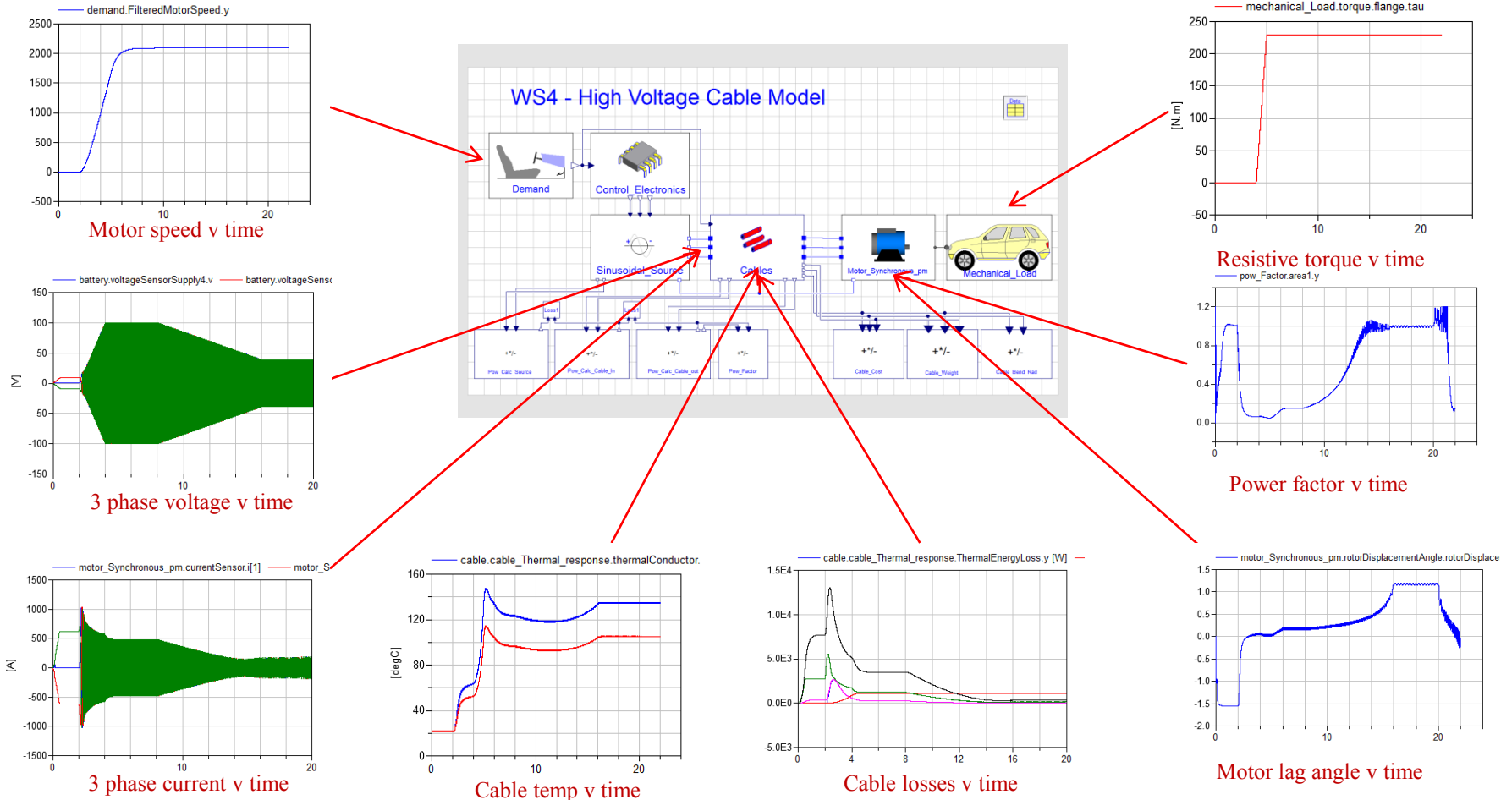
- Medium/high fidelity electrical & electro-mechanical subsystem models used to construct a high frequency coupled electrical system model in Dymola.
- Example: Coupled electro-mechanical model provides representative cable loading conditions.

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Example Use Cases – HV Electrical Transients

Model Outputs

- Example: Plots showing a typical 100kw 8pole pm synchronous motor ramping from 0 to 2000rpm.



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 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.
- For more information on example use cases (Vehicle Supervisory Control & Regenerative Braking) see the LCVTP dissemination event on 27th Oct.