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Electrified Powertrain Vehicle Simulation in Simulink

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Models == Understanding
Model-Based Design

Systematic use of models throughout the development process

Modeling

Simulation

Automation

Coding

Verification

Fast repeatable tests

Fast agile development loops
Electric Vehicle Example

- **3-Motors Architecture**
  - Rear: 2 x 40kW Motor
  - Front: 60kW Motor
  - 50kW-hr battery

- **Torque Vectoring Capability**
  - Independent dual motors

- **Use Model-Based Design to**
  - Assess performance
  - Develop control algorithms
  - Visualize and test
  - Deploy to hardware
Model Use Cases Across the V-cycle

EV Design Exploration/Component Sizing

Control Design

Subsystem Design

Drivability Validation

PIL Testing

HIL Testing
Electric Vehicle Energy Management Strategy & Performance Simulation
Powertrain Blockset Features

Library of blocks

- Energy Storage and Auxiliary Drive
- Drivetrain
- Propulsion
- Transmission
- Vehicle Dynamics
- Vehicle Scenario Builder

Pre-built reference applications
EV Energy Management Strategy (EMS)

- Instantaneous torque (or power) command to actuators (electric machines)

- Subject to constraints:

\[
\tau_{\text{min}}(\omega) \leq \tau_{\text{act}} \leq \tau_{\text{max}}(\omega) \\
P_{\text{chg}}(\text{SOC}) \leq P_{\text{batt}} \leq P_{\text{disch}}(\text{SOC}) \\
I_{\text{chg}}(\text{SOC}) \leq I_{\text{batt}} \leq I_{\text{disch}}(\text{SOC})
\]

- Attempt to minimize energy consumption, maintain drivability
**EV Energy Management Strategy (EMS) Process**

1. Create torque split vector

$$\begin{bmatrix} -\text{Min Rear Torque} \\ \vdots \\ +\text{Max Rear Torque} \end{bmatrix}$$

2. Check constraints, determine infeasible conditions

$$\tau_{\text{min}}(\omega) \leq \tau_{\text{act}} \leq \tau_{\text{max}}(\omega)$$

$$P_{\text{chg}}(SOC) \leq P_{\text{batt}} \leq P_{\text{disch}}(SOC)$$

$$I_{\text{chg}}(SOC) \leq I_{\text{batt}} \leq I_{\text{disch}}(SOC)$$

$$\tau_{\text{demand}} = \tau_{\text{front}} + \tau_{\text{rear}}$$

3. Calculate and minimize cost function (Battery Power)

$$\min_{\tau_{\text{rear}}} P_b(\tau_{\text{rear}})$$
EV Energy Management Strategy (EMS) Process
Optimizing Front and Rear Gear Ratios

- A pareto curve exists between energy usage and acceleration performance
- A cost function can be used to help determine the best set of ratios
- Higher weight towards system efficiency leads to lower overall gear ratios

\[
\min_{N_f, N_r} (0.55E_{FTP} + 0.45E_{HWY}) W_1 + W_2 (T_0 - 120KPH)
\]
Electric Vehicle Torque Vectoring Simulation

- 6-DOF Vehicle
- 2-DOF Tire + Brake
- Suspension
- Steering
Vehicle Dynamics Control – Torque Vectoring

Average Steer Angle

Tire Slip Angle = \frac{(a+b)r}{r}

\[ \text{Average Steer Angle} = \frac{a+b}{r} \]

Greater lateral acceleration with 8.7% less steering input

Longer linear tire slip angle region and 5.7% greater lateral acceleration

A Torque Vectoring Strategy for Improving the Performance of a Rear Wheel Drive Electric Vehicle

Jyotishman Ghosh, Andrea Tonoli, Nicola Amati
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Vehicle Dynamics Control – Torque Vectoring

Steering = 45° Right
WOT
Red = TV On
Blue = TV Off
Vehicle Model Simulation – Driver-in-the-Loop
Subsystem & Components Modeling
-- Motor / Motor Control

Different Fidelity of Motor Modeling:

- Map Based
- Detail Model (Inverter controller + nonlinear motor model)
- High Fidelity Model
  - FEA simulations
  - or dyno data used to obtain flux table
Subsystem & Components Modeling
-- Battery / BMS

Open circuit potential

Exponential relaxation

Instantaneous response

\[ E_{\text{m}} \]

\[ R_1 \]

\[ R_0 \]

\[ C_1 \]

\[ V_{\Omega} \]

\[ R_0 (\Omega) \]

\[ 5^\circ C \]

\[ 20^\circ C \]

\[ 40^\circ C \]

\[ R_1 (\Omega) \]

\[ C_1 (F) \]

\[ \text{SoC} \]

\[ \text{emf (V)} \]
Subsystem & Components Modeling
-- Cooling System (Battery/Electrical)

- Multi-physics model:
  *Moist Air – 2-Phase Fluid – Thermal Liquid*

- Thermal management algorithm design, power consumption estimate & component sizing

![Diagram of the Cooling System with labels for Air In, Air Out, Ref In, Ref Out, Coolant In, Coolant Out, Compressor, and Coolant Pump.]

*Auxiliary Power*

*p-h diagram for design & diagnostics*
Control Feature Testing and Validation
-- One-Pedal Control

- One Pedal algorithm allows for braking behavior with only pedal actuation
- Zone calibration effects drivability behavior and “Fun To Drive” characteristics
Processor –in-the-Loop (PIL) Simulation
NXP + MathWorks Collaboration Demo
Processor –in-the-Loop (PIL) Simulation
NXP + MathWorks Collaboration Demo
Hardware-in-the-Loop (HIL) Simulation

11100101
CAN Cable

Speedgoat Hardware in-the-loop System

Embedded Controller Hardware

Target Computer Hardware

Speedgoat Rapid Control Prototyping System

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Summary

- EV Design Exploration/Component Sizing
- Control Design
- Subsystem Design
- Drivability Validation
- PIL Testing
- HIL Testing

Subsystem Design
Key Takeaways

Use Simulink based virtual vehicle capabilities to:

- Quantify tradeoffs between vehicle performance characteristics
- Develop and verify control features
- Verify detail components behavior and their affects in vehicle system
- PIL/HIL tests