System Integration of a Complete Electric Vehicle Power Train

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CAD  Physics Based Solvers  Embedded
Virtual Prototyping
Subassembly integration

ROM
Co-Simulation
Software integration
Fuel Consumption Model
Requirements
Fuel Consumption – Hybrid Model
Systems Modeling
Fuel Consumption Results

<table>
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Electric Machine Design

Losses:
- Eddy Current
- Core
- Winding

Resulting Temperature and Force

Input Results to Harmonic Solver
Reduce Order Model: Construction

Notice that the back electromotive force includes the $d\theta/dt$ components.
More accurate: Maxwell – Simploter Transient Coupling

- Detailed evaluation of torque ripple
- Evaluation of core loss and eddy current loss
- Evaluation of current ripple
- Direct coupling generation with finite element method Maxwell

Simulation of direct coupling with the finite element method (Maxwell). Coupling the back electromotive force using a voltage equation

Equivalent calculation time for FEM is required.
0D Approach: Electrical Circuit for Li-ion Battery: 1 Cell

Resistance and Capacitance is a function of Temperature and State Of Charge (SOC)

\[
\frac{d}{dt} \left[ \frac{SOC}{V_1} \right] = \begin{bmatrix} 0 & 0 \\ 0 & -\frac{1}{R_1C_1} \end{bmatrix} \begin{bmatrix} SOC \\ V_1 \end{bmatrix} + \begin{bmatrix} \frac{1}{Q} \\ -\frac{1}{C_1} \end{bmatrix} I(t)
\]

\[
V(t) = V_{OCV}(SOC) + V_1 - (R_s + R_{PTC}) I(t)
\]
CFD + Circuits

Systems Engineering
- Requirements Engineering
- System Integration & Test
  - Integrated Product Change Management

Baseline Design
- Setup
- Solution

Full Electric Drive
- Setup
- Solution

Hybrid ANSYS
- Setup
- Solution

Battery - CFD
- Setup
- Solution

Battery - ROM
- Setup
- Solution

Geometry
- Parameters
- Maxwell 3D Design

Maxwell 3D
- Geometry
- Setup
- Solution

Fluid Flow (FLUENT)
- Geometry
- Mesh
- Setup
- Solution
- Results
- Parameters

Static Structural
- Geometry
- Mesh
- Setup
- Solution
- Results
- Parameters

Battery - 3D ElectroChem
- Setup
- Solution

Parameter Set
Embedded Software

- Requirements Engineering
- Systems Engineering
- Validation & Verification

- Systems Modeling
- System Integration & Test

Integrated Product Change Management

Embedded Into Chip

C Code and/or VHDL

Graphical representation of control and drive cycle.
Full system
System Modeling with ROM Models
Fuel Consumption

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Graph showing fuel consumption over time for ICE Only, Hybrid, and Hybrid ROM.
Conclusion

Integrating product and software lifecycle management
Integrates teams, disciplines and workflows