HEV/EV systems consist of a variety of components.
Different physics interact with each other in one component
Different components interact with each other in a system
Rotor Loss in 3PH Induction Motor – Siemens

Motor with its cage removed

Simulated vs Measured Results

- 36 slot with cage
- 36 slot without cage
- 60 slot with cage

Maxwell Results with cage
Reduction in Magnet Loss for PMSM Motor – Siemens

- Permanent magnets located on spinning rotor
- Reduce eddy losses by cutting the magnets
- Need to find optimum number of axial cuts

Induced currents and eddy losses due to rotation
Reduction in Magnet Loss for PMSM Motor – Siemens

- For magnets, add cuts using insulation boundaries
- Same mesh re-used between cases
- Reduces Eddy Currents and Loss

![Normalized Power Loss](image)

- Bar chart showing normalized power loss for different numbers of cuts.
  - Number of cuts: 0, 1, 4, 8, 16
  - Normalized power loss values for each case.
OCV test data vs. Maxwell transient analysis
Skewed rotor

-20.0 -15.0 -10.0 -5.0 0.0 5.0 10.0 15.0 20.0
0.00 0.01 0.01 0.02 0.02 0.03 0.03
Time (s) Voltage (V)

Measured emf Calculated emf (maxwell)

0 1000 2000 3000 4000 5000 6000 7000
0 50 100 150 200 250 300 350
losses current generator mode calculated measured adjusted

Integrated Starter Alternators – Ford
Electrical Machine (Prius) – Electromagnetic and Thermal Coupling
High Power Inverter Systems

- 3d IGBT pack model and EM study
- Parasitic model extraction
- IGBT circuit model
- Far Field Study for Electric Field EM
High Power Inverter Systems

Current Distribution
IGBTs on, Diodes off

The structure is meshed using automatic and adaptive meshing.

Power Module from Q3D for board parasitics
Thermal Model Extraction for IGBTs

- Apply each heat source individually
- Measure temperature at nodes of interest (parametric analysis)
- Specify the geometry of the multi-heat-source system
- Transfer T(time) into Zth(time)
- Filter
- Normalize
- Extract parameters through curve fitting
- Generate model

Software tools:
- ANSYS Icepad
- Simplorer
Busbars – Electrical, Thermal, Structural Coupling

Current Density in Maxwell

Deformation in Mechanical

Temperature in FLUENT
Simulating Thermal Management of Battery Modules for the Propulsion of Hybrid Vehicles - Magna
Full Hybrid Electrical Vehicle Battery Pack System Design, CFD Simulation and Testing - Ford & Delphi

- Airflow path into the battery pack
- Airflow path and air outlet

The front view of the pack with the two bricks assembled and inlet busbar.

Velocity contour of airflow through the brick, inlet and outlet plenum.
Battery Electro-Thermo Modeling - NREL

Figure 4: 2001 module. Left: Voltage distribution in each cell. Right: Current density in the module; insert shows the highest current density through the weld junction.

Figure 5: Model predictions for 2001 module. Temperature distribution in the polypropylene case after the start of 100 A discharge.
Input with Variations
• Gap Thickness
• Cell Resistance
• Flow Rate

Outputs with variations
• Max temperature
• Differential temperature
• Pressure drop
Model Order Reduction for a Battery Module - GM

State space model gives the same results as CFD. State space model runs in less than 5 seconds while the CFD runs 2 hours on one single CPU.

A Battery Module Coupled Analysis

Voc=f(SOC, U1.Temp_block_1)
Newman Pseudo 2d Electrochemistry Model in Simplorer

- Electrochemical Kinetics
- Solid-State Li Transport
- Electrolytic Li Transport
- Charge Conservation/Transport
- (Thermal) Energy Conservation

\[ \frac{\partial (\varepsilon_c e_c)}{\partial t} = \nabla \cdot (D_e \nabla e_c) + \frac{1-t^+}{F} j^{Li} \]

\[ j^{Li} = a_z i_0 \left\{ \exp \left[ \frac{\alpha_c F}{RT} \eta \right] - \exp \left[ -\frac{\alpha_c F}{RT} \eta \right] \right\} \]
Newman Model – Quantitative Comparison

**Simplorer’s Results**

- $x = L_p + L_s + L_n$
- $x = L_p + L_s$
- $x = L_p$
- $x = 0$

**White’s Results**

3D Electrochemistry Modeling

Li concentration in electrodes during discharge
Single Battery Cell Thermal Model

The model is based on the work of:
- Newman & Tidemann (1993);
- Gu (1983);
- Kim et al (2008)*

\[ \nabla \cdot (\sigma \nabla \phi) = J \quad \text{Transfer current} \]

\[ J = Y (\phi_p - \phi_n - U) f(T) \]

U and Y are derived from experimentally obtained polarization curve, dependent on Depth of Discharge (DOD) & Temperature

\[ U = a_0 + a_1(DOD) + a_2(DOD)^2 + a_3(DOD)^3 \]
\[ Y = a_4 + a_5(DOD) + a_6(DOD)^2 \]

Results of a Prismatic Lithium-Ion Cell

Geometry & Mesh

Temperature

Current Density
From Electrochemistry to Single Cell Thermal Model

\[ \eta = (\phi_1 - \phi_2) - U \]

\[ I = k(c_1) \alpha (c_{max} - c_{min}) \alpha (c_{max}) \alpha \]

\[ \frac{\partial (\varepsilon c_1)}{\partial t} = \nabla \cdot (D \nabla c_1) + \frac{1-t^*}{F} j^\mu \]

\[ j^\mu = \sigma_i I_0 \left\{ \exp \left[ \frac{\alpha_x F}{RT} \eta \right] - \exp \left[ - \frac{\alpha_x F}{RT} \eta \right] \right\} \]

\[ U = a_0 + a_1(DOD) + a_2(DOD)^2 + a_3(DOD)^3 \]

\[ Y = a_4 + a_5(DOD) + a_6(DOD)^2 \]

Current vectors at Cathode plate: \( I_p \)

Current vectors at Anode plate: \( I_n \)

\( J = \text{Current Density} \quad J(t, x, y, T) \)
Simplorer FLUENT Co-Simulation

Simplorer Battery Circuit Model

Heat Dissipated

Temperature

FLUENT Battery CFD Model
Simplorer FLUENT Co-Simulation

Heat dissipation

Discharge curve

Simplorer Battery Circuit Model

Heat Dissipated

Temperature

Temperature

FLUENT Battery CFD Model
System Simulation Example

Model Extraction from FEM / CFD

Thermal Domain

Electrical Domain

Mechanical Domain

VHDL-AMS Macro-Model

IGBT Device Characterization
Conclusion

• ANSYS simulation tools have been widely used by our customers to design various HEV components. Some perform single physics analysis while others consider multiphysics.

• The interaction of different components can also be considered using ANSYS system tool Simpler. 
Thank you!!

Valued

YOU!

Customer

ANSYS
Simplorer System Model for Actuator Valve

**Electrical**
- EMF = 12.7V
- Ohm

**Magnetic**
- Ideal Limiter to stop spring and mass
- Mechanical Dynamics: Spring, Spacer, Damping, Mass

**Hydraulic**
- Pressure sources, Variable Orifice

**Forces**
- Orifice opening and fluid flow

- Coil Current
- Armature Position
- Curve Info: R1.1
- Curve Info: MASS_TRB1.S
- Orifice opening and fluid flow