Optimized Battery Management Solutions through Simulation

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Ansys

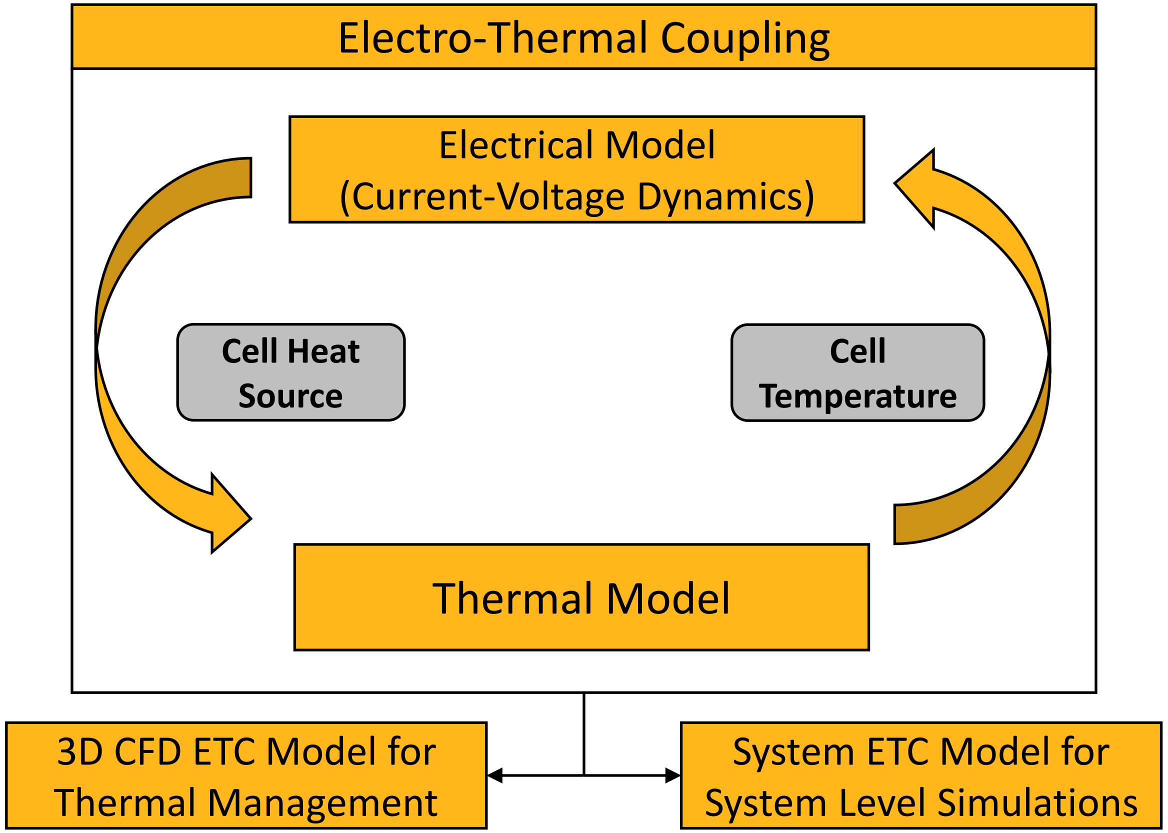
Agenda

- Thermal and electrical fields in a battery
- Deriving Reduced Order Models (ROM) from 3D field simulation
- Model based system engineering

What is an Electro-Thermal Coupling (ETC) Model?

- An electro-thermal coupled (ETC) battery model is a two-way coupled electric-thermal model to simulate the coupled electrical and thermal behavior of a battery module or pack.
  - CFD based ETC uses CFD as the thermal model.
  - System ETC uses thermal network or a ROM as the thermal model.

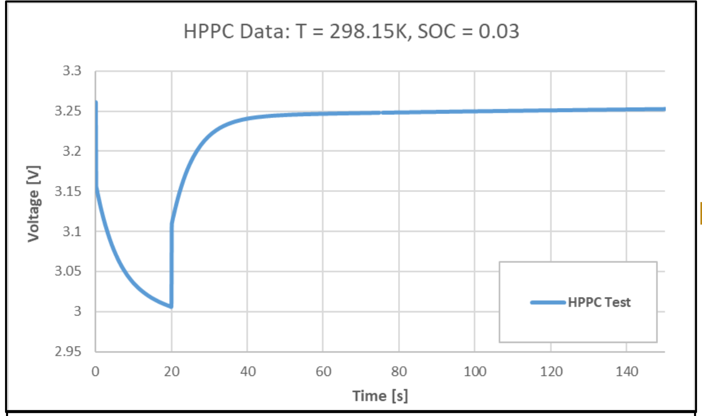
Many companies can do one of the two. And Ansys can perform both.



Electrical Modeling - Equivalent Circuit Model (ECM)

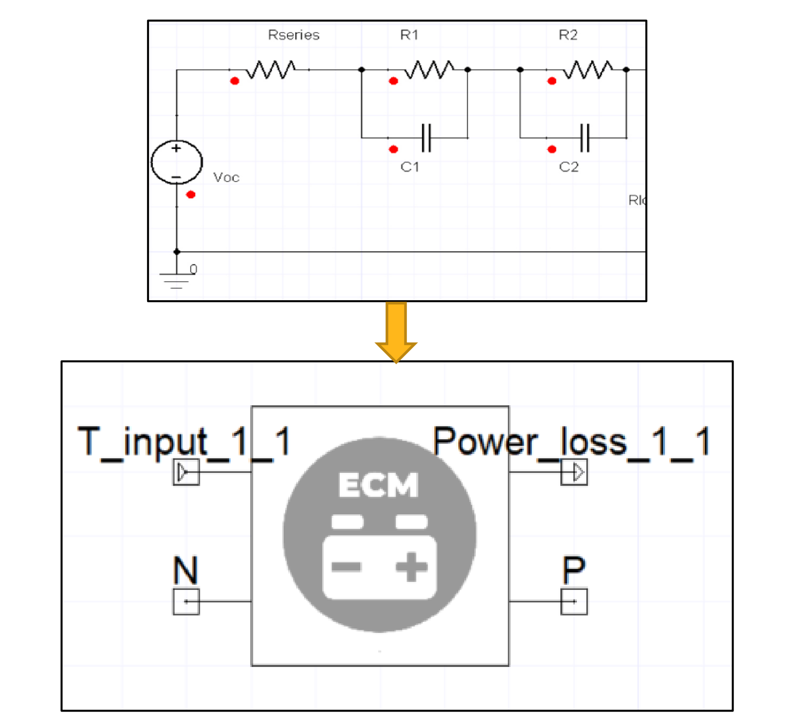
- Current Voltage dynamics of a cell or module can be modeled using Equivalent Circuit Model (ECM).

HPPC Test Data

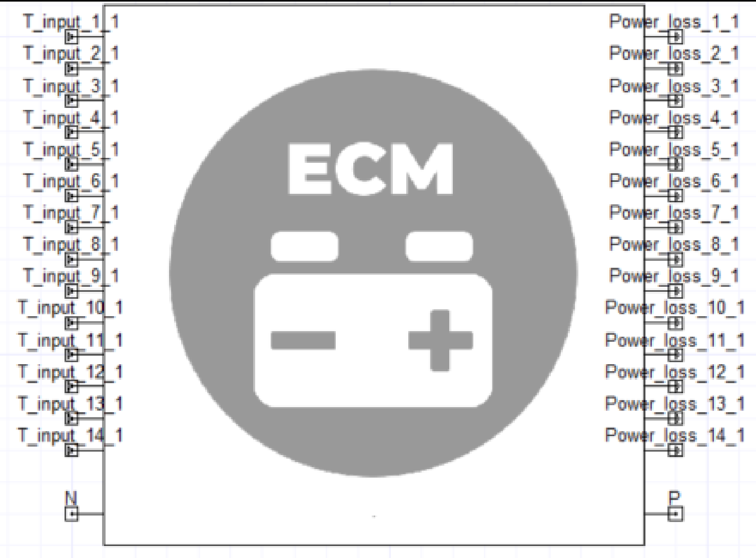


Pulse discharge applied to a cell to obtain voltage vs time HPPC curves.
Multiple HPPC curves at different temperature and SoC levels are used to create an ECM.

Cell Level ECM

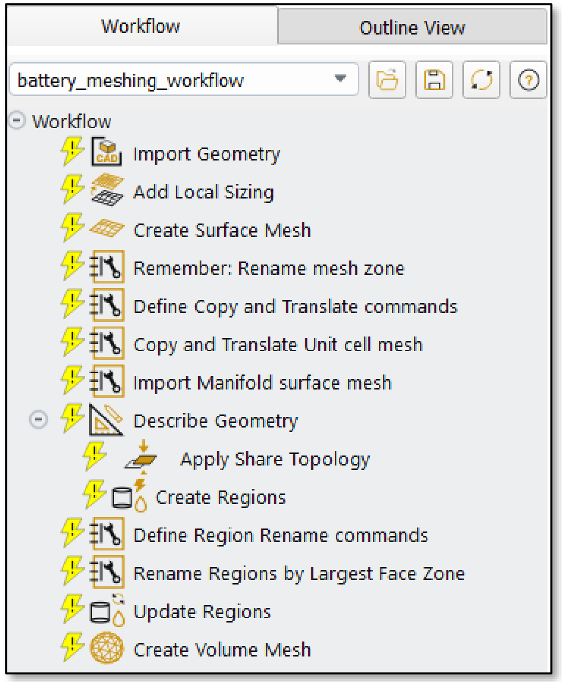


Module Level ECM

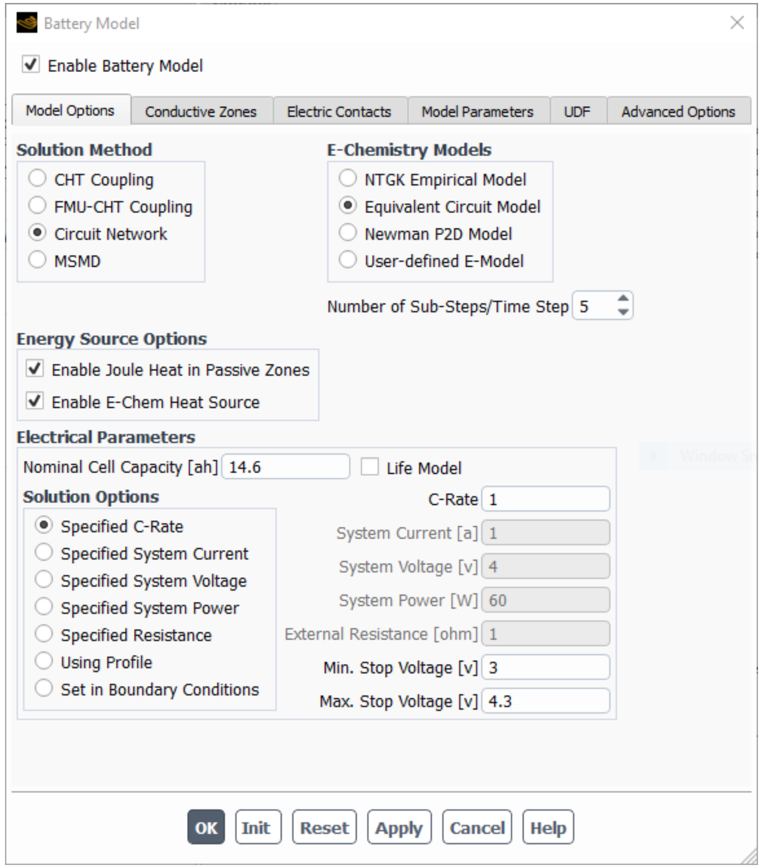


While many companies can create ECMs, Ansys accept customer ECMs through FMUs.

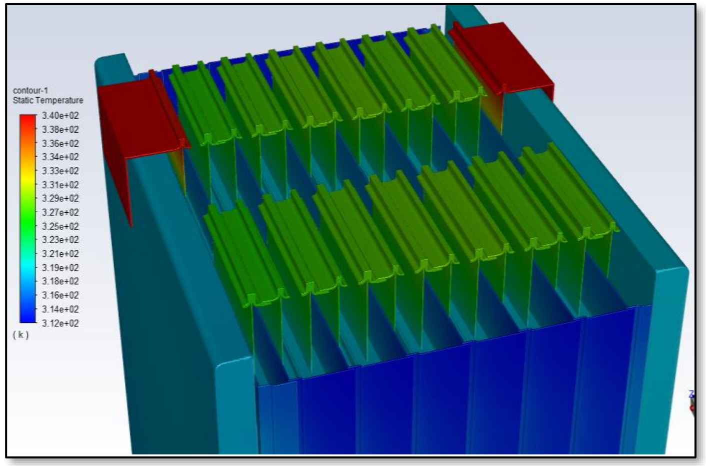
Thermal Model for CFD Based ETC – Full 3D CFD



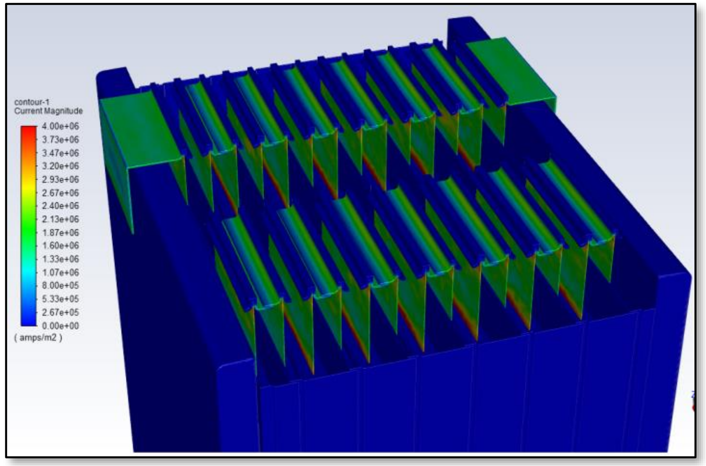
Fast Pre-Processing (Meshing Template)



Battery Model in Fluent



Temperature Contour



Current Density Contour

Both meshing and solver use Fluent -> Streamlined workflow

Agenda

- Thermal fields in a battery
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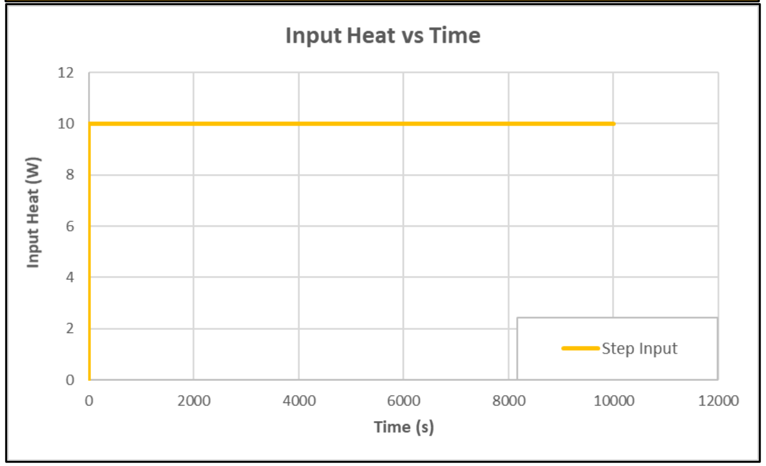
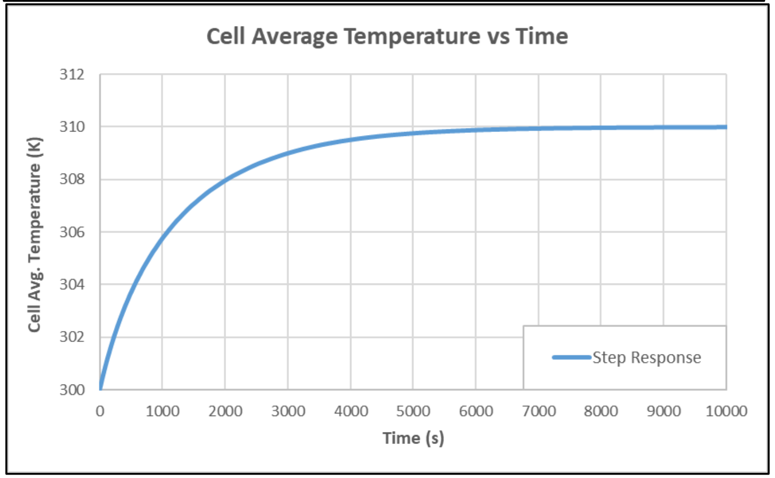
Thermal Model for System ETC - Reduced Order Model (ROM)

- Thermal Network approach – Need extensive tuning and calibration of thermal resistances and capacitances
- ROMs – More generic and easier to generate
- ROMs are created using training data from 3D CFD based ETC model

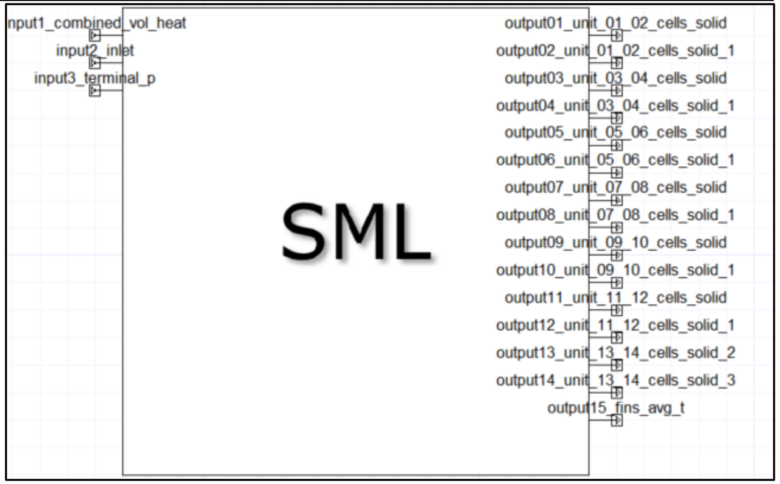
Step Input (Heat)



Step Response (Temperature vs Time)



ROM



Fluent

Twin Builder

ROMs are as accurate as CFD and 300x faster than a thermal network for a pack, reported by our customers.
ROMs are created from 3D CFD based ETC with only minutes of additional man hr.

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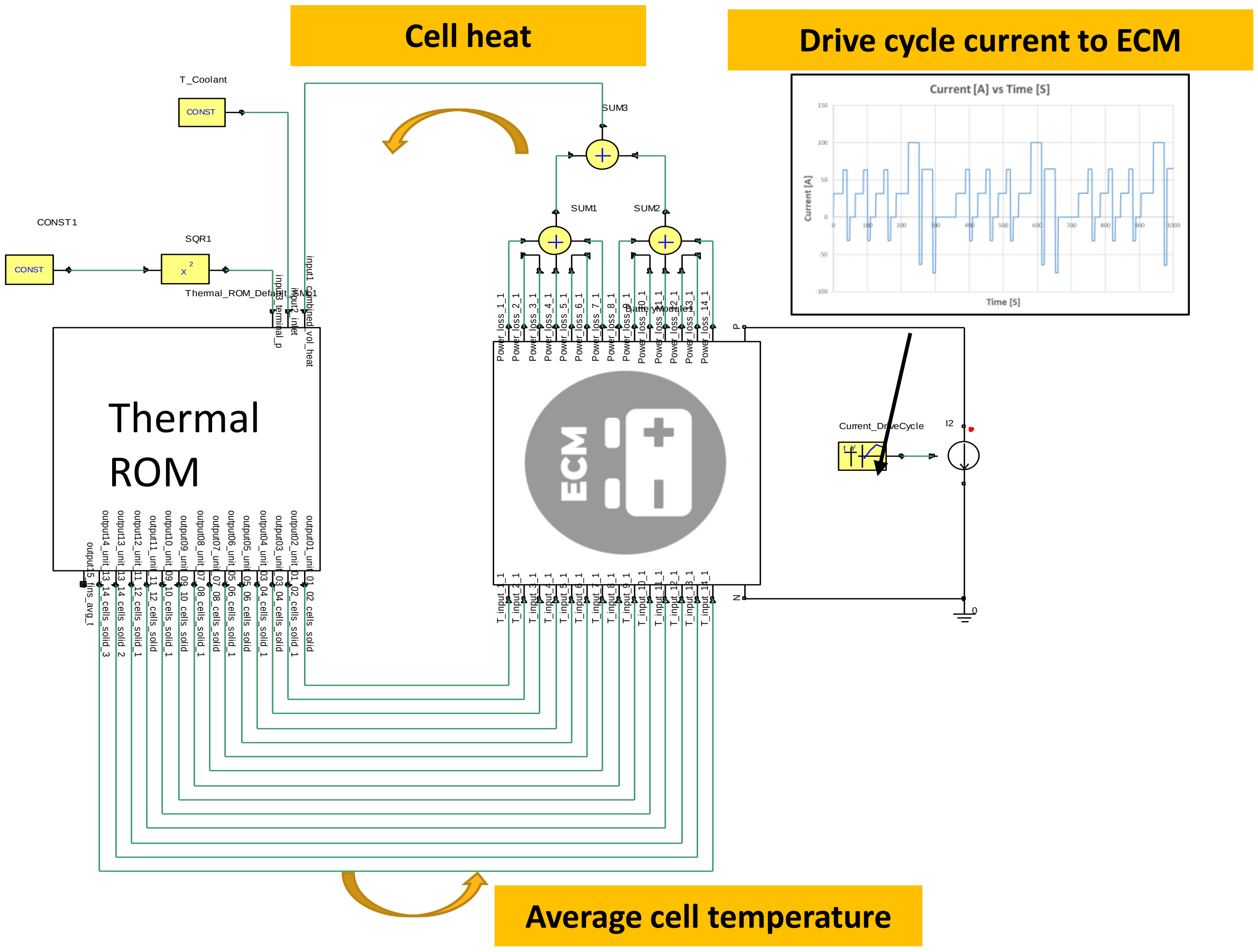
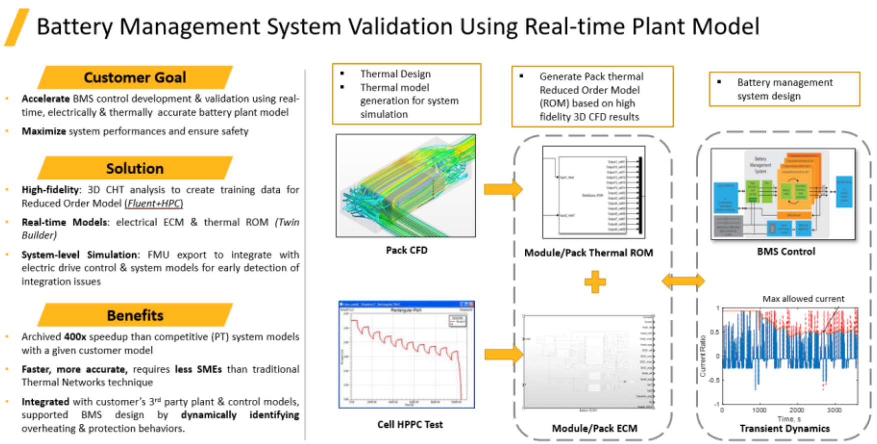
Coupling of ECM and ROM in Twin Builder

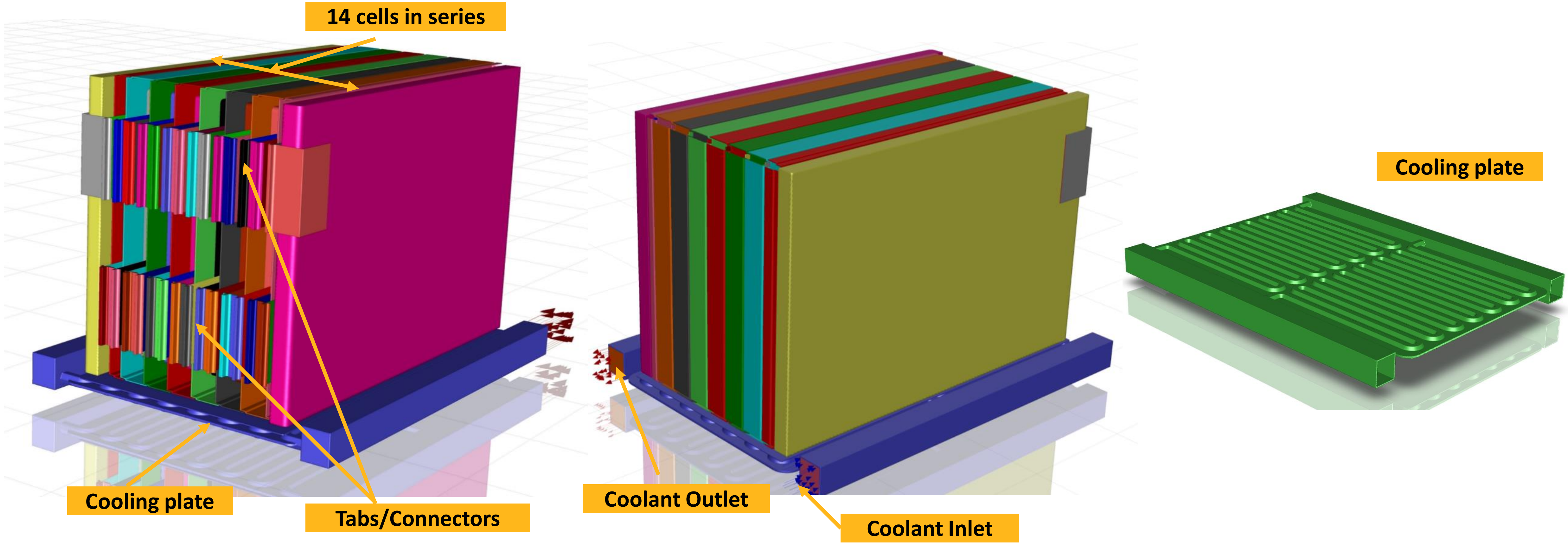


ROMs can be exported into any third-party system tool accepting FMUs, for instance GT suite and Simulink. Using ROM as a plant model for BMS is one main application.



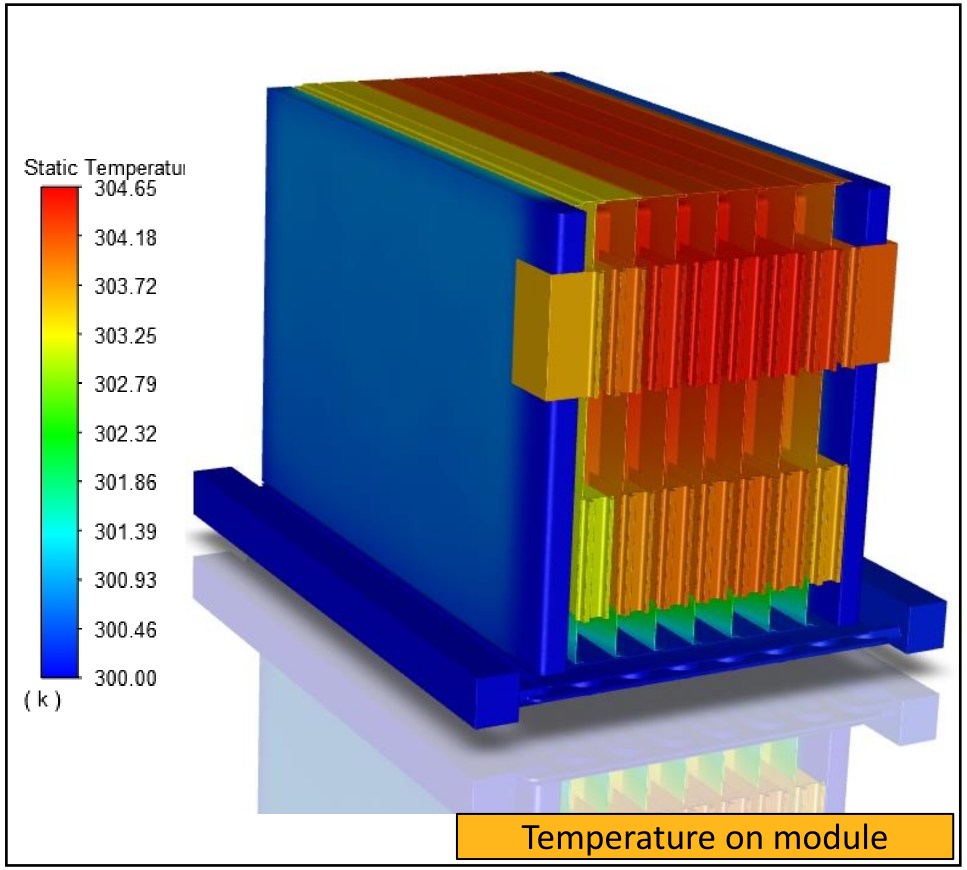
- Y. Liu, Xi Hu, W. Zhao, S. Zhang, "An Electro-thermal Coupled Battery Model for a 48V Li-on Battery Pack Using Reduced Order Thermal Model", battery conference 2021.

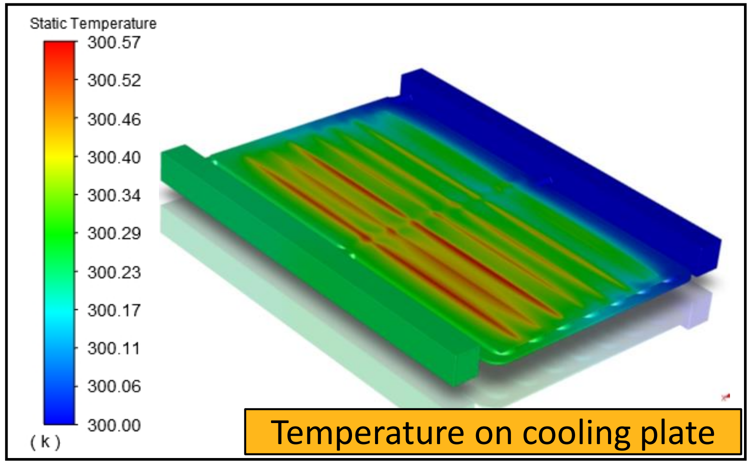
Validation of the Two ETC Models

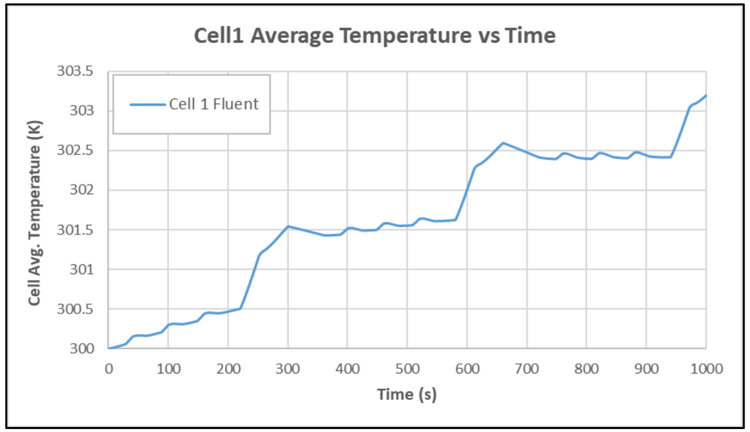


- Model used in this study consists of 14S1P configuration with tabs and busbars
- Water flows through cooling plate attached to the module
- Total mesh size ~ 6 Million cells

Results from 3D CFD Based ETC Model

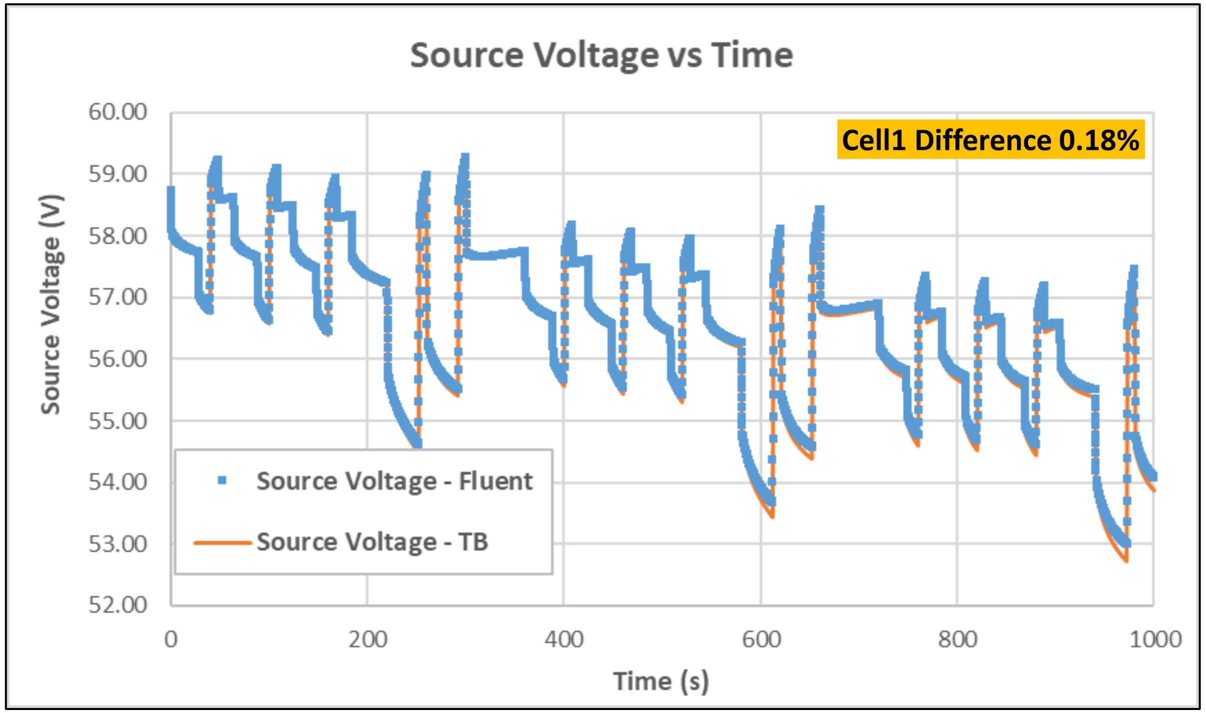


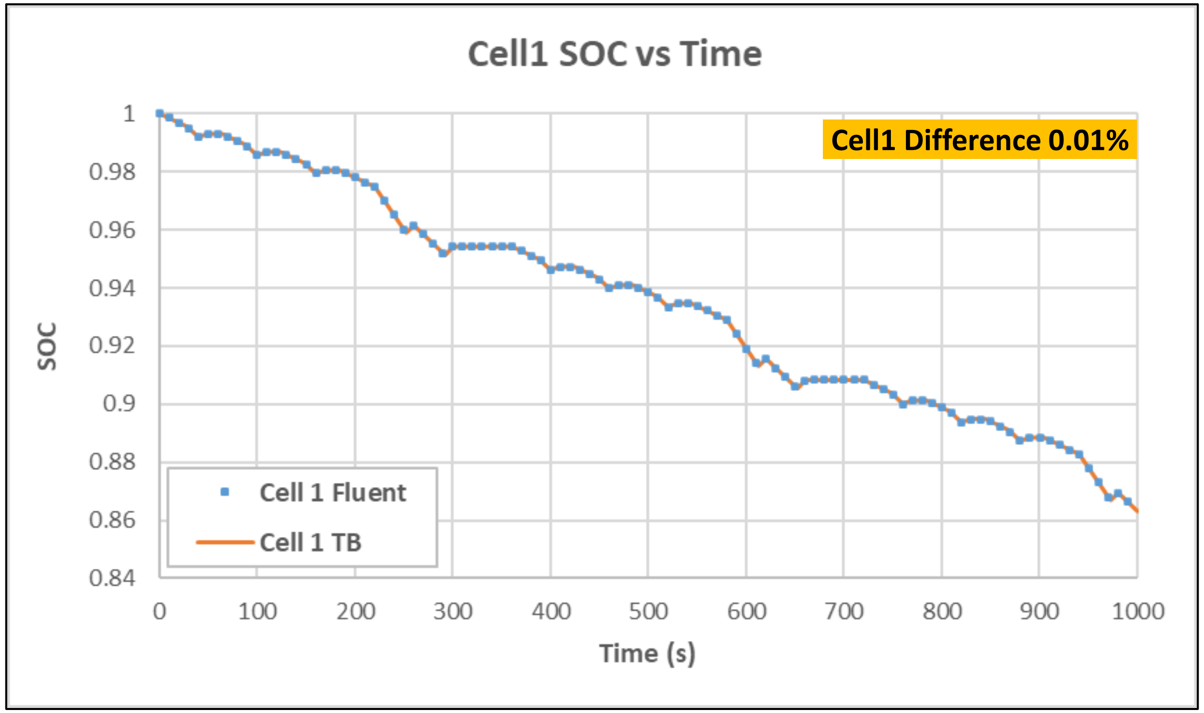




- CFD simulation for 1000s of physical time took approx. 1.5 days on 64 cores
- CFD generates a lot of high-fidelity data in 3D
- However, such high-fidelity data might not be required in system level simulations or while designing BMS

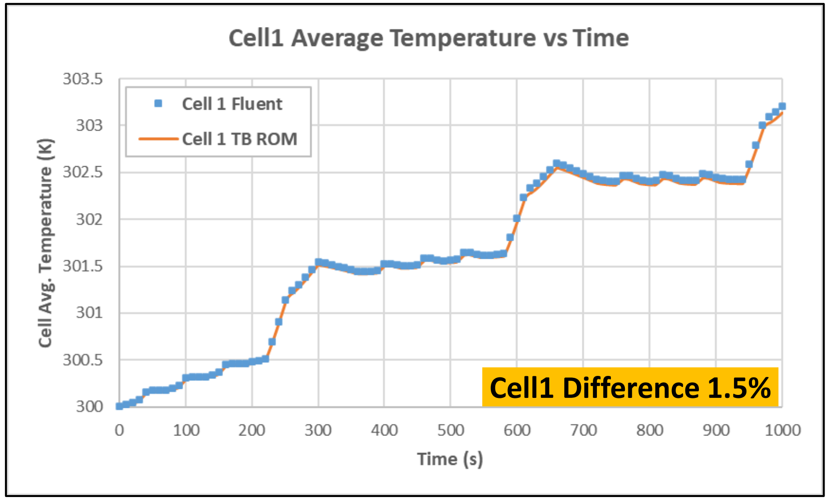
Comparison of Two ETC Model Results – Electrical Quantities

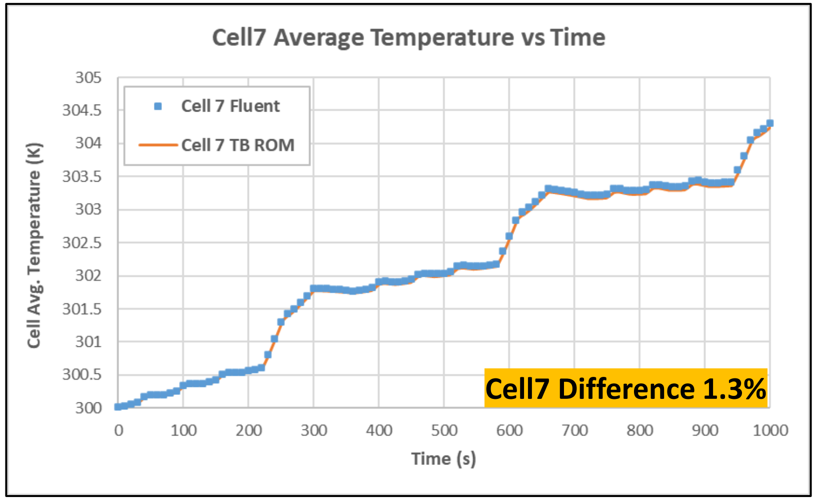


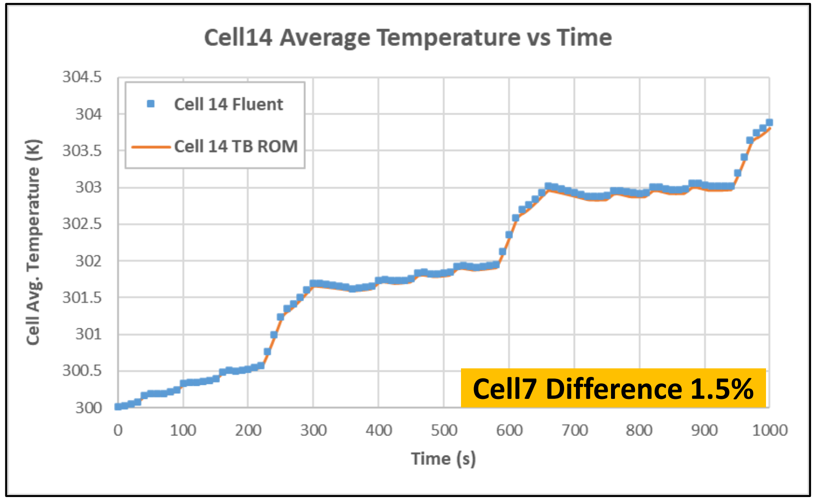


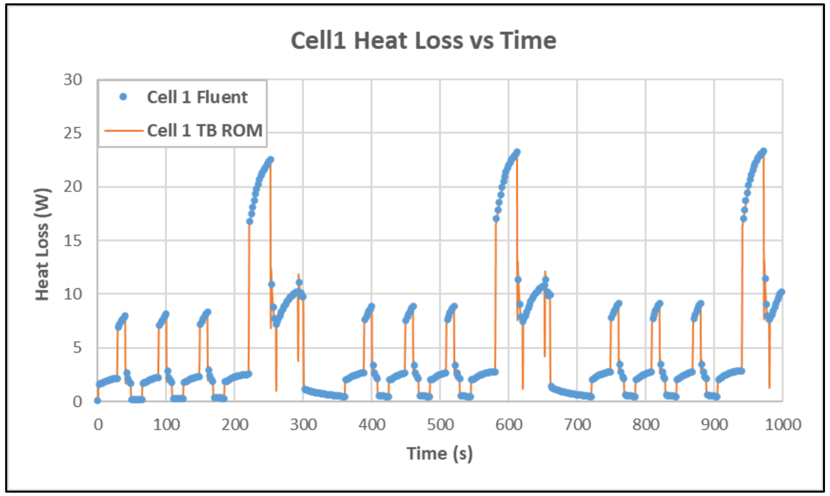
- Difference in source voltage by the two ETC models is within 0.18%
- Difference in SoC predicted by the two ETC models is within 0.01%

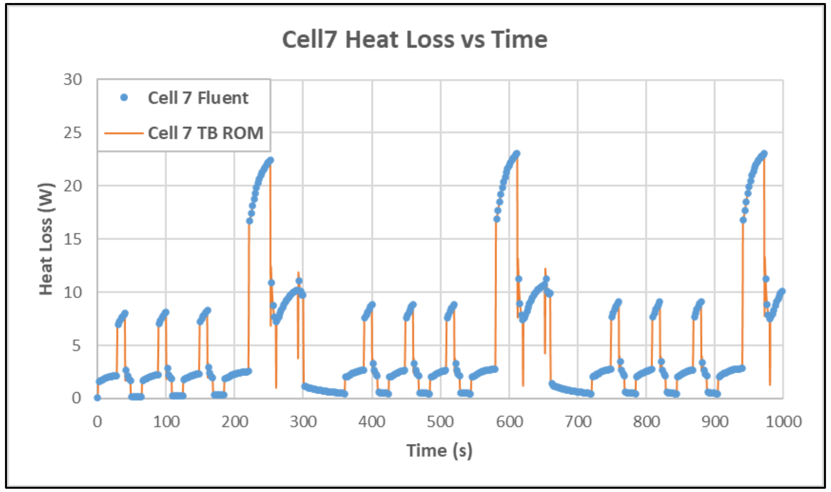
Comparison of Two ETC Model Results – Thermal Quantities

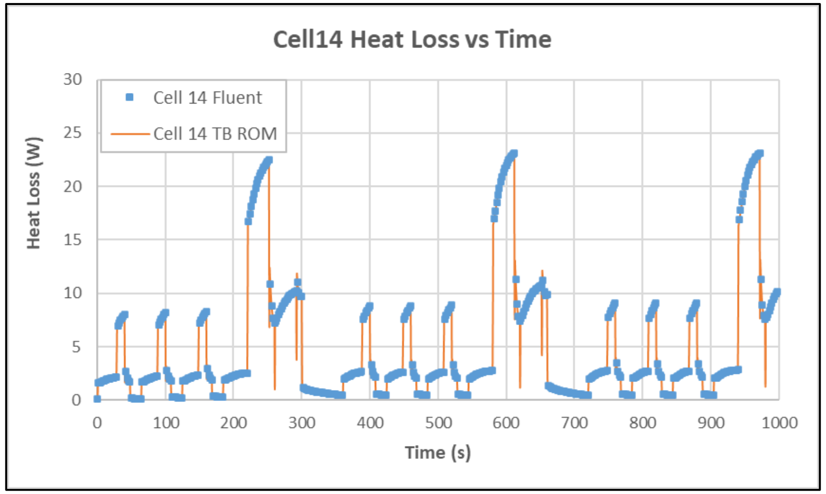










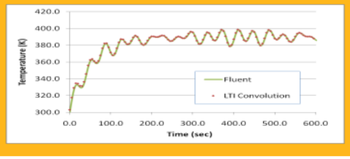


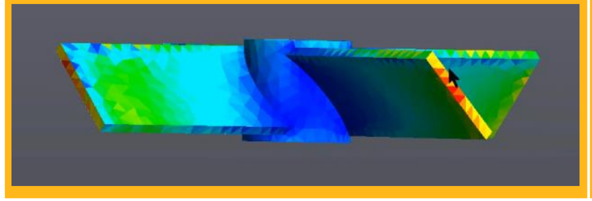
- Difference in temperature predicted by the two ETC models is within 1.5%

Performance Comparison

	3D CFD Based ETC	System ETC
# of cores	64	1
Total Time	36 hours	< 10 seconds
Available Results	3D as well as 2D data available	Average data at pre-specified locations

3D Matrix

	Linear	Non-Linear
Steady	WB Response Surface optiSLang MOP	
Transient	LTI-ROM	Dyna-ROM LPV-ROM

	Linear	Non-Linear
Steady	Static Rom Builder (WB ROM-Builder)	
Transient	SVD-ROM	Dyna-ROM for field data

Ansys
Home Matrix

Summary

- Fluent CHT simulations are more accurate than other vendors – reported by customers.
- With a battery 3d CFD based ETC model in Fluent, it takes only a few minutes of man hour plus required CPU time to create the thermal ROM.
- The ROM is many orders of magnitude faster than the CFD model.
- The ROM is as accurate as the 3d CFD.
- For a pack-level simulation, the Ansys ROMs are about 300x faster than a thermal network approach used by other vendors - reported by our customers.
- ROMs are used widely by our customers for applications that require real-time, for instance, BMS design.

- X. Hu, A. Kshatriya, X. Wang, B. Ahrenholz, and S. Folio, "A Thermal Electric Two-Way Coupled Battery Pack Model for an All Electric VW Motorsport Racer" SAE paper 2019-01-0593
- Y. Liu, Xi Hu, W. Zhao, S. Zhang, "An Electro-thermal Coupled Battery Model for a 48V Li-on Battery Pack Using Reduced Order Thermal Model", battery conference 2021.
- D. Guan, "BESS System Modeling Using Ansys", Ansys webinar 2021.

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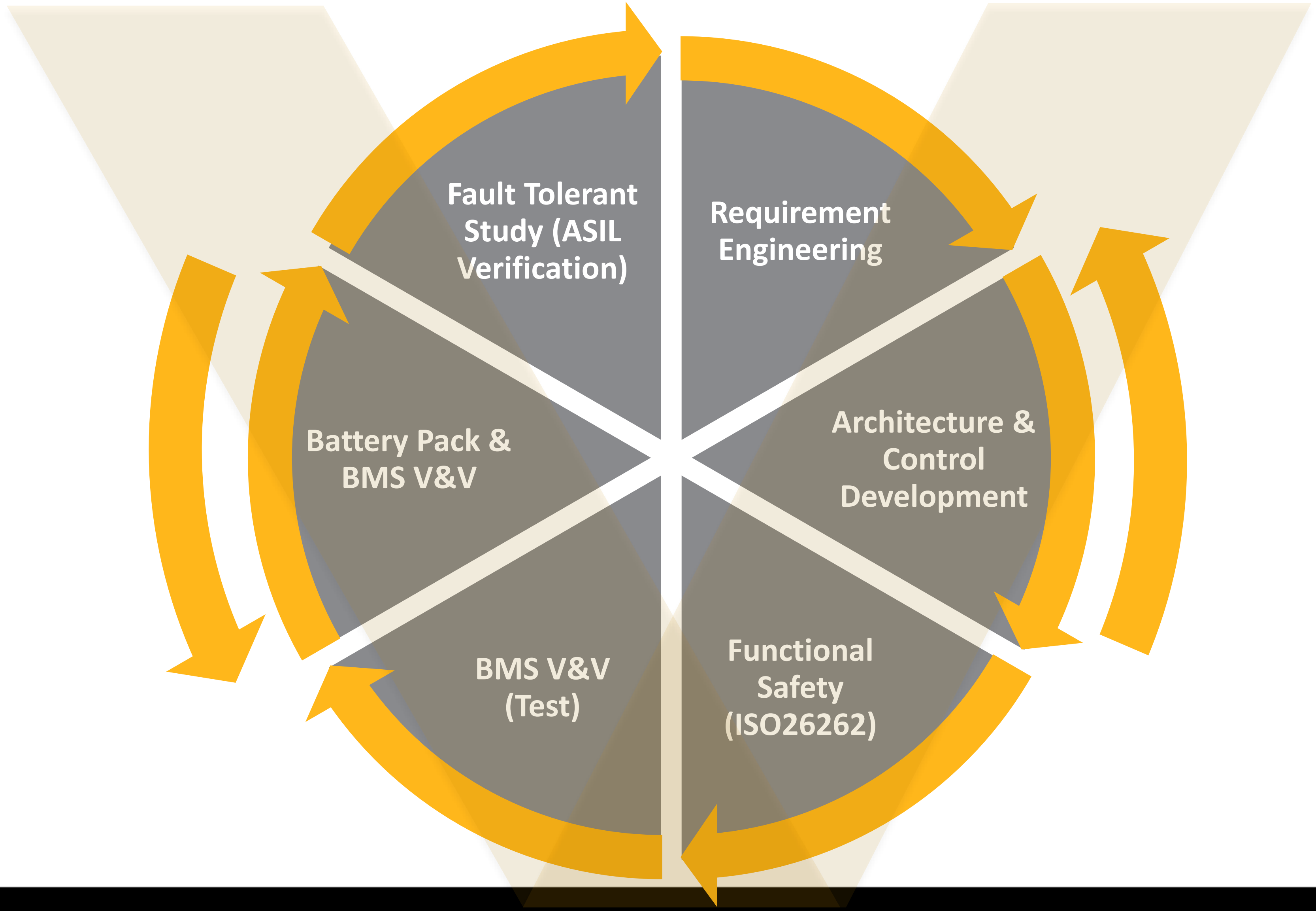
Ansys Solution on BMS



WHY? BMS Integration with Battery Pack

BMS Integration

- Virtual validation & verification of BMS code integrated with Battery pack

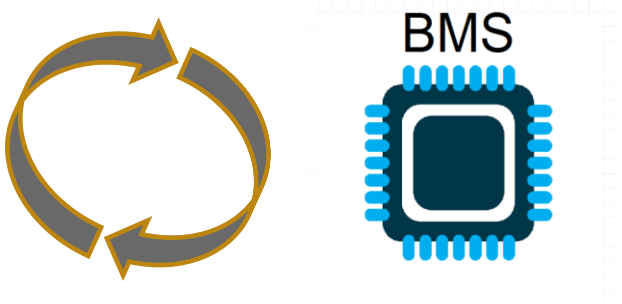
Breaking down silos by integrating the Battery pack with BMS

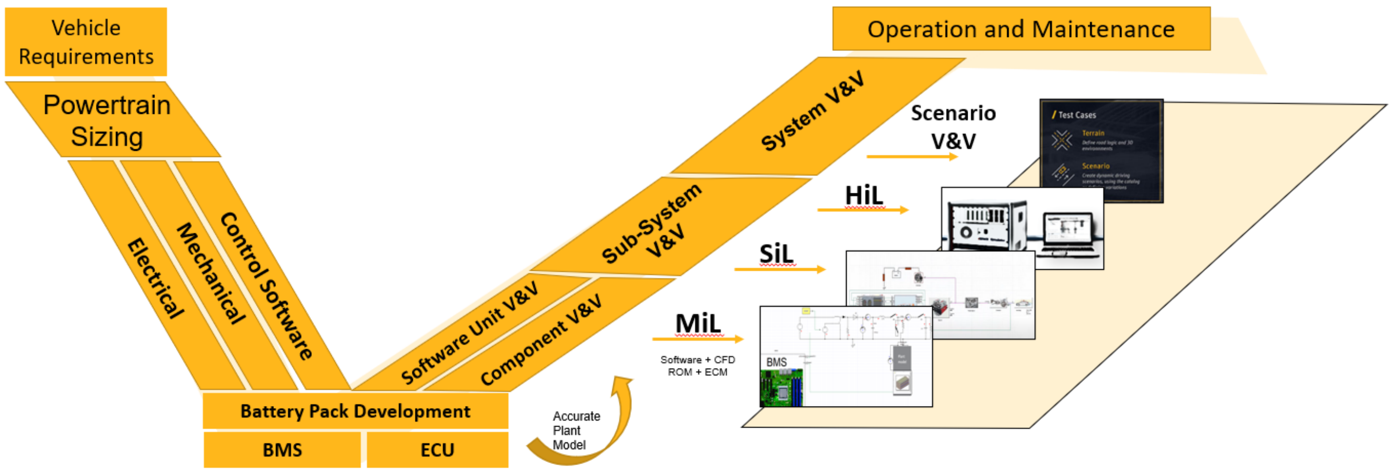
Ensure that BMS Code behaves as expected at system level along with Battery Pack

Optimize the Battery Pack cooling early in the product development stage with BMS integration

Compress the development cycle by early MiL and ensure SiL/HiL testing

Picture of a module





Integrating the High-Fidelity 3D Physics with BMS to simulate the entire Battery system

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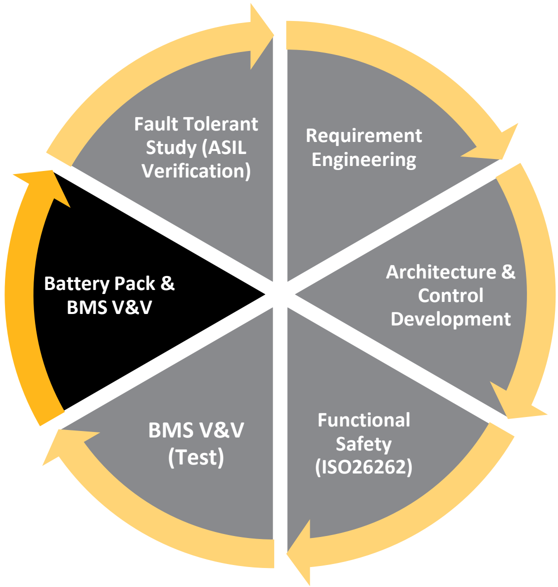
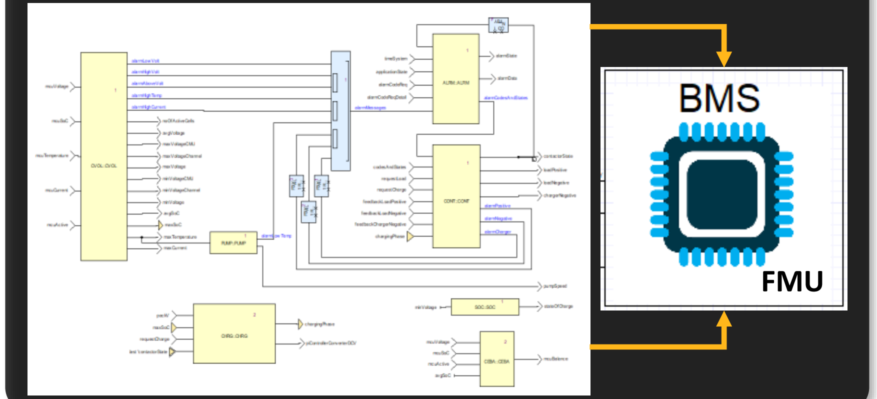
HOW?: Verifying BMS Controls with virtual Battery pack model



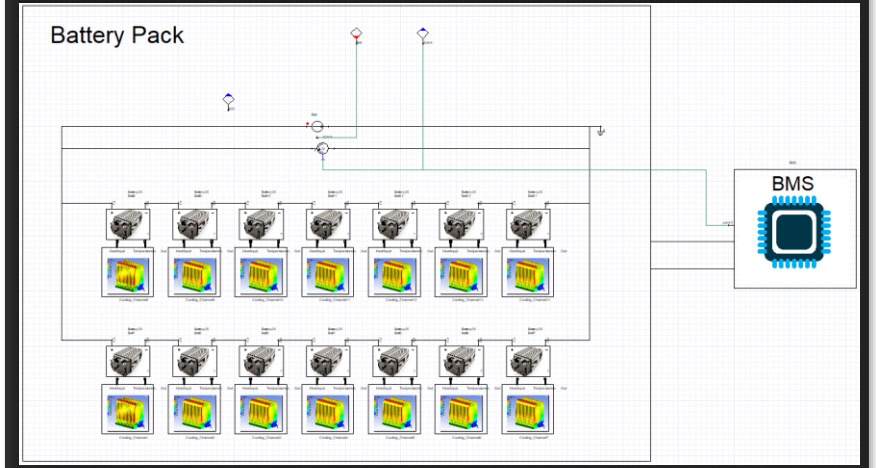
SCADE Suite

BMS Control Development



Twin Builder

Verification of BMS Controls with Battery Pack

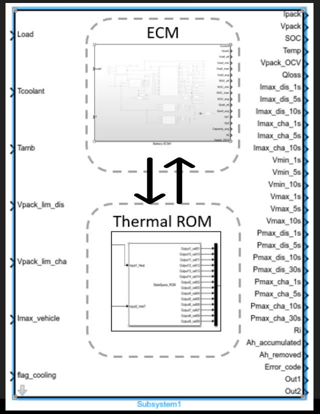


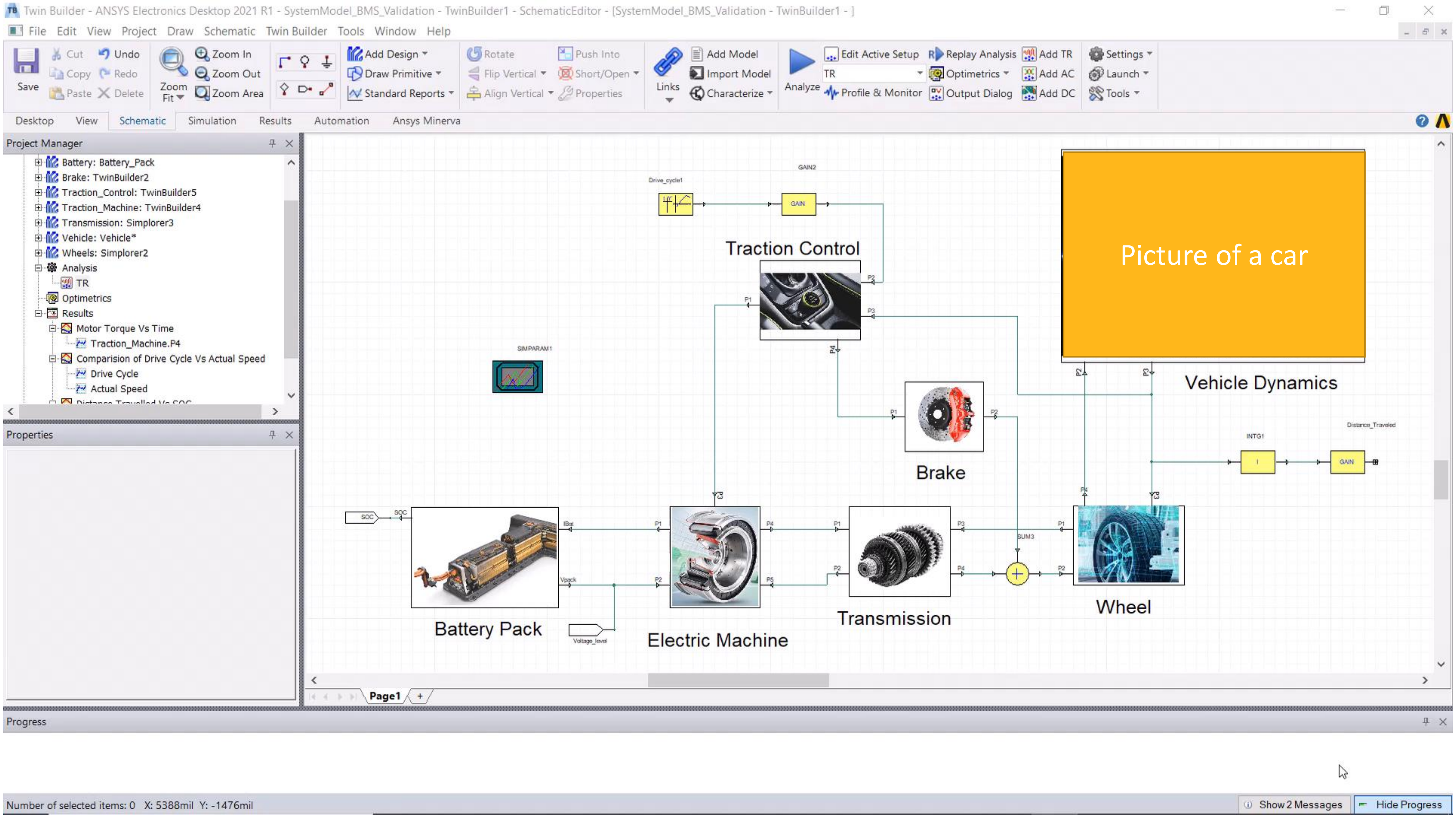
- *Integrating the BMS Model with Battery in TB environment.*
- *Understand how BMS Controls the battery pack behavior over a drive cycle.*
- *Understand the Battery thermal management from the CFD point of view.*

Ansys Fluent

Battery Pack Thermal Management

Picture of a module




Twin Builder - ANSYS Electronics Desktop 2021 R1 - SystemModel_BMS_Validation - TwinBuilder1 - SchematicEditor - [SystemModel_BMS_Validation - TwinBuilder1 -]
Project Manager
Battery: Battery_Pack
Brake: TwinBuilder2
Traction_Control: TwinBuilder5
Traction_Machine: TwinBuilder4
Transmission: Simplorer3
Vehicle: Vehicle*
Wheels: Simplorer2
Analysis
TR
Optimetrics
Results
Motor Torque Vs Time
Traction_Machine.P4
Comparision of Drive Cycle Vs Actual Speed
Drive Cycle
Actual Speed
Properties
Traction Control
Picture of a car
Vehicle Dynamics
Brake
Battery Pack
Electric Machine
Transmission
Wheel
Progress
Number of selected items: 0 X: 5388mil Y: -1476mil
Show 2 Messages
Hide Progress

Battery Management System Development

Customer Goal

- Develop a safety-driven control center that monitors the battery state (SoC, SoH), optimize the performances and ensure safety
- Comply with Safety Standards e.g. **ISO26262 (up-to ASIL D)**

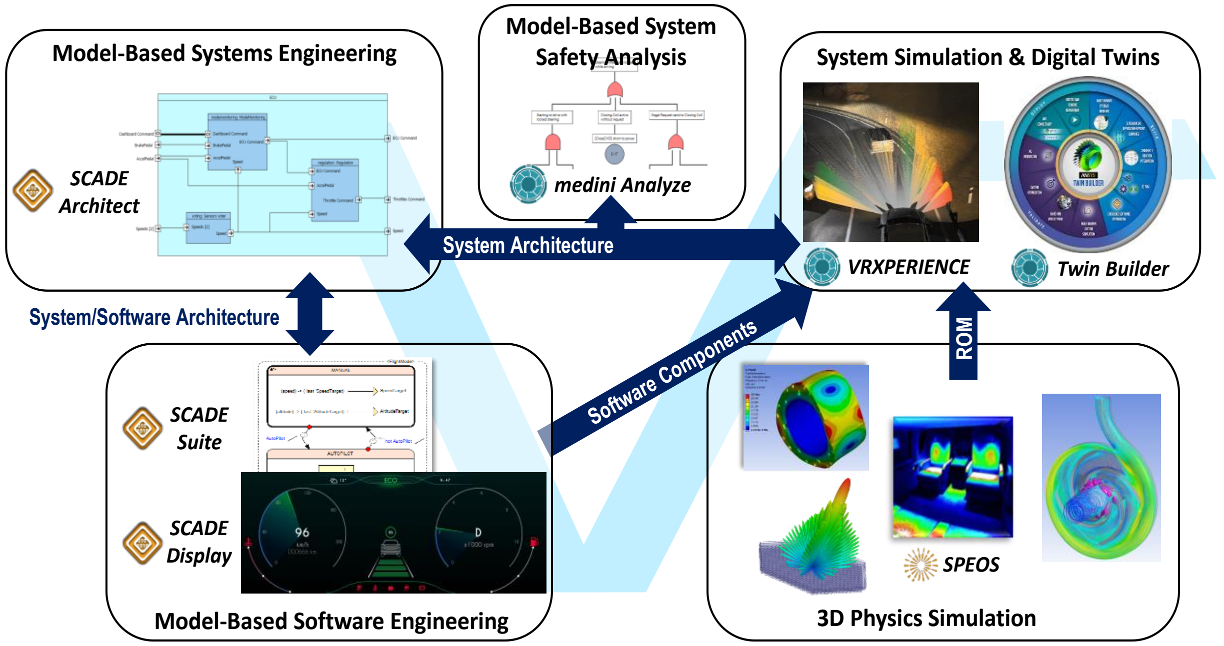
Solution

- **Model Based** System Safety Analyses (FuSa)
- **Model Based** software development and simulation including automatic code generation **(ACG)**
- **Model Simulation** for early detection of design issues

Benefits

- **Compliance with Automotive Standards**: ISO 26262 and AUTOSAR
- **Productivity:** 50% Saving vs. Manual Coding - Elimination of debug, review and V&V activities
- **2x Increase in time to market:** Early detection of flaws, automated production of readable, portable, high performance and high-quality codes, and improved long-term maintainability

Model Based Safety-driven workflow (ISO 26262 compliant)



"Utilizing SCADE increased our development **automation by 15%,** highly reliable code with zero manual review, permitting us to swiftly innovate new ECU technology and accelerate its path to market faster than ever"

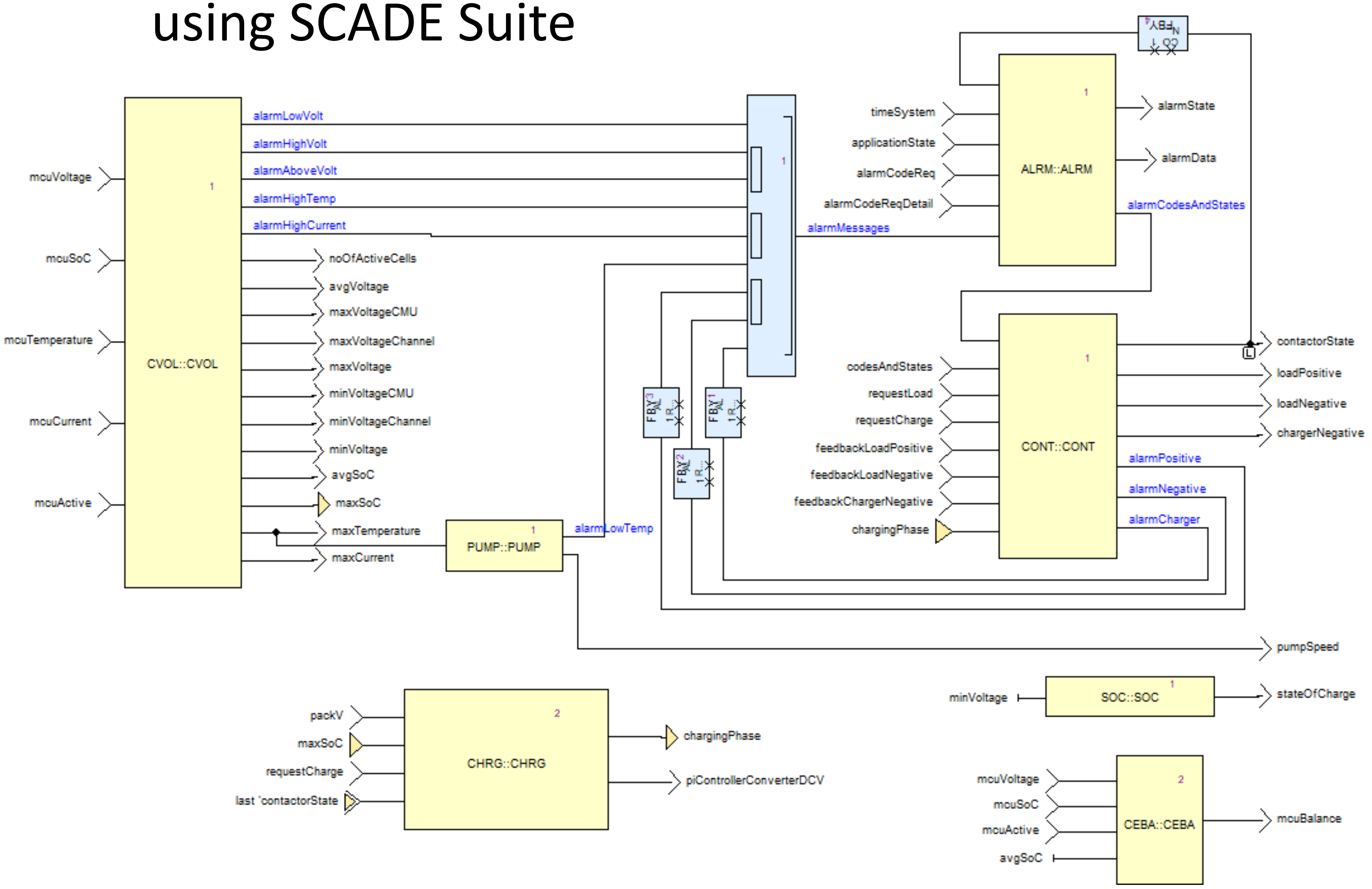
-Yuji Kawakami

Subaru electronics engineering department

Functional Design

SCADE SUITE

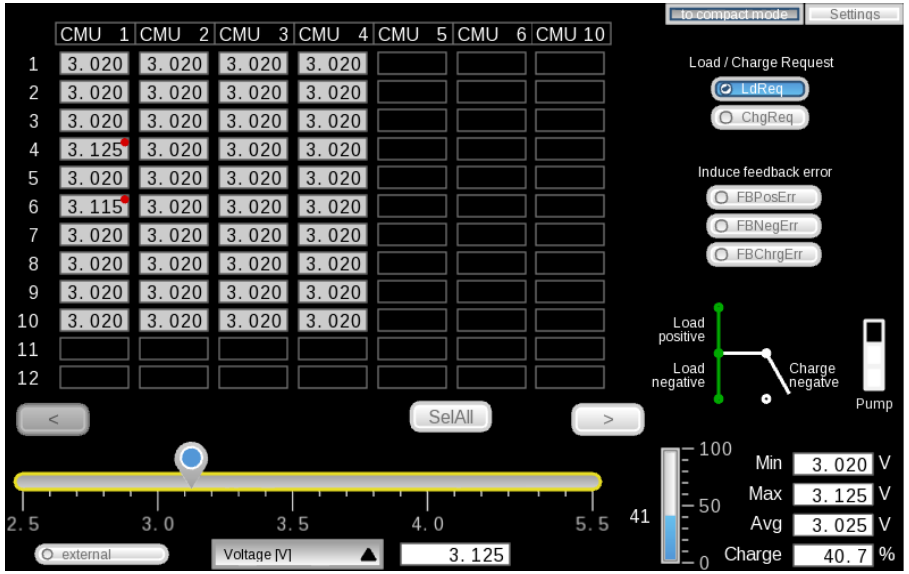
- Functional Design of BMS using SCADE Suite



Simulation Window

Done with SCADE Display

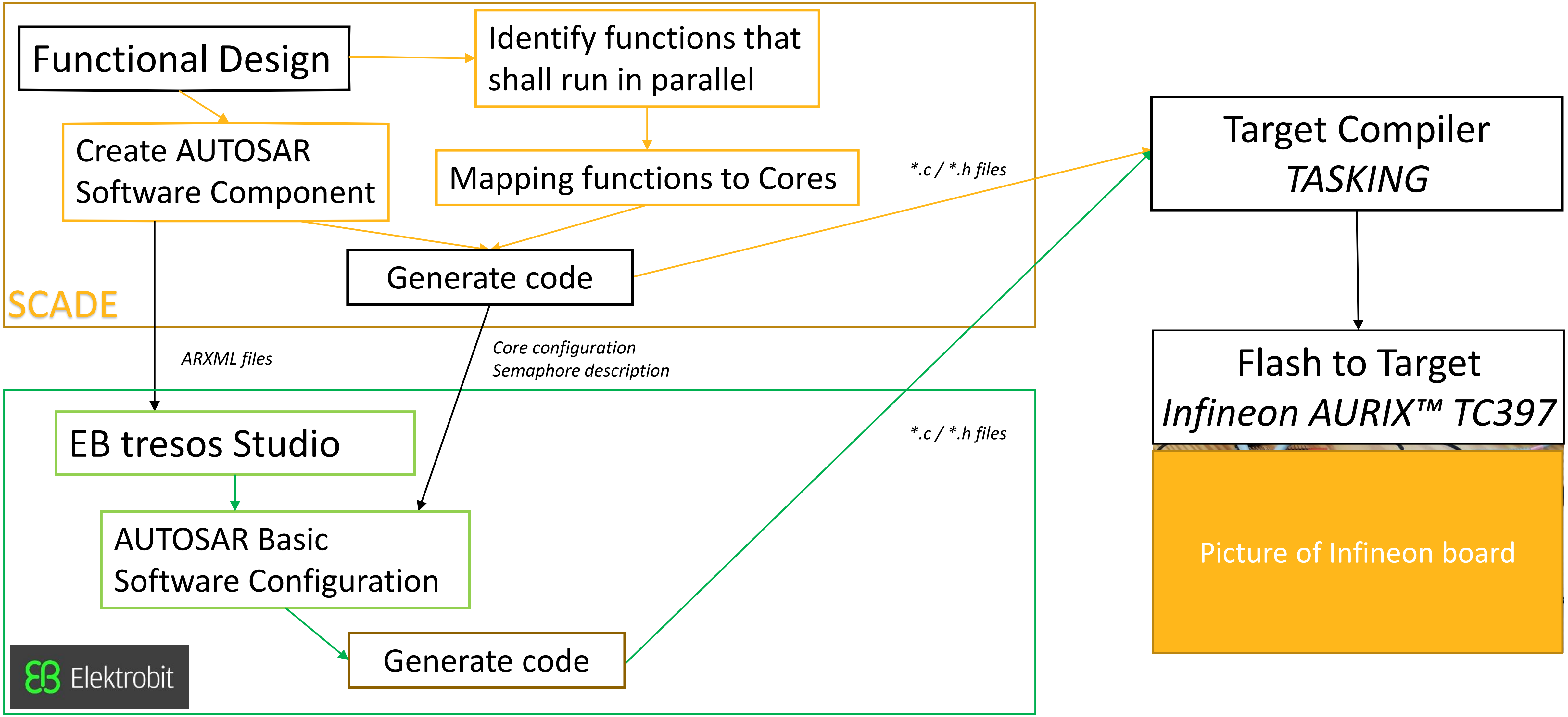
SCADE DISPLAY



Key Features:

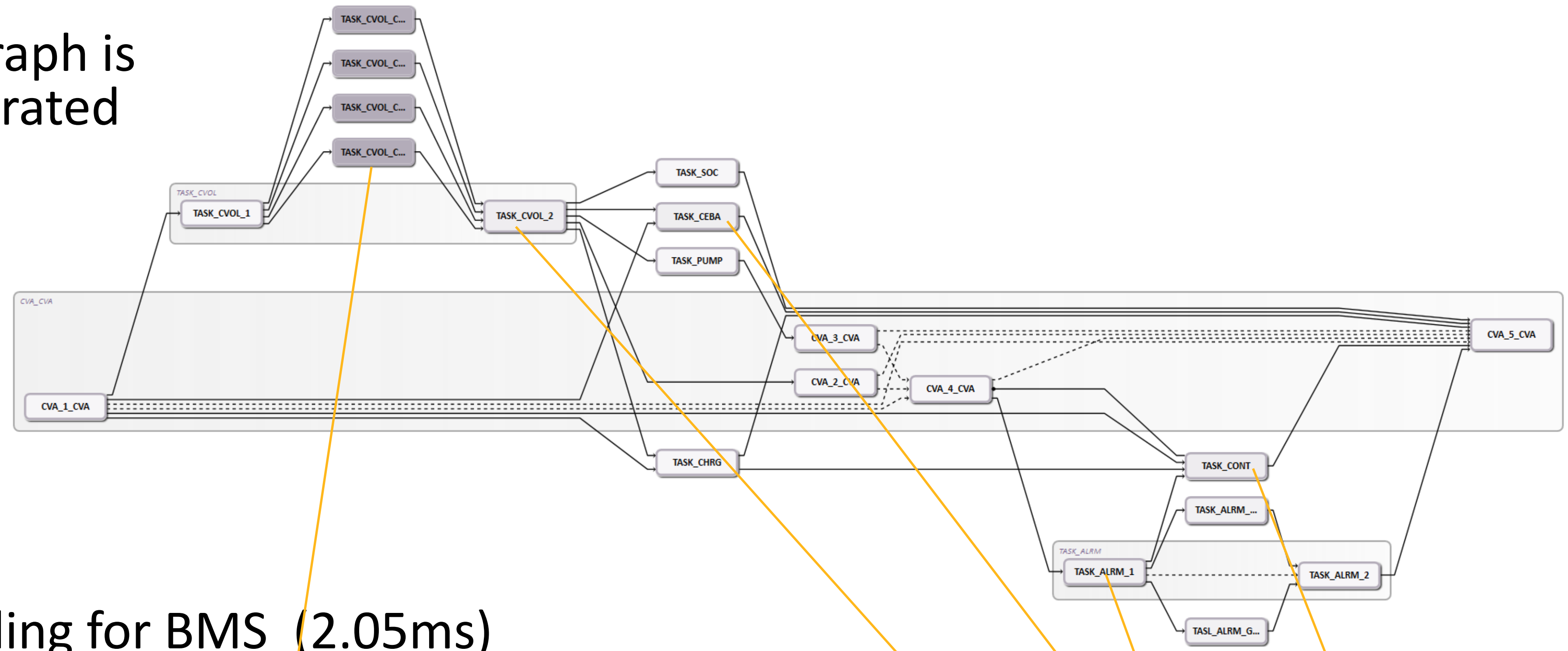
- 32 Cell Monitor Units (CMU)
- 12 Cells per CMU (=384 cells)
- Cell Balancing
- Charging Process
- Alarm Handling
- Water Cooling
- State Of Charge Calculation

Workflow: Multi Core



Mapping Functions to Cores

- The dependancy graph is automatically generated (MultiCoreUI Tool)
- WCETs needed for scheduling are calculated by aiT (Absint)
- Multi-Core Scheduling for BMS (2.05ms)

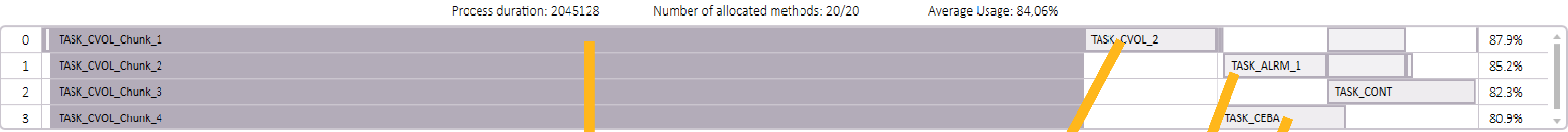


Process duration: 2045128 Number of allocated methods: 20/20 Average Usage: 84,06%

0	TASK_CVOL_Chunk_1	TASK_CVOL_2			87.9%
1	TASK_CVOL_Chunk_2		TASK_ALRM_1		85.2%
2	TASK_CVOL_Chunk_3			TASK_CONT	82.3%
3	TASK_CVOL_Chunk_4		TASK_CEBA		80.9%

Cores

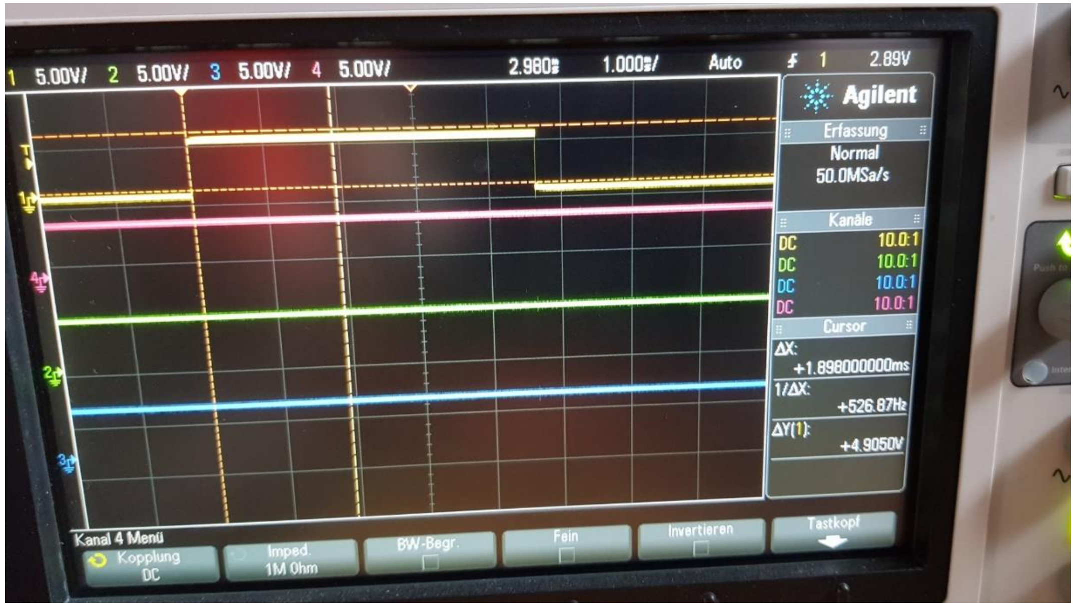
Comparison Scheduling (Host) vs. Reality (Target)



Process duration: 1900000 (1.9ms)

Results – Single-Core vs. Multi-Core

- Single-Core (4.64ms)



- Multi-Core (1.9ms)

All 384 cells are active