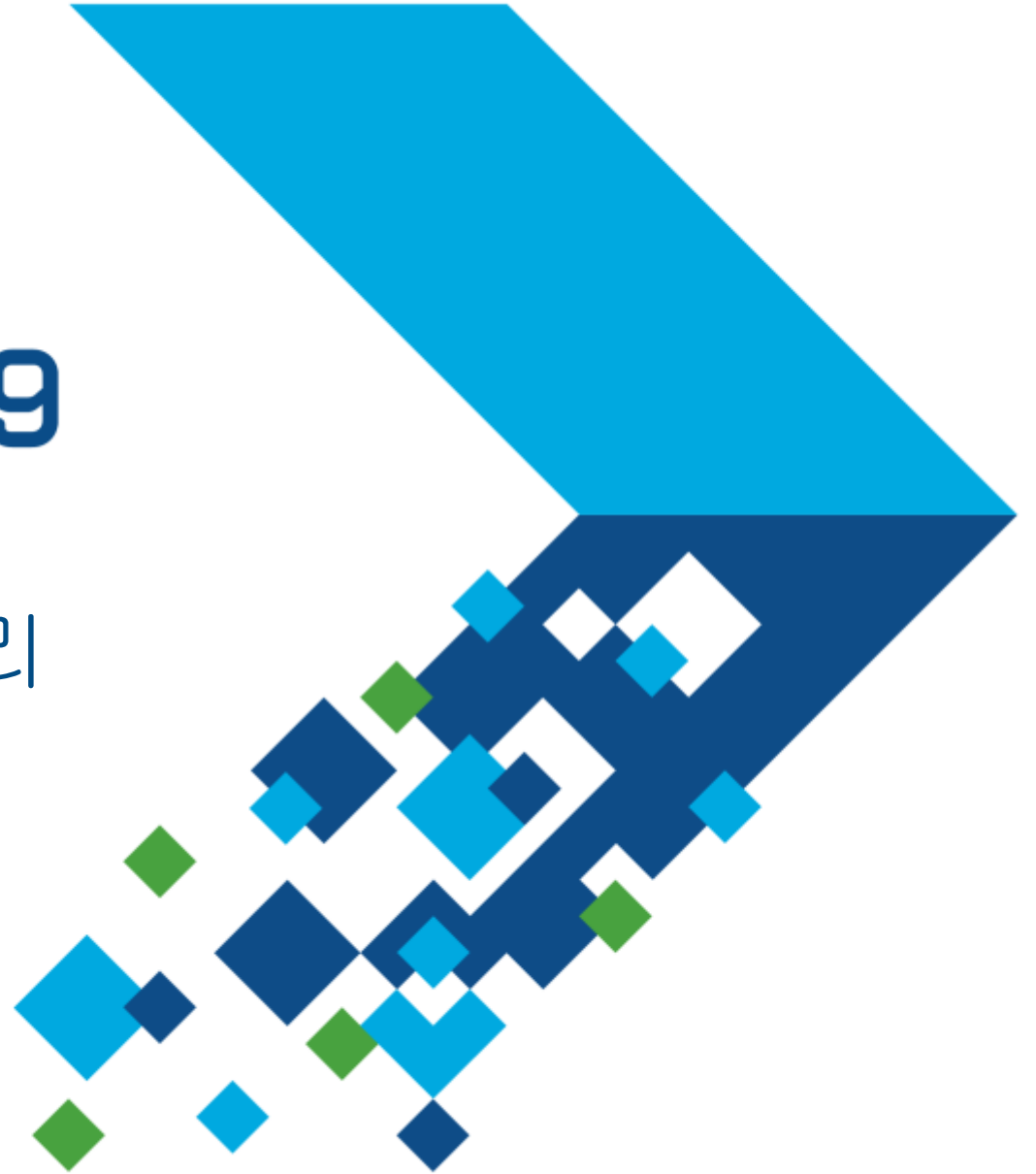


MATLAB EXPO 2019

Simulink를 이용한 배터리 관리
시스템(Battery Management
System)개발

강효석



Motivation

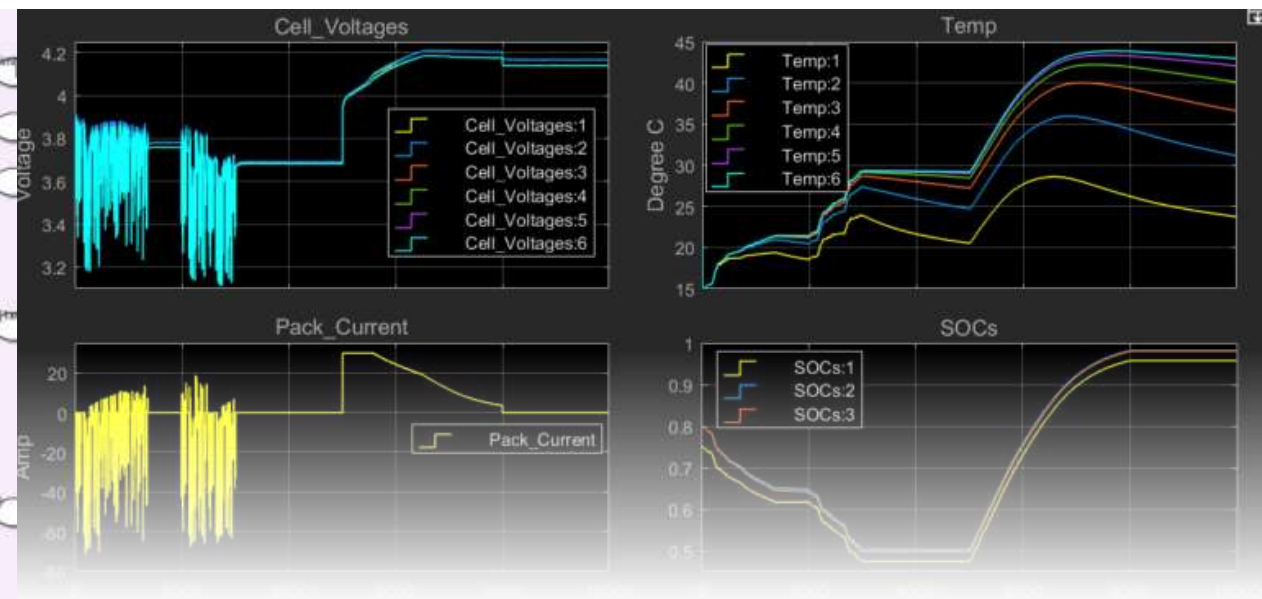
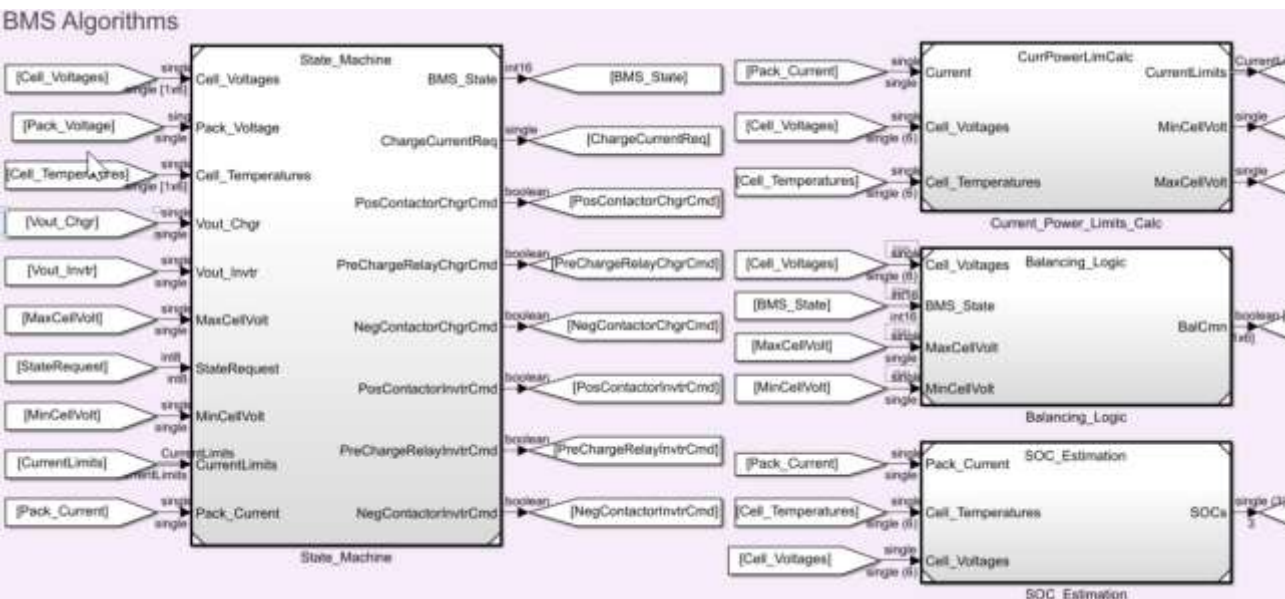
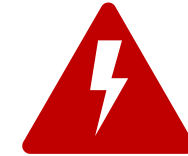
Collaboration
Multi-Domain
Physical Modeling



Short Iteration Cycles
Virtual Prototyping



Safety Critical System
HIL Testing



What is BMS?

Software

Electronics

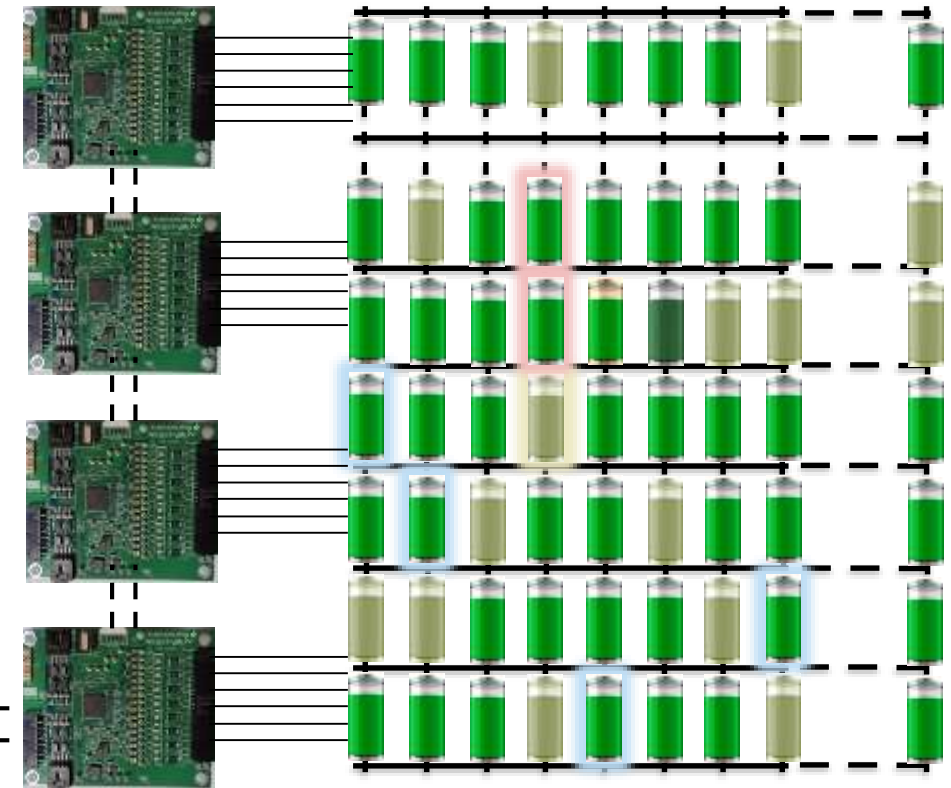
Battery Pack

```
if (((uint32_T)State_Machine_DW.temporalCounter_i3) < 15U) {  
    State_Machine_DW.temporalCounter_i3 = (uint8_T)((int32_T)((int32_T)  
        State_Machine_DW.temporalCounter_i3) + 1));  
}  
  
if (((uint32_T)State_Machine_DW.is_active_c2_State_Machine) == 0U) {  
    State_Machine_DW.is_active_c2_State_Machine = 1U;  
    State_Machine_DW.is_MainStateMachine = State_Machine_IN_Standby;  
    *rtu_BMS_State = 0;  
    State_Machine_DW.MonitorCurrLimMode = MonitorCurrLimModeType_NoCurrLimFault;  
    State_Machine_DW.MonitorCellVoltageMode =  
        MonitorCellVoltageModeType_NoCellVoltFault;  
    State_Machine_DW.Delta = (real32_T)fabs((real_T)((real32_T)  
        ((*rtu_Pack_Voltage) - sum_gyOECAG3(rtu_Cell_Voltages))));  
    State_Machine_DW.FaultPresent = false;  
}
```



Supervisory tasks
SOC estimation
Contactor management
Isolation monitoring
Fault detection and recovery
Thermal Management
Current & Power Limits

MATLAB EXPO 2019



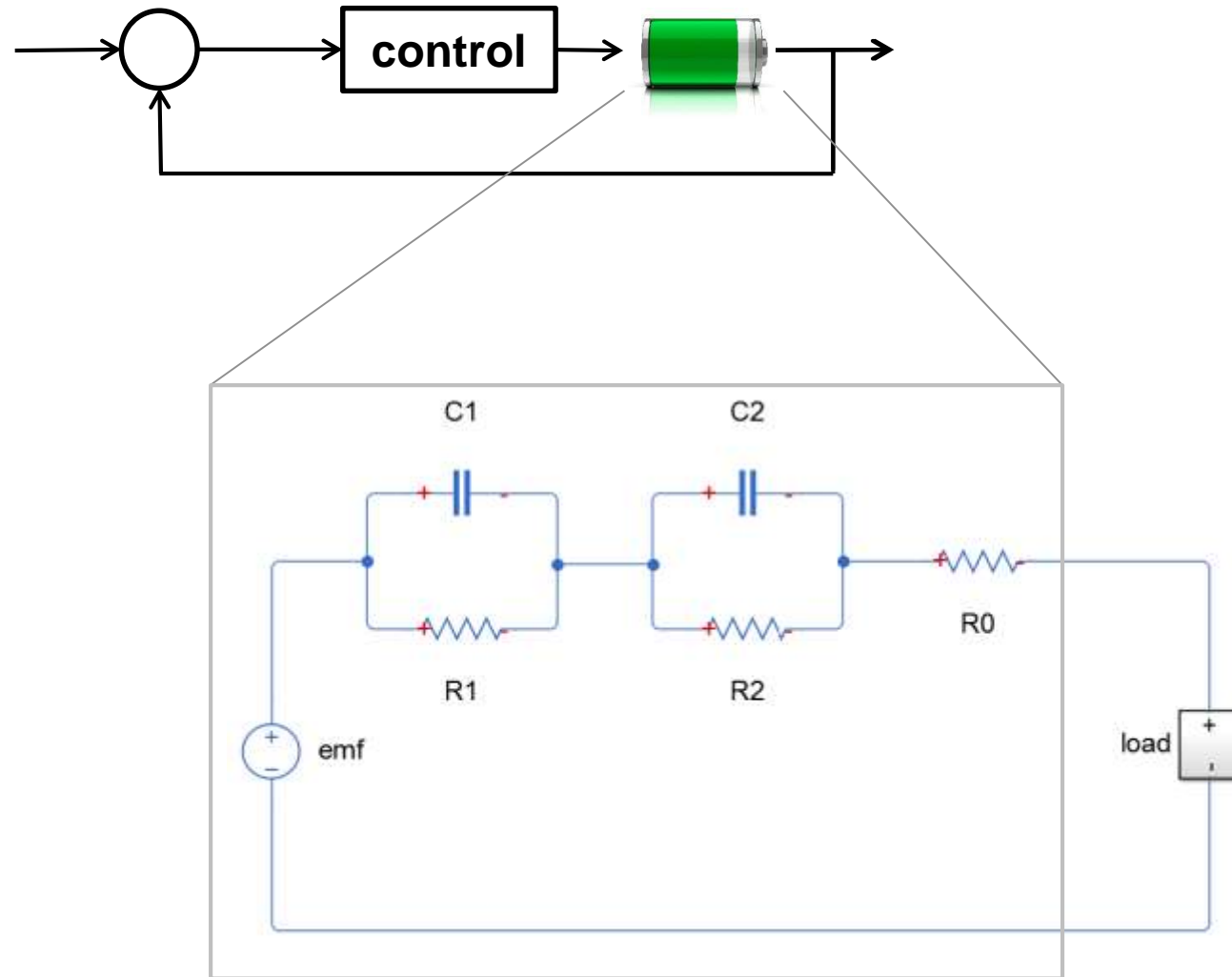
Block Voltage,
Temperature Measurement
Cell Diagnostic
Cell Balancing

Agenda

- Battery Modeling
 - Equivalent Circuit Model
 - Expansion of Physical Model
- Algorithm Development
 - Algorithm Modeling
 - Code Generation
- Hardware-In-the-Loop Test

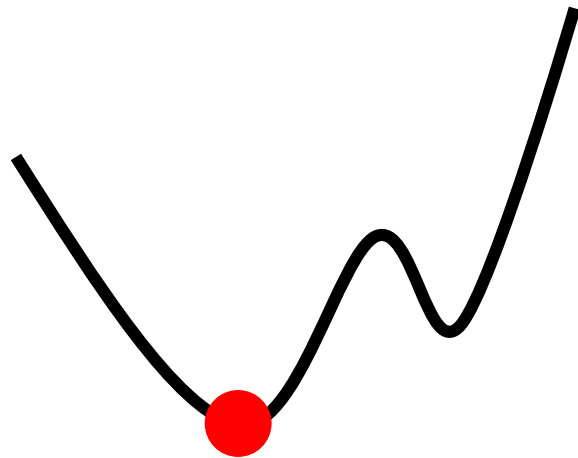
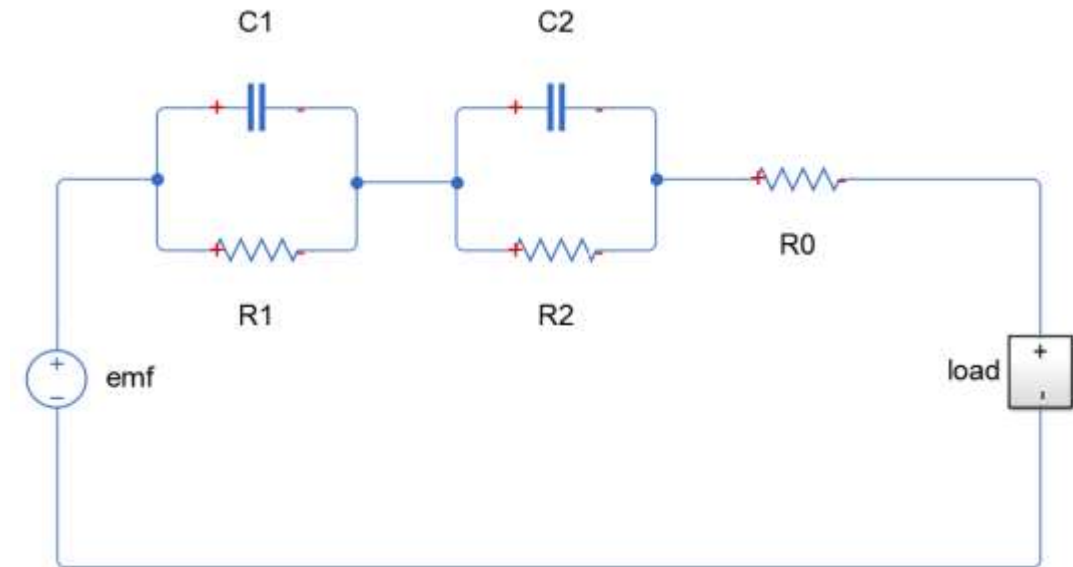


Battery Modeling



Battery Modeling

- Equivalent Circuit
- Parameter Estimation



High Fidelity Electrical Model with Thermal Dependence for Characterization and Simulation of High Power Lithium Battery Cells

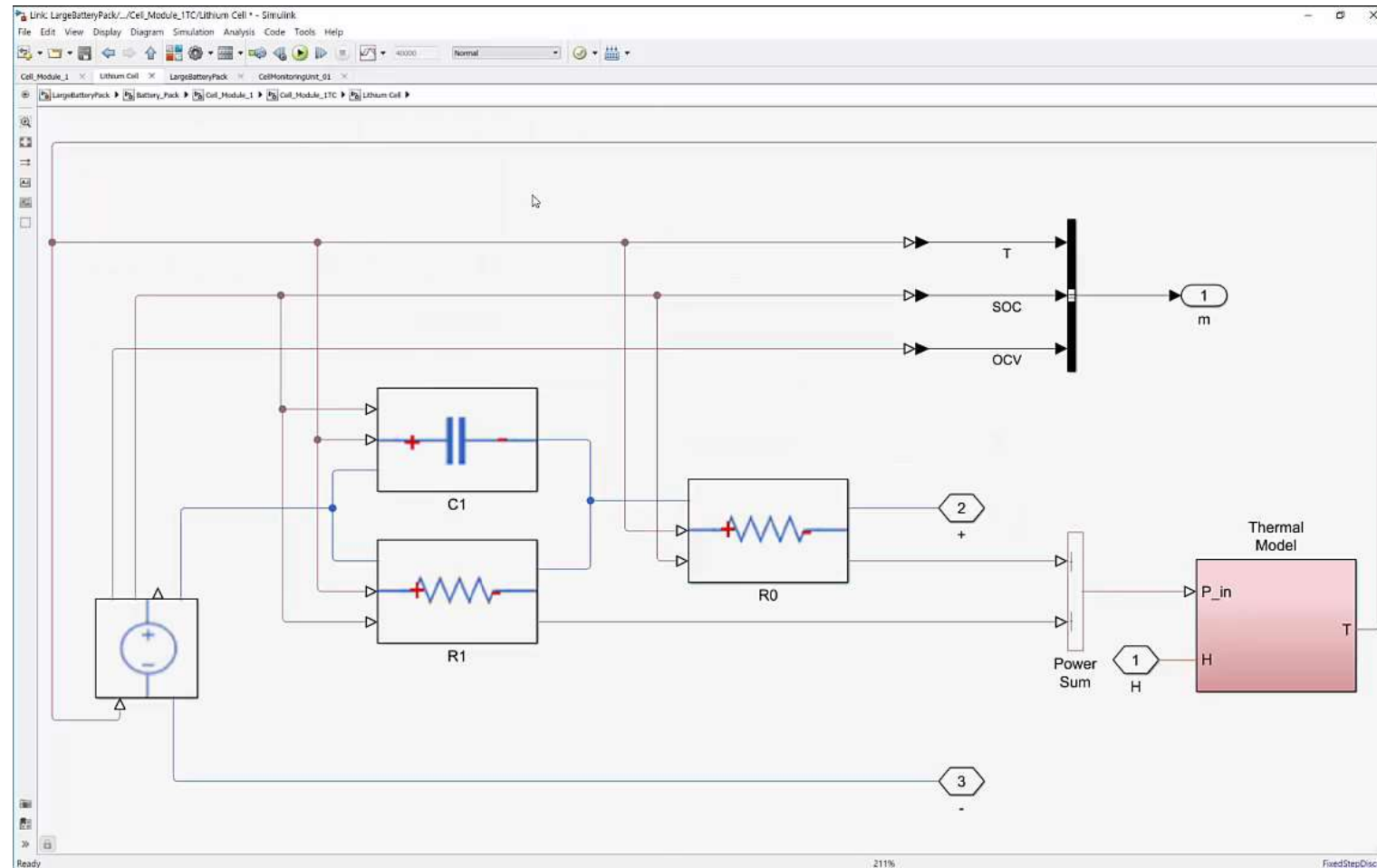
Tarun Huria, Massimo Ceraolo
Department of Energy and Systems Engineering
University of Pisa
Largo Lazzarino, Pisa 56122 Italy
m.ceraolo@ing.unipi.it

Javier Gazzarri, Robyn Jackey
MathWorks
39555 Orchard Hill Place, Suite 280
Novi, MI 48375 USA
robyn.jackey@mathworks.com

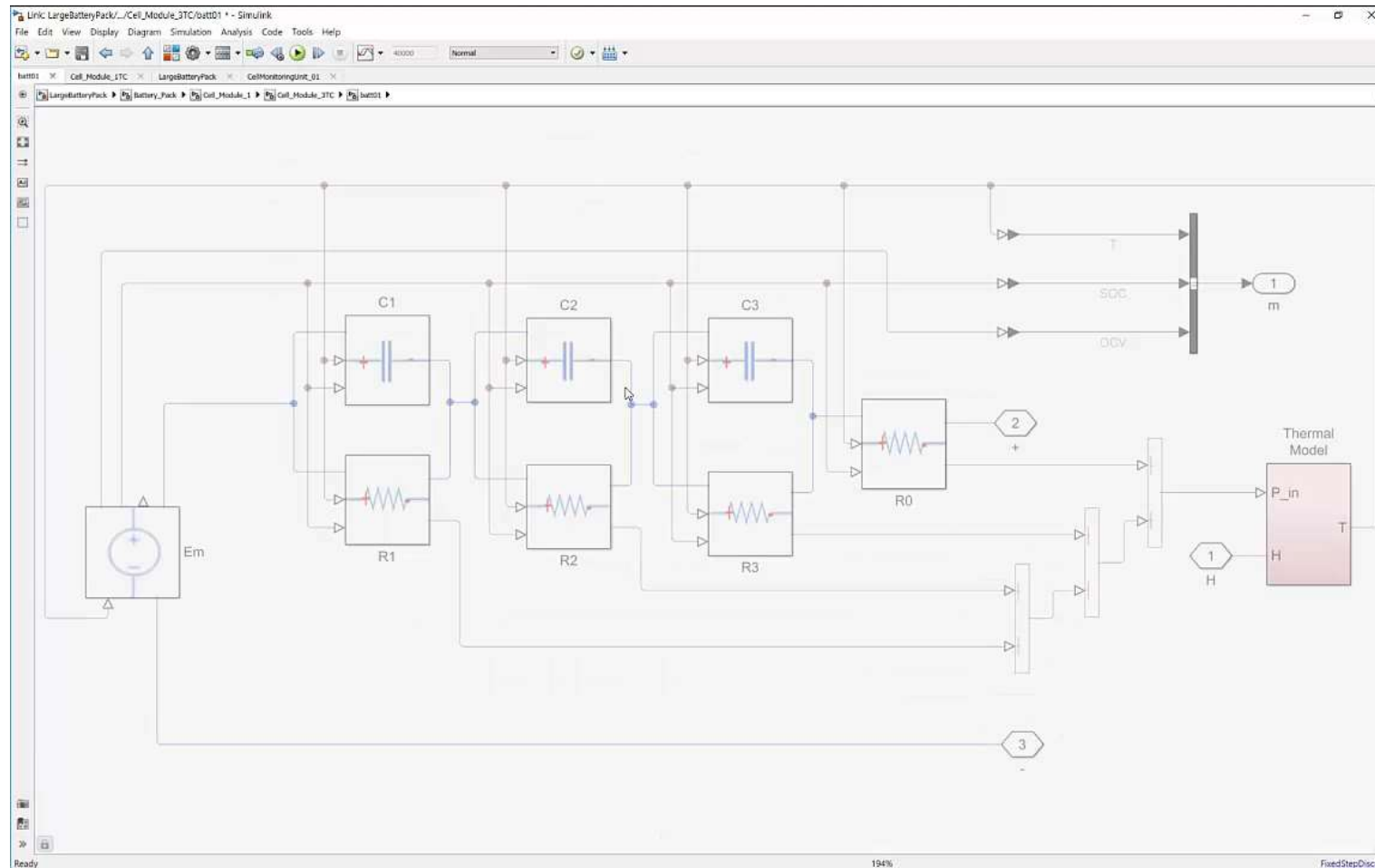
Abstract— The growing need for accurate simulation of advanced lithium cells for powertrain electrification demands fast and accurate modeling schemes. Additionally, battery models must account for thermal effects because of the paramount importance of temperature in kinetic and transport phenomena of electrochemical systems. This pa-

OCV open circuit voltage (V)
 P_i power dissipated inside the cell (W)
 Q_c extracted charge from cell (Ah)
 R_n resistor n , where n is a natural number (Ω)
 R_f convection resistance ($W^{-1} m^2 K^{-1}$)

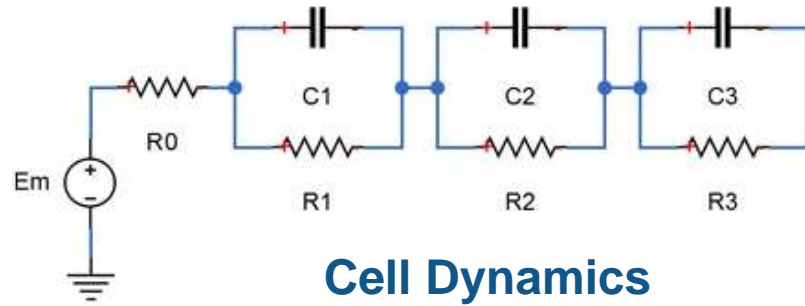
Cell Modeling Using 1RC circuit



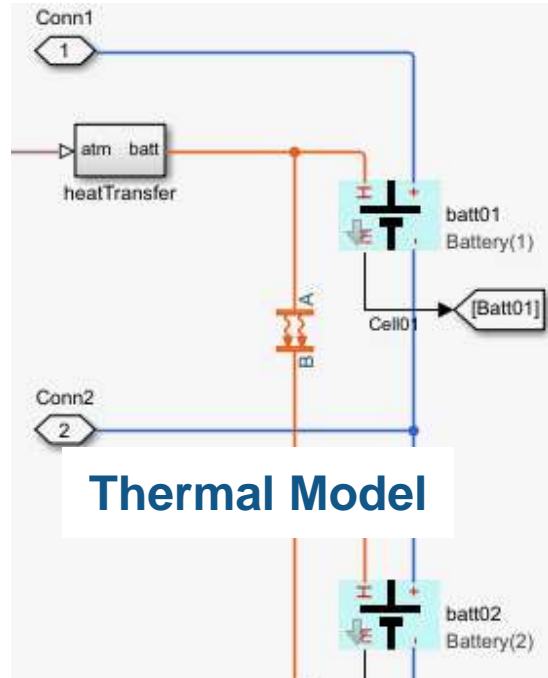
Cell Modeling Using 3RC circuit



Battery Cell \leftrightarrow Large Battery Pack

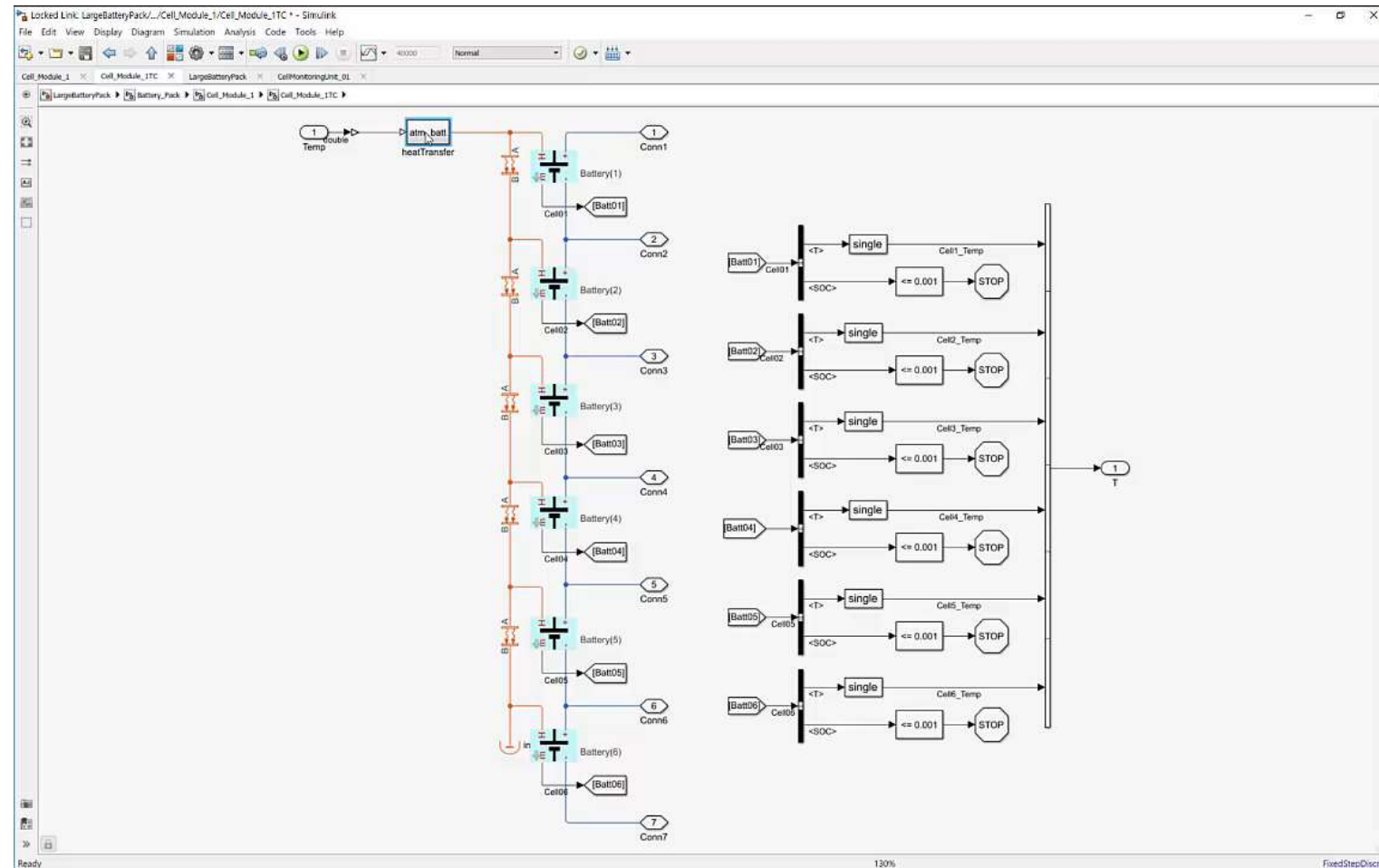


Cell Dynamics

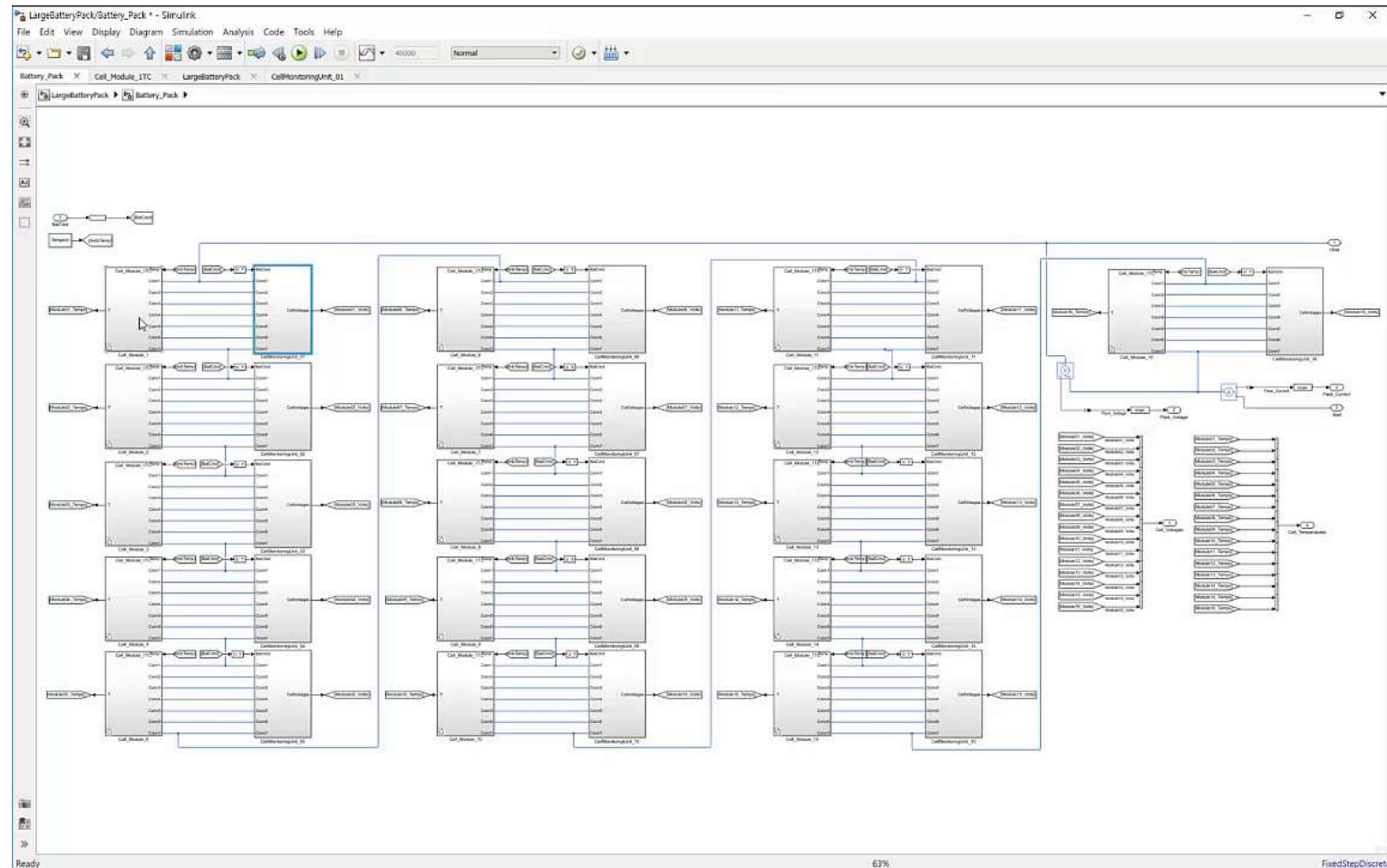


Thermal Model

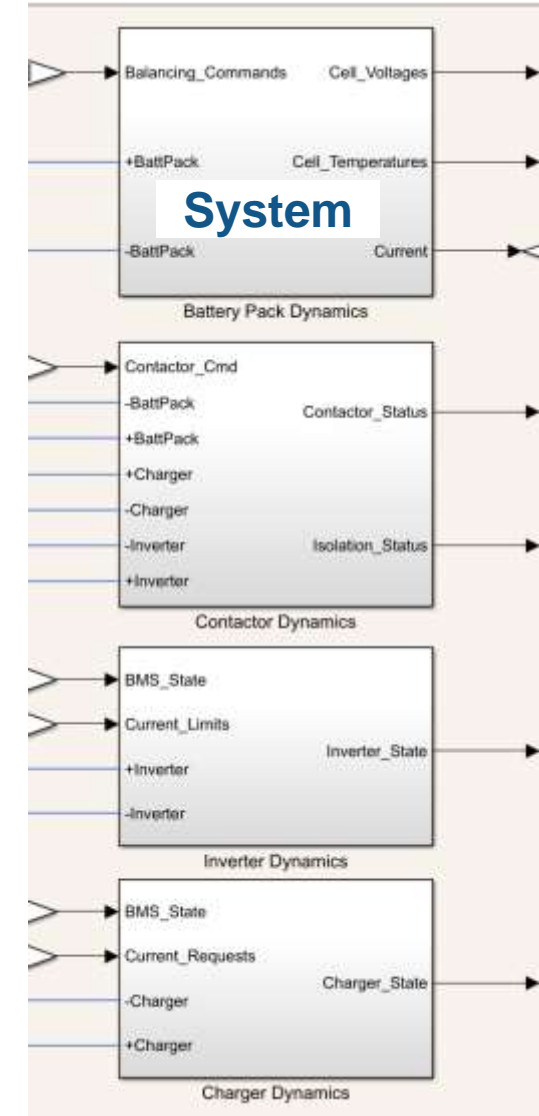
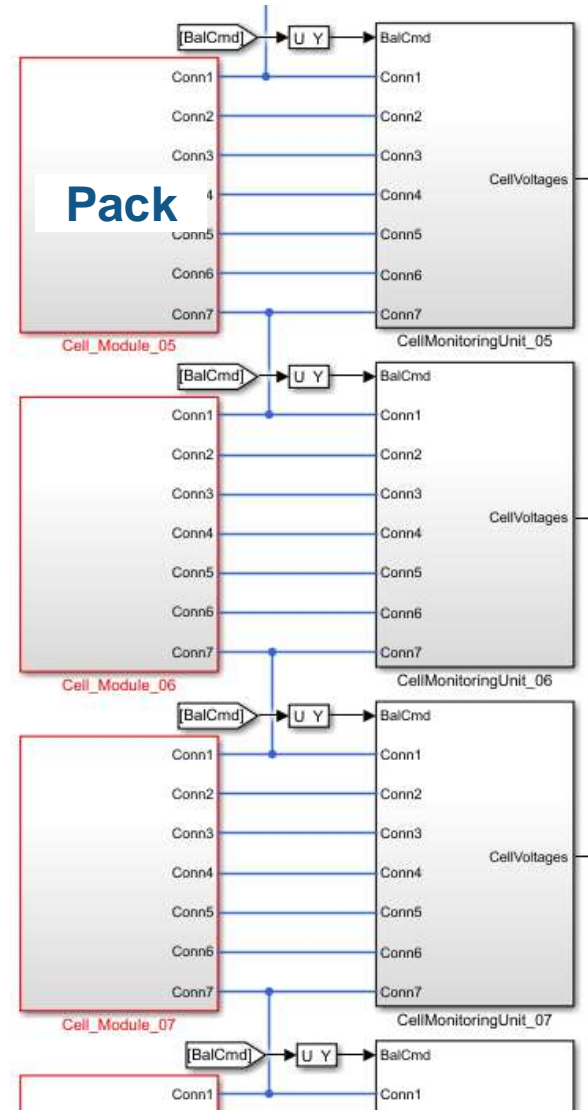
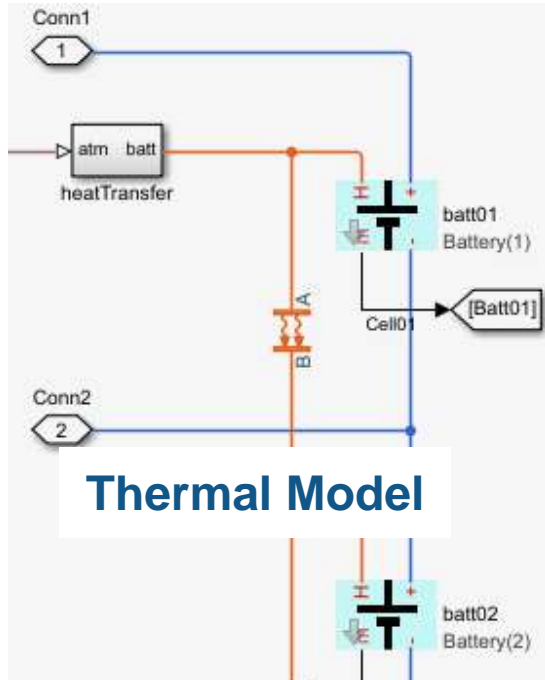
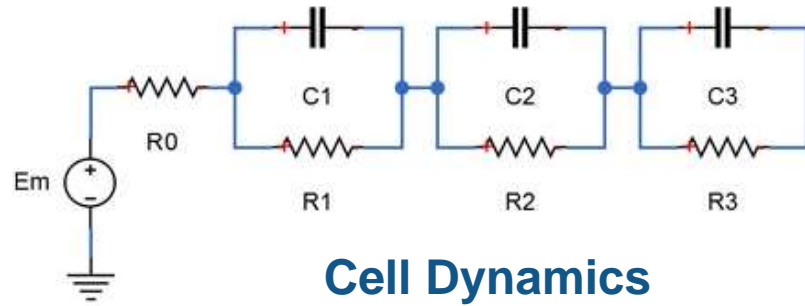
Battery Pack Modeling with Thermal Dynamics



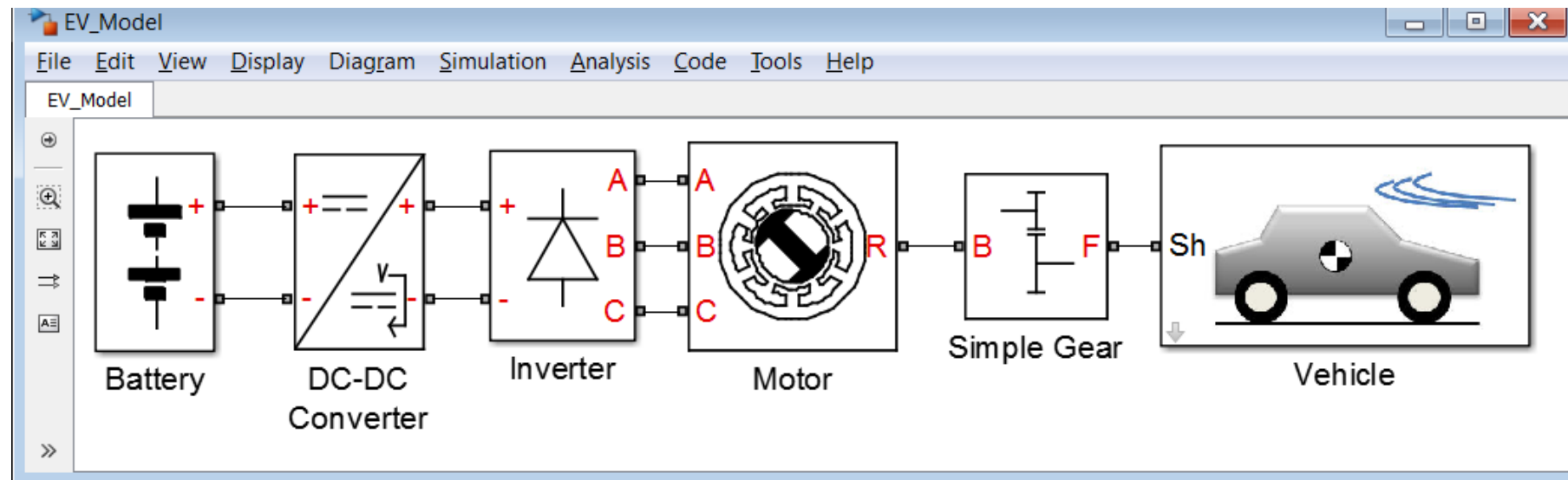
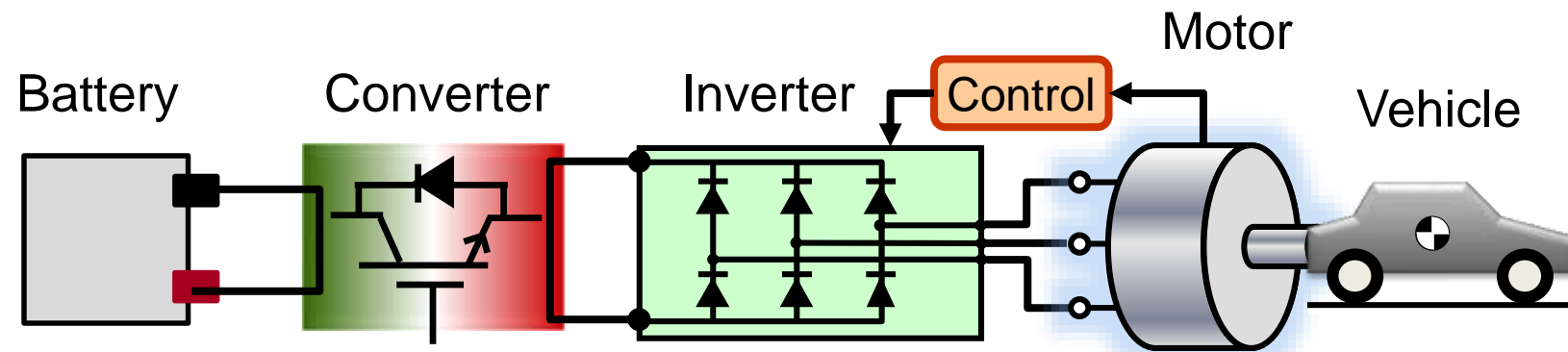
Large Battery Pack Modeling



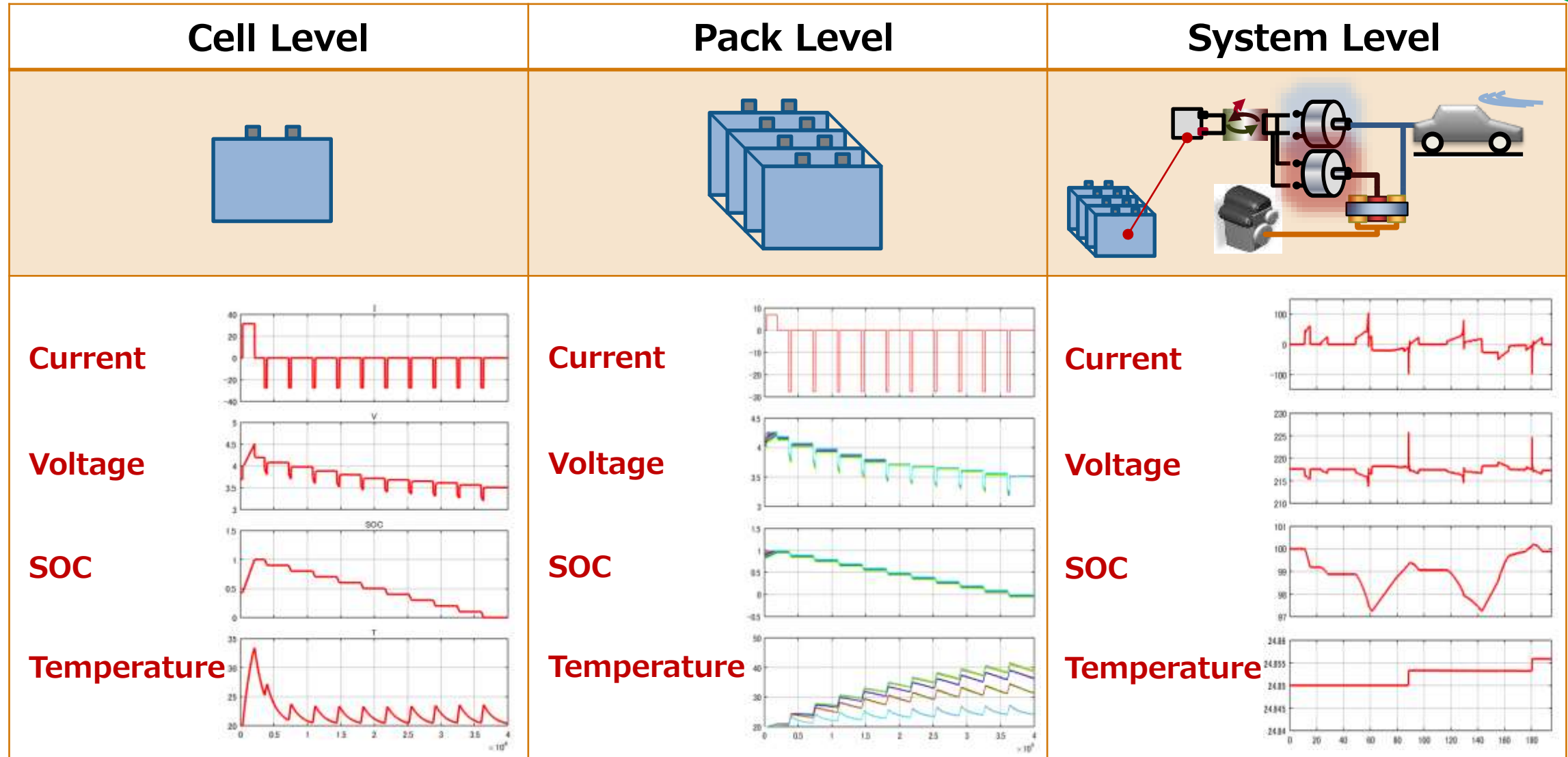
Battery Cell \leftrightarrow Large Battery Pack



System Level Simulation - Collaboration



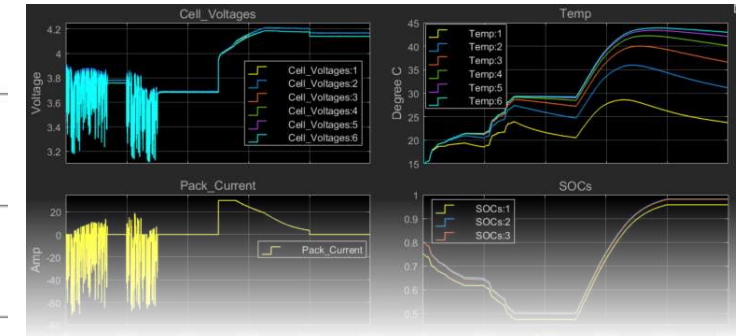
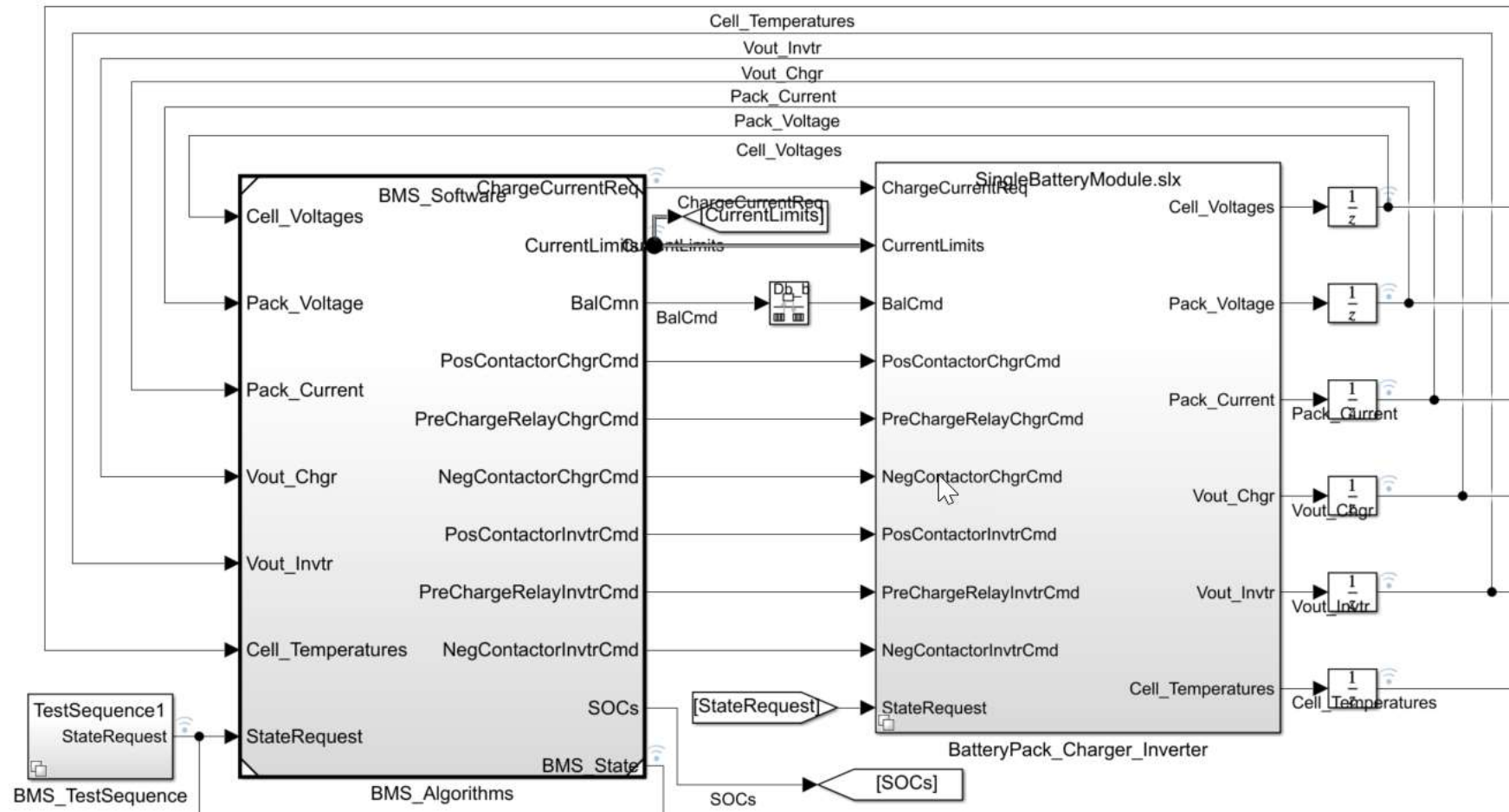
Simulation Level



Agenda

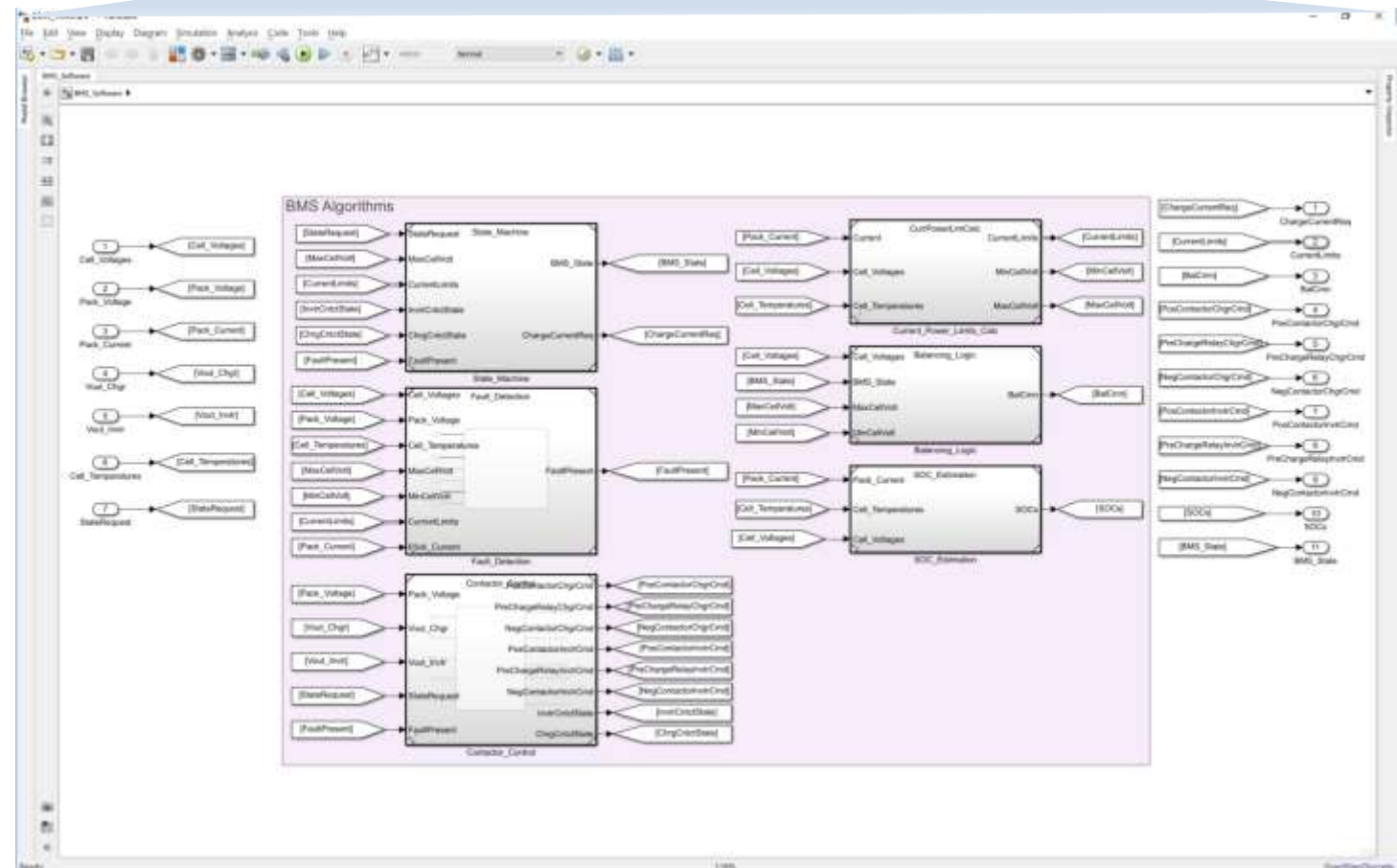
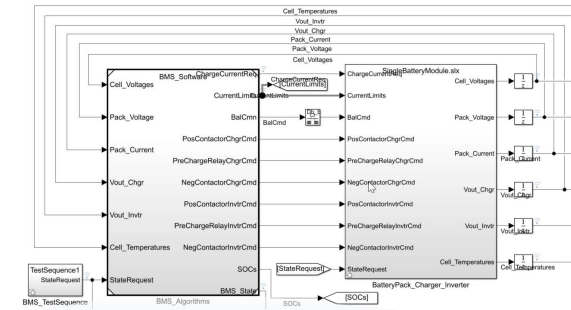
- Battery Modeling
 - Equivalent Circuit Model
 - Expansion of Physical Model
- Algorithm Development
 - Algorithm Modeling
 - Code Generation
- Hardware-In-the-Loop Test

Develop & Test Algorithms in Simulink

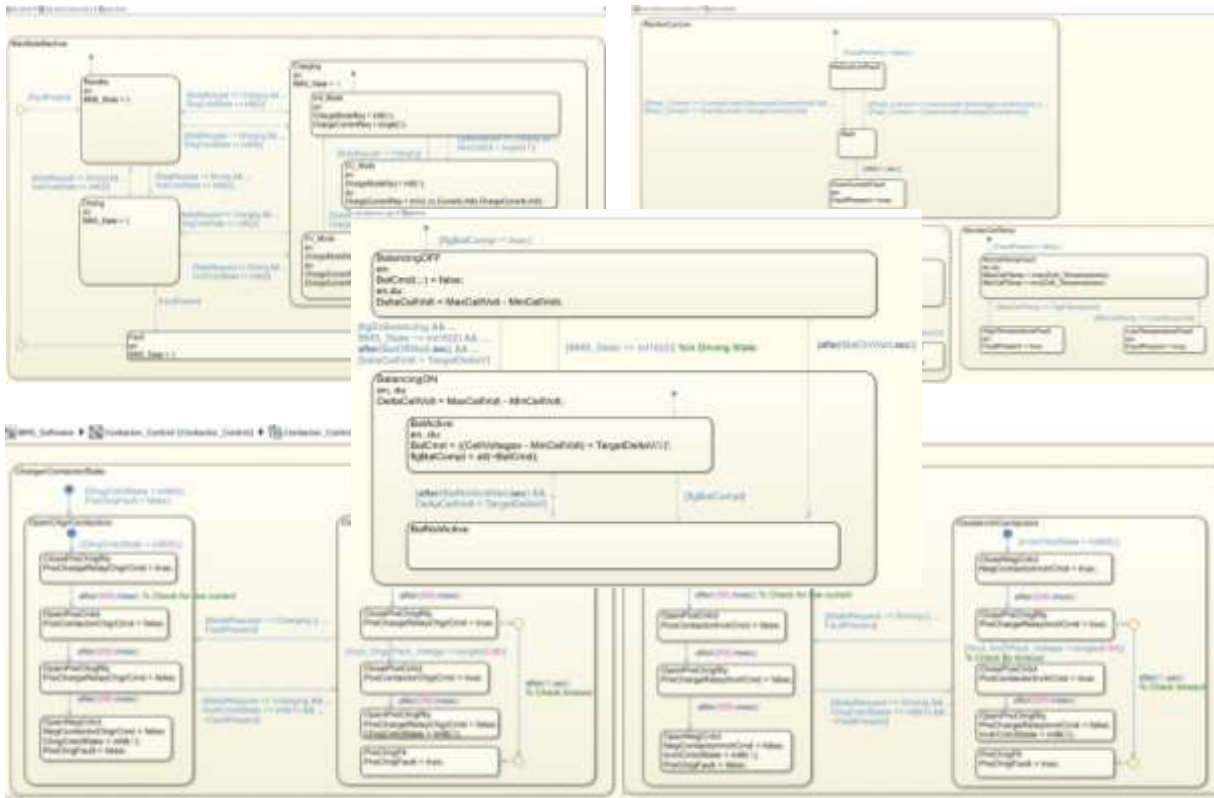


BMS Algorithm

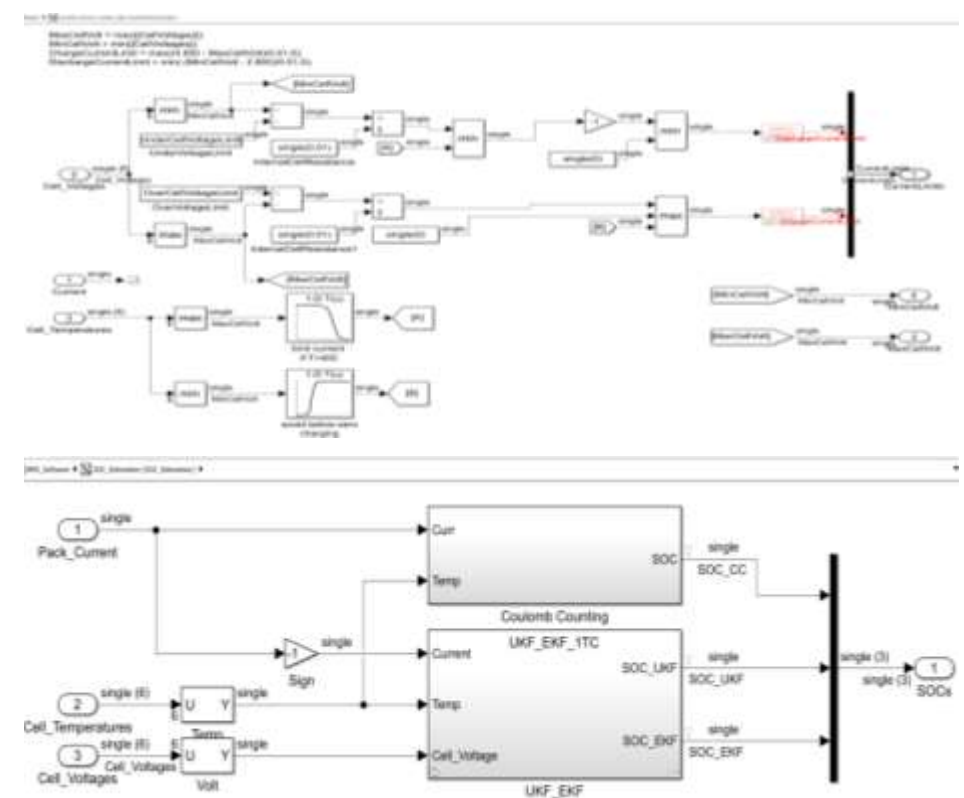
- Supervisory control
- Fault detection and recovery
- Contactor management
- Current & Power Limits
- Cell Balancing
- SOC estimation



Make it easy to design algorithms

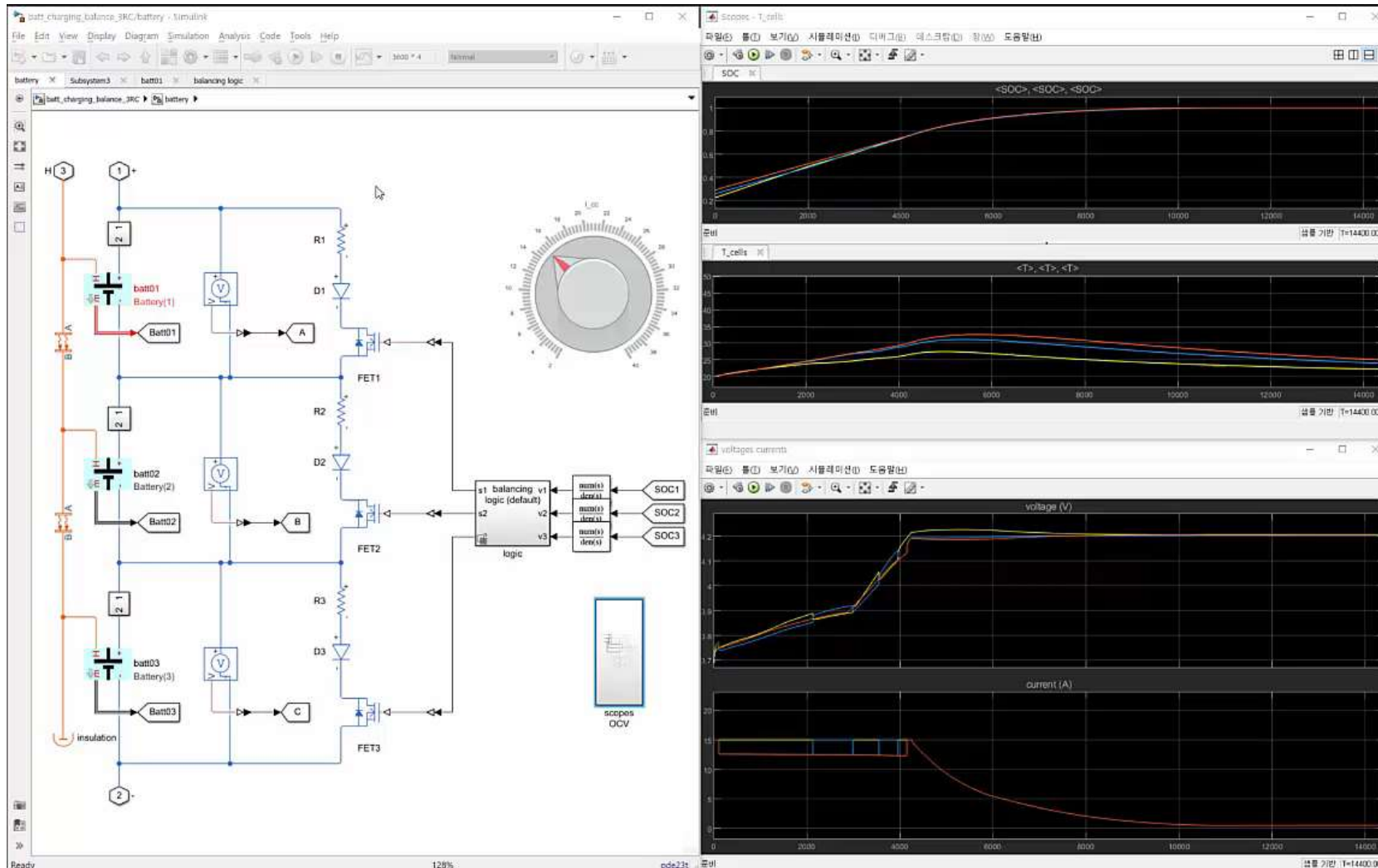


Stateflow

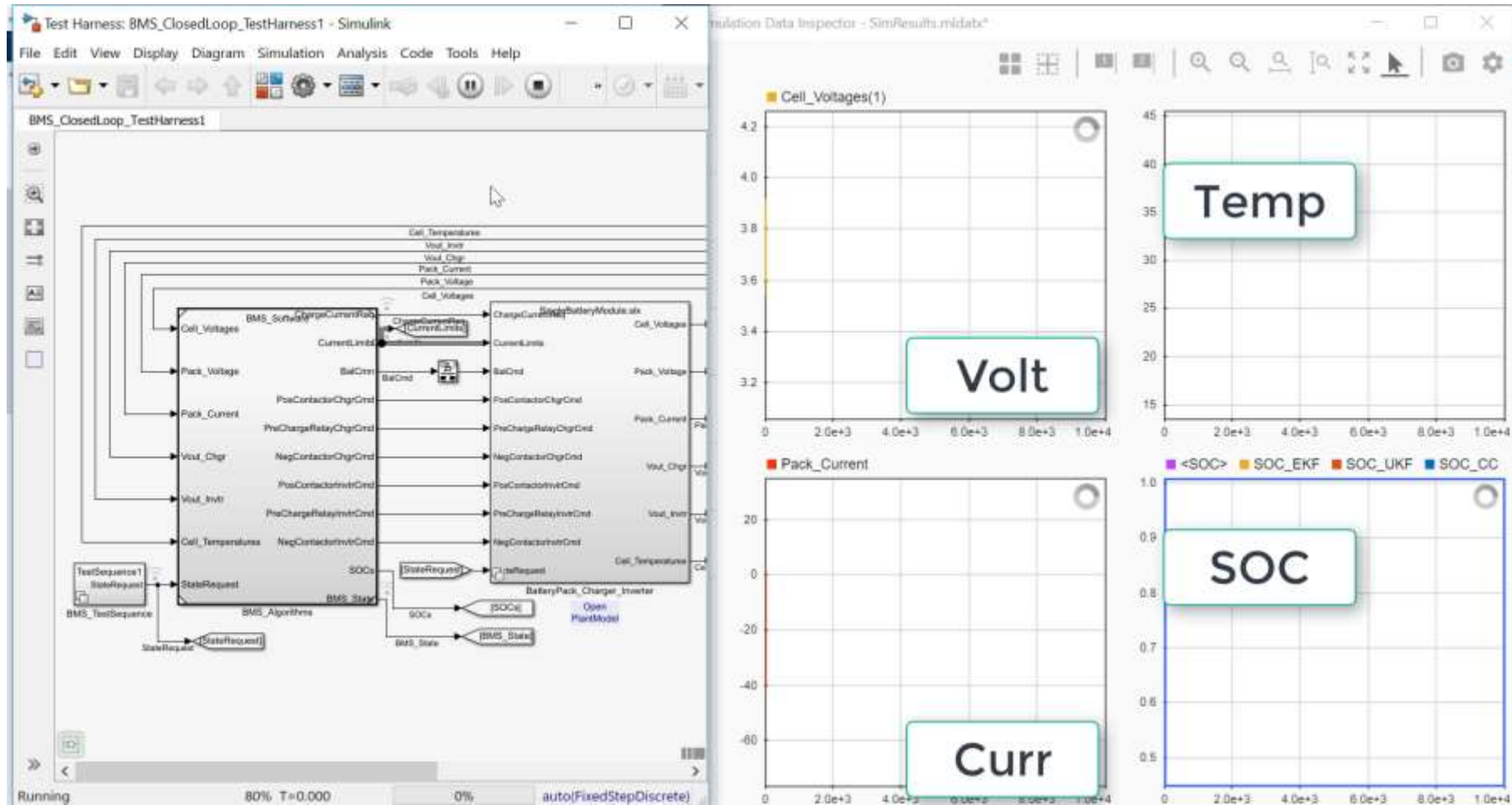


Simulink

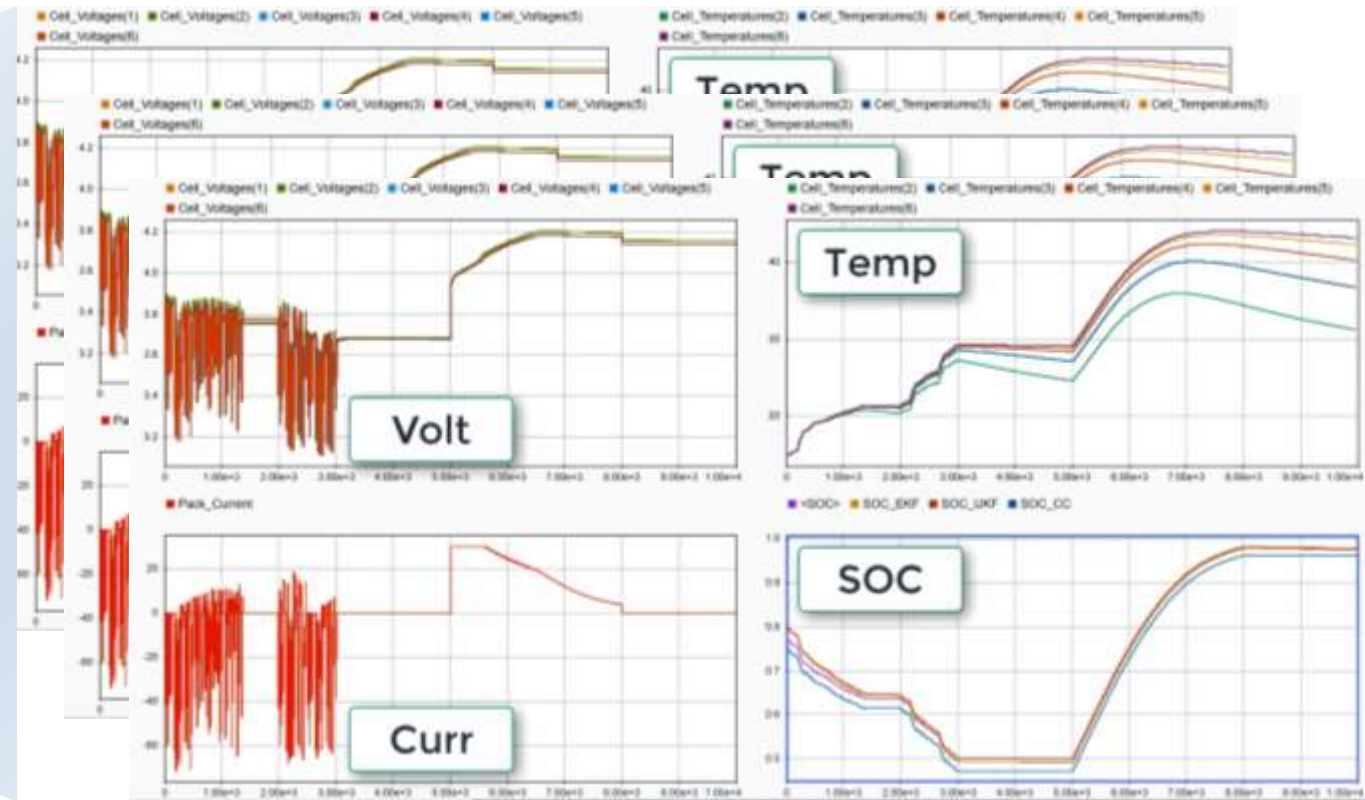
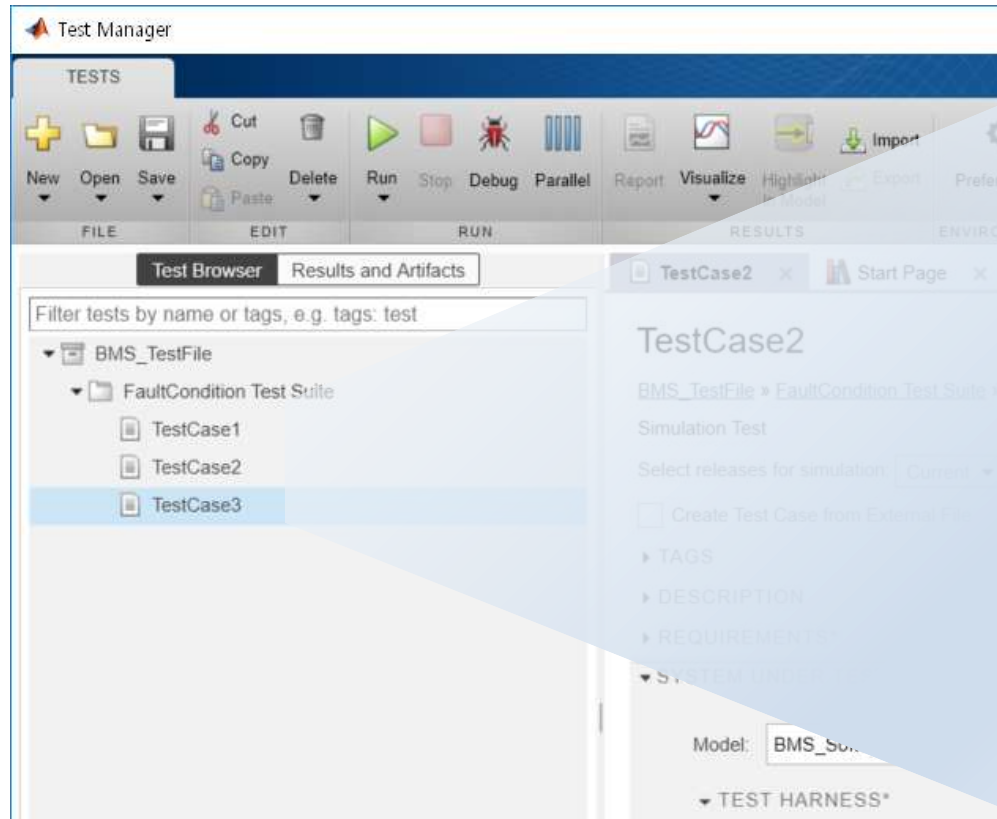
Passive Cell balancing



Test with Algorithms



Test with Algorithms using Simulink Test



Generate C/C++ Code From BMS Algorithm Models



BMS Algorithms



Find:

Match Case

Subsystem Report

Traceability Report

Find out more:

간편해진 C/C++코드 생성 설정 방법 소개

Tech Talk Special 트랙
유재홍



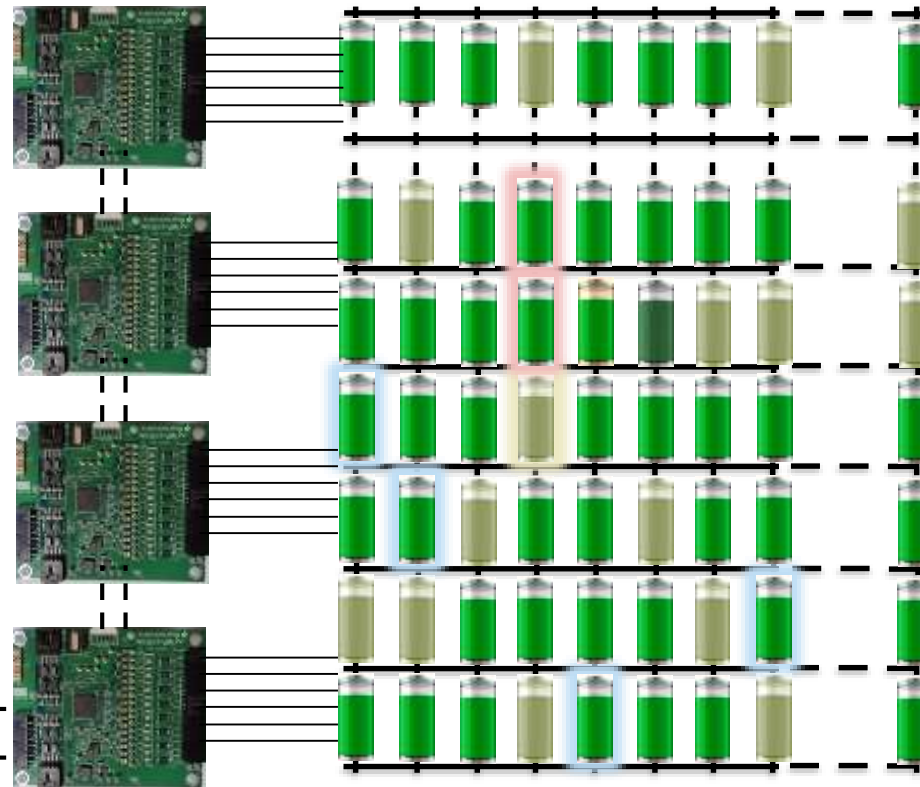
```
torCurrLimModeType_NoCurrLimFault;
```

```
lt;
sal_T)((real32_T)
Cell_Voltages));
```

Agenda

- Battery Modeling
 - Equivalent Circuit Model
 - Expansion of Physical Model
- Algorithm Development
 - Algorithm Modeling
 - Code Generation
- **Hardware-In-the-Loop Test**

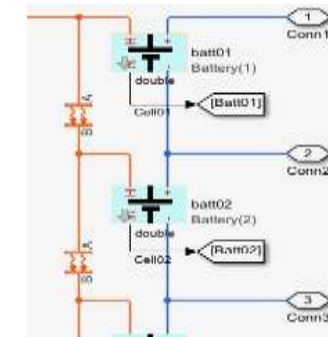
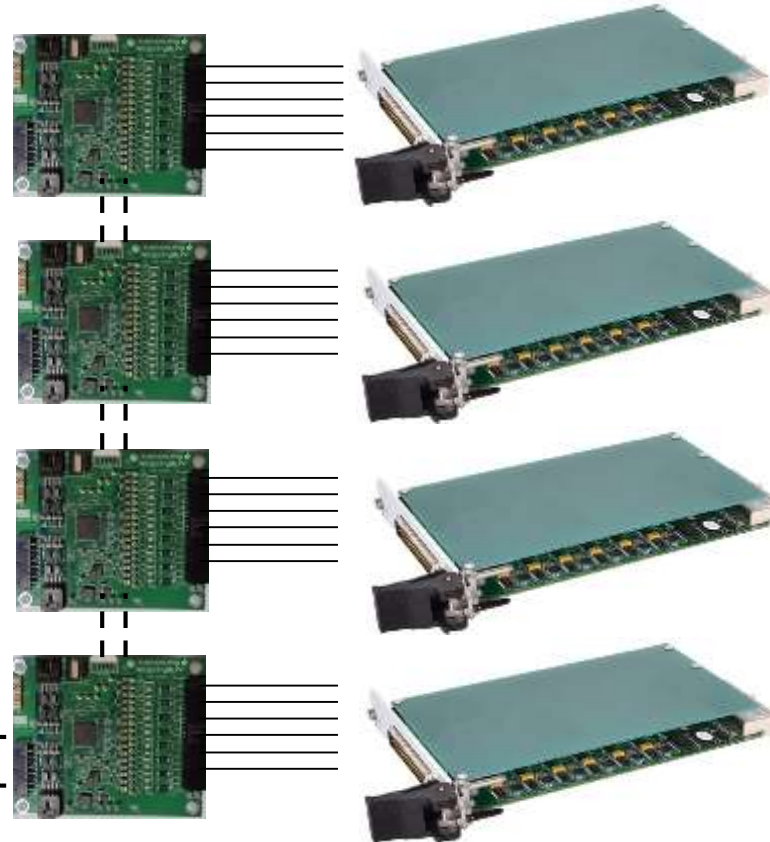
Perform HIL Testing for BMS ECUs (1/2)



Testing ECUs with Battery Cells

- Longer test cycles
- Difficult to reproduce results
- Limited test automation
- Difficult to test fault conditions

Perform HIL Testing for BMS ECUs (2/2)



Automatic Code
Generation

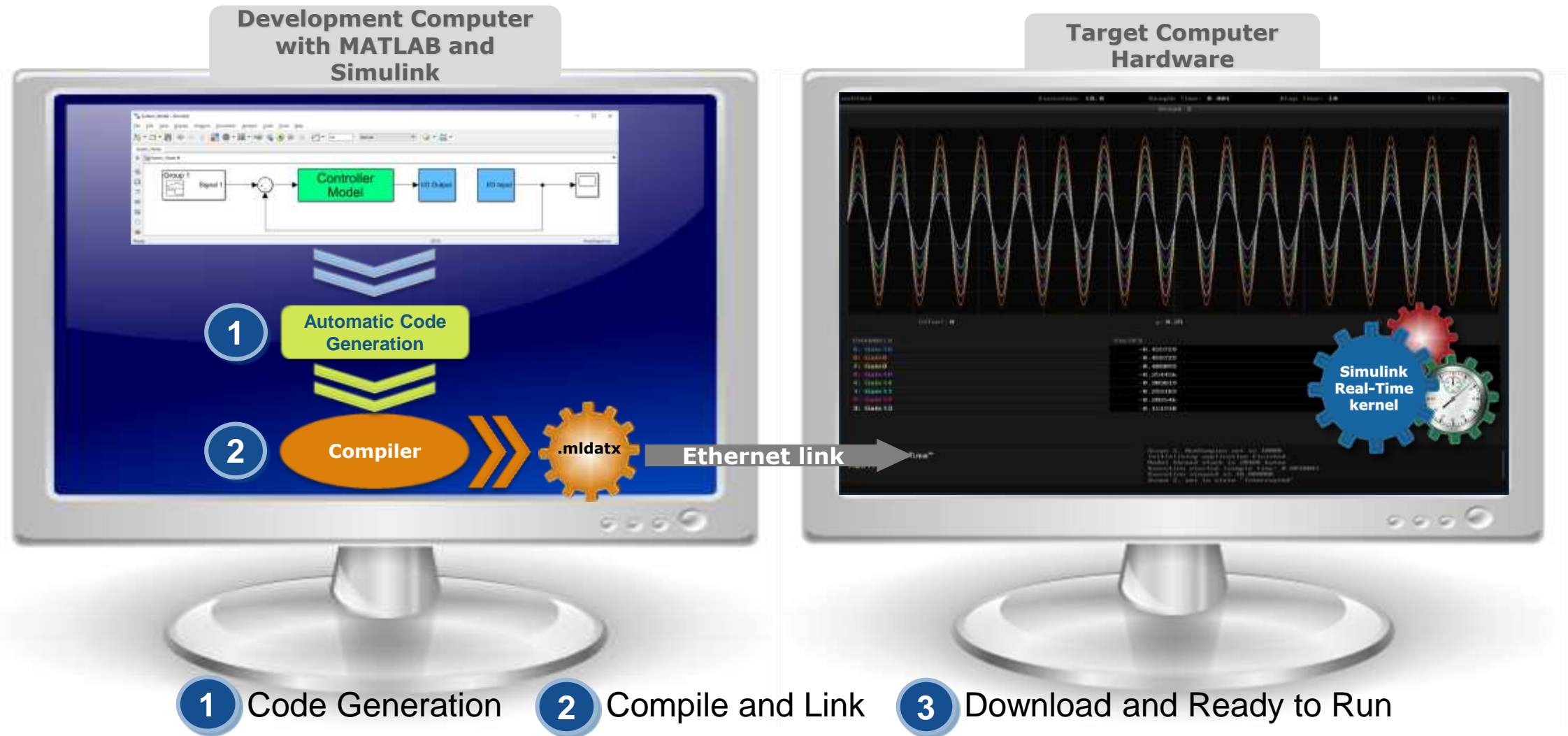


Wiring and Signal
Conditioning



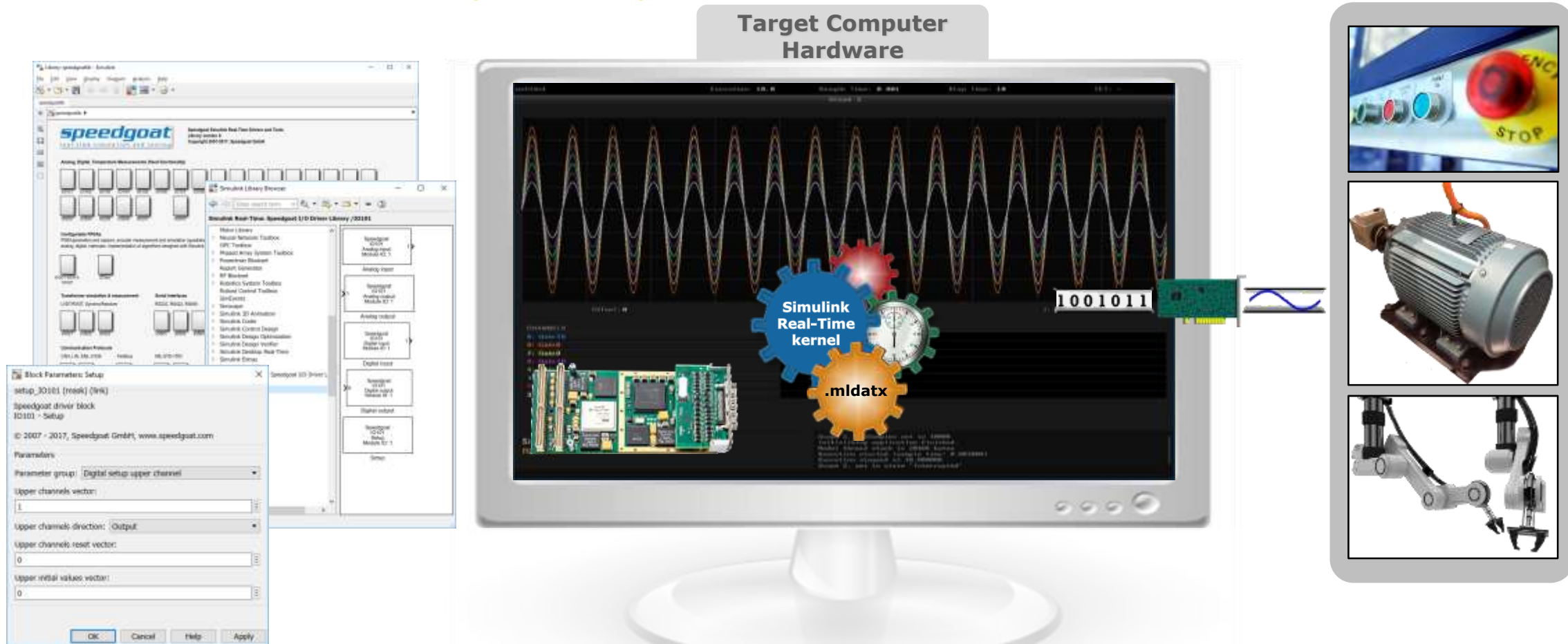
What is Simulink Real-Time?

From Desktop Simulation to Real-Time Execution



What is Simulink Real-Time?

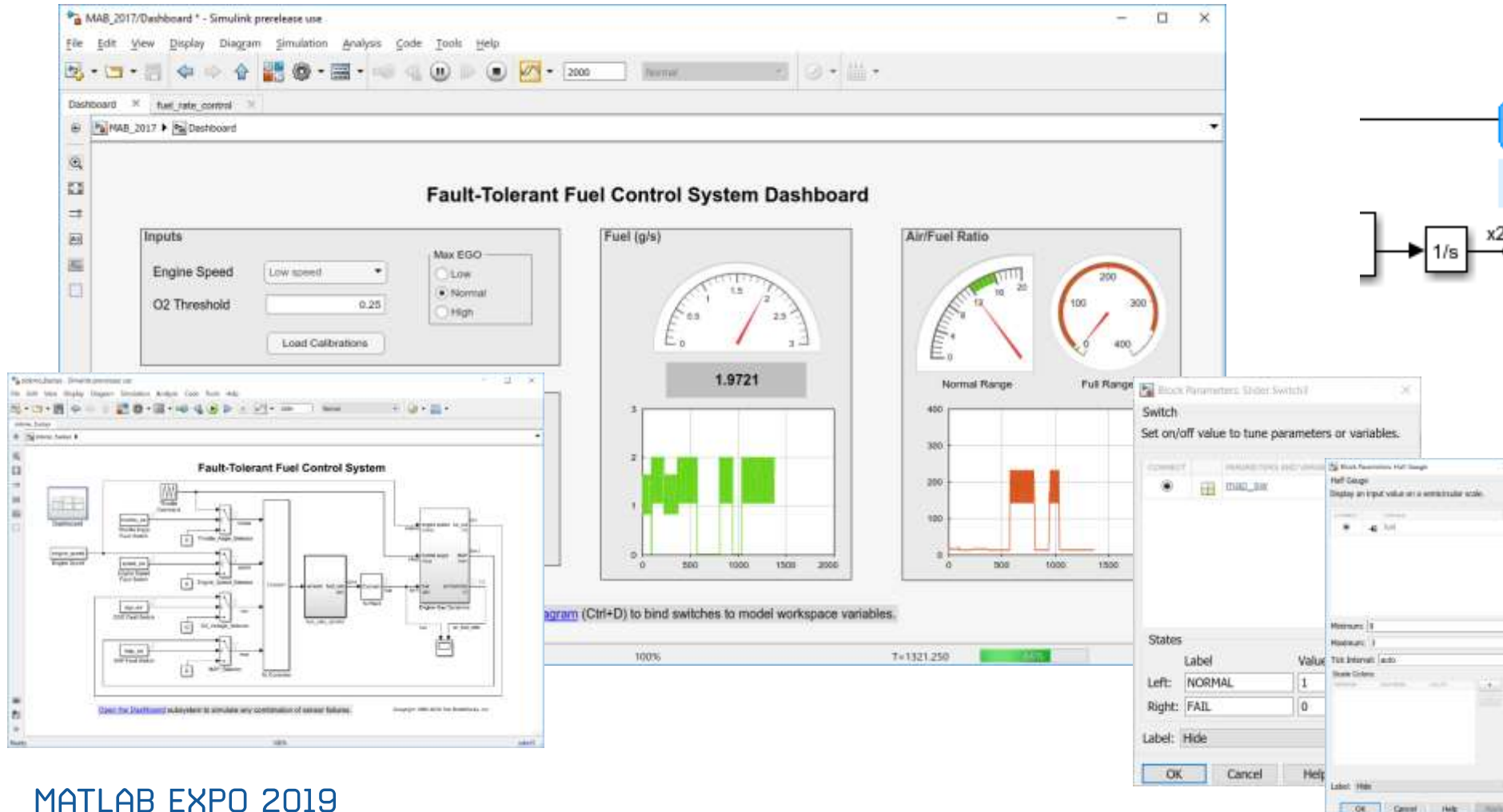
Connect to Your Physical System



- Support for a broad range of I/O types and communication protocols
- Easy drag and drop and configuration within a Simulink model

Fast-Track from Desktop to Real-Time Simulation and Testing

Add HMI and scope blocks to Simulink for real-time tuning, monitoring, and data logging



Speedgoat Machine



Real-time target machine

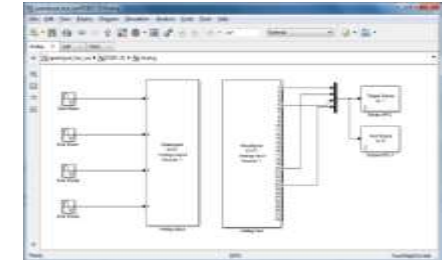


I/O modules installed in target machine

- Real-time target machines for office, lab, and field use
- 200+ commercial off-the shelf I/O modules
- Each target machine is configured to meet your I/O, environmental, and sample rate requirements
- Simulink Real-Time is expressly and exclusively designed to work together with Speedgoat hardware
- Most current MATLAB release always supported



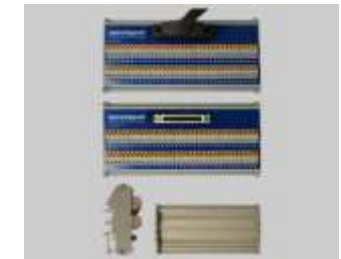
Simulink driver blocks



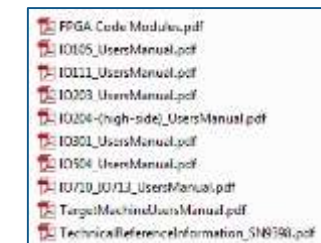
Simulink test models



I/O cables



Terminal boards



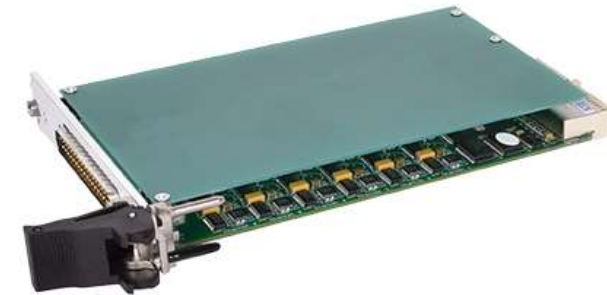
Documentation



Support, Training, Consulting,
and Warranty Services

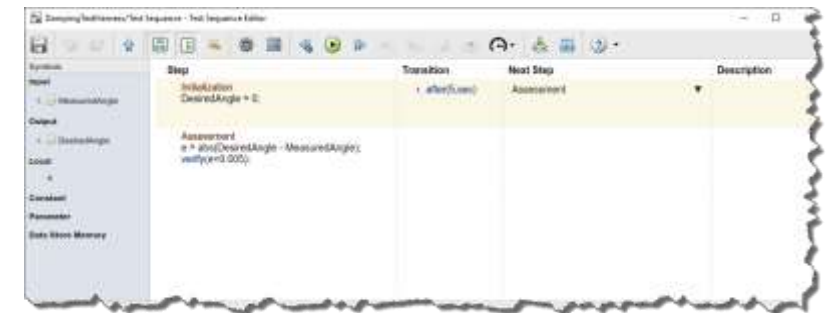
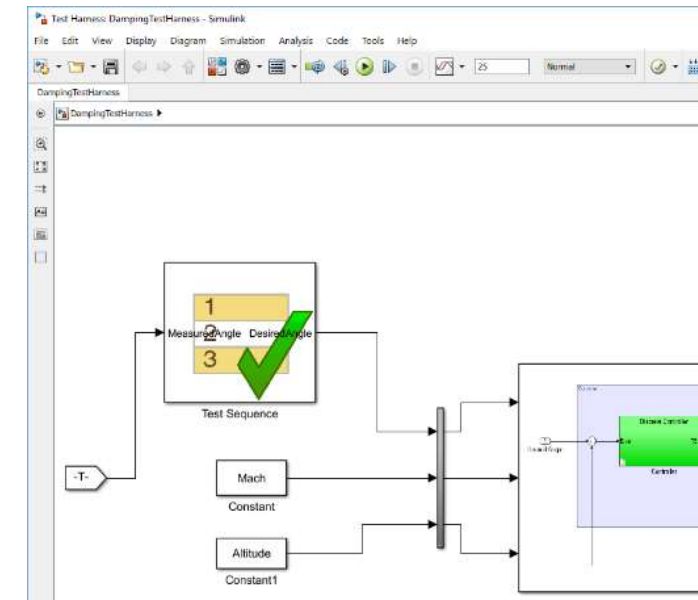
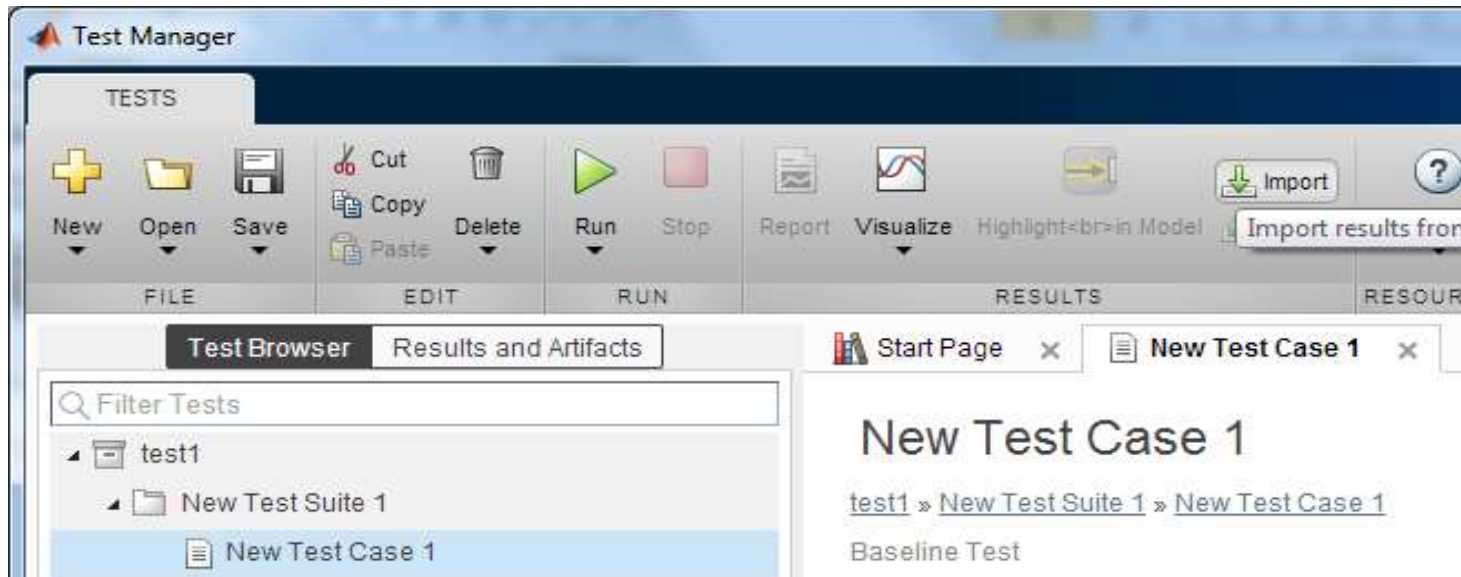
IO991: Battery Emulation I/O Module

- Key Features:
 - 6 independent isolated channels
 - Architecture allows series & parallel combinations
 - Independent power and sense lines
 - Voltage range of 0-7 V with 14-bit resolution
 - 300 mA source to load
 - 100 mA sink adjustable in 16 steps
- Enables:
 - Test automation and repeatable testing
 - Fault testing safely
 - Reuse testcases from earlier desktop testing



Automated Testing with Simulink Test

Real-Time Test Automation, Ideal for Hardware-in-the-Loop



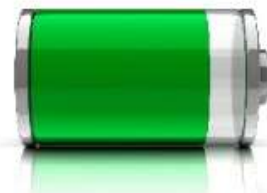
Download real-time application

Collect verification data



Target Computer

I/O



Physical System

LG Chem Develops AUTOSAR - and ISO 26262 - Compliant Software for a Hybrid Vehicle Battery Management System

Challenge

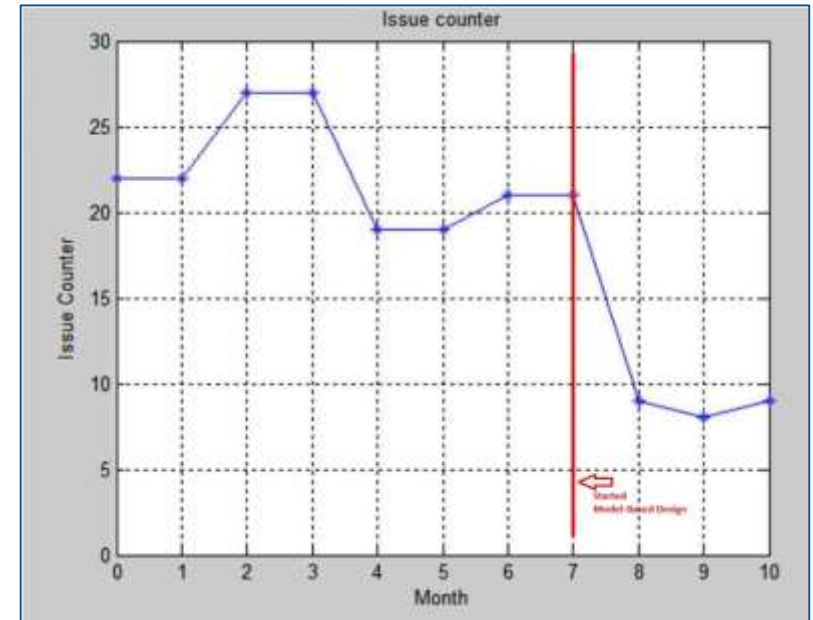
Design and implement production battery management system (BMS) software for the Volvo XC90 plug-in hybrid

Solution

Use Model-Based Design with MATLAB and Simulink to model, simulate, verify, and generate production code for AUTOSAR application layer software components

Results

- Existing library of core components reused languages
- Software issues reduced by more than 50%
- ISO 26262 ASIL C certification achieved



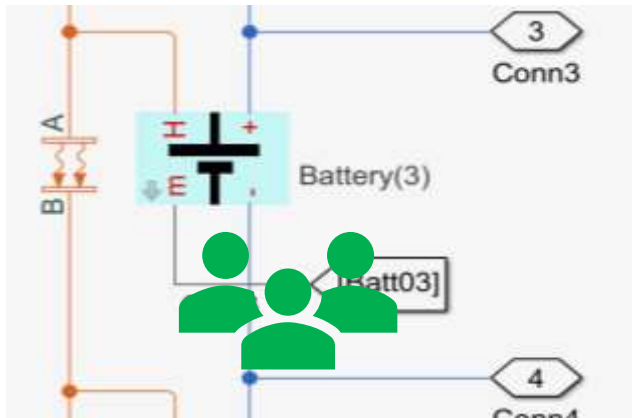
Issue counts for software releases before and after the adoption of Model-based Design.

"Model-Based Design with MATLAB and Simulink] enables us to increase component reuse, reduce manual coding, improve communication with our customers, and ultimately deliver higher-quality BMS in less time."

- Won Tae Joe, LG Chem

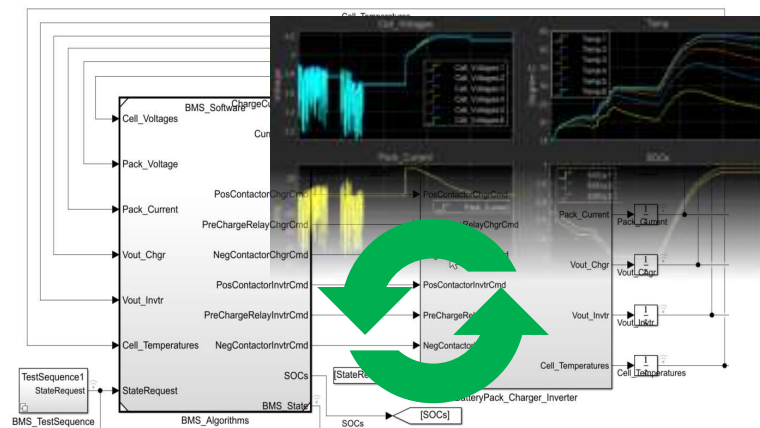
Summary

Collaboration
Physical Modeling



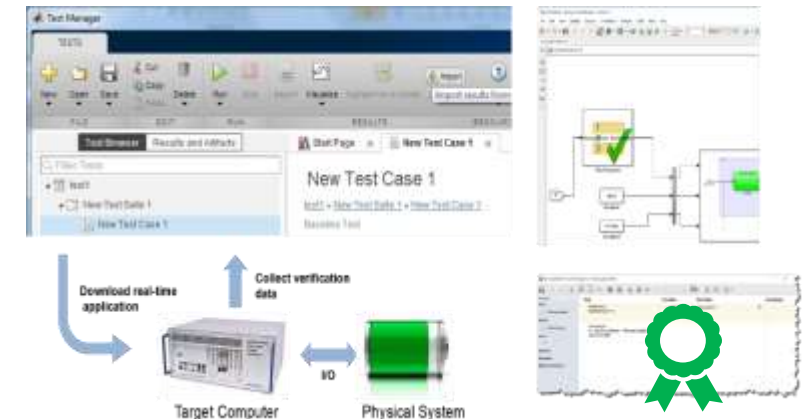
Collaborate Across
Domains

Short Iteration Cycles
Virtual Prototyping



Reduce Iteration Time

Safety Critical System
HIL Testing

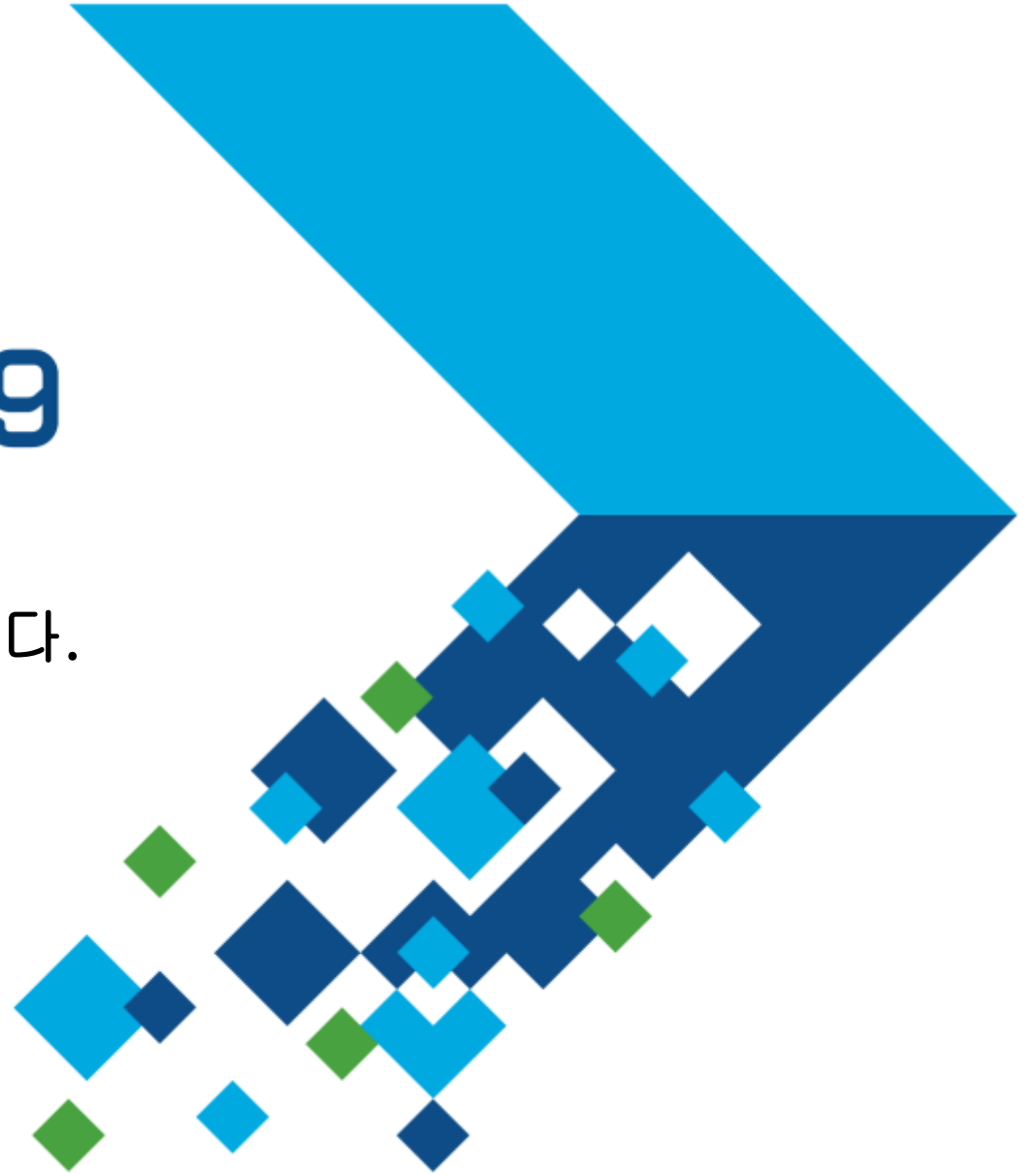


Functional Safety
Certification

MATLAB EXPO 2019

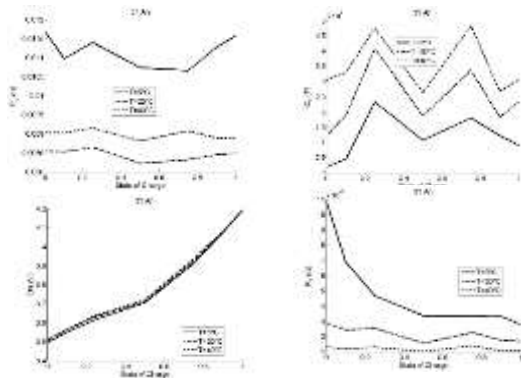
데모 부스와 상담부스로 질문 하시기 바랍니다.

감사합니다

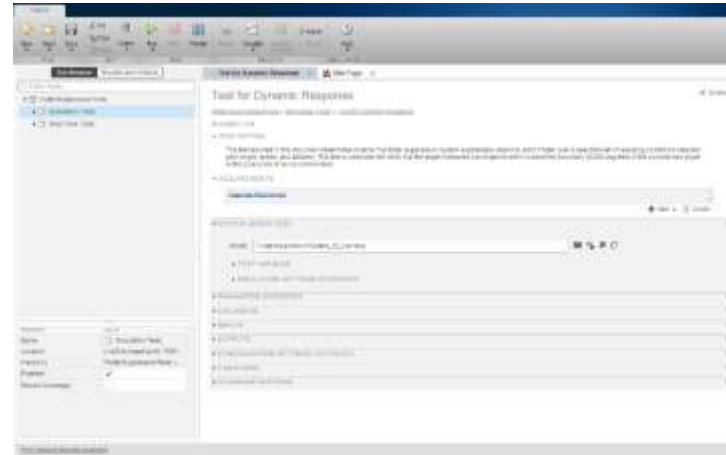


Taking It Further

Parameter Estimation



Test Automation



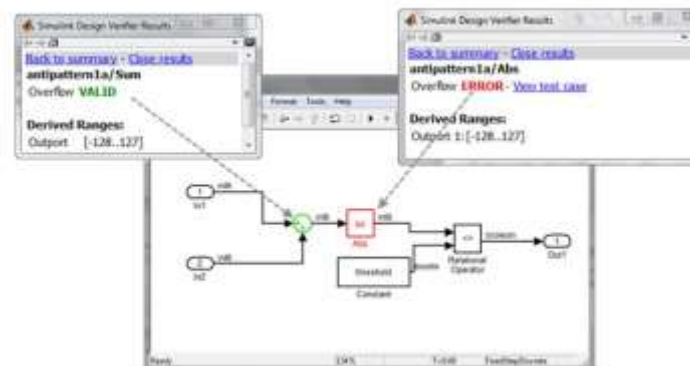
HDL Code Generation



Model Checks

- Modeling Standards for Secure Coding (CERT C, CWE, ISO/IEC TS 17961)
 - Check configuration parameters for secure coding standards
 - Check for blocks not recommended for C/C++ production code deployment
 - Check for blocks not recommended for secure coding standards
 - Check usage of Assignment blocks
 - Check for switch case expressions without a default case
 - Check for bitwise operations on signed integers
 - Check for equality and inequality operations on floating-point values
 - Check integer word lengths
 - Detect Dead Logic
 - Detect Integer Overflow
 - Detect Division By Zero
 - Detect Out Of Bound Array Access
 - Detect Violation of Specified Intermediate Minimum and Maximum Values

Design Error Detection



Model Coverage

Summary											
Model Hierarchy Complexity		Current Run			Delta			Cumulative			
		St	E1	MCDC	St	E1	MCDC	St	E1	MCDC	
1	Subsystem: antipattern Ia/Sum	31	34%	41%	17%	3%	3%	3%	3%	3%	17%
2	Logic	28	34%	38%	17%	3%	3%	3%	3%	3%	17%
3	IF Logic	24	34%	38%	17%	3%	3%	3%	3%	3%	17%
4	IF Logic	11	34%	38%	17%	3%	3%	3%	3%	3%	17%
5	IF Logic	4	34%	38%	17%	3%	3%	3%	3%	3%	17%
6	IF Logic	3	34%	38%	17%	3%	3%	3%	3%	3%	17%
7	IF Logic	2	34%	38%	17%	3%	3%	3%	3%	3%	17%
8	IF Logic	1	34%	38%	17%	3%	3%	3%	3%	3%	17%
9	IF Logic	1	34%	38%	17%	3%	3%	3%	3%	3%	17%
10	IF Logic	1	34%	38%	17%	3%	3%	3%	3%	3%	17%
11	Subsystem: antipattern Ia/Sum	31	34%	41%	17%	3%	3%	3%	3%	3%	17%
12	Subsystem: antipattern Ia/Sum	28	34%	38%	17%	3%	3%	3%	3%	3%	17%
13	Subsystem: antipattern Ia/Sum	24	34%	38%	17%	3%	3%	3%	3%	3%	17%
14	Subsystem: antipattern Ia/Sum	11	34%	38%	17%	3%	3%	3%	3%	3%	17%
15	Subsystem: antipattern Ia/Sum	4	34%	38%	17%	3%	3%	3%	3%	3%	17%
16	Subsystem: antipattern Ia/Sum	3	34%	38%	17%	3%	3%	3%	3%	3%	17%
17	Subsystem: antipattern Ia/Sum	2	34%	38%	17%	3%	3%	3%	3%	3%	17%
18	Subsystem: antipattern Ia/Sum	1	34%	38%	17%	3%	3%	3%	3%	3%	17%
19	Subsystem: antipattern Ia/Sum	1	34%	38%	17%	3%	3%	3%	3%	3%	17%
20	Subsystem: antipattern Ia/Sum	1	34%	38%	17%	3%	3%	3%	3%	3%	17%

Learn More about Battery Management System

WHITE PAPER

Developing Battery Management Systems with Simulink and Model-Based Design

<https://www.mathworks.com/discovery/battery-models.html>



Battery Modeling

Search Math

Model batteries when designing battery-powered systems

Technical Articles and Newsletters

Search Technical Artic

Technical Articles

Modeling and Simulating Battery Performance for Design Optimization

By Cecilia Wang, Romeo Power

Battery Modeling

Search MathWorks.com

Examples and How To

- Battery Management System Development in Simulink (7:17) - Video
- Lithium Battery Model with Thermal Effects for System-Level Analysis (24:05) - Video
- Automating Battery Model Parameter Estimation using Experimental Data (25:28) - Video
- Real-Time Simulation of Battery Packs Using Multicore Computers (22:57) - Video
- Battery Simulation and Controls - Consulting Services
- Sifting Through Multisource Data for Safer Battery Materials with Machine Learning - Article

Papers

- High Fidelity Electrical Model with Thermal Dependence for Characterization and Simulation of High Power Lithium Battery Cells - IEEE 2012
- Battery Model Parameter Estimation Using a Layered Technique - SAE 2013
- Simplified Extended Kalman Filter Observer for Battery SOC Estimation - SAE 2013
- Battery Pack Modeling, Simulation, and Deployment on a Multicore Real Time Target - SAE 2014
- Model-Based Parameter Identification of Healthy and Aged Li-ion Batteries for Electric Vehicle Applications - SAE 2015