

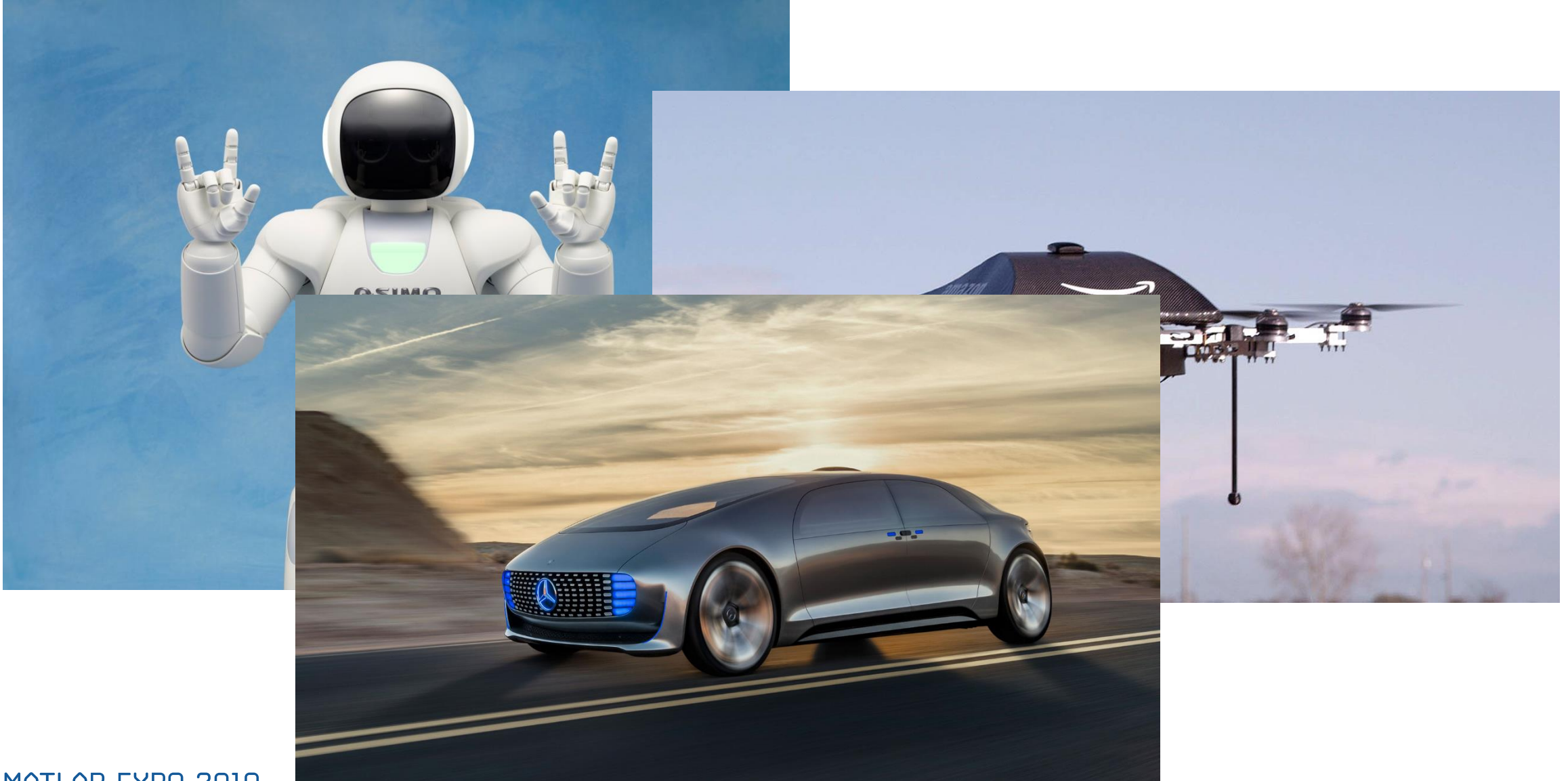
# MATLAB EXPO 2019

## Developing Battery Management System using Simulink

Prasanna Deshpande



# Smarter systems require efficient battery



# Challenges in Battery Modeling and Management

## Battery Pack

- Modeling electro-chemical cell and its thermal dependency
- Scaling up the cell model to a battery pack model



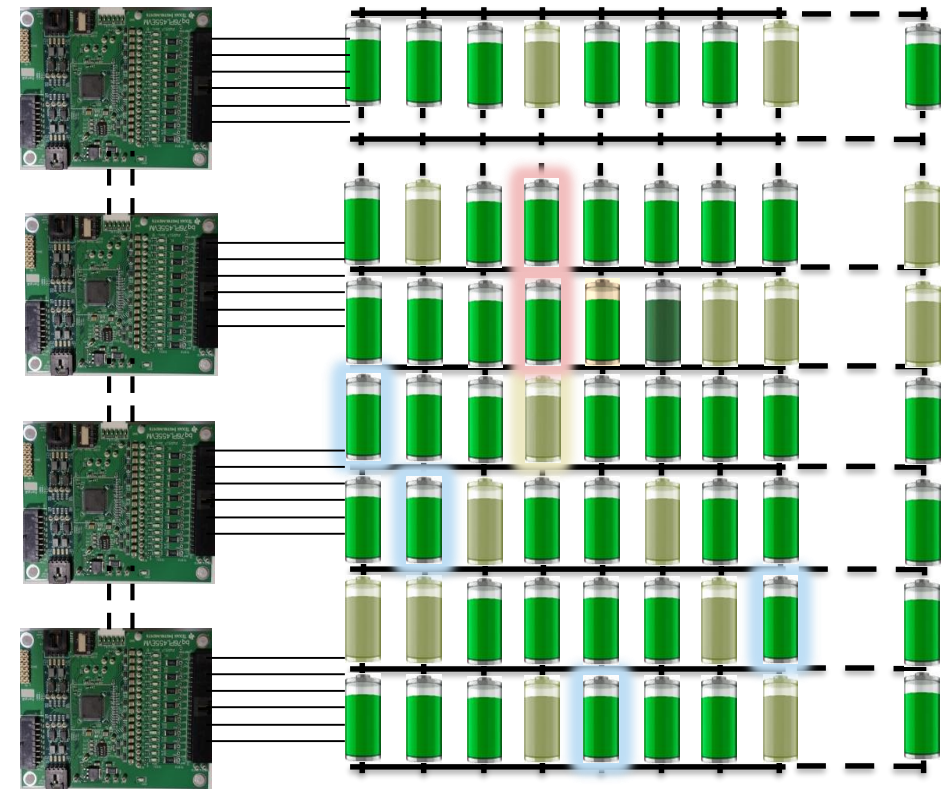
- Modeling electro-chemical cell and its thermal dependency
- Scaling up the cell model to a battery pack model

# Challenges in Battery Modeling and Management

## Electronics

- Block / module voltage & temperature measurement
- Cell balancing, Contactor & pre-charge circuits

## Battery Pack



- Block voltage & temperature measurement
- Cell balancing, Contactor & pre-charge circuits
- Modeling electro-chemical cell and its thermal dependency
- Scaling up the cell model to a battery pack model

# Challenges in Battery Modeling and Management

Current & Power Limits

Fault Handling

- How to design and verify different Battery Management functions?

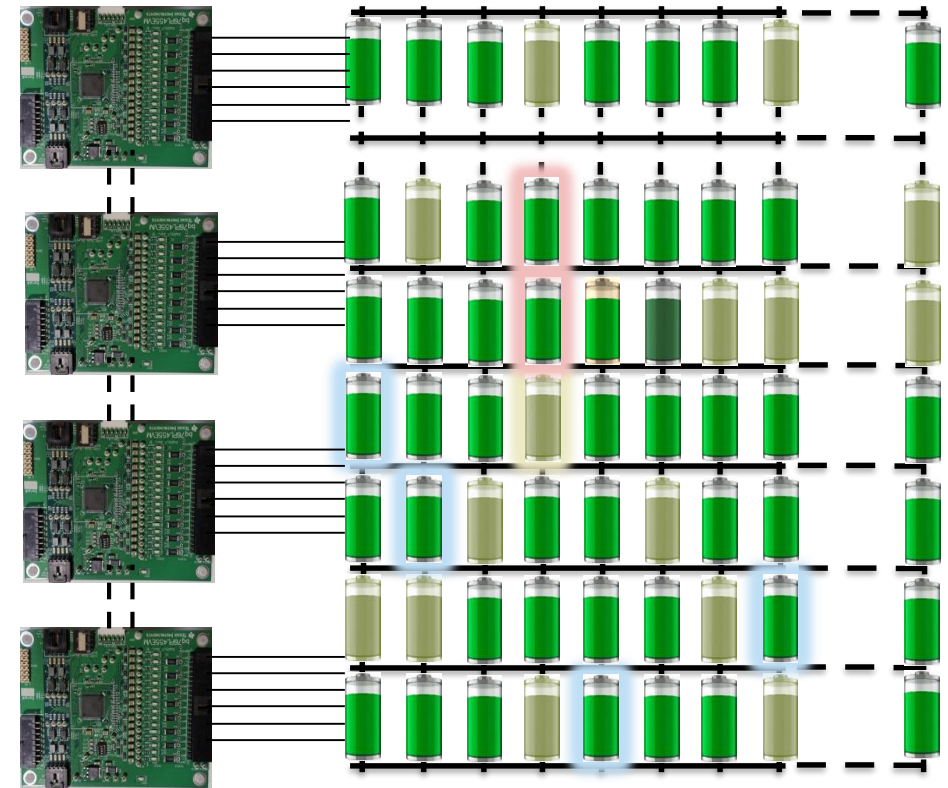
SoC Estimation

Thermal Management

Contactor Management

Electronics

Battery Pack



- Block voltage & temperature measurement
- Cell balancing, Contactor & pre-charge circuits
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- Scaling up the cell model to a battery pack model



# Challenges in Battery Modeling and Management

## Software

```

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));
}

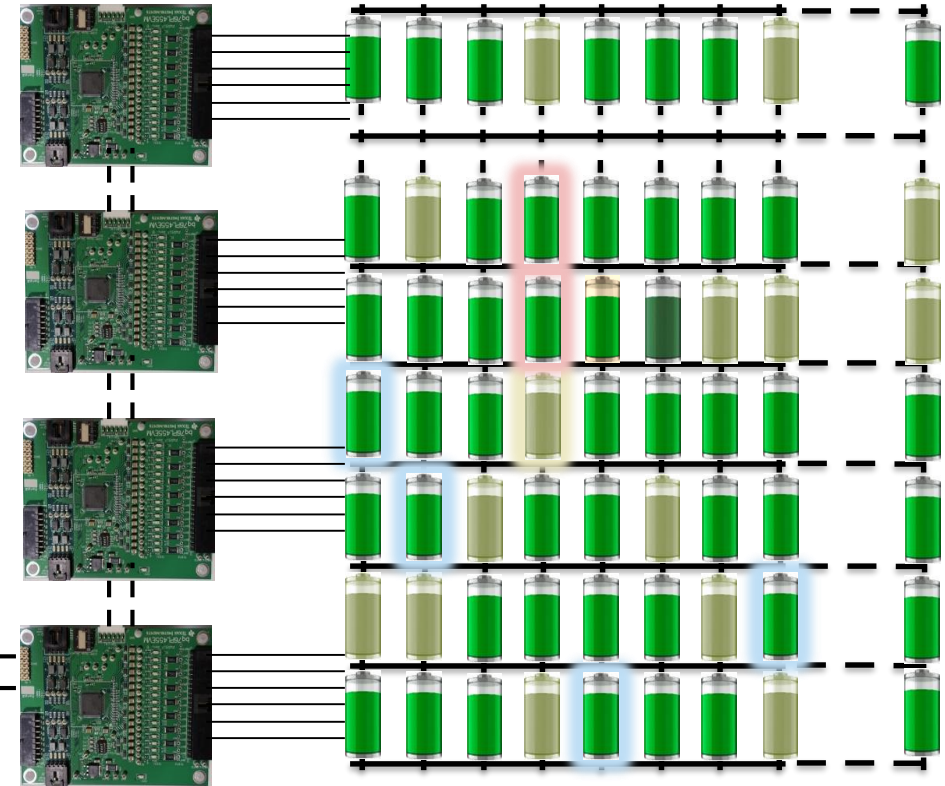
if (((uint32_T)State_Machine_DW.is_active_c2_State_Machine) == 0U) {
    State_Machine_DW.is_active_c2_State_Machine = 1U;
    State_Machine_DW.is_MainStateMachine = State_Machine_IN_Standby;
    *rty_BMS_State = 0;
    State_Machine_DW.MonitorCurrLimMode = MonitorCurrLimModeType_NoCurrLimFault;
    State_Machine_DW.MonitorCellVoltageMode =
        MonitorCellVoltageModeType_NoCellVoltFault;
    State_Machine_DW.Delta = (real32_T)fabs((real_T)((real32_T)
        ((*rtu_Pack_Voltage) - sum_gyOCKAG3(rtu_Cell_Voltages))));
    State_Machine_DW.FaultPresent = false;
}

```



How to design and verify different  
Battery Management functions?

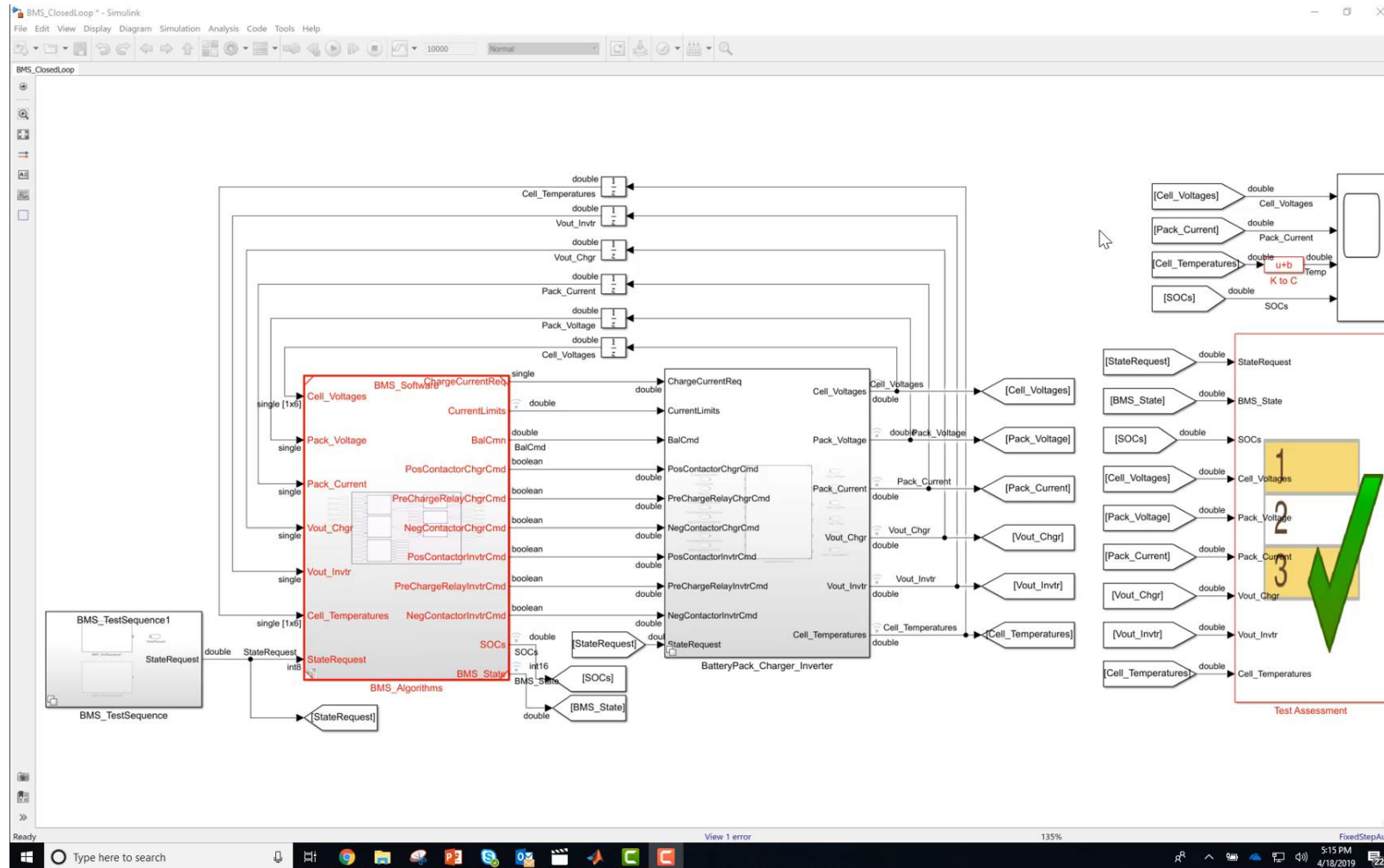
## Electronics



## Battery Pack

- Block voltage & temperature measurement
- Cell balancing, Contactor & pre-charge circuits
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- Scaling up the cell model to a battery pack model

# Solution: System level simulation model for Battery



# Agenda

- Capturing Dynamics of Battery Cell → Large Battery Pack
- Modeling the electronics: Contactors, Inverters, Loads
- Developing Battery Management Algorithms
- Generating C/C++ Code from BMS Algorithms
- Perform HIL Testing for BMS ECUs

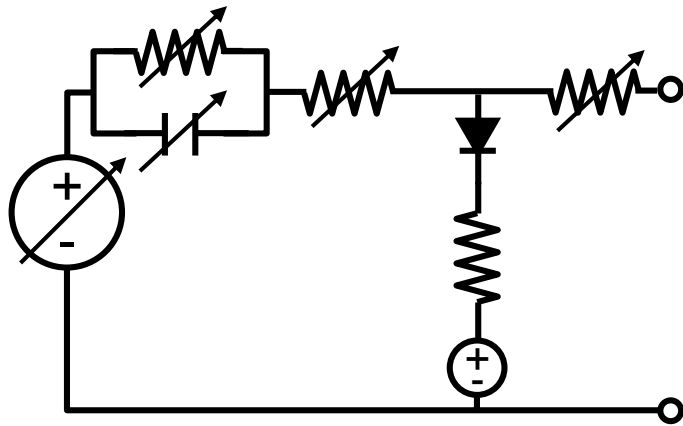


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# Battery cell modeling as RC equivalent circuit

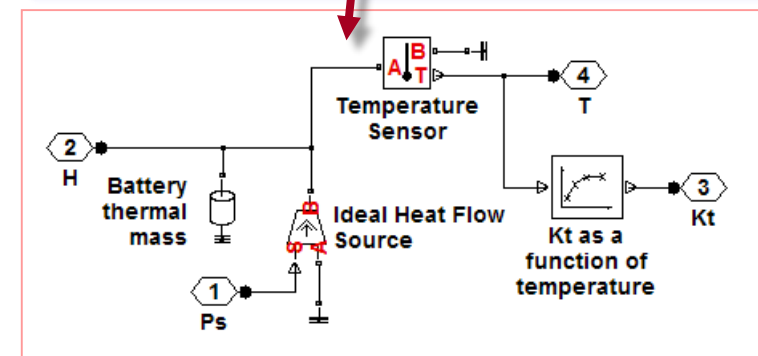
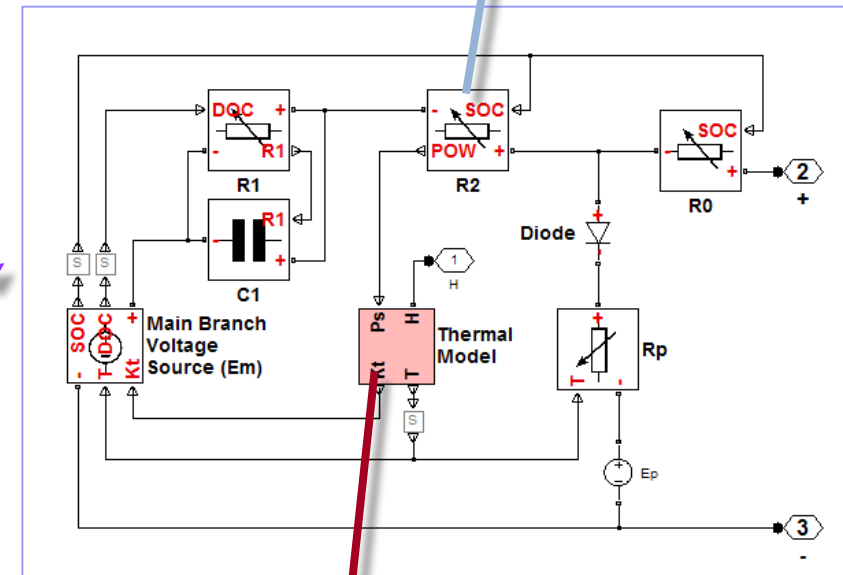
- 1RC Equivalent circuit representation of Battery cell
- Resistors, capacitor, and voltage source are dependent upon SOC and temperature



Battery cell equivalent discharge circuit

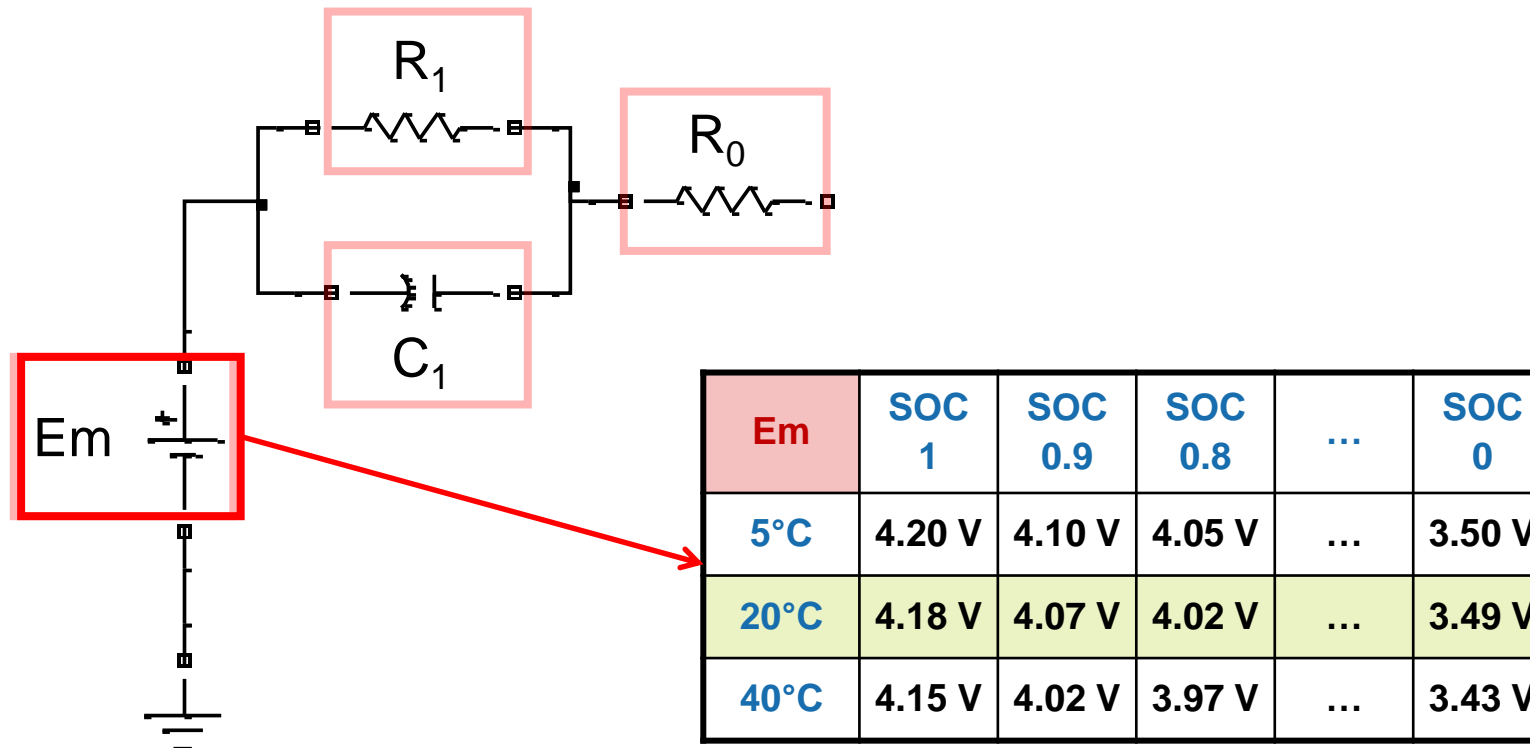
equations

```
v == i*R20*exp(A21*(1-  
pow == v*i;  
end
```

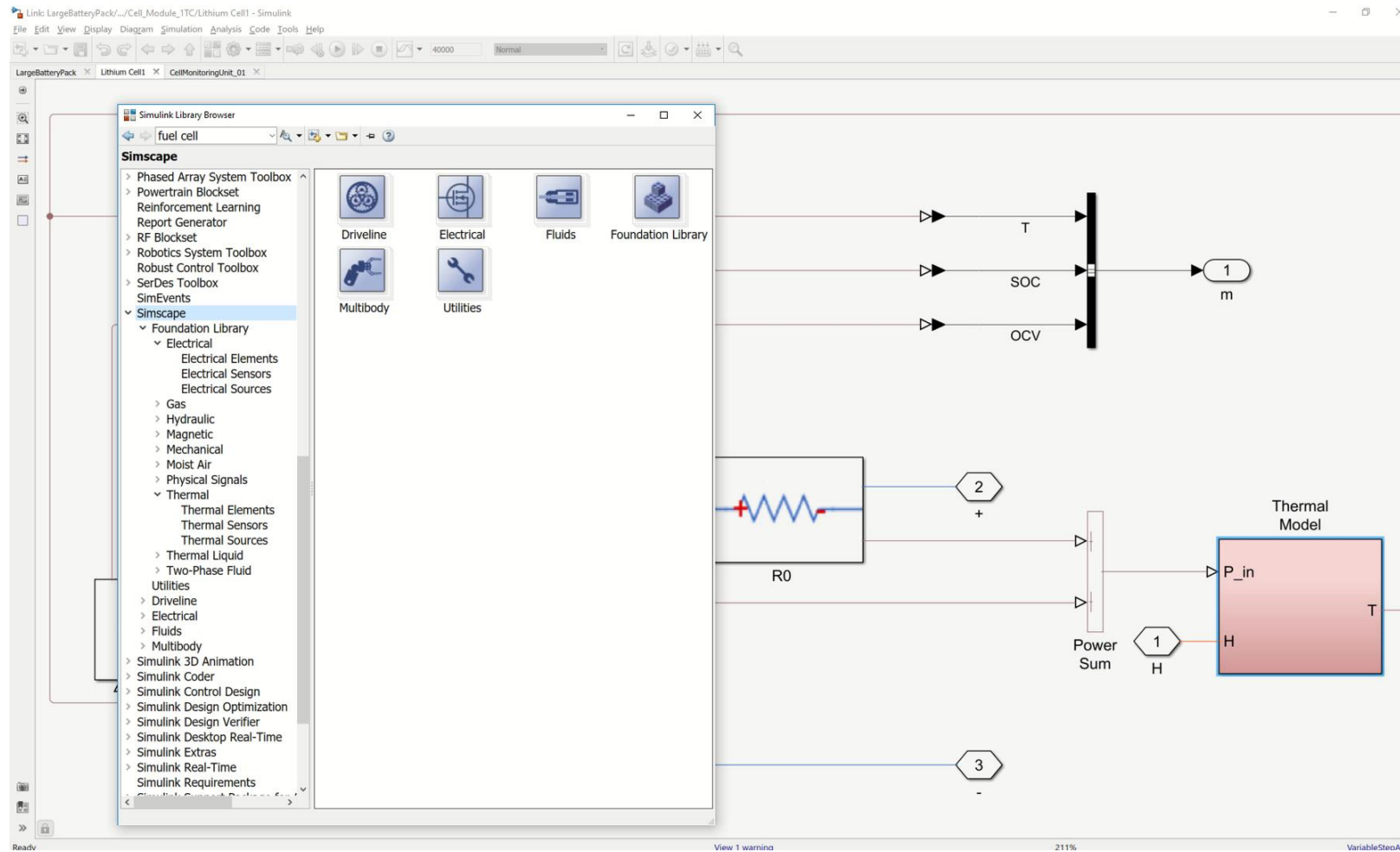


# Circuit Elements – Lookup Tables

- Lookup tables can be used for each circuit element
  - Values will characterize the battery performance

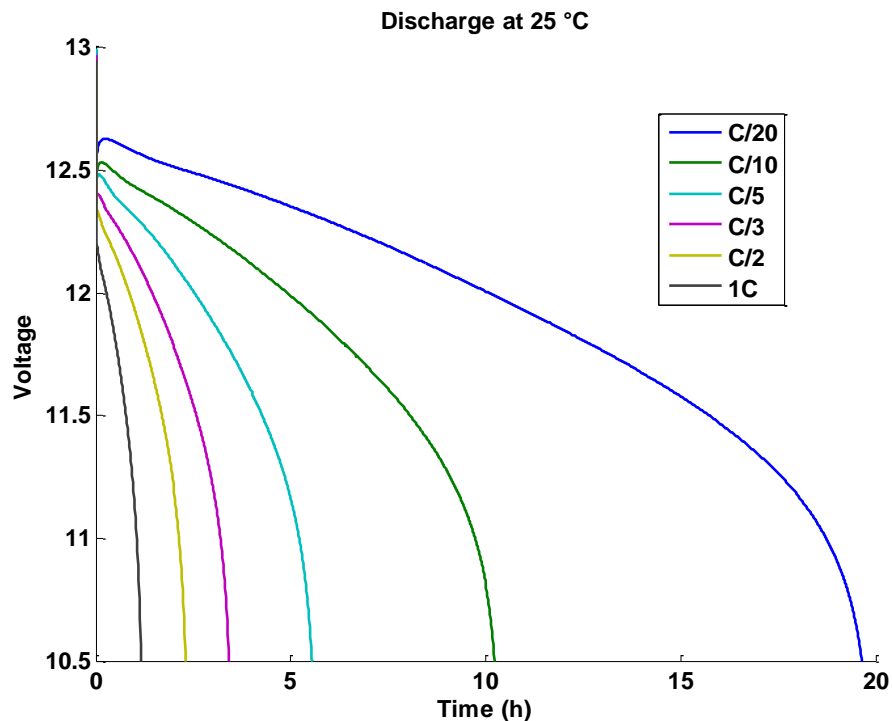


# Multi-domain modeling of battery pack using Simscape



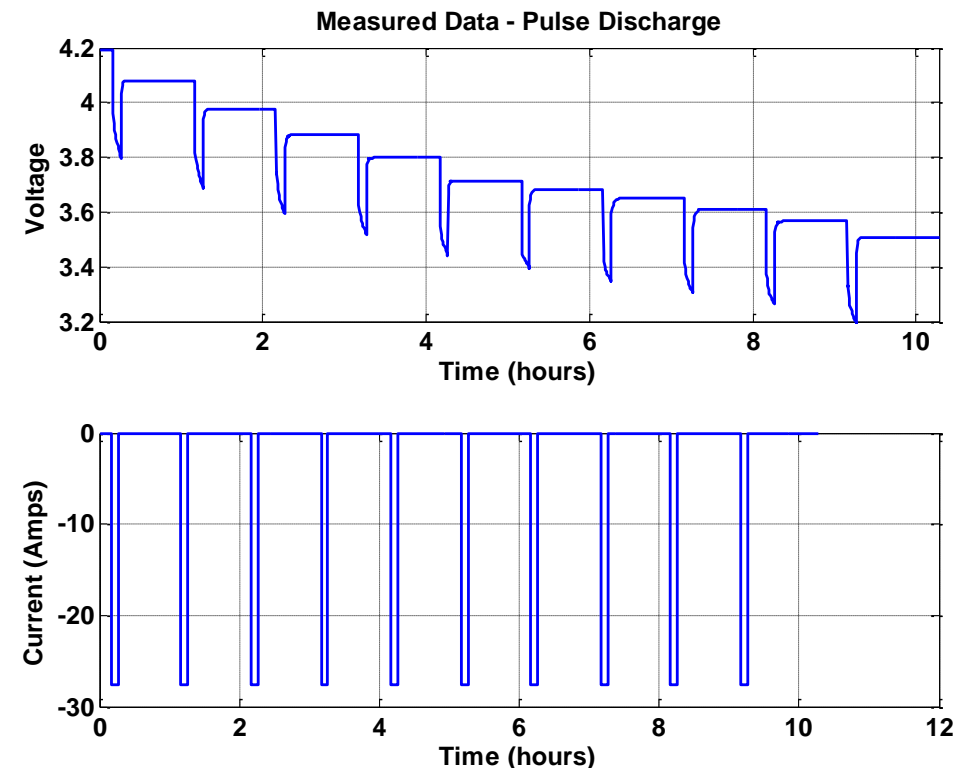
# Battery data is collected by conducting a series of tests with the battery

- Used to determine battery capacity
  - Multiple Temperatures
  - Multiple Currents

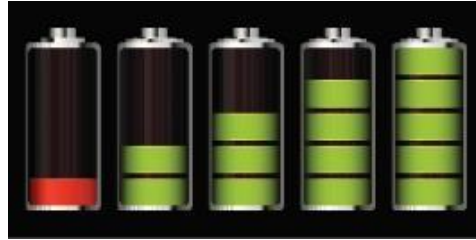


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- Used to determine battery dynamics
  - Range of SOC
  - Multiple Temperatures
  - Multiple Currents
  - Discharge and Charge Curves



# Discovery Page on MathWorks website: Battery modeling



## 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

Javier Gazzarri, Robyn Jackey  
MathWorks

**SAE International**

### Battery Model Parameter Estimation Using a Layered Technique: An Example Using a Lithium Iron Phosphate Cell

2013-01-1547

Published  
04/08/2013

Robyn Jackey, Michael Saginaw, Pravesh Sanghvi and Javier Gazzarri  
MathWorks

Tarun Huria and Massimo Ceraolo  
Università di Pisa

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**SAE**  
INTERNATIONAL®

### Model-Based Parameter Identification of Healthy and Aged Li-ion Batteries for Electric Vehicle Applications

2015-01-0252  
Published 04/14/2015  
Copyright © 2015 SAE International  
doi:10.4271/2015-01-0252  
[saeltpow.saejournals.org](http://saeltpow.saejournals.org)



# Shipping examples in Simscape

The screenshot displays the Simscape Examples documentation page. The left sidebar contains a 'CONTENTS' section with a 'Category' list. The main content area shows three examples, each with a circuit diagram and a description. The three examples are highlighted with a red box:

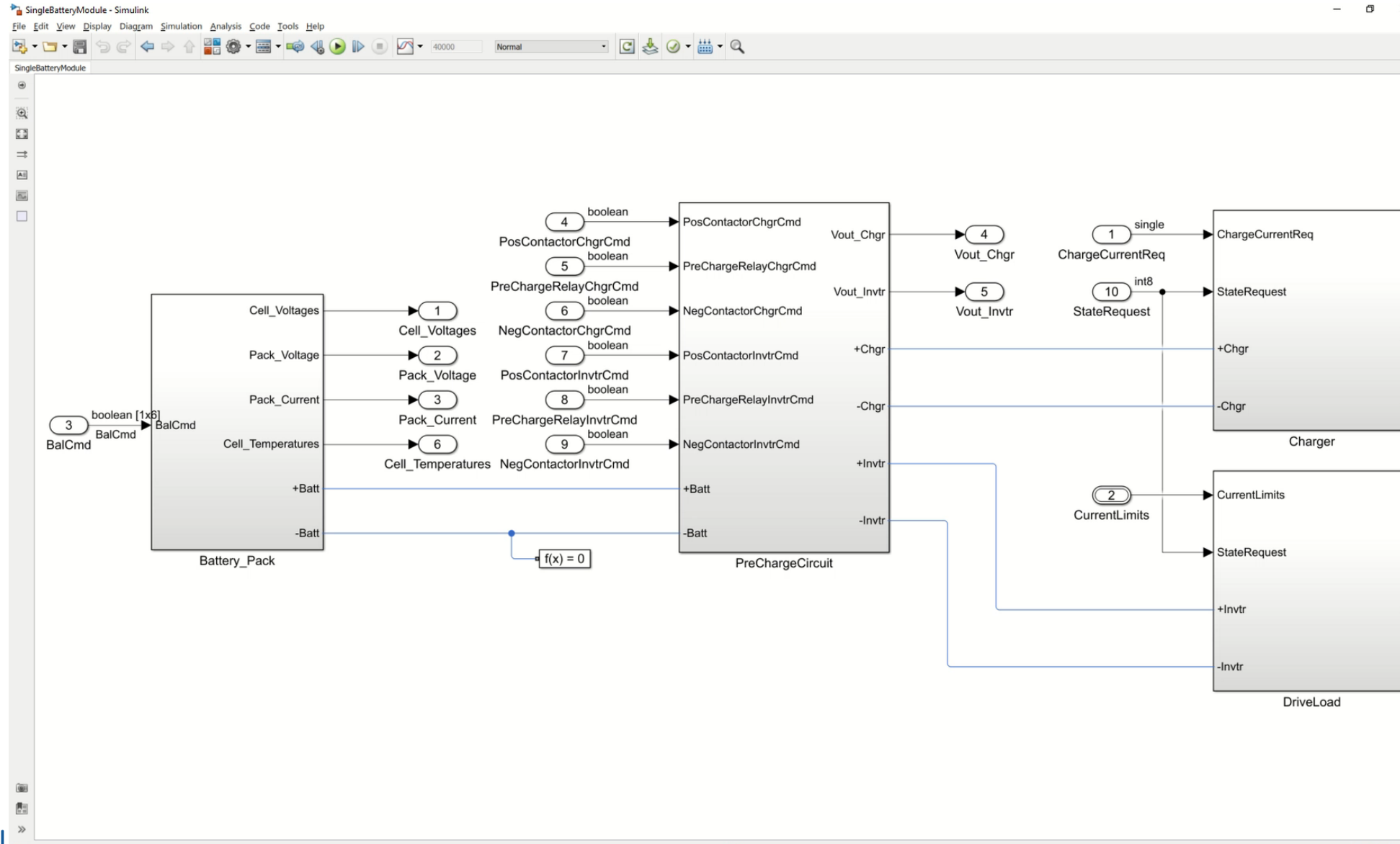
- Lithium-Ion Battery Pack With Fault**: Simulate a battery pack consisting of multiple series-connected cells in an efficient manner. It also shows how a fault can be introduced into one of the cells.
- Lithium Battery Cell - One RC-Branch Equivalent Circuit**: Model a lithium cell using the Simscape™ language to implement the elements of an equivalent circuit model with one RC branch. For the model, parameters values are set to match the 1.5V variant of this motor. The model implements the nonlinear equations of the equivalent circuit components.
- Lithium Battery Cell - Two RC-Branch Equivalent Circuit**: Model a lithium cell using the Simscape™ language to implement the elements of an equivalent circuit model with two RC branches. For the model, parameters values are set to match the 1.5V variant of this motor. The model implements the nonlinear equations of the equivalent circuit components.

file:///C:/Program%20Files/MATLAB/R2019a/help/physmod/simscape/examples/lead-acid-battery.html

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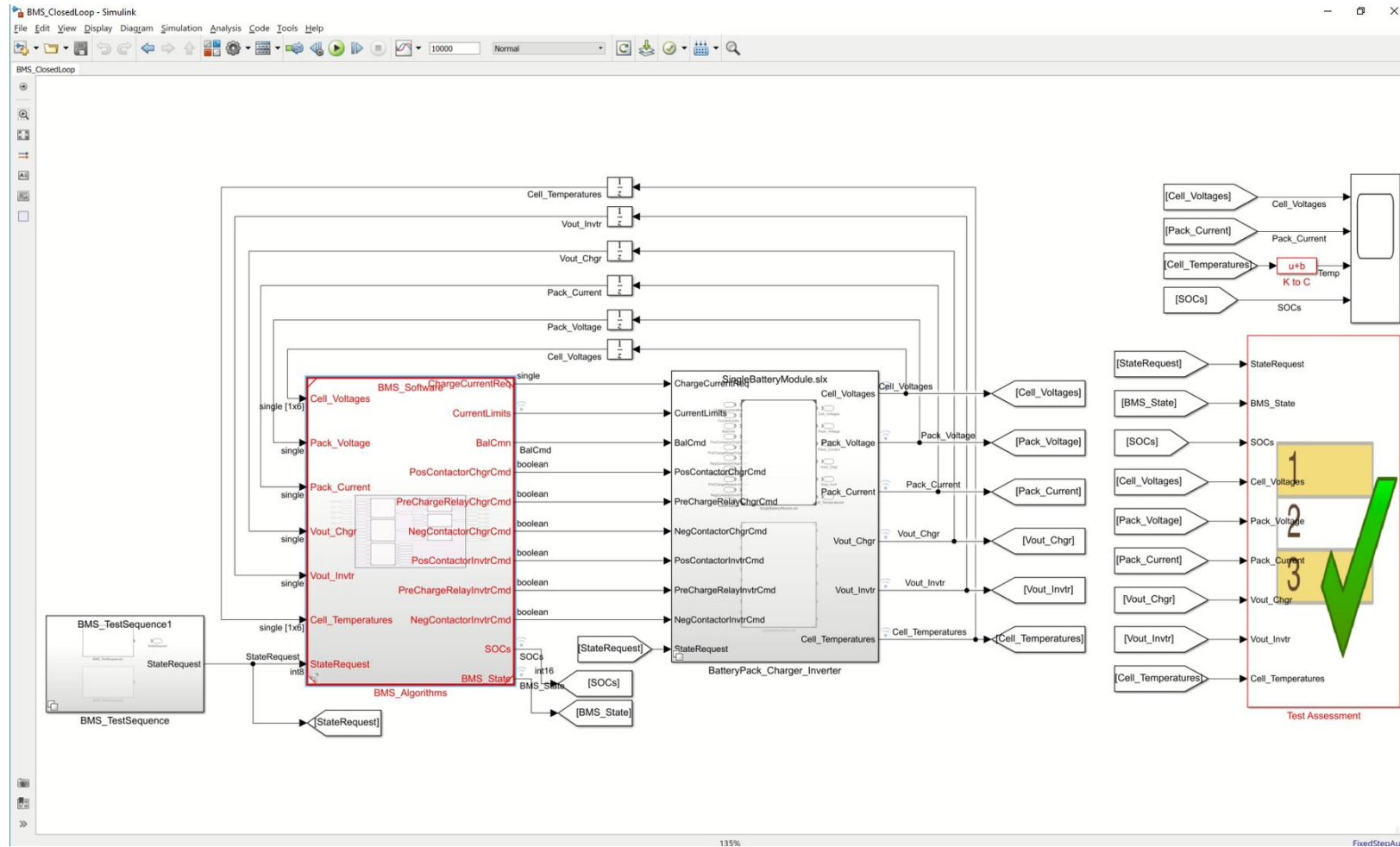
# Role of electronics: Cell voltage measurement and pre-charge



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# Battery Management Functions



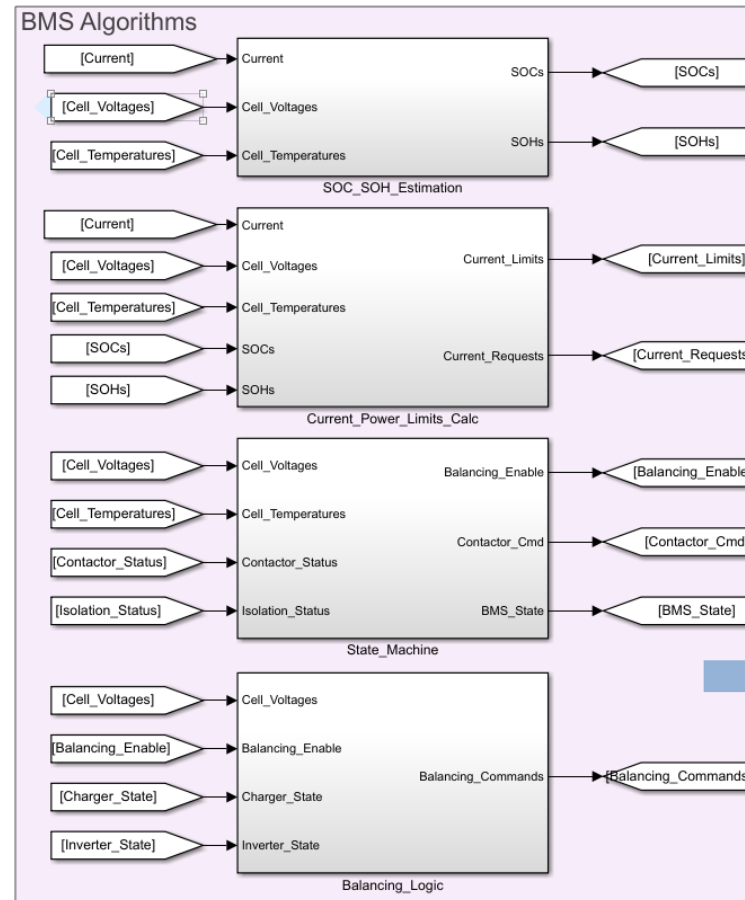
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# Generate C/C++ Code From BMS Algorithm Models

- Generate target optimized C/C++ code using Embedded Coder
- Fine-tune code optimizations, package and build generated code



Web Browser - BMS\_Software\_Golden Code Generation Report

BMS\_Software\_Golden Code Generation Report

Location: file:///C:/Users/cpatel/MATLAB/Projects/BMS\_HIL\_Demo/src/BMS\_Software\_Golden\_

**Contents**

- [Summary](#)
- [Subsystem Report](#)
- [Code Interface Report](#)
- [Traceability Report](#)
- [Static Code Metrics Report](#)
- [Code Replacements Report](#)

**Generated Code**

[+] Main file

- [ert\\_main.c](#)

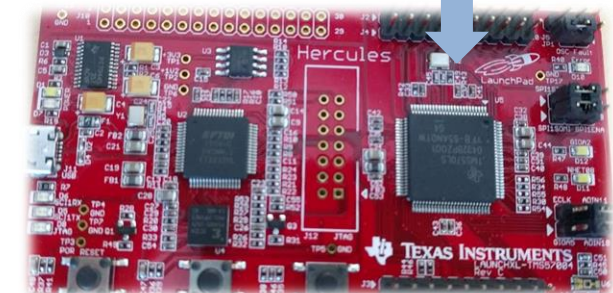
[+] Model files

- [BMS\\_Software\\_Golden.c](#)
- [BMS\\_Software\\_Golden.h](#)
- [BMS\\_Software\\_Golden\\_private](#)
- [BMS\\_Software\\_Golden\\_types](#)

[+] Shared files (3)

```

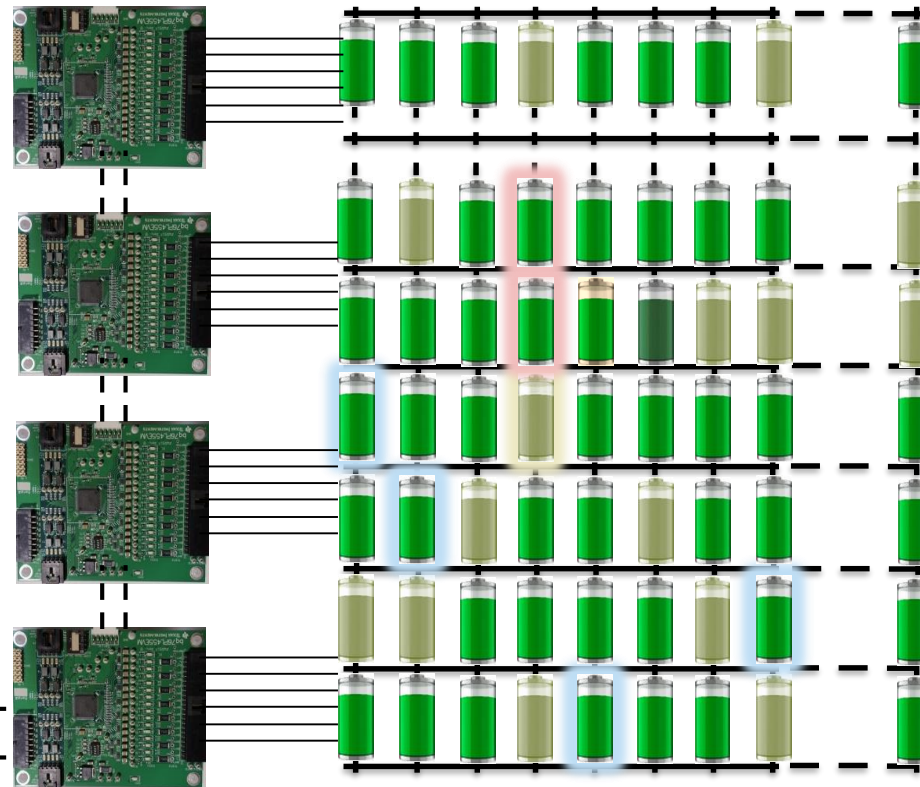
132 }
133
134 /* Model step function */
135 void BMS_Software_Golden_step(CellVoltages Cell_Vo
136 real32_T *ChargeCurrentReq, CurrentLimits *Curre
137 real32_T *BalSw2, real32_T *BalSw3)
138 {
139     real32_T ex;
140     real_T sortV[3];
141
142     /* Copy value for root input 'sRoot>/Cell Volta
143     BMS_Software_Golden_U.Cell_Voltages = Cell_Volta
144
145     /* Copy value for root input 'sRoot>/enCharging
146     BMS_Software_Golden_U.enCharging = enCharging;
147
148     /* Chart: 'sRoot>/BMS_Logic' incorporates:
149     * Input: 'sRoot>/Cell_Voltages'
150     * Input: 'sRoot>/enCharging'
151     * Output: 'sRoot>/ChargeCurrentReq'
152     */
153     if (((uint32_T)BMS_Software_Golden_DW.temporalCo
154         BMS_Software_Golden_DW.temporalCounter_i1 = (u
155         BMS_Software_Golden_DW.temporalCounter_i1) +
156     }
157
158     /* Gateway: BMS_Logic */
159     /* During: BMS_Logic */
160     if (((uint32_T)BMS_Software_Golden_DW.is_active_
161     {
162         /* Entry: BMS_Logic */
163         BMS_Software_Golden_DW.is_active_c2_BMS_Softwa
  
```



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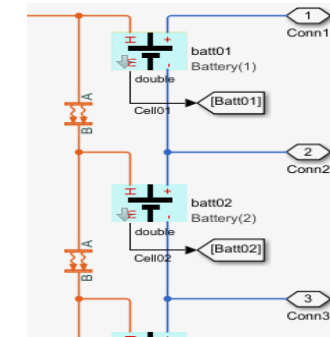
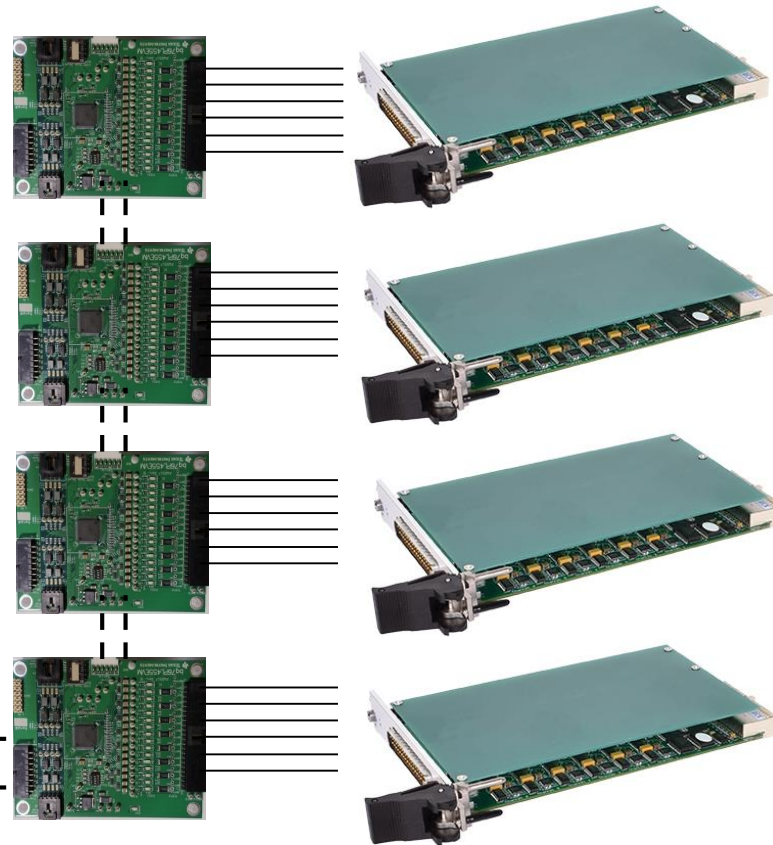
# Perform HIL Testing for BMS ECUs (1/3)



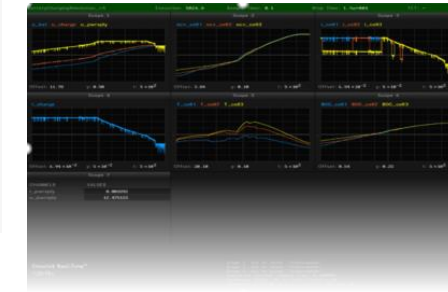
## Testing ECUs with Battery Cells

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

# Perform HIL Testing for BMS ECUs (2/3)



Automatic Code Generation



1001011100101

Wiring and Signal Conditioning



# Perform HIL Testing for BMS ECUs (3/3)

## 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

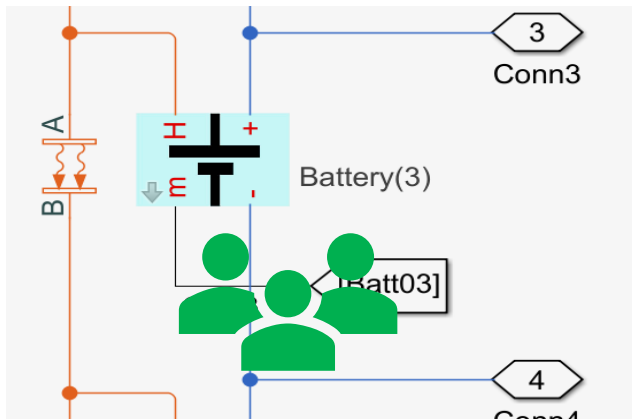
### Enables:

- Test automation and repeatable testing
- Fault testing safely
- Reuse testcases from earlier desktop testing



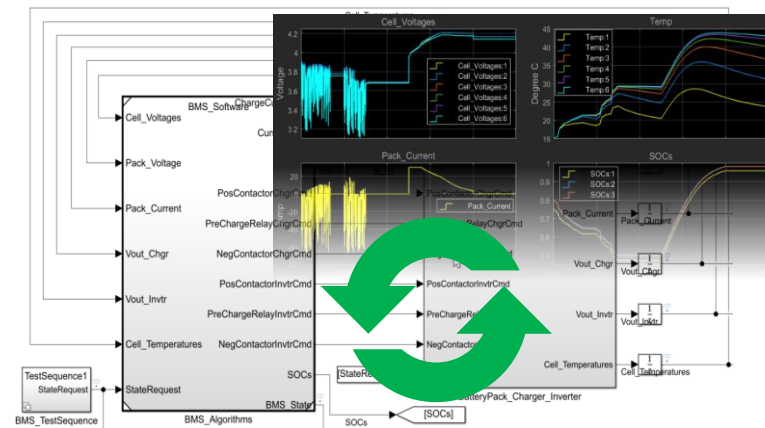
# Summary

## Multi-Domain



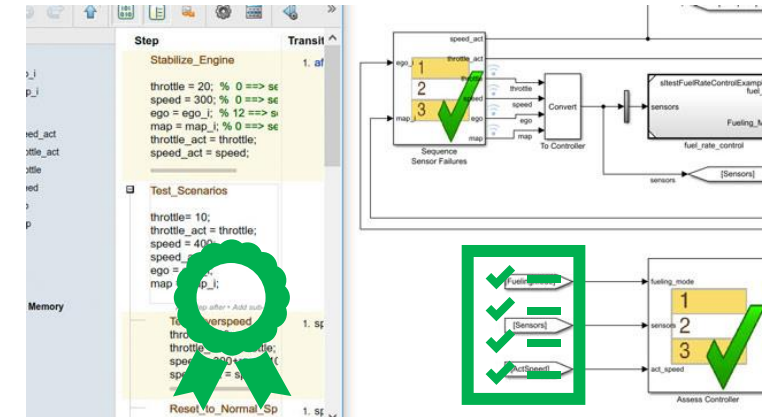
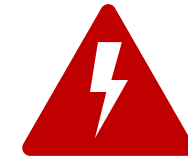
**Collaborate Across Domains**

## Long Iteration Cycles



**Reduce Iteration Time**

## Safety Critical System



**Functional Safety Certification**



# 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