MATLAB EXPO 2019

Developing Battery Management System using Simulink

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Agenda

- What is BMS and what engineers worry about?
- Start with single battery cell and build a pack
- Design BMS algorithms
- Generate code and deploy
- Model V&V
- Hardware-in-Loop testing
- Summary



What is BMS?



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

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Block Voltage, **Temperature Measurement Cell Diagnostic Cell Balancing**



Motivation





Where do we start?



Gain insight into cell behavior and model it



Equivalent Circuit Model



 $[E_x R_x C_x] = f(SOC, Temperature...)$



Battery Cell Blocks in Simscape

- Chose block for fidelity and simulation speed
- Parameterize as function of SOC & Temperature
- Add thermal and fade effects
- Create custom battery blocks using Simscape language or Simulink

	Main	Dynamics	Fade	Thermal	Variable						
	Vector	es, SOC:	[0, .25, .7								
	Temperature dependent tables:										
	Vector of temperatures, T:										
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BattCun

BattTemp





Parameter Estimation





Parameter Estimation





Look-up Tables



Repeat parameter estimation for each Temperature break-point in LUT

SOC

0

....

MathWorks[®]

Start with Simulation Battery Cell $\leftarrow \rightarrow$ Large Battery Pack







Evaluate System Behavior







Discharge + Charge





Discharge Only



Charge Only



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Evaluate SOC Estimation



Generate C/C++ Code From BMS Algorithm Models



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Did we generate code too early? Is this ready to ship?

What if there are bugs?

Where are they? How do we find them?





Why Testing, Verification and Validation

Safety Critical System

Functional Safety Certification





Typical Development Workflow





Challenge: Errors introduced early but found late





Validate Design via Desktop Simulation





Model-Based Design Workflow





Model-Based Design Verification Workflow





How do we test?





Systematic Functional Testing with Simulink Test





Create Test Harnesses

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Systematic Functional Testing with Simulink Test

Use Test Manager to:

- Author, execute, manage test cases
- Review, export, report

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📣 Test Manager

FORMAT

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Manage and Organize TestCases





How do we know we have enough test?





How do we know we have enough test?





Integrate with requirements tools and author requirements



- Import from:
 - Word / Excel
 - IBM® Rational® DOORS®
 - ReqIF[™] standard
- Update synchronizes changes from source
- Edit and add further details to import
- Author requirements
- Export ReqIF
 - Enables roundtrip with external tools



Import External Requirements & Author New Requirements





SW Requirements - Implementation Status

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iew: Requirements •		A # + 1	Charles (Charles)			(JOBINI)		
lew: Requirements ▼	ID #30 #31 #76 #77	Summary State Machine Architecture BMS State and Charging Mode BMS Fault Monitoring Current Limitation	calculation					



Track Implementation and Verification

Requirements - crs_controller	B C			Search	
Index	ID	Summary	Implemented	Verified	
∽ 🖫 crs_req_func_spec	—	_			
~ 🖹 1	#1	Driver Switch Request Handling			
₿ 1.1	#2	Switch precedence			
■ 1.2	#3	Avoid repeating commands			
> 🖹 1.3	#4	Long Switch recognition			
🖹 1.4	#7	Cancel Switch Detection			
₿ 1.5	#8	Set Switch Detection			
₿ 1.6	#9	Enable Switch Detection			
			Implementation Status	Verification Status]
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MATLAB EXPO	2019			Missing	



Requirements Verification with Simulink





Link Tests to Requirements

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How do we know we have enough test?





Coverage Analysis to Measure Testing





Measure Model Coverage

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Addressing Missing Coverage



Simulink Design Verifier



Addressing Missing Coverage

New Test Cases



Full Coverage



Test Cases



Automatic Test Generation

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Systematic Simulation Testing





Real-Time Testing of Battery Management System

Testing BMS with Battery Cells

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







Main Controller47

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Battery Pack

Measurement & Diagnostics



Hardware-In-Loop Testing of Battery Management System

Testing BMS with Emulated Battery Cells

- Reduce testing time
- Test fault conditions safely
- Automate testing







Challenges in setting up HIL testing for BMS

Execute Large Battery Models in Real-time

- Cell Voltages: ~100Hz
- Current: ~1kHz (Accurate Coulomb Counting & current derating calculations)
- Cell / Pack Temperatures: ~1 to 10Hz (Large time constant for thermal system)

Sensor and Fault Emulation

- Produce Isolated Voltages
- Sink and Source Current
- Support Series and Parallel Configuration
- Temperature simulation







Execute Large Battery Models in Real-time

Prepare Model for Real-time Simulation (if using Simscape)

- Use Simscape Local Solver
- Configure fixed-cost simulations
- Try "Partitioning" option for non-linear systems*

Reducing model complexity

- Select right variant of battery block to match desired model fidelity
- Reduce order of charge dynamics by selecting fewer number of time-constants





Sensor and Fault Emulation

Battery Emulation (IO991-06)

- 6 independent isolated channels
- Architecture allows series and parallel stack combinations
- Voltage range of 0-7 V with 14-bit resolution
- Source 300mA and sink 100 mA

Temperature Sensor Emulation

- RTD (PT100, PT1000) low resolution 6 channel module
- Thermocouple accurate 32 channels
- High precision resistor simulation modules

Fault Insertion

- 1A to 40A current handling; Up to 4 fault buses
- Electromechanical or MOSFET switches





Conclusion







Leverage models to communicate technical specifications, design implementation, results and maintain traceability Test your design iterations every step of the way through simulations and Hardware-In-Loop testing Gain confidence in design and work towards 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	s.html
- ▲ MathWorks®	
Battery Modeling	Search Math
Model batteries when designing battery-power	ed systems
Technical Articles and Search Technical Artic Newsletters	Technical Articles 👻
Modeling and Simulating Battery Performance for Desigr By Cecilia Wang, Romeo Power	n Optimization
File Exchange	earch File Exchange
MATLAB Central - Files Authors My File Exchange Contribute About Design and Test Lithium Ion Battery Manager version 1.0.1 (8.95 MB) by Chirag STAFF This example project can be used as a reference design to get started with Management System with MATLAB and Simulink	nent Algorithms

Battery Modeling

Examples and How To

Battery Management System Development in Simulink (7:17) - Video

Search MathWorks.com

- 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

Download Link to File Exchange

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THANK YOU