WELCOME

HALLO

BIENVENUE

SCHÖN, DASS DU DA BIST!
MODULAR BMS DEVELOPMENT
IN RAPID PROTOTYPING OF
AUTOMOTIVE E/E SYSTEMS

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WE TALK ABOUT
MODULAR BMS DEVELOPMENT FOR AUTOMOTIVE E/E SYSTEMS

MATLAB EXPO 2019

- More Than Engineers -
- Future Mobility Trends -
- BMS Functionality and Requirements -
- Modeling Approach -
- Algorithms in Action -
- What does the Future Look Like? -
WHO ARE WE?

MORE THAN ENGINEERS
A RELIABLE PARTNER FOR ELECTRONICS

WE ARE

ELECTROMOBILITY
SMART MOBILITY
MECHATRONICS
FUNCTIONAL SAFETY

ENGINEERING
CONSULTING
SOFTWARE
WE WILL WORK TOGETHER

TOWARDS YOUR

GOALS WITHOUT

MAKING COMPROMISES

ENGNEERS

FROM

DUBAI, CHINA, BAVARIA, BADEN AND SWABIA

3-LEVEL

DEVELOPMENT APPROACH

9

LOCATIONS

ELECTRONICS

ACTUATORS INTEGRATION

SENSORS INTEGRATION

BATTERY SYSTEM

AUTOMOTIVE ETHERNET

ELECTRONIC INTEGRATION

ALGORITHM/AI

FUNCTIONAL SAFETY

SKILLS

2017 EMPLOYEE DEVELOPMENT 2021
FUTURE MOBILITY TRENDS
Motivation

Battery Systems are Expensive

- Battery packs make up ~ 35% of total BEV costs
- Useful to come up with a workflow for battery system development to estimate:
  - Number of cells, modules, packs
  - Series /Parallel configurations
  - Range, capacity
- Goal ➔ To come up with computationally inexpensive, yet accurate battery models/system simulations to avoid error realization deep down in the design process

Source: JPMorganChase; BCG analysis
INTRODUCTION

BMS FUNCTIONALITY AND REQUIREMENTS
Introduction

BMS – Basic Idea

- Embedded system $\rightarrow$ function-built electronics + processing
  - Protects user
  - Protects battery
  - Prolongs life of battery
  - Maintains battery in a functional state
  - Tells controller how to use pack effectively in real-time

Figure 1: Battery pack assembly in automobile
Introduction

BMS – Functionality

- **Sensing/High Voltage Control** - Voltage, current, temp. sensing, precharge, detect ground faults;
- **Protection** - overcharge, over-discharge, over-current, short circuit, extreme temps.
- **Interface** - Range estimation, communications, data recording/reporting
- **Performance Management** - SOC estimation, power limit computation, cell balancing
- **Diagnostics** - Abuse detection, SOH estimation

Figure 2: Overview of components involved in a BMS
Introduction

Parallel Connected Modules

Series Connected Modules

PCM

SCM
EQUIVALENT CIRCUIT MODELING
Modeling Approach

Empirical Modeling

- Equivalent Circuit Models (ECMs) - dynamics of this circuit approximates Li-ion cell behavior
- Accounts for hysteresis voltages
- $R_0, C_1, \text{ and } R_1$ represent diffusion processes, functions of SOC, Temperature
- State space representations make implementation of control/estimation algorithms possible

Figure 3: Equivalent Circuit Model Representation
Modeling Approach

Process Overview

Static Testing → Raw Data

Profile Testing → Raw Data

Laboratory tests

Cell Current

MATLAB function

OCV Correlation

Lookup tables

Structure Array

Empirical Cell Model

Voltage Estimation

Initial Conditions

h(0), z(0), iR(0)

v(t)

i(t)
PERFORMANCE AND DIAGNOSTICS
Algorithm Development

BMS Measurement Loop

- **Voltage, current, temp measurements**
  - Real time measurements taken using voltage, current and temperature sensors
  - When real data unable, state space model used to generate ‘real’ data

- **SOC Estimation**
  - Kalman filters (EKF and SPKF) applied to state space models of ECMs
  - KF methods are optimal for SOC estimation
  - Implemented using MATLAB function files

- **SOH Estimation**
  - Using SOC estimates from previous step, capacity predictions can be made
  - Degradation can be quantified to give an ‘SOL’

- **Cell Balancing**
  - Active/Passive balancing methods used depending on the application
  - Cells can be balanced using Stateflow™

- **Power Limits**
  - Compute voltage operating limits
  - Minimize incremental degradation based on previous state and parameter computation
Algorithm Development

Kalman Filtering

- KF based SOC estimation methods are very robust in comparison to voltage/current based methods
- Different implementations of the Kalman Filter possible – Extended Kalman Filter (EKF), SPKF (Sigma Point Kalman Filter), etc.
- Choice depends on complexity/system requirements

Figure 4: Model-based state estimation
Algorithms in Action

Kalman Filtering

Prior knowledge of state

\[ P_{k-1|k-1} \]

\[ \hat{u}_{k-1|k-1} \]

Prediction Step

Based on physical model

\[ P_{k|k-1} \]

\[ \hat{u}_{k|k-1} \]

Update Step

Compare prediction to measurements

\[ P_{k|k} \]

\[ \hat{u}_{k|k} \]

Output State Estimate

Measurements

\[ \hat{y}_k \]

Next Timestep

\[ k \leftarrow k + 1 \]

\[ \hat{u}_{k} \]

\[ \hat{y}_{k} \]

\[ \hat{u}_{k} \]

\[ \hat{y}_{k} \]

\[ P \] - Uncertainty

\[ \hat{u} \] - State Estimate

\[ \hat{y} \] - Measurement

\[ k \] - Timestep

Source: https://wikipedia.org/wiki/Kalman_filter
SAMPLE USE CASE

ALGORITHMS IN ACTION
Algorithms in Action

OCV vs SOC Correlation

*Tests done on a 30Ah automotive battery cell
Algorithms in Action

Dynamic Cell Parameters

*All graphs plotted against temperature*
Algorithms in Action

Voltage Estimation

```
Voltage Estimation with Dynamic Parameters
```

```
Voltage Estimation with Dynamic Parameters
```

```
0 100 200 300 400 500 600
Time (min)
```

```
0 100 105 110 115 120 125 130
Time (min)
```

```
2.7 2.8 2.9 3.0 3.1 3.2 3.3 3.4 3.5 3.6
Voltage (V)
```

```
2.7 2.8 2.9 3.0 3.1 3.2 3.3 3.4 3.5 3.6
Voltage (V)
```

```
Real
```

```
Model
```

```
Real
```

```
Model
```
Algorithms in Action

SOC Estimation using Kalman Filtering

*Tests done on a 30Ah automotive battery cell
WHAT DOES THE FUTURE LOOK LIKE?

OUTLOOK
Outlook

Physics Based Models (PBMs)

- Empirical approach is **good**, but physics based cell models (PBM) are **optimal** for developing a **robust** BMS.
- Deal with diffusion, kinetics down to the molecular level.
- Computation costs for PBMs are high, research going into obtaining reduced order models (ROM).
- Next generation BMS will be driven by control/estimation algorithms developed around PBMs.
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Algorithms in Action

Desktop Validation

- Use model of cell to create synthetic test data.
- Allows access to “truth” of all cell and algorithm states
- Validity of results limited by the accuracy of cell model.
Algorithm Development

In a Nutshell:

- Voltage
- Current
- Temperature

Empirical Model Based Estimator

- Capacity
- SOC
- Resistance

Pack Computation

- Power
- Energy
Algorithms in Action

Simple Application to a Battery Electric Vehicle (BEV)

Required Velocity → Required Acceleration → Required Force → Required Torque

Current Speed ← Current Acceleration ← Current Force ← Maximum Torque

Motor Power → Battery Power

Battery SOC
Algorithms in Action

Results

![Graphs showing speed, battery current, and battery SOC over time.](image-url)
Results