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

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MODULAR BMS DEVELOPMENT FOR AUTOMOTIVE E/E SYSTEMS

WE TALK ABOUT

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

MATLAB EXPO 2019
WHO ARE WE?

MORE THAN ENGINEERS
WE ARE
A RELIABLE PARTNER FOR ELECTRONICS

ELECTROMOBILITY
SMART MOBILITY
MECHATRONICS
FUNCTIONAL SAFETY

+ ENGINEERING
+ CONSULTING
+ SOFTWARE
WE WILL WORK TOGETHER

TOWARDS YOUR

GOALS WITHOUT

MAKING COMPROMISES

3-LEVEL

DEVELOPMENT APPROACH

ELECTRONICS

ACTUATORS INTEGRATION
SENSORS INTEGRATION
BATTERY SYSTEM
AUTOMOTIVE ETHERNET
ELECTRONIC INTEGRATION
ALGORITHM/AI
FUNCTIONAL SAFETY

SKILLS

ENGNEERS
FROM
DUBAI, CHINA, BAVARIA, BADEN AND SWABIA

9 LOCATIONS

2017 EMPLOYEE DEVELOPMENT 2021
MOTIVATION

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 ➔ 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
EQUIVALENT CIRCUIT MODELING
Modeling Approach

Empirical Modeling

- Equivalent Circuit Models (ECMs) - dynamics of this circuit approximates Li-ion cell behavior
- Accounts for hysteresis voltages
- $R_0$, $C_1$, 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 -> OCV Correlation
Profile Testing -> Raw Data -> Empirical Cell Model -> Voltage Estimation
Cell Current -> Voltage Estimation

Laboratory tests

Initial Conditions: $h(0), z(0), i_{Rj}(0)$

Simulation

Modeling

MATLAB function
Lookup tables
Structure Array
ALGORITHM DEVELOPMENT

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

Optimization – fminsearch, fminbnd
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](image-url)
Algorithms in Action

Kalman Filtering

Prior knowledge of state → $P_{k-1|k-1}$ → Prediction Step

Based on physical model

$\hat{u}_{k-1|k-1}$ → $P_{k|k-1}$ → Update Step

Compare prediction to measurements

Next Timestep $k \leftarrow k + 1$

Output State Estimate

$\hat{u}_k$ → Measurements

Measurements $\hat{y}_k$

Source: https://wikipedia.org/wiki/Kalman_filter

$P$ - Uncertainty
$\hat{u}$ - State Estimate
$\hat{y}$ - Measurement
$k$ - Timestep
ALGORITHMS IN ACTION

SAMPLE USE CASE
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
Algorithms in Action

SOC Estimation using Kalman Filtering

*Tests done on a 30Ah automotive battery cell
OUTLOOK

WHAT DOES THE FUTURE LOOK LIKE?
Physics Based Models (PBM)

- 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 PBM are high, research going into obtaining reduced order models (ROM)
- Next generation BMS will be driven by control/estimation algorithms developed around PBM
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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
Simple Application to a Battery Electric Vehicle (BEV)
Results
Algorithms in Action

Results

- Battery Demand
- Motor Speed (rpm)
- Motor Torque