Battery Core Functions [BCF/SoX]

BMS and LFP CF

Content

1

Hybrid SoC Model

AVL developed hybrid model bringing SoC model accuracy of +/-2% for LFP batteries

2

SoH Model Development

Novel approaches to SoH model development including machine learning, electrochemical analysis, and cloud data analytics.

3

Cell Characterisation Testing Optimisation

Two example methods of approach

Why Accurate BCF Estimation is Essential in Modern EVs

Impact on Vehicle Performance

Driving Range: Accurate SoC helps in predicting how far the EV can travel before needing a recharge.

Battery Efficiency: Proper SoH assessment ensures optimal battery usage and longevity.

Enhancing User Confidence:

Reliability: Accurate SoC and SoH estimations reduce range anxiety among users.

Safety: Predicts potential battery failures and maintenance needs, enhancing overall vehicle safety.

Economic and Environmental Benefits:

Cost Efficiency: Maximises the lifecycle of the battery, reducing replacement costs.

Sustainability: Efficient battery usage helps in reducing environmental impact by minimising waste.

Accurate SOx estimation is a cornerstone of modern EV technology, driving safety, efficiency, sustainability, and user trust. It is vital for meeting the demands of next-gen mobility.

Battery Management and Core Functions

Cell

System

Function

SAFETY & DIAGNOSIS

- Isolation detection
- HV interlock
- Safety monitoring

AUXILIARY FUNCTIONS

- Start-up / Shutdown
- Signal acquisition / actuator control
- Main contactor control
- Pre-charge function
- Thermal management

BATTERY CORE FUNCTIONS

- State of Charge (SOC)
- State of Health (SOH)
- State of Function/Power limit prediction (SOF)
- Battery Balancing
- Battery Charge Time Estimation
- Cell Anomaly Detection
- Thermal Propagation /Venting detection
- Battery lifetime prediction

DIAGNOSIS

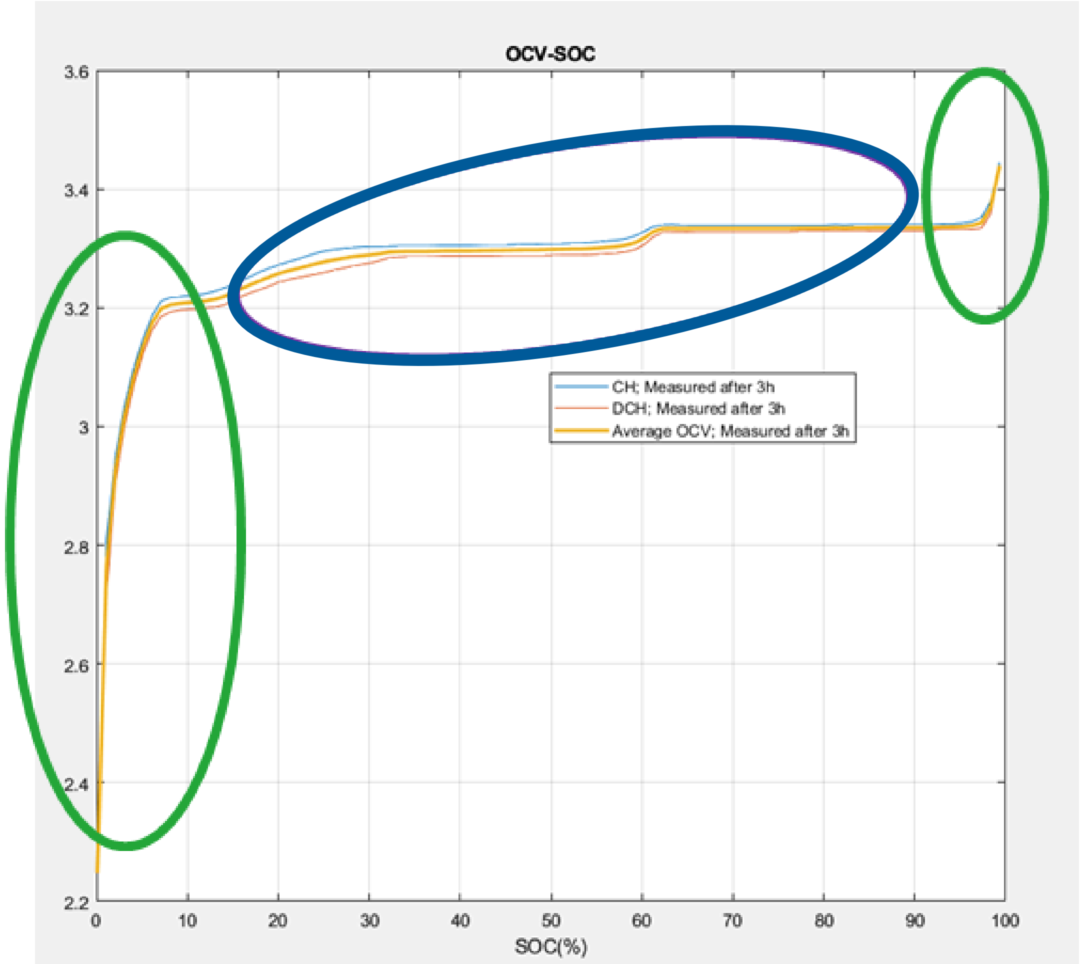
- Diagnosis functions
- Error-management

INTERFACE & COMMUNICATION

- Vehicle interface (CAN)
- Diagnosis interface
- Logistic-information
- Actuator control (external)
- Re-programming

Virtual Development | Design & Development | V&V & Testing Efficiency | AI & Data Analysis | PM, Process & Quality

Battery SoC Accuracy – Technical Challenges with LFP



LFP OCV vs. SoC Curve

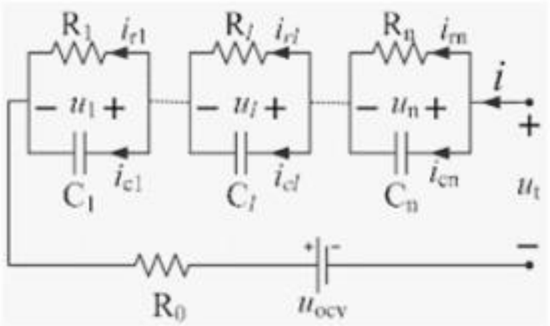
- **LFP** chemistry has **growing market share**, particularly with Chinese cells because of reduced cost and volatility, as well as material accessibility

- However, LFP has a **flat SoC vs. OCV curve** in the "middle region", as well as **non-linear "tails"** at low and high SoC

Battery SoC Estimation – AVL Solution

Hybrid approach combines conventional & electrochemical models for high accuracy

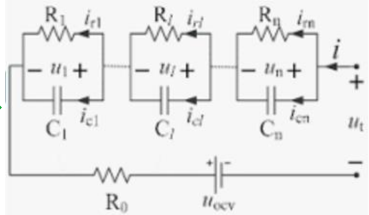
Equivalent Circuit Model (Conventional)

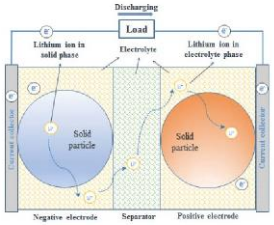


Empirical Approach

Conventional model tracks SoC well, lacks capturing dynamics

AVL Advanced Model



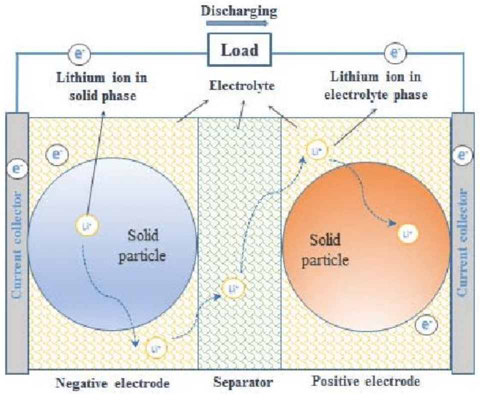


Hybrid Approach

Establishes analogy between conventional & electrochemical model

Addresses BOTH LFP Challenges

Electrochemical Model

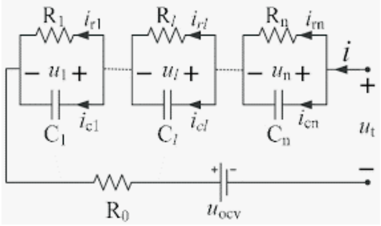


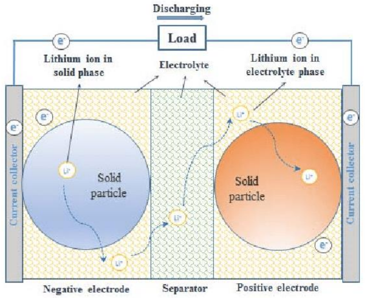
Physics-based Approach

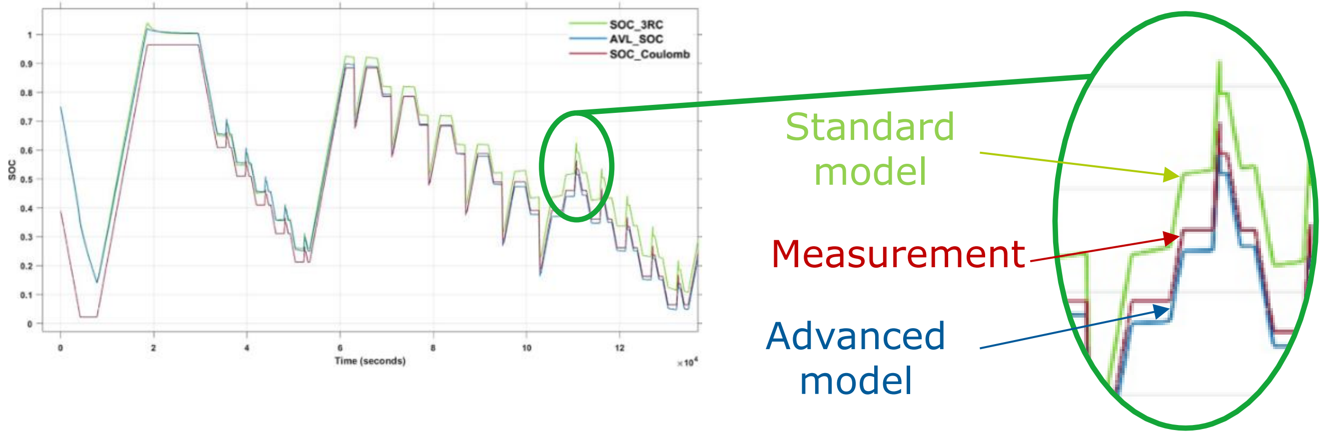
Captures cell dynamics well, but computationally expensive

AVL Solution

Battery SoC Estimation for LFP Chemistry







AVL advanced model

±2%

accuracy for advanced SoC estimation model for LFP chemistry achieved

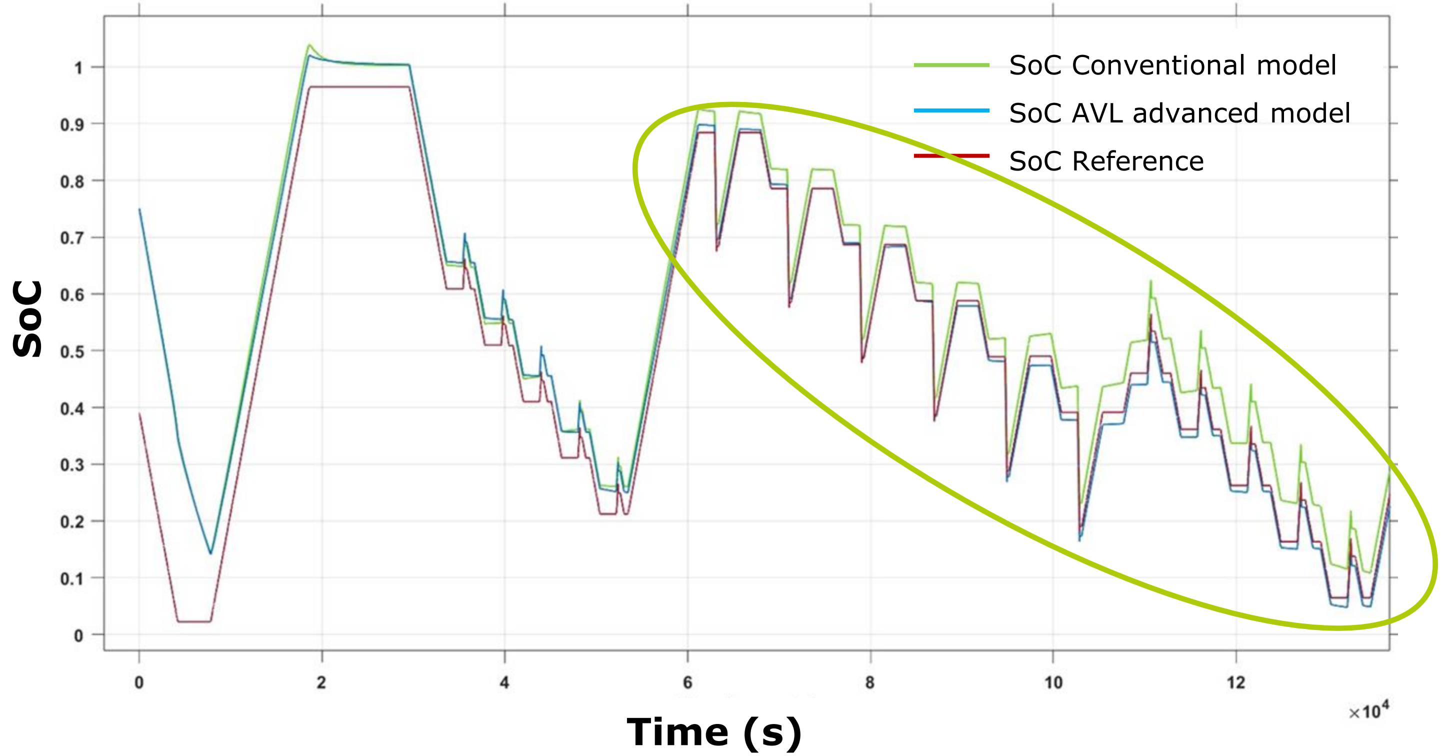
*Between 10 & 45°C

Reference – Evaluation Results

Conventional model* vs AVL advanced model for LFP battery

*3RC equivalent circuit model

Condition
Battery: LFP
Initial SoC error: > 35% at RT



In both models, the initial 35% SoC error gradually converges towards the reference SoC during charging and discharging.

AVL advanced model corrects and aligns accurately to reference SoC target

Key Drivers for SOH Accuracy Improvement

Enhanced Battery Safety	•Accurate SOH helps predict failures that could lead to dangerous events eg: **Cell Anomaly/TP Detection**. •**Early Fault Detection:** Enables proactive maintenance and replacement, mitigating safety risks.
Extended Battery Life	•**Optimised Usage Patterns:** Precise SOH allows for tailored charging and discharging cycles to minimise degradation. •**Lifecycle Management:** Ensures batteries are utilised to their maximum potential before recycling or replacement.
Improved EV Performance	•**Reliable Range Predictions:** Accurate SOH supports precise State of Charge (SoC) calculations, reducing range anxiety. •**Consistent Power Delivery:** Maintains consistent energy output for optimal vehicle performance.
Cost Savings	•**Lower Operational Costs:** Reduces the need for premature battery replacements, minimizing ownership costs. •**Better Warranty Management:** Improves claims validation by providing reliable data on battery usage and health.
Regulatory Compliance	•**Regulations as a driver:** European Union (EU) Battery Regulation (2023/1542), UNECE - GTR, CARB - Advanced Clean Cars (ACC) II Program •**Battery Reuse & Recycling:** Accurate SOH facilitates secondary use of EV batteries in stationary storage applications.

LFP SoH Development for +/- 3% SoH Accuracy*

*Between 10 & 45°C

Cloud Utilisation Brings New BMS Requirements & Function

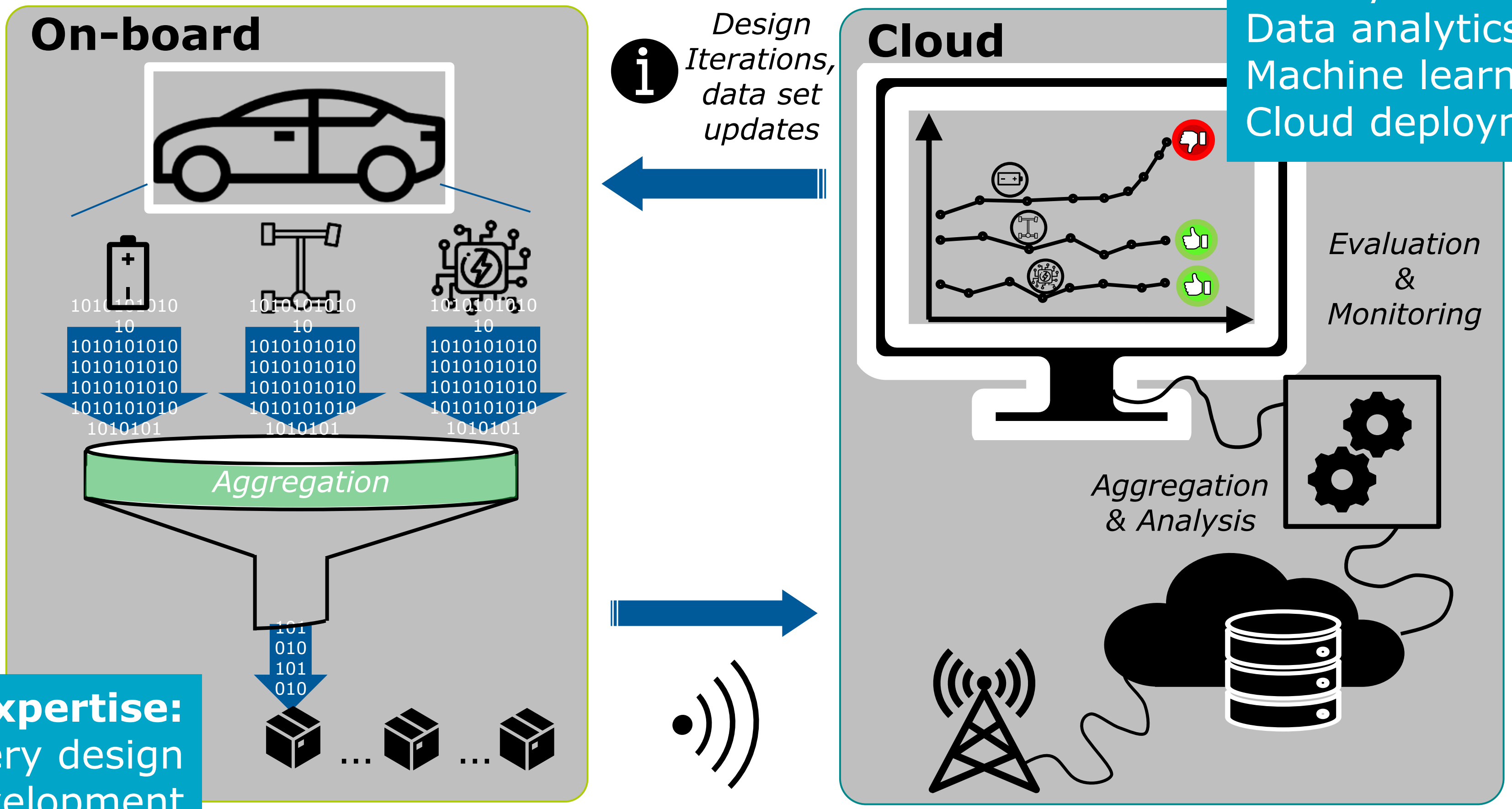
Enabling the Benefits of SoX Enhancement via Cloud and OTA Updates

Benefit

Knowhow in BMS, data analytics and cloud service

Optimised BMS feature selection and aggregations for later cloud analytics

Cloud analytics based on physics informed ML



AVL Expertise:
Battery modelling
Data analytics
Machine learning
Cloud deployment

AVL Expertise:
Battery design
BMS development
Vehicle Integration

Machine Learning Based SoH Model in On-Board Application

Enabling the Benefits of SoH Enhancement via ML and/or Cloud Data Analytics

Aggregation & Analysis

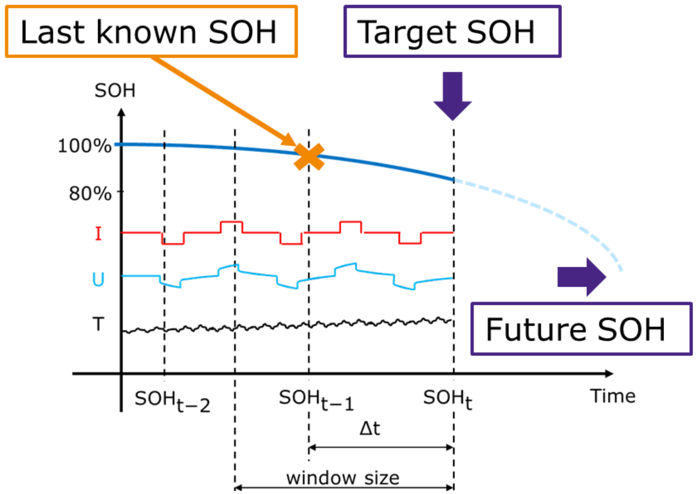
Transfer Learning Approach

1. Learn best possible features from data with big variance
2. Transfer feature set
3. Train model on lifetime cell measurements to learn “the knee point”
4. Transfer model information
5. Train final model on real customer usage with a big fleet

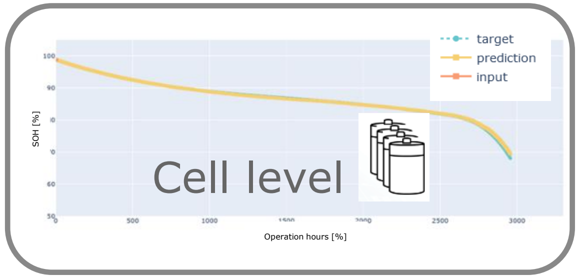
High Level Modeling Approach

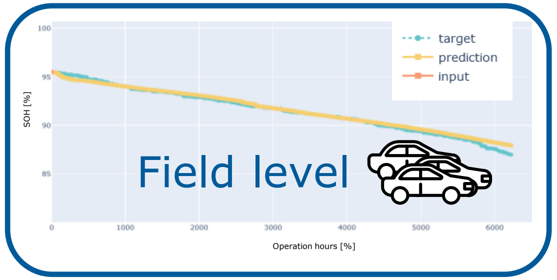
Model Input Features

- Statistical metrics
- Charging patterns
- Load
- Dynamics
- SoC behavior
- Usage heatmap



Exemplary Modelling Results



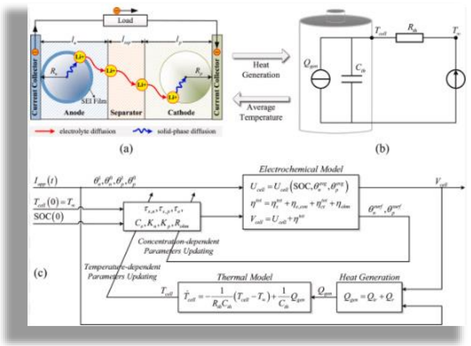


Reduced Error up to 30%

HiL System for BMS Core Function Validation

Two approaches possible for BMS HiL validation:

- Hybrid method: cell tester and chamber combined with the HiL system - physical cell(s) in place of a cell model
- Model method utilising an electrochemical cell model derived from characterisation testing



Battery Model

VS.

Cell Tester & Chamber
1 – 6 Cells

Measured cell voltage & temp.

Control current

Enhance cell data to 120+ channels

HIL System

Cell voltages, temps., current
Vehicle CAN signals, etc.

BMS Output signals: CAN, etc.

BMS

No **Pack Hardware** Needed

Less or No cells required

Faster verification enabling test **time reduction**

Simulated **special case testing** (e.g., unbalanced aging) possible

*Available Q4 2024

BoL
Beginning of Life

Battery Model Calibration

2-3 months

- Optimised pulses to excite chemical dynamics of the cells
- Different SoC and temperature levels
- Temperature data based on cell packaging for the temperature model
- SoC-OCV map generation

Characterization Cell Tests

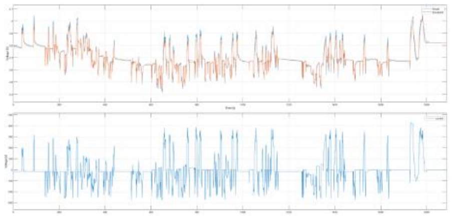
~ 2 weeks

- Optimisation loop with → Battery Model Calibration Tool (**BMCT**) – Matlab application
- BMCT done one cell level
- Calibration of battery aging parameters based on accelerated aging test

Battery Model Calibration

~ 6 weeks

- Output of BMCT parameter set is validated on cell level

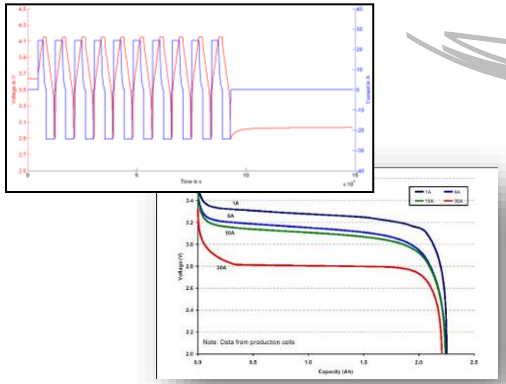


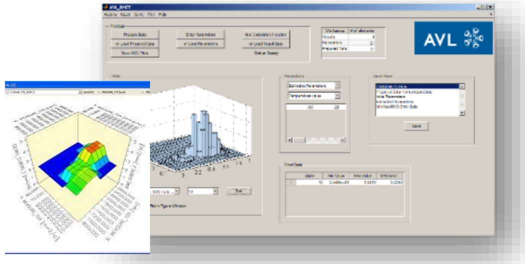
Battery Model Validation

~ 6 weeks

- Battery model parameters change according to project needs
- Testing of the model for quality verification and customer requirements

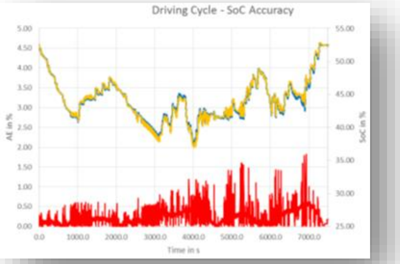
Verification & Integration





Software Verification:

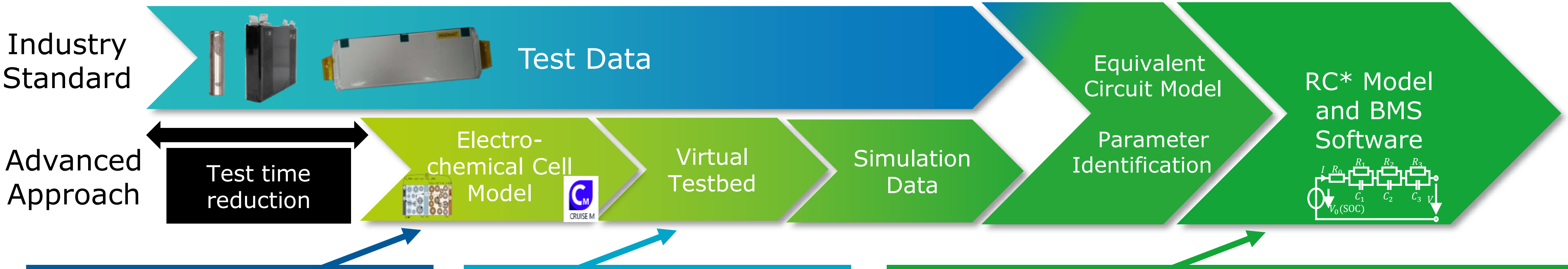
- Model-in-the-Loop (MiL)
- Software-in-the-Loop (SiL)
- Hardware-in-the-Loop (HiL)



Standard Calibration Process is ~6 Months (BoL) & ~18 Months (EoL)

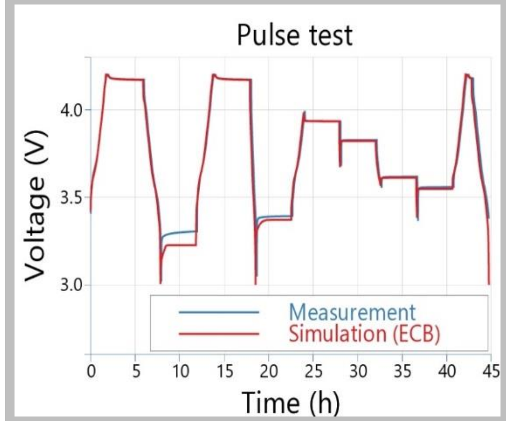
Reducing Cell Testing Efforts for Model Calibration

Existing Cell / Electrochemical Model Recalibration for 2^{nd} Use-Case



EC Model

High accuracy



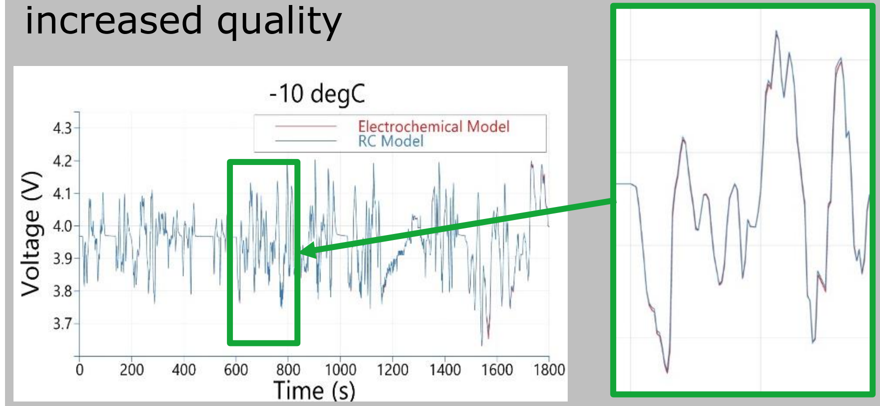
Virtual Tests

Virtual test is 3058x faster than real measurement!
HPPC Test

- Real Test: 35.100 min (585h)
- Virtual : 11 min

RC Model for BMS or System Simulation

Advanced BMS with reduced physical testing, reduced time and cost investments, and increased quality



BoL Model Calibration in 14 Weeks, and EoL Calibration in 8 Months

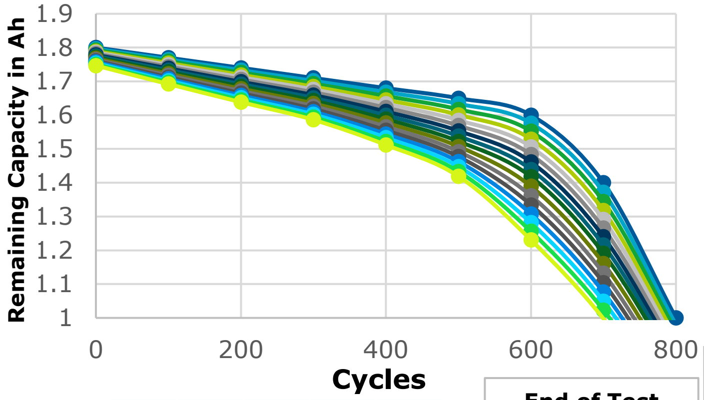
Battery Testing Time Reduction

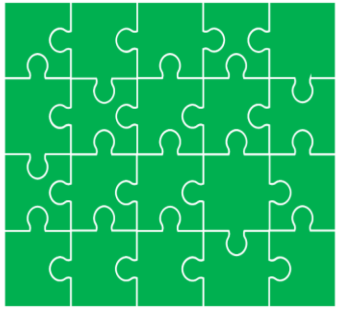
End of Life (EoL) Prediction in Testing using AI/ML SoH

Benefit

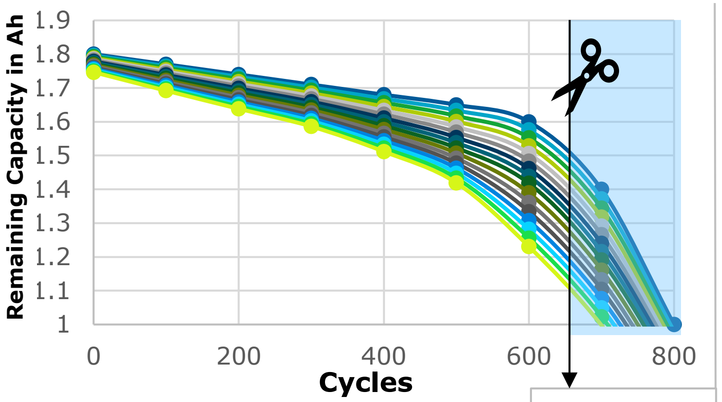
Reduced testing time

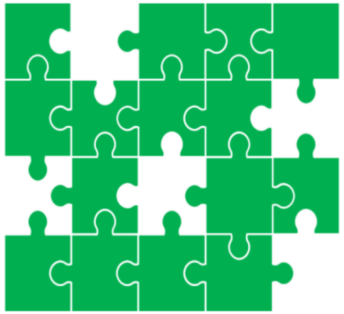
Same test outcome





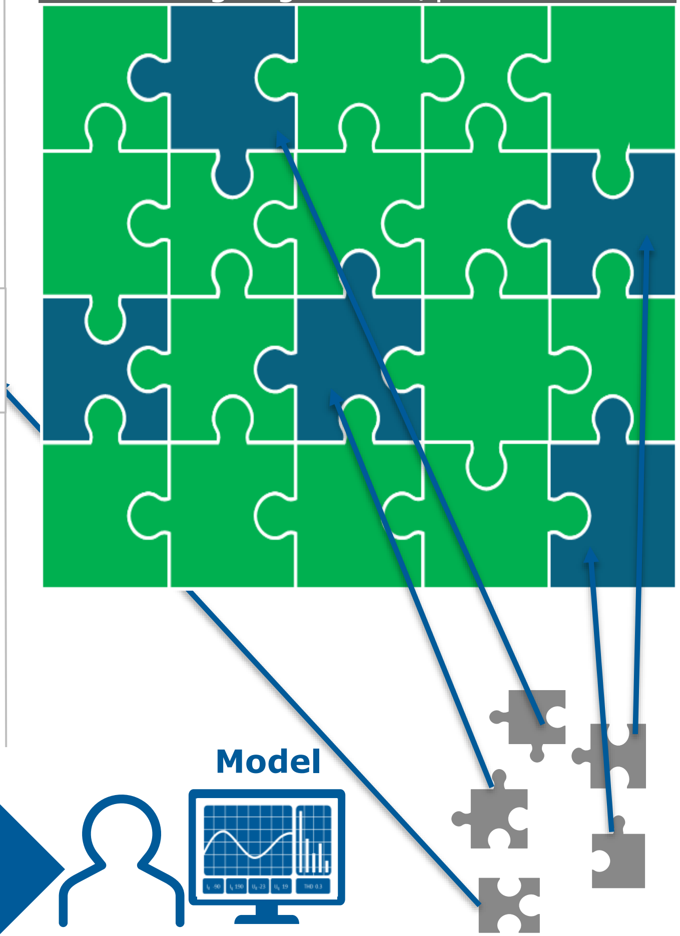
Ageing Model



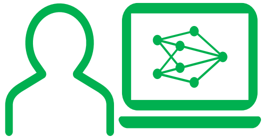


Reduce testing time by trimming the design points which need longer ageing time

Model uses the data from faster ageing tests to predict the EoL characteristics of the standard ageing of cells/packs

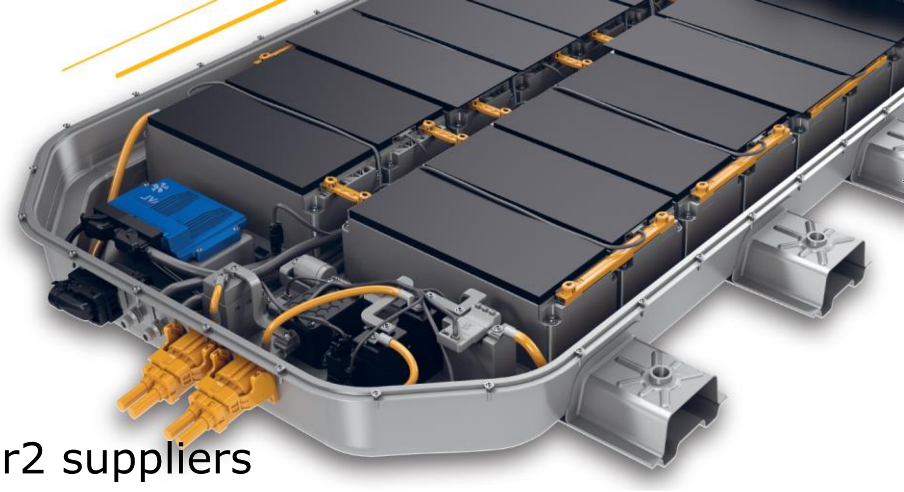


Test Plan



BENEFIT: Reduction of test time by 20%

Model



BMS and Core Function References

- **Advanced Development**
  - **Wireless BMS CMC with RF** based on 2-layer PCB for Tier2
  - **Evaluation of new BMS communication technologies** for 3 Tier2 suppliers
  - **1500V BMS development** for ESS supplier
  - **Advanced Battery Core Function development** with internal R&D

- **BMS (SoP) projects active in 2024 @ AVL**
  - Battery Core Development for two German OEMs – **Until 2028**
  - Advanced BCF Development for Korean OEM – **SoP 2027**
  - Advanced BCF Development for Japanese OEM – **SoP 2028**
  - PHEV BMS SOP development (2 variants) from concept to **SoP 2024** and series support with Tier1
  - BMS SOP development for 12V Li-Ion BMS – **SoP 2026**
  - BMS SW SOP development for 48V motorcycle OEM – **SoP 2024**

Thank you

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