Battery SOC and SOH Estimation using a Hybrid Machine Learning Approach

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Who We Are

Independent software integrator partner bringing scale and dependability to build and integrate software features to accelerate the journey from prototype to production.
Challenges in conventional methods for estimating SOC & SOH

- Measurement Noise
- Integration Error
- Initial SOC calculation error
- Peukert’s Coefficient
- Incorrect Battery Parameterization of battery models
- Best fit tuning challenge

Proposed methodology

In the hybrid approach, SOC's generalization and nonlinearity approximation capability are significantly enhanced
Machine learning based *Hybrid Approach*

**Influencing Factors of SOC**

1. **Current Measurement**
   - Sensor resolutions and inaccuracy

2. **Voltage Measurement**
   - DC Offset Errors, AC noise

3. **Temperature Dependency**
   - Incorrect Battery Characterization

4. **Internal Resistance**
   - Calculation inaccuracies

Patent # 202021049709
Workflow of proposed hybrid SOC estimation approach

Arrive at training inputs
- Obtain HPPC test data
- Tune Plant Model
- Select data profiles/subsets for training NN
- Tune Kalman filter

Building, training & tuning Neural Network
- (MATLAB DeepLearning Toolbox pro)
  - Extract training features and form training data
  - Train the Neural Network
  - Replace KF with trained NN
  - Validate performance on untrained/unseen data
  - Increase training data size

Implementation
- Performance satisfactory
  - Yes: Deploy on hardware and validate performance
  - No: Increase training data size

Building Simulink model & generate code
Training Process for a Neural Network

Training Stages

A model with a Kalman filter is used to collect data from two open-source runs.

The collected data includes the features and the target variable.

MATLAB's Deep Learning Toolbox is used to train a NN to map input features to the target output.

To prevent overfitting, a portion of the data is held out for validation checks.

Several networks are trained to find the one that generalizes well across all the unseen datasets.
Arrive at training inputs

- Dataset Inputs
- Tuned Battery Plant Model
- Kalman Filter Co-efficients tuned for best case accuracy on a particular dataset
Arrive at training inputs

Inputs and Outputs of the Kalman Filter System along with additional Dataset Signals are used to Train the Neural Network.
Final Model design

Neural Network Simulink Systems replace the Kalman Filter of previous design
Neural Network design

Simulink NN Model

Polarization Voltage

SOC

Simulink NN Model
Model performance

Number of error occurrences (log scale)

Error = $\text{abs}(V_{\text{pred}} - V_{\text{meas}})$

Error Occurrence = focv(error) > 5%
Model performance

Number of error occurrences (log scale)

ACG Performance using Simulink Embedded Coder

<table>
<thead>
<tr>
<th>Memory Segment</th>
<th>Memory Sub-Segments</th>
<th>NN-SW Design Hosted on MPC5746R</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAM</td>
<td></td>
<td>515 Bytes</td>
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<tr>
<td>ROM</td>
<td>Code</td>
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<td>Constants</td>
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<tr>
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Summary

• Application of AI/ML along with domain has consistently yielded the desired estimate of cell SOC at acceptable accuracy levels.

• Conventional methods were less complex and accurate, the increase in computational power and usage of powerful toolchain from MathWorks has encouraged to explore the complex techniques to enhance the algorithms

• The MathWorks environment provided the required computational and design toolboxes to seamlessly enable this workflow of designing and training the neural network, simulating in a closed-loop environment, and generating production-grade embedded code for deployment on hardware.

• Further, this study was mainly for mild hybrid applications; for fully battery electrical, the computational aspect becomes more challenging. Further, these algorithms of SOC and SOH can be extended to integrate with a vehicle control unit and thereby improve the electrical range and achieve better fuel economy. And all this development is possible in a shorter time due to powerful simulation toolchains from Mathworks.
OEMs & Tier1s rely on KPIT for HEV/EV technologies including Domains:

- BMS, Charger, Inverter, DC-DC Converter, VCU – BEV, HEV

30+ Programs executed on Hybrid and Electric Vehicles

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Software integrator partner, managing vehicle programs with multiple clients

Production ready software components for EVCC, CCS, GB/T, CHAdeMO and BMS

Global delivery model (Germany, US, India, Thailand)

End-to-end validation partner for xEVs – SIL, MIL and HIL testing | Automation strategy

Your partner for software development and integration for electrification

Thank You