Impact of current ripple on Li-ion battery ageing
Sven De Breucker 18/11/2013
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Introduction

» Benefits of dc-dc converter in HEV/PHEV/BEV:
  ▪ Less cells: combine low-voltage battery with high-voltage inverter
  ▪ Electric motor: wider speed range without early field weakening
  ▪ Lower current rating motor for given power rating or same current but higher specific power
  ▪ Operation causes current ripple: switching of HB
Introduction

Dc-dc converter: Importance of current ripple is acknowledged

» Parallel capacitor

» Interleaved multi-phase converter without

» Impact of current ripple

» High-frequency models
Introduction

Battery research:

» Low frequency range: μHz to Hz
  » Electrochemical reactions in charge transfer and diffusion process
  » Electrochemical impedance spectroscopy models: SoC estimation
  » Prediction of ohmic and polarisation voltage drop
  » Multiple time-constant model for dynamic powertrain simulations

» Low current ripples
Introduction

Scope of this presentation:

» Interaction between high-amplitude high-frequency current ripple of dc-dc converter and battery
» Reduction of current ripple: LCL-filter
» Expose two identical batteries to large and small current ripples simultaneously
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Test set-up:

- 2 * 100 A dc-dc converter: 8 kHz
- 70 kW grid-connected inverter: dc-bus at 650 V
- Batteries:
  - Kokam LiPo
  - 40 Ah, 3.7 V
  - 82 in series
  - 12 kWh
- BMS with balancing
LCL-filter

- \( L_1: 220 \, \text{uH} \)
- \( C: 230 \, \text{uF} \)
- \( L_2: 25 \, \text{uH} \)

![Graph showing frequency response](image)

Time-domain waveforms:
- \( I_{L1}(A) \)
- \( I_C(A) \)
- \( I_{Bat}(A) \)

- \( I_{dc} = 100 \, \text{A} \)

![Diagram of LCL-filter circuit](image)
Tests required

- **Combined Cycle Life Tests:** simulate driving and charging behaviour of PHEV
  - Charge-Depleting Cycle Life Tests: pure EV driving
  - Charge-Sustaining Cycle Life Tests: HEV driving
- **Reference Performance Tests:**
  - Hybrid Pulse Power Characterization Tests:
    - $R_{(dis)charge}$, $P_{(dis)charge}$
  - 10-kW Constant Power Discharge Test: Wh/Ah
Tests

Charge-Depleting Cycle Life Tests Profile
- 11 consecutive Charge Depleting Cycle Life Test Profiles
- Upper 7 Ah: prevent overcharge
- Lower 10 Ah: prevent overdischarge
- 30 % energy margin: 4.9 kWh available
Tests

Charge-Sustaining Cycle Life Test Profile:

- 50 Wh discharge, 56.3 Wh charge (90% efficiency)
- 33 consecutive Charge-Sustaining Cycle Life Test Profiles
- Total Combined Cycle Life Test: 115.5 minutes

![Graph showing power vs. time for discharge and charge phases.](image)
## Filter configuration

<table>
<thead>
<tr>
<th></th>
<th>BAT 1</th>
<th>BAT 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st month</td>
<td>L</td>
<td>LCL</td>
</tr>
<tr>
<td>2nd month</td>
<td>LCL</td>
<td>L</td>
</tr>
<tr>
<td>3rd month</td>
<td>LCL</td>
<td>LCL</td>
</tr>
</tbody>
</table>

- **I**<sub>Bat1</sub> (A) - L<sub>dc</sub> - L<sub>pp</sub> = 75 A
- **I**<sub>Bat2</sub> (A) - L<sub>dc</sub> - L<sub>pp</sub> = 2 A

**Diagram**

- Batteries: BAT1, BAT2
- Inverter (3ph)
- DC-BUS
- DC/DC
- L(CL)
- 3ph-grid
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Impact of current ripple on battery

Evolution of discharge and regen resistance:

» Dominant impact of T

» Current ripple: no measurable impact
Impact of current ripple on battery

Evolution of discharge and regen power:

- Bat1: strong reduction of $P_{dc}$ after 1 and 2 months
- Bat2: mild reduction $P_{dc}$ and $P_{regen}$, $T$ dominant
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Conclusions

Ageing of batteries is present, but not related to current ripple

Double-layer effect: double layer capacitor

» Very small charge layer between electrode/electrolyte + large surface

Both currents at surface of electrode:

» $I_{DL}$ is in parallel with $I_{CT}$ at electrode surface: reduces current ripple of charge transfer reaction

» $I_{CT}$ carries dc-current + part of high frequency current ripple

⇒ Design of battery takes DL into account?

⇒ Increasingly important in new high frequency converters (GaN)
Questions ?