Modellering och analys av samverkan mellan batteri och spänningsomvandlare i elektriska drivlinor

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Single LiPo HEV Cell

- Left: LiPo heavy-HEV prismatic cell\(^1\)
- Right: LiPo HEV cell\(^2\) during 1C-rate charging for 10%–100% SOC.
- Red lines: Fitted data for \(f>10\, \text{Hz}\).

\(^1\)Measurement carried out by A. Bessman, Div. Applied Electrochemistry
Single LiPo HEV Cell

- $R_{ser} = 1.89 \, m\Omega$
- $L_{ser} = 334.8 \, nH$
- $E_{cell} = 3.7 \, V$
- $C_{par} = 16.5 \, F$

- $R_{ser} = 3.03 \, m\Omega$
- $L_{ser} = 90.7 \, nH$
- $E_{cell} = 3.7 \, V$
- $C_{par} = 3.30 \, F$

- 100-500 nH (geometry dependent)
DC Bus Voltage

- Data from\(^3\)
- 400 V → 108 series-connected cells
- Assume 2 parallel stacks (total 216 cells)

Battery Cable

- Five meter coaxial cable
- Inner conductor diam.: 7.1 mm (120 A at 3 A/mm², 48 kW at 400 V)
- Inside diam. of outside shield: 10.2 mm
- Polystyrene insulator (ε_r = 2.6)

\[
C_{\text{cable}} = \frac{2\pi \varepsilon_r \varepsilon_0 L}{\ln(D_{\text{out}}/D_{\text{in}})}
\]

\[
L_{\text{cable}} = \frac{\mu_r \mu_0 L}{2\pi} \ln(D_{\text{out}}/D_{\text{in}})
\]

- \(R_{\text{cable}}\)
- \(L_{\text{cable}} = 0.19 \, \mu\text{H}\)
- \(C_{\text{cable}} = 2 \, \text{nF}\)
Battery Cable

- Five meter coaxial cable
- Inner conductor diam.: 7.1 mm (120 A at 3 A/mm², 48 kW at 400 V)
- Inside diam. of outside shield: 10.2 mm
- Polystyrene insulator ($\varepsilon_r = 2.6$)

\[ C_{\text{cable}} = \frac{2\pi \varepsilon_r \varepsilon_0 L}{\ln(D_{\text{out}}/D_{\text{in}})} \]
\[ L_{\text{cable}} = \frac{\mu_r \mu_0 L}{2\pi} \ln(D_{\text{out}}/D_{\text{in}}) \]

\[ R_{\text{cable}} \]
\[ L_{\text{cable}} = 0.19 \, \mu\text{H} \]
\[ C_{\text{cable}} = 2 \, \text{nF} \]
Electric Drive

- Si-IGBT switches (switching frequency limited to 10–30 kHz)
- Al electrolytic capacitors (energy density up to 1 J/cm\(^3\))
- Four-pole, 50 kW PMSM
  - \(L_d = 0.23\) mH, \(L_q = 0.56\) mH, \(\psi_m = 104\) mVs, \(R_s = 7.9\) mΩ
  - 150 Arms with \(\cos(\phi) = 0.89\) at 6000 rpm and 77 Nm (49 kW)
Battery Current

- 10 kHz switching frequency
- 10 % current ripple around (or less) than 1 mF
Capacitor Requirements

- 600 V IGBT, 10 kHz, 1 mF → capacitor volume approximately 2 soda cans (670 cm³, assuming 0.27 J/cm³)
Battery Current Measurements in Bus

- Idling
Battery Current Measurements in Bus

- Regenerative breaking
A Setup for Subjecting Ripple Currents to Battery Cells

- 16x R-Shunt
- Climate Chamber
- 100A Fuse
- 16x Li-ion Cells
- 4x DCG
- 10x LC filter
- 10x CRG
- Multiplexer
- Safety System
- PXIe
- Safety Card
- Power Cables
- Voltage Sense
- Current Sense
- Temperature Sense
- CAN bus
- Heartbeat
- Digital Signals
- Safety Command
A Setup for Subjecting Ripple Currents to Battery Cells

- Left: Climate chamber (temperature and humidity control)
- Right: Electronics and data acquisition
A Setup for Subjecting Ripple Currents to Battery Cells

- Left: Two prismatic cells with heat sinks
- Right: High-frequency ripple generator (up to 100 kHz, 60 A)
A Setup for Subjecting Ripple Currents to Battery Cells

- Labview control setup
Characterization

- In addition to 1C capacity analysis, we use:
  - Galvanostatic intermittent titration (GITT)
  - Incremental capacity analysis (ICA)
- These techniques yield information about the cause of capacity loss
Causes of capacity loss

- Loss of active material
- Changes in cell chemistry
- SOC slippage
Multi-channel characterization

- Time cost: 4 days per cell
- 10 – 16 cells per experiment
- Potential to save weeks by parallelization
Charging with Superposed Ripple Current

• Adding a ripple component when charging is “good”:

• Adding a ripple component when charging is “bad”:

• Sunil Kumar’s MSc thesis project
Summary

- Ripple current limitations sizing passive components (dc-link filter)
- Relatively unknown what effects ripple currents have on Li-ion cells
- Initial measurements on a bus show both high-frequency switching ripple currents and harmonics of lower order
- A setup for analyzing ripple current effects on 16 individual battery cells (including cell characterization) has been built
  - First long-term measurements just to be initiated
  - Ripple-current during charging will also be considered initially