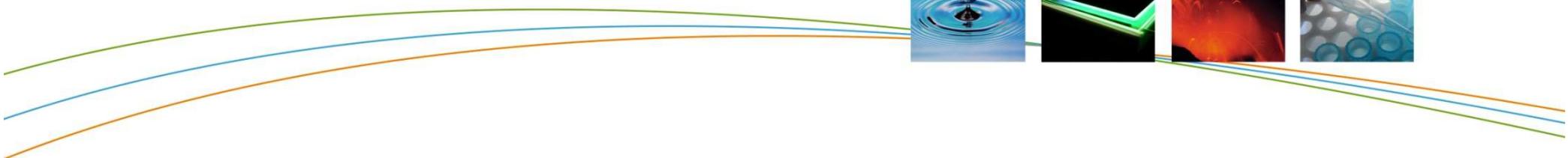




vito

vision on technology



20/11/2013

Impact of current ripple on Li-ion battery ageing

Sven De Breucker 18/11/2013

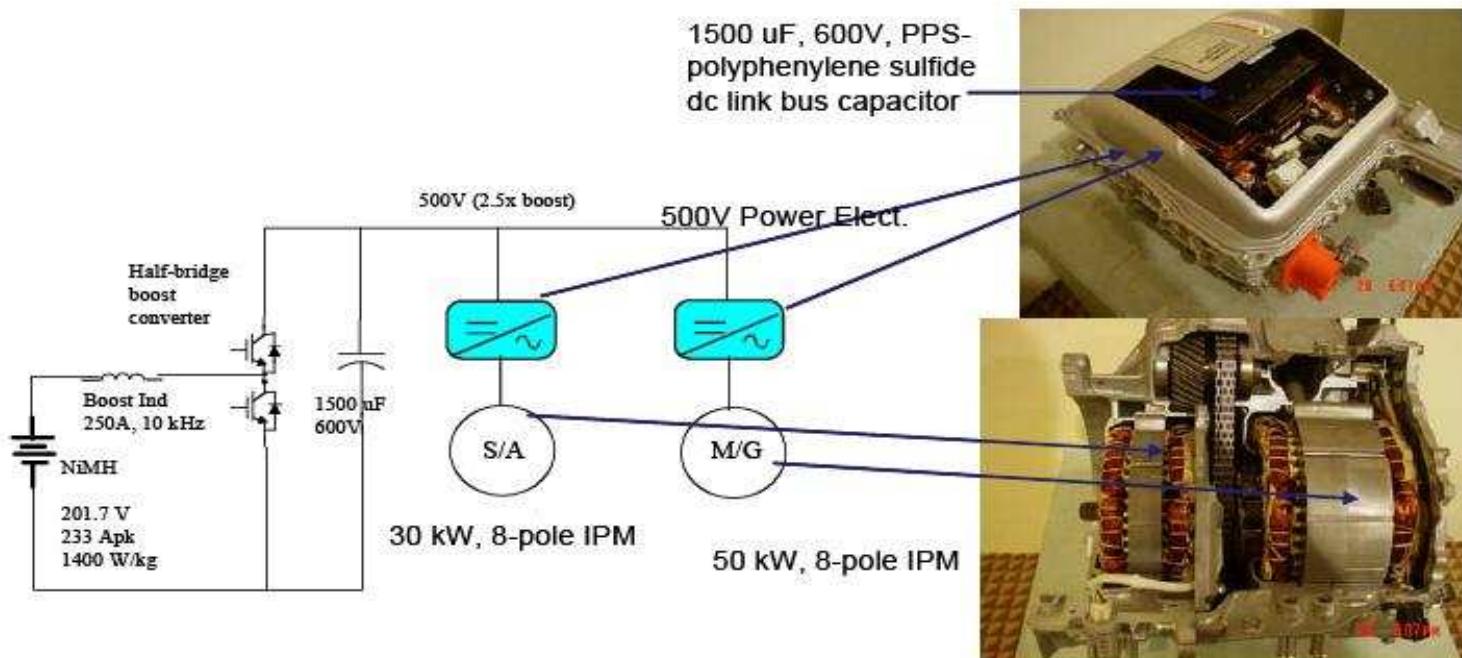
Contents

- » Introduction
- » Test set-up and tests
- » Impact of current ripple on battery
- » Conclusions

Introduction

» Benefits of dc-dc converter in HEV/PHEV/BEV:

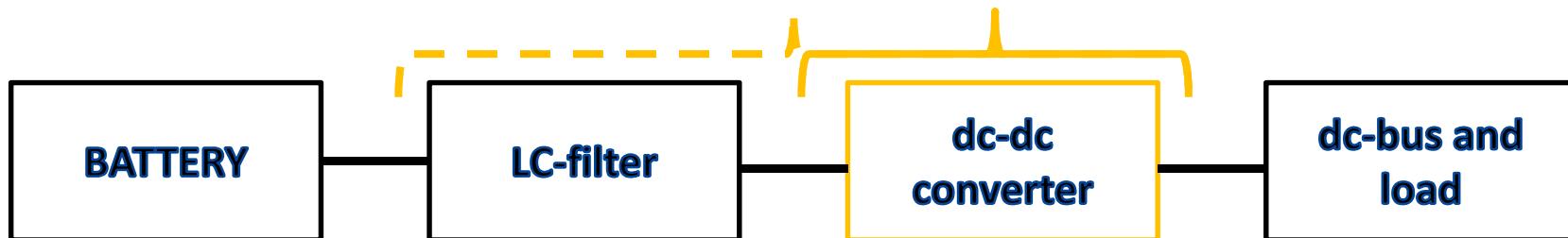
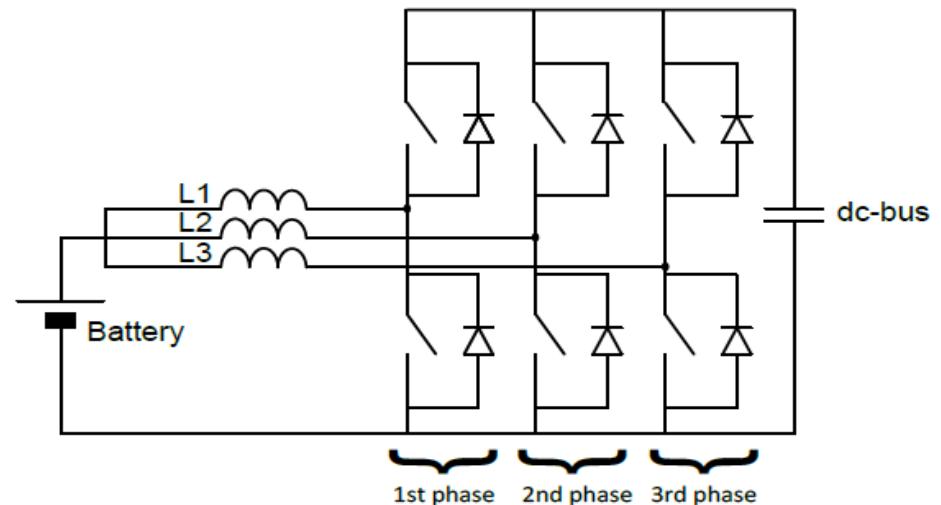
- Less cells: combine low-voltage battery with high-voltage inverter
- Electric motor: wider speed range without early field weakening
- Lower current rating motor for given power rating or same current but higher specific power
- Operation causes current ripple: switching of HB



Introduction

Dc-dc converter: Importance of current ripple is acknowledged

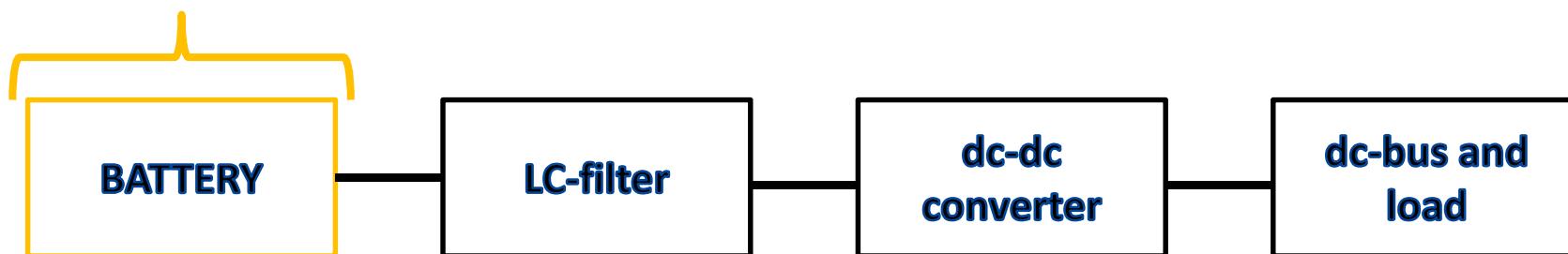
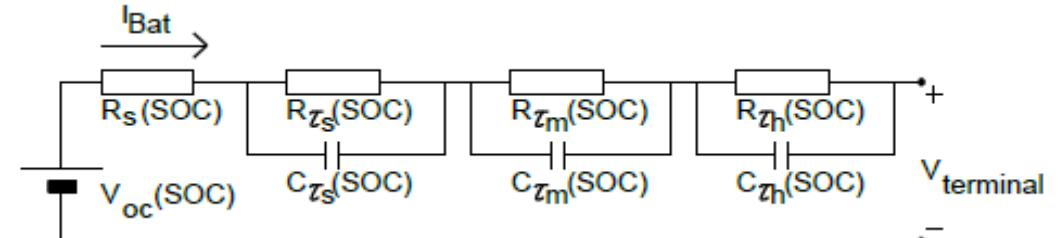
- » Parallel capacitor
- » Interleaved multi-phase converter
- without
- » Impact of current ripple
- » High-frequency models



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



Contents

- » Introduction
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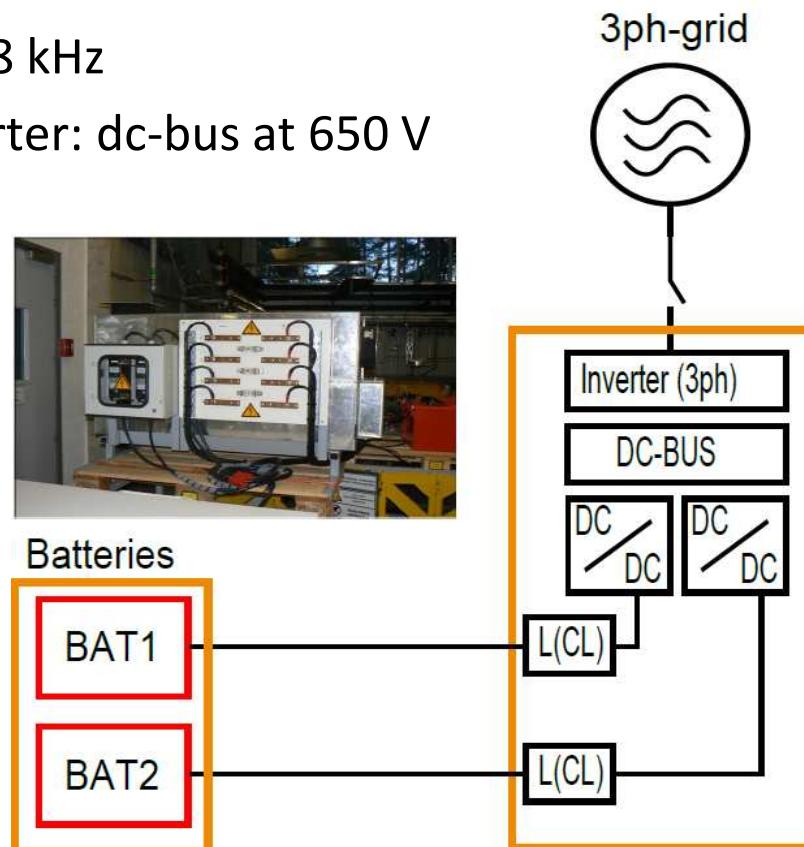
Test set-up

Test set-up:

- » 2 * 100 A dc-dc converter: 8 kHz
- » 70 kW grid-connected inverter: dc-bus at 650 V

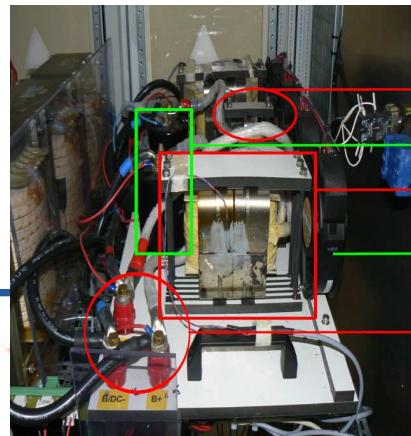
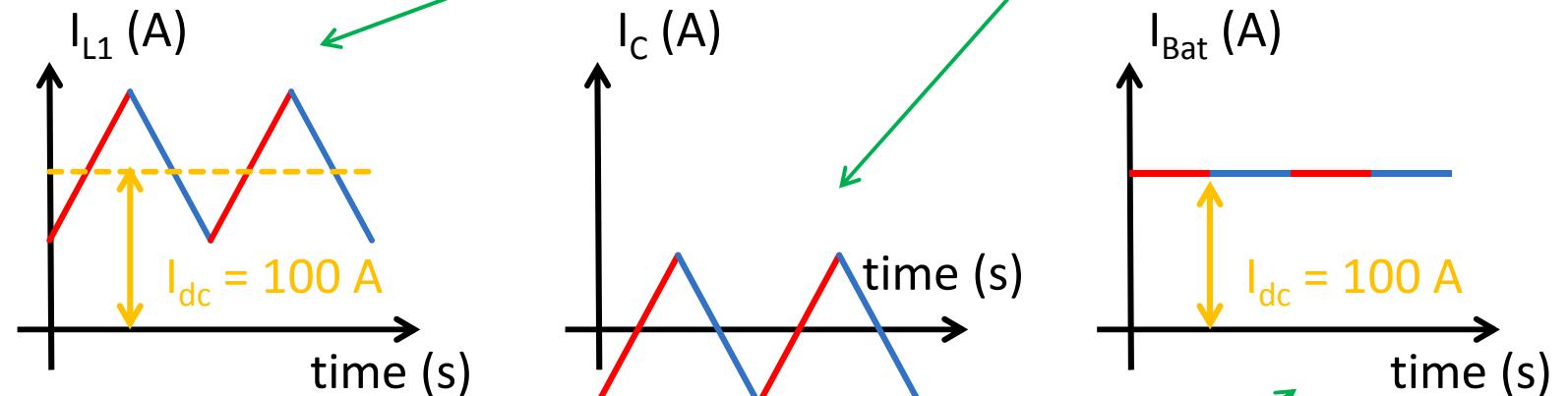
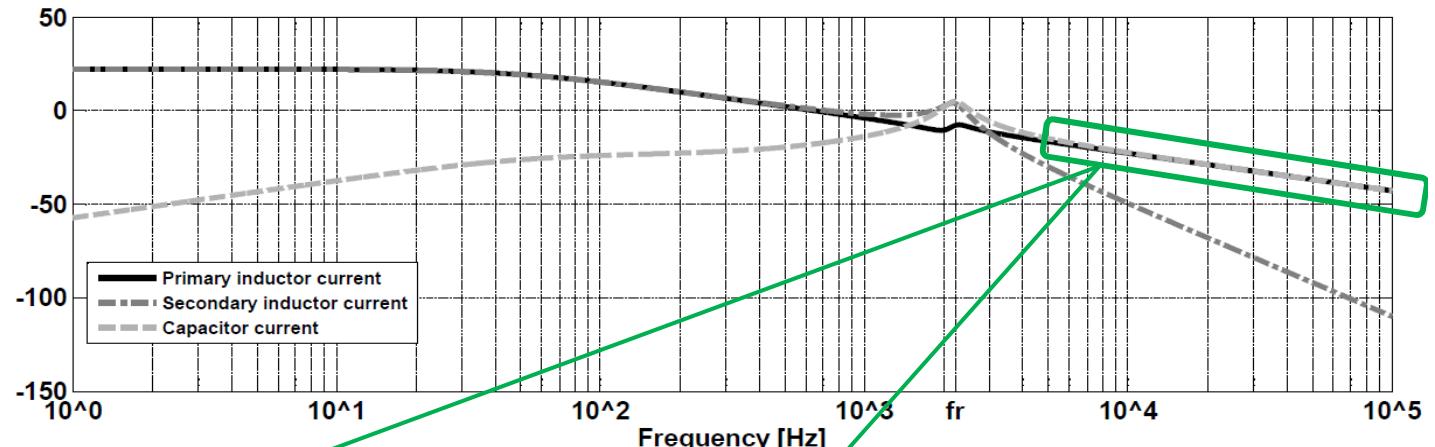
Batteries:

- » Kokam LiPo
- » 40 Ah, 3.7 V
- » 82 in series
- » 12 kWh
- » BMS with balancing

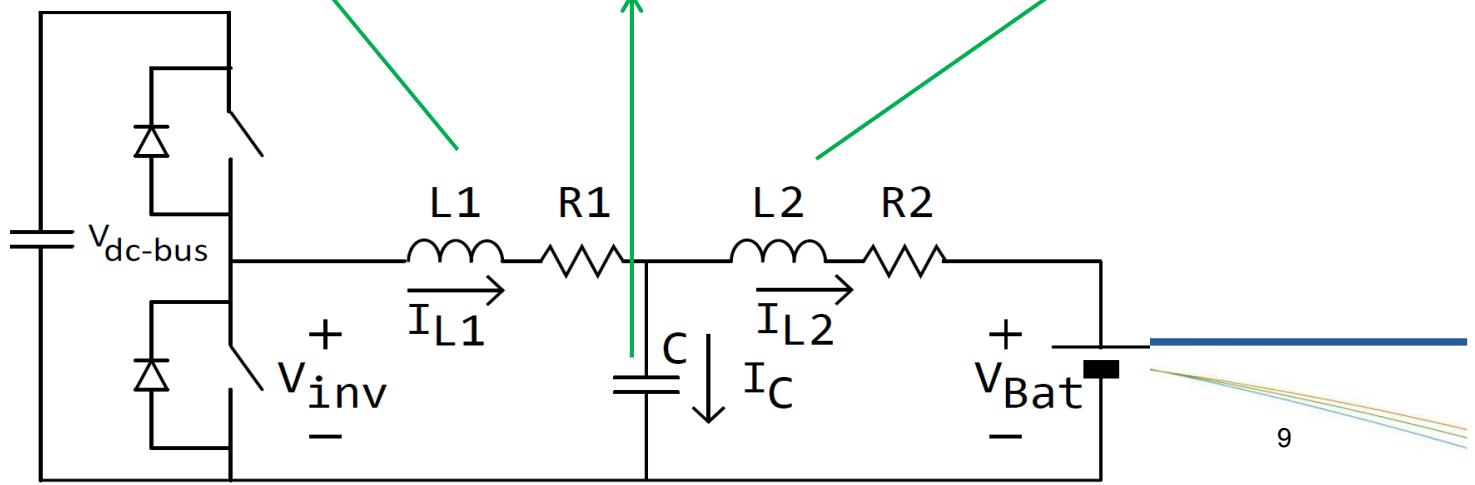


LCL-filter

- » L1: 220 μ H
- » C: 230 μ F
- » L2: 25 μ H



Secondary inductor of second LCL-filter
Capacitors of LCL-filters
Primary inductor of first LCL-filter
Cooling fans
Connection to dc-dc converters and battery of first LCL-filter



Tests

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



INL/EXT-07-12536

**U.S. Department of Energy
Vehicle Technologies Program**

**Battery Test Manual
For Plug-In Hybrid Electric Vehicles**

REVISION 0

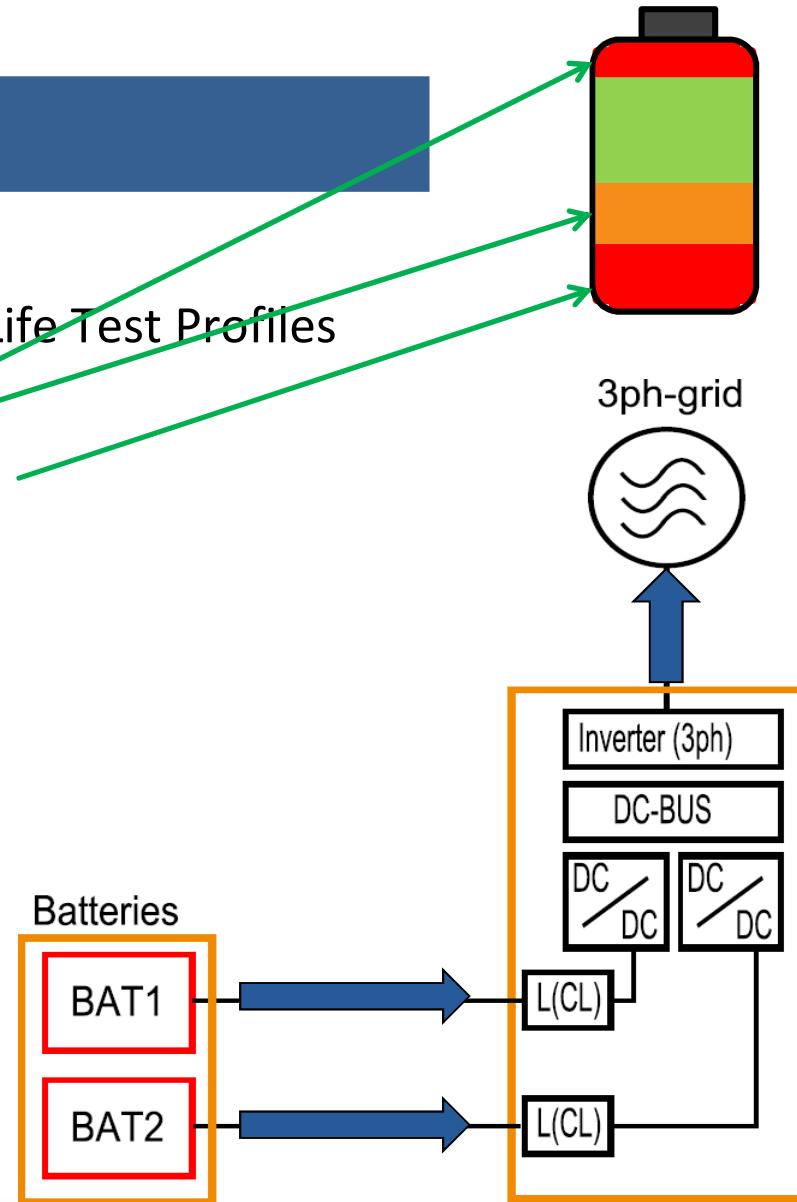
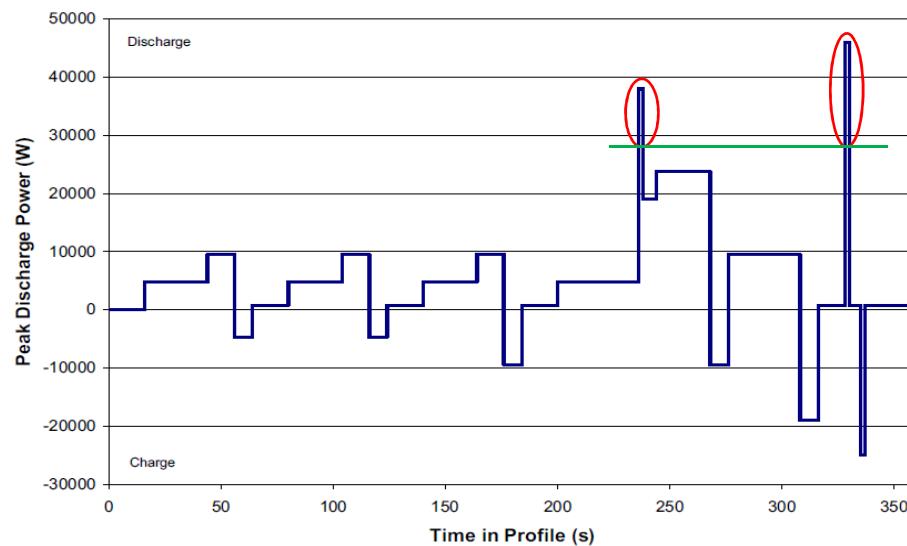
MARCH 2008

The Idaho National Laboratory is a U.S. Department of Energy National Laboratory
Operated by Battelle Energy Alliance

Tests

Charge-Depleting Cycle Life Tests Profile

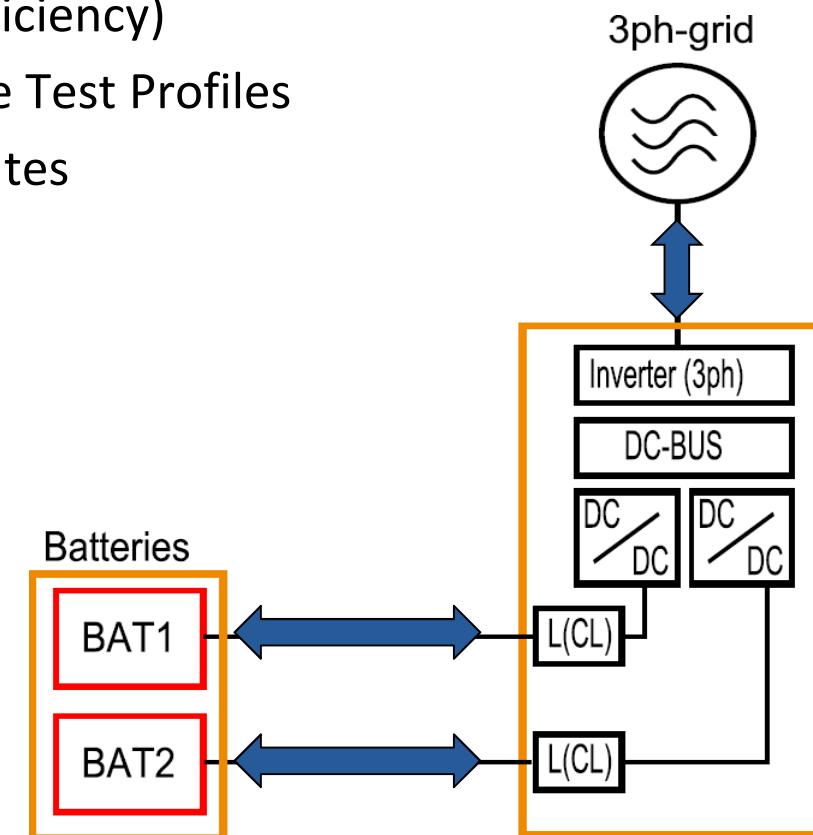
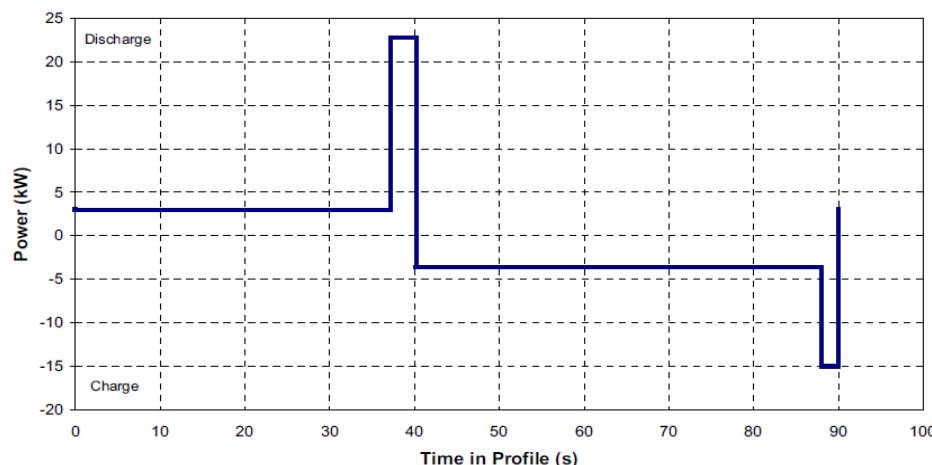
- 11 consecutive Charge Depleting Cycle Life Test Profiles
- Upper 7 Ah: prevent overcharge
- Lower 10 Ah: prevent overdischarge
- 30 % energy margin: 4.9 kWh available



Tests

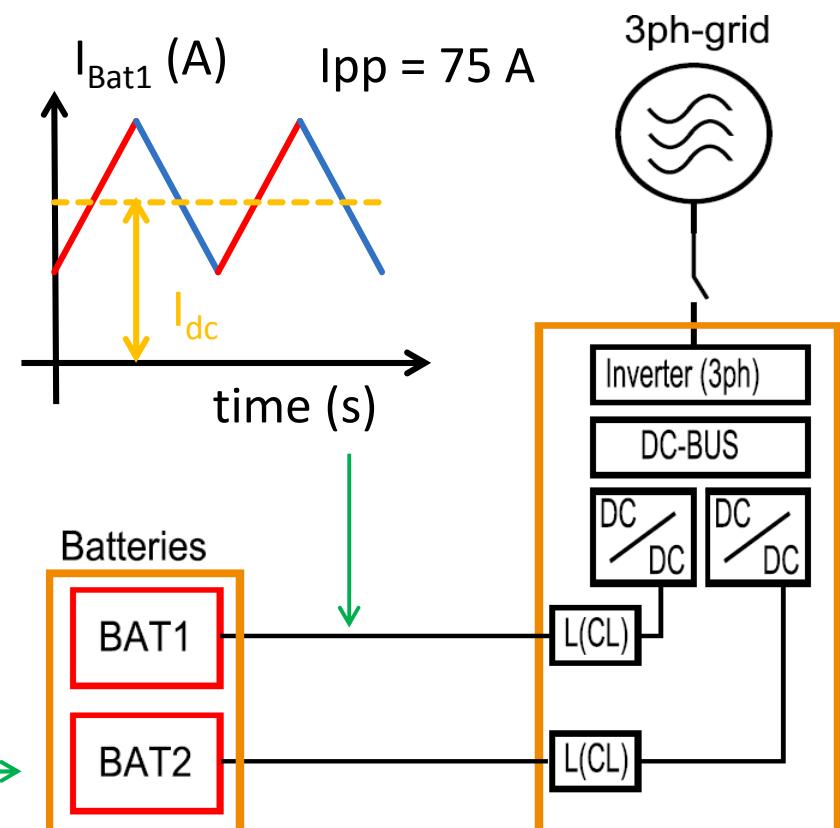
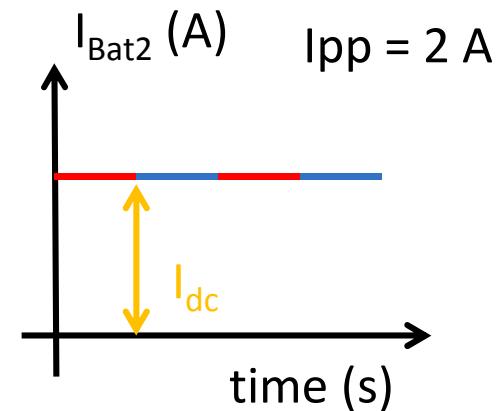
Charge-Sustaining Cycle Life Test Profile:

- 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



Filter configuration

	BAT 1	BAT 2
1st month	L	LCL
2nd month	LCL	L
3rd month	LCL	LCL



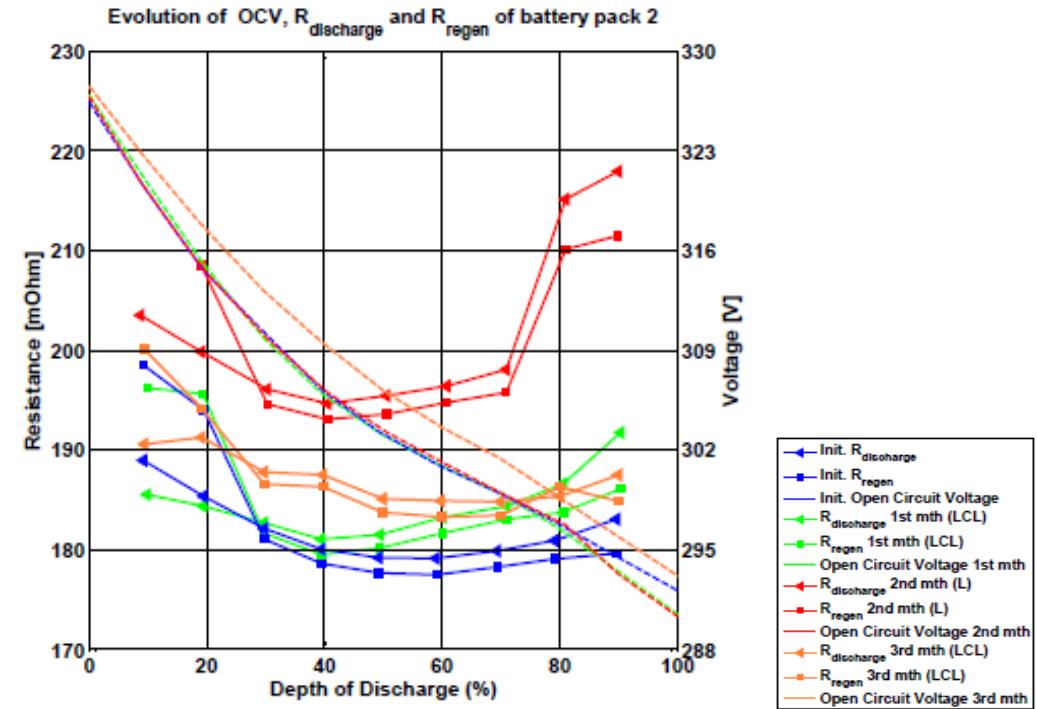
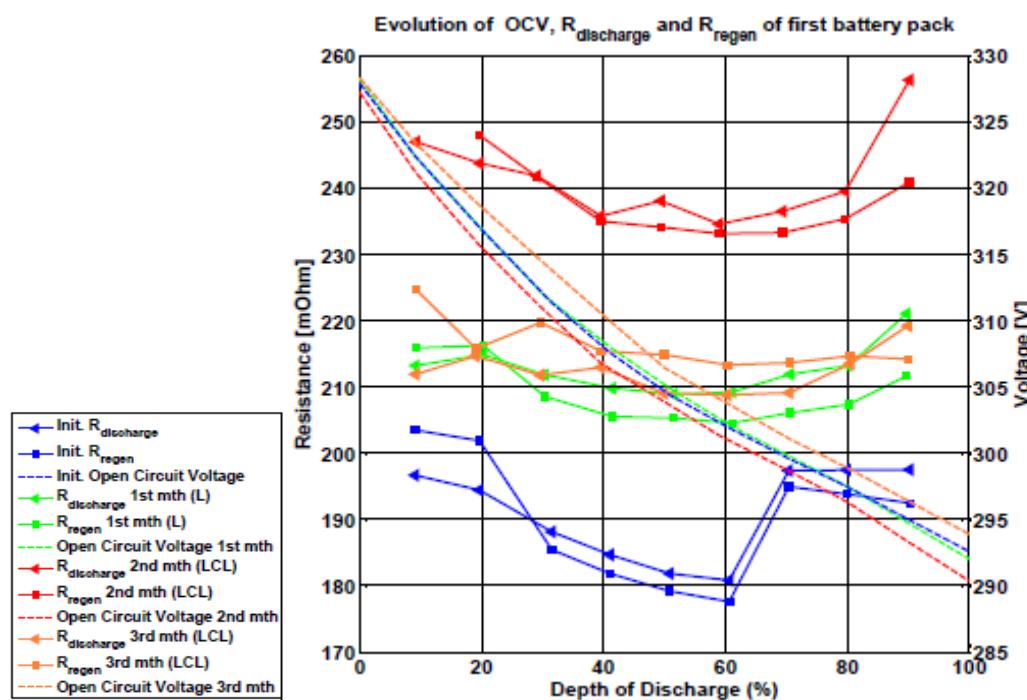
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Impact of current ripple on battery

Evolution of discharge and regen resistance:

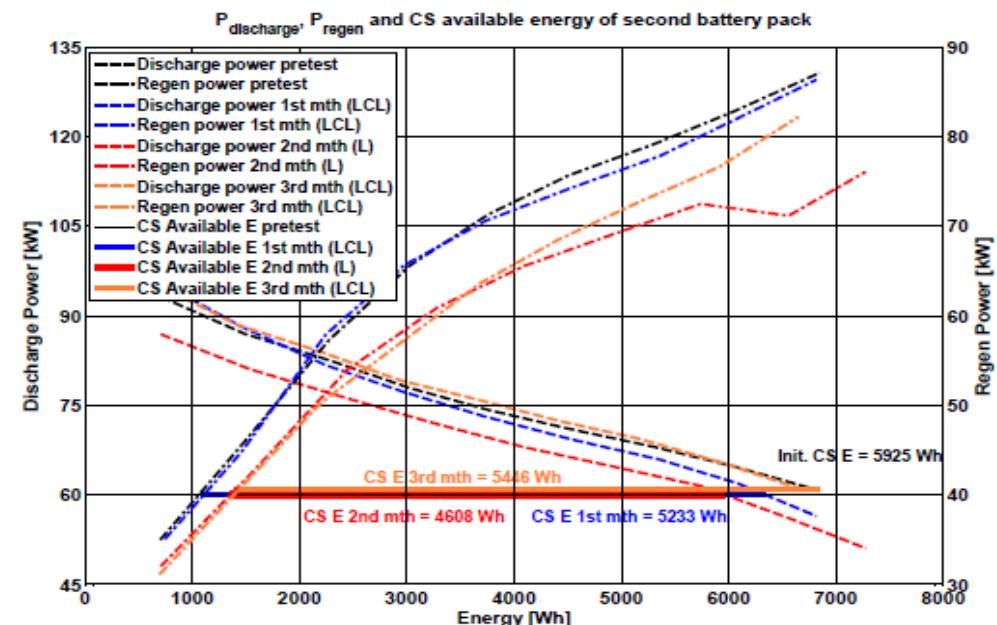
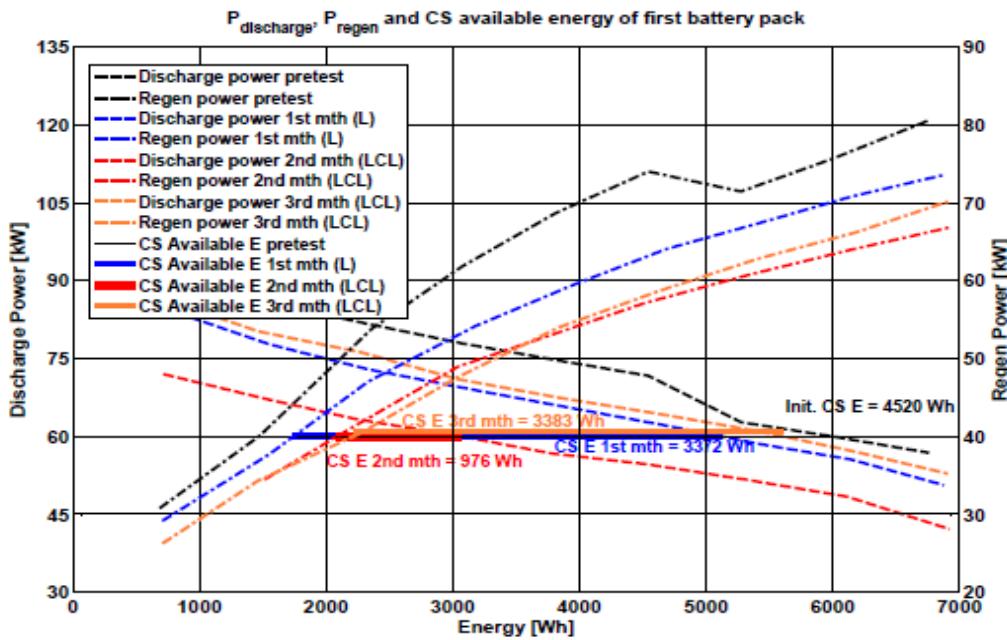
- » Dominant impact of T
- » Current ripple: no measurable impact



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

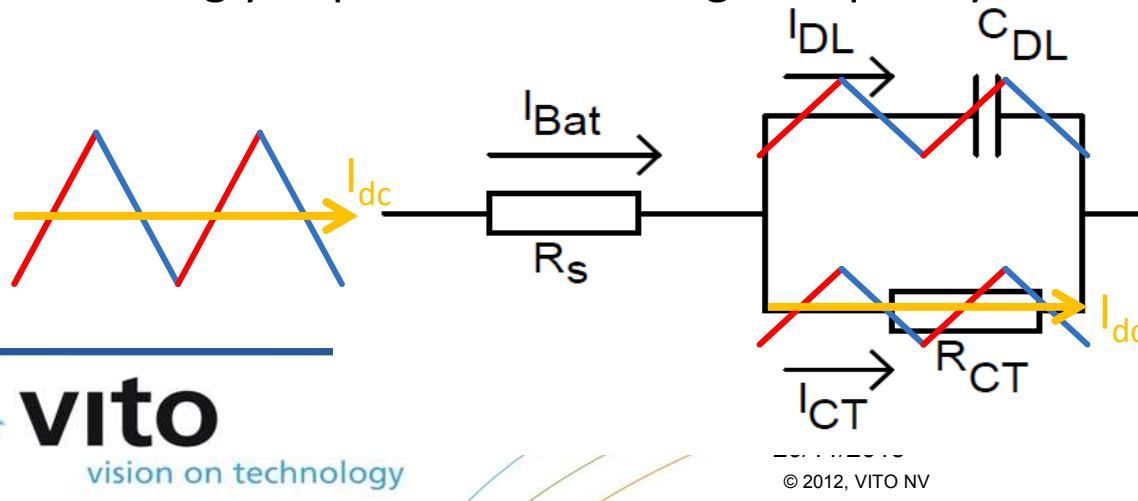
Ageing of batteries is present, but not related to current ripple

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 ?