



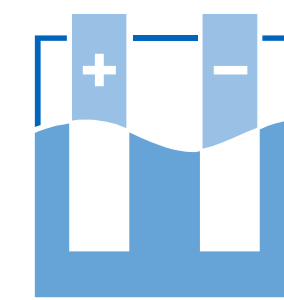
Effects of compensating Current in the parallel Connection of Battery Cells

Markus H. Hofmann, Marco Steinhardt, Martin J. Brand and Andreas Jossen

Chair of Electrical Energy Storage Technology

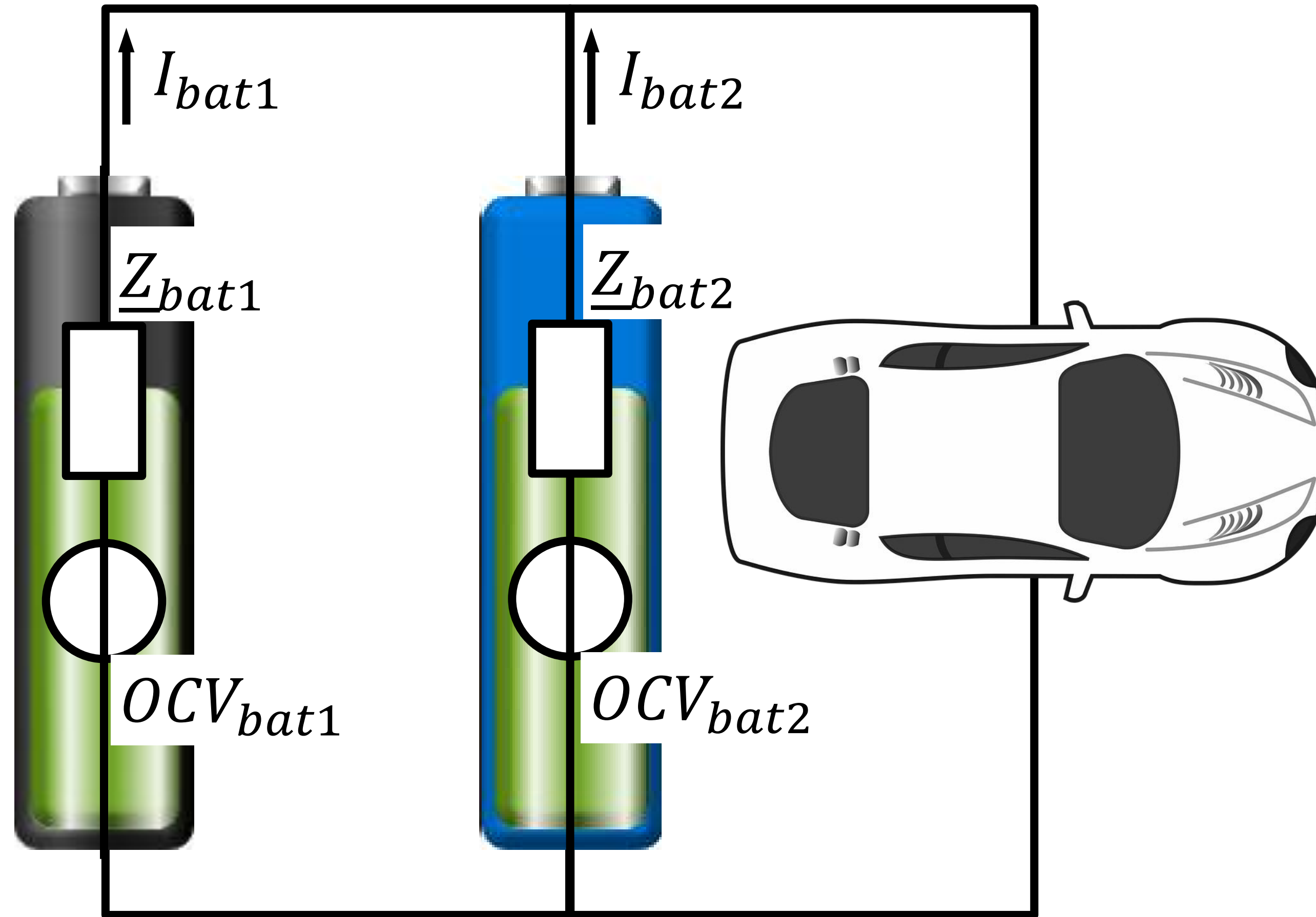
EVS – Montréal, 21. June 2016

Technical University of Munich



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Electrical Energy Storage Technology

Motivation



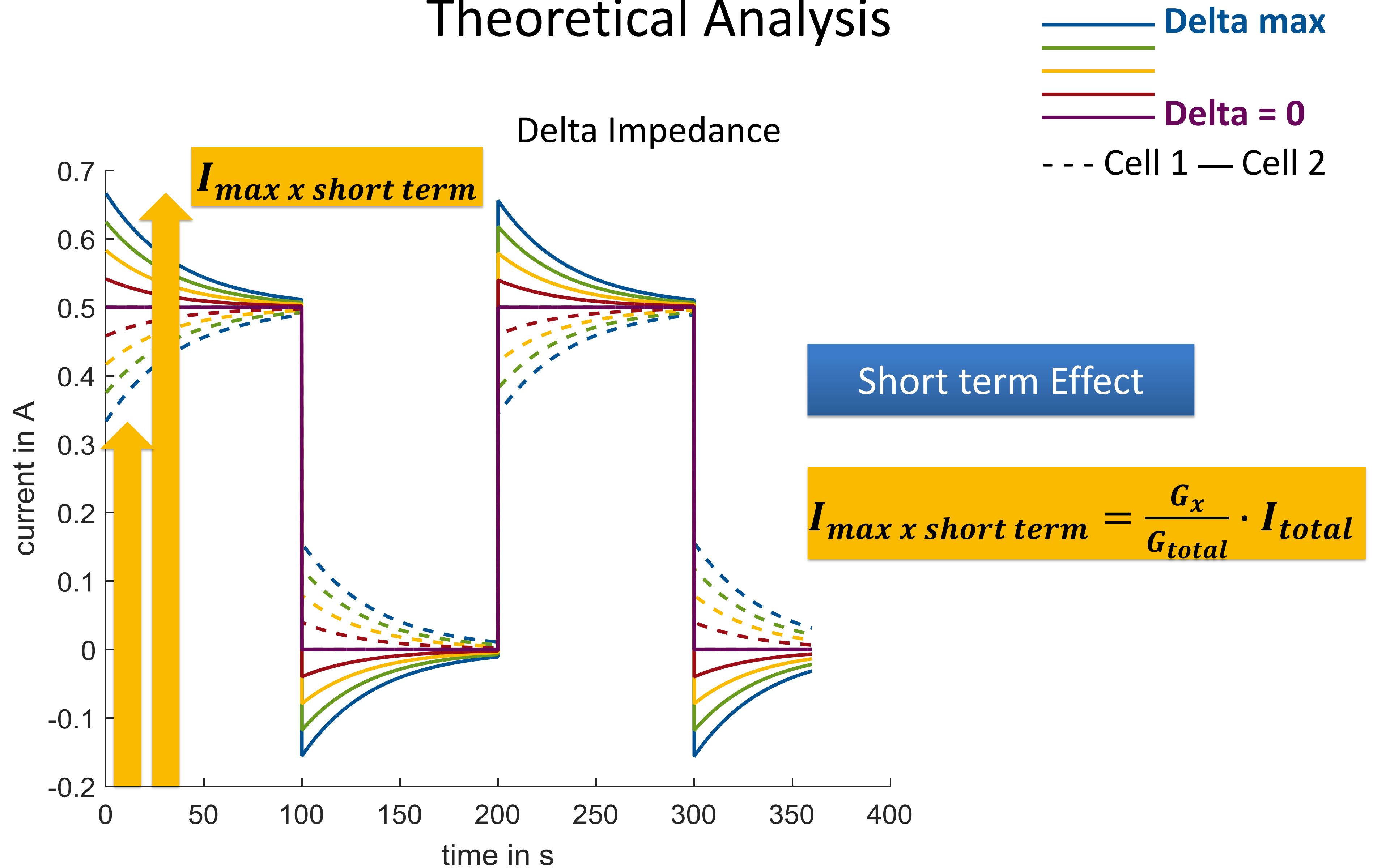
~~$I_{bat1} = I_{bat2}$~~ ???

$Z_{bat1} \neq Z_{bat2}$
 $OCV_{bat1} \neq OCV_{bat2}$
 $I_{bat1} \neq I_{bat2}$

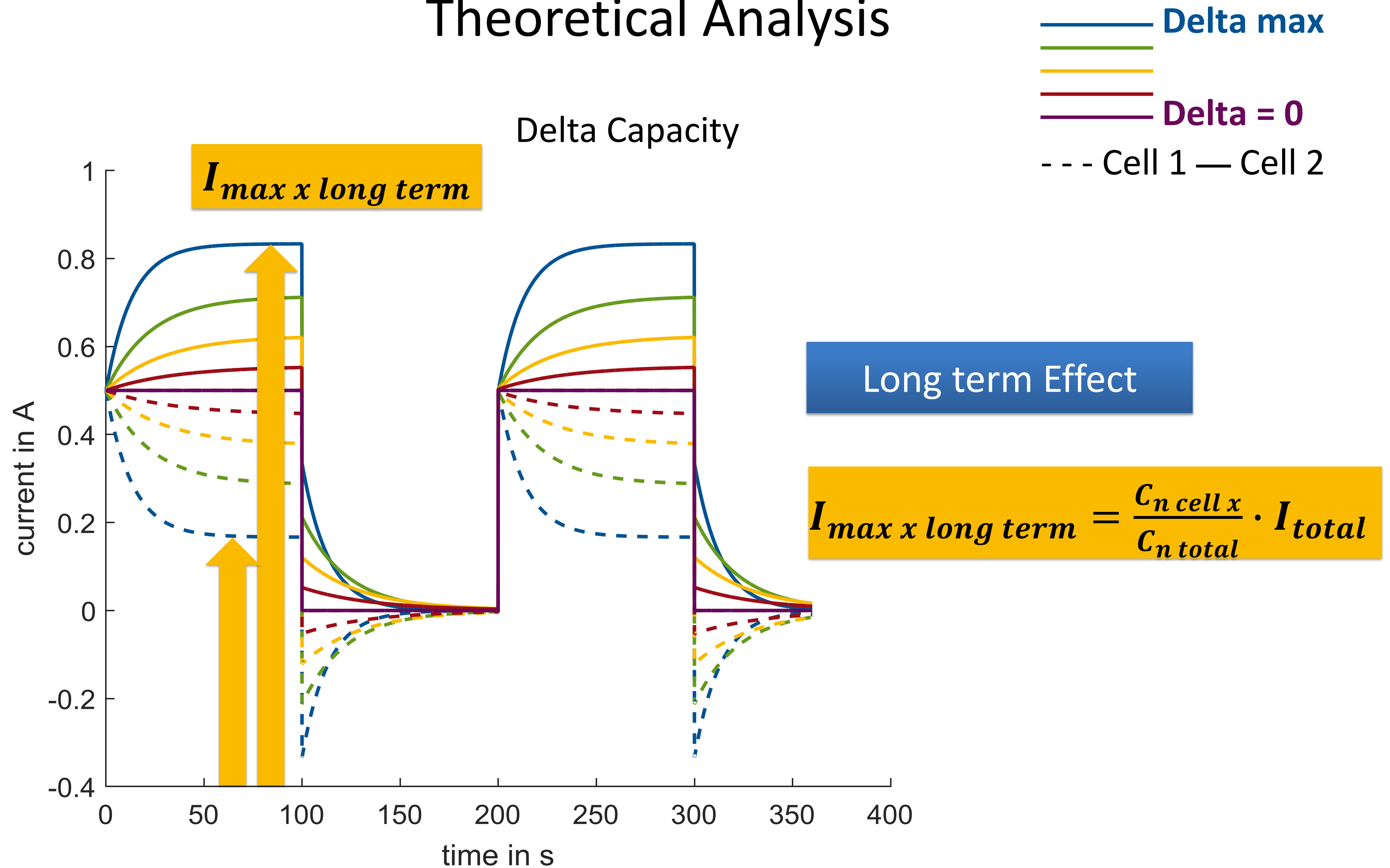
Reasons:

- Parameter variance
- Temperature difference
- Different ageing
- Different cells
- Different SOC

Theoretical Analysis



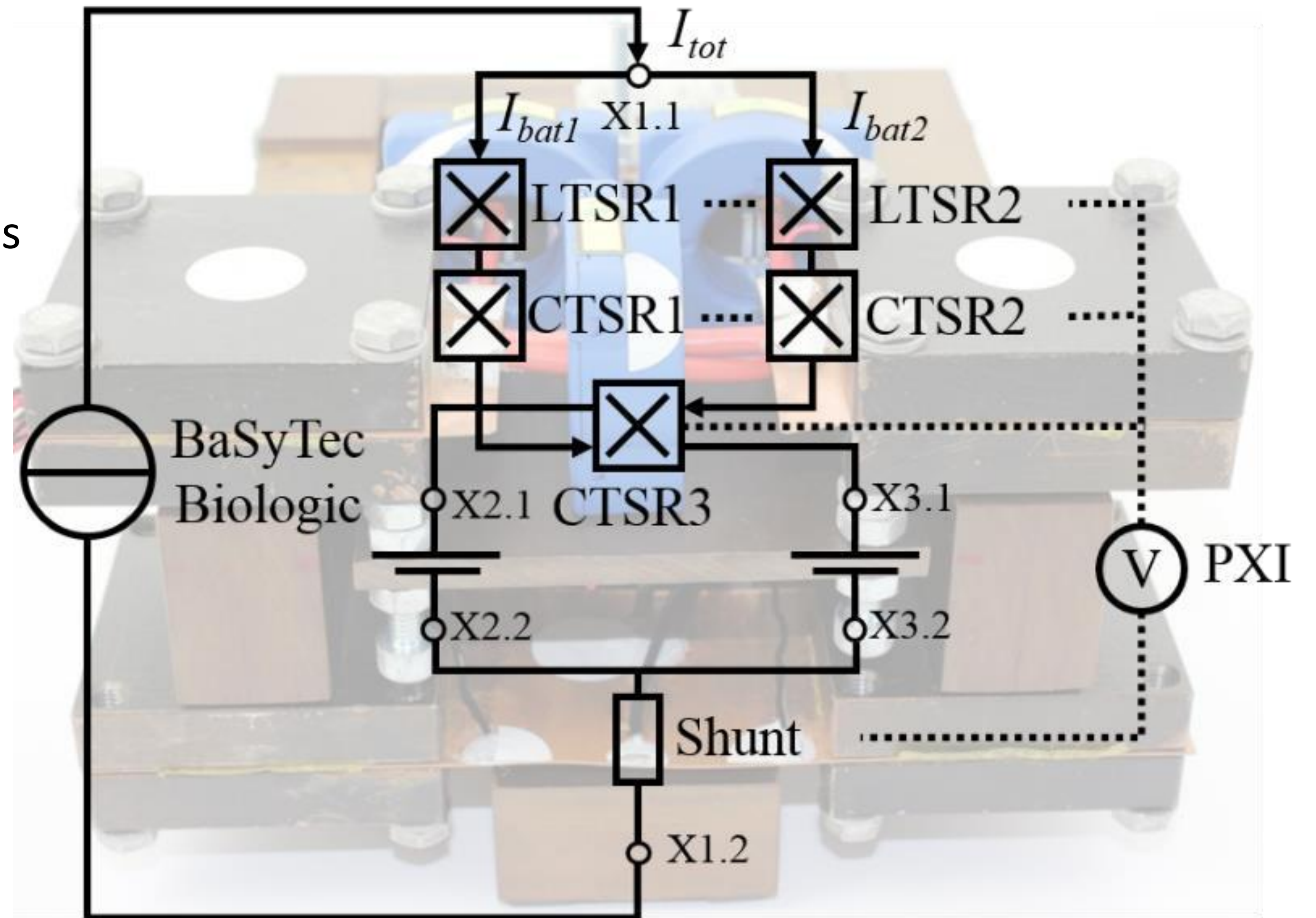
Theoretical Analysis



Measurement

Requirements

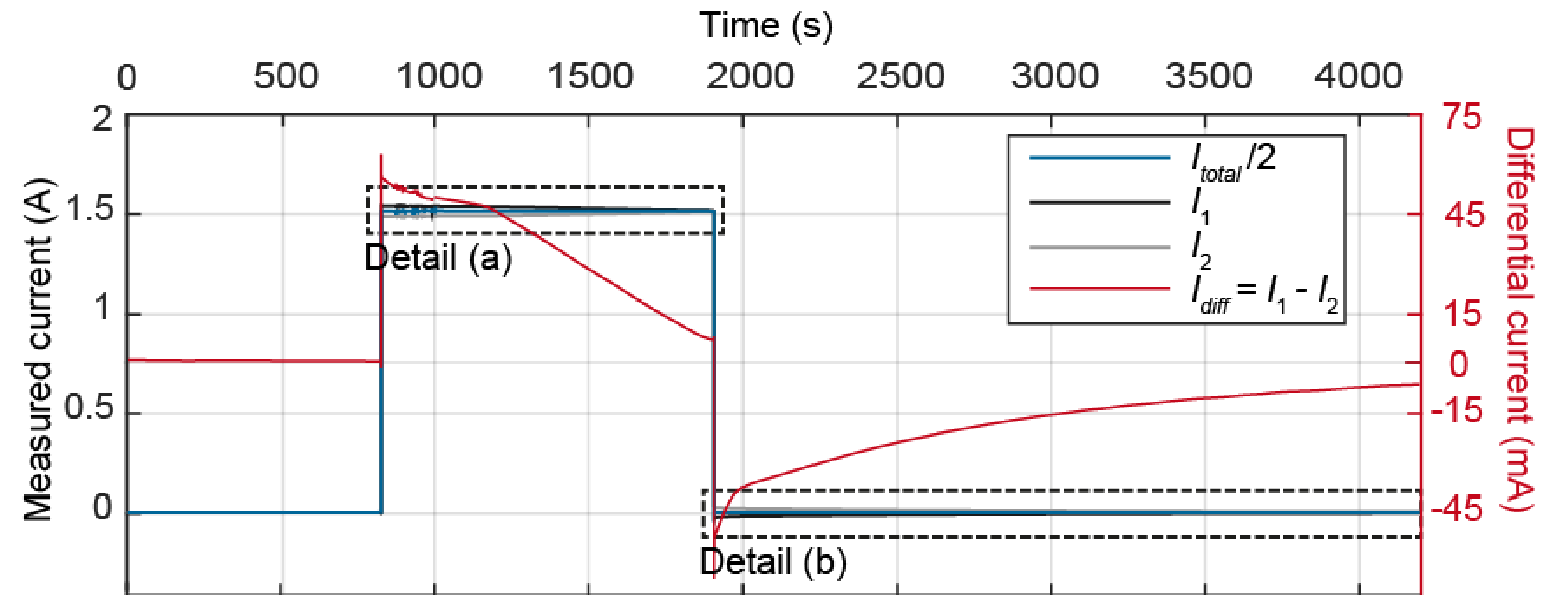
- High precision measuring
- Low additional impedance
- No differences in the strings
- Cylindrical 18650 cells



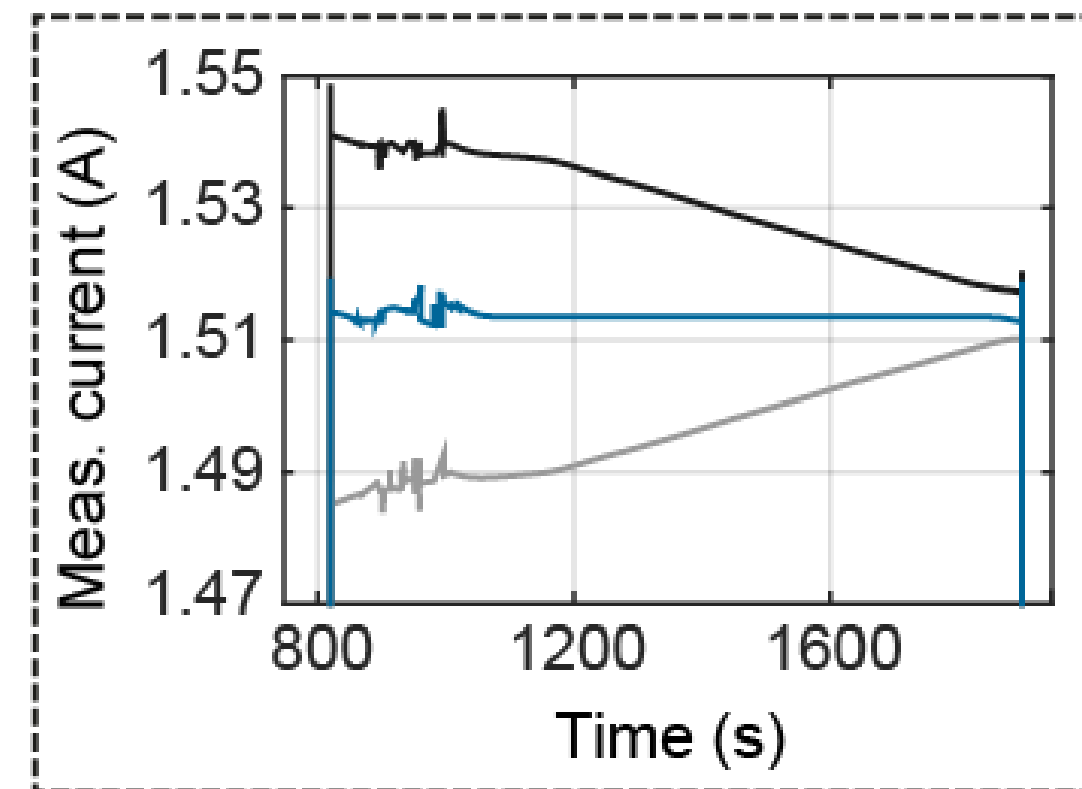
Measured Results

Different Impedance

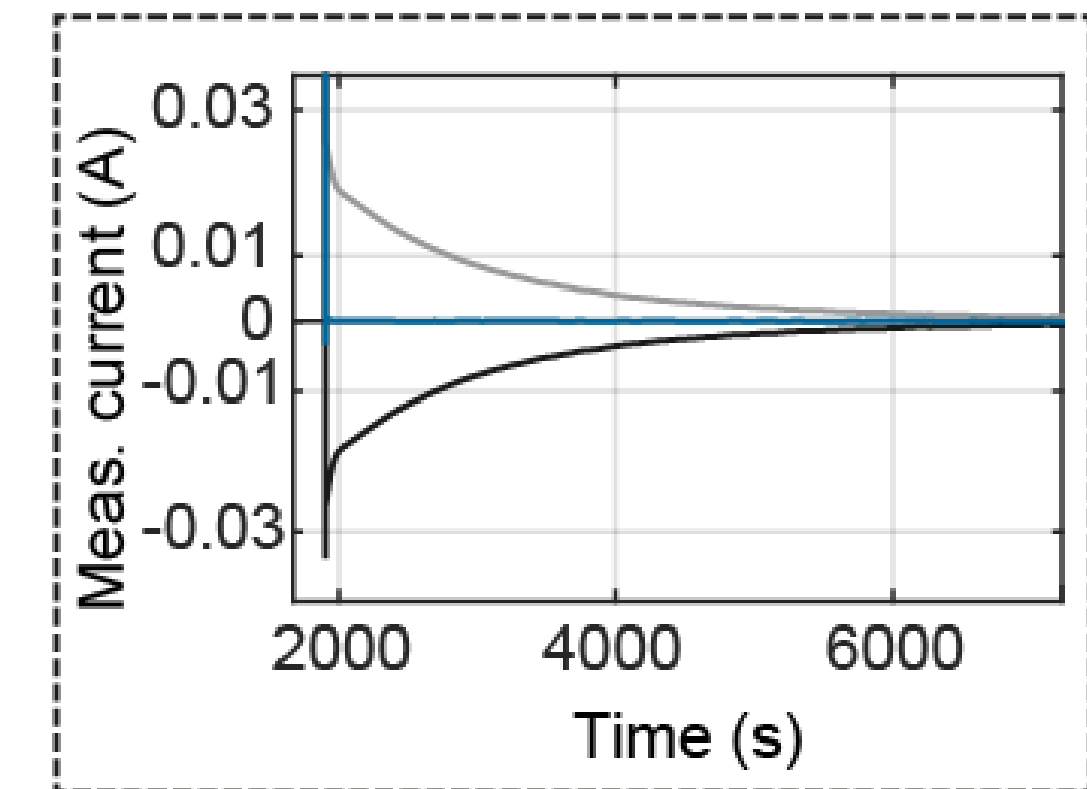
Short term Effect



Detail (a)



Detail (b)

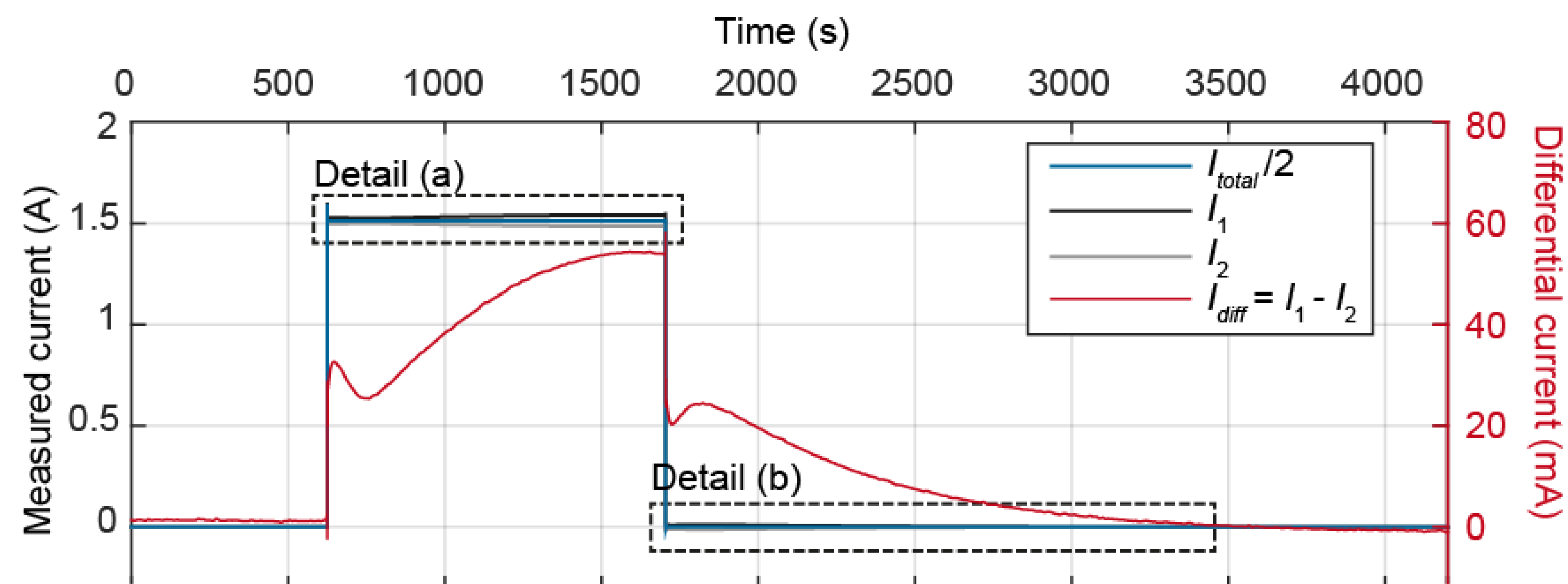


	Cell 1	Cell 2
Capacity	1.95 Ah	1.95 Ah
Ohmic Resistance	68.8 mΩ	73.2 mΩ

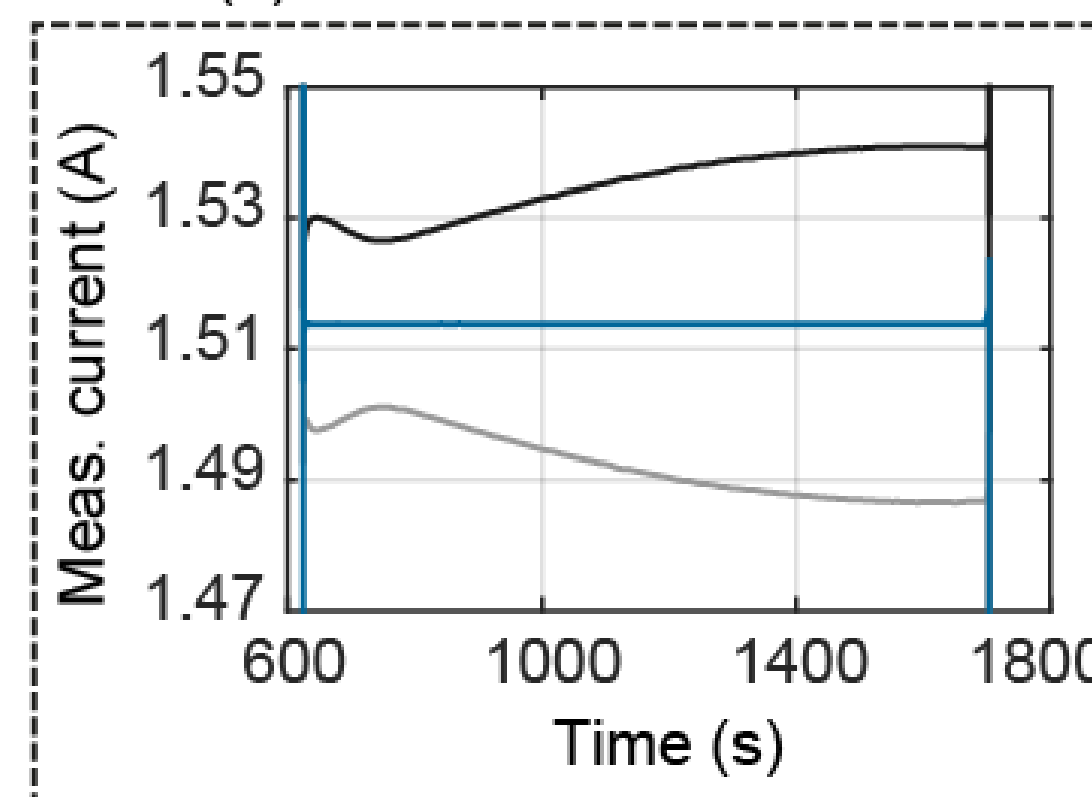
Measured Results

Different Capacity

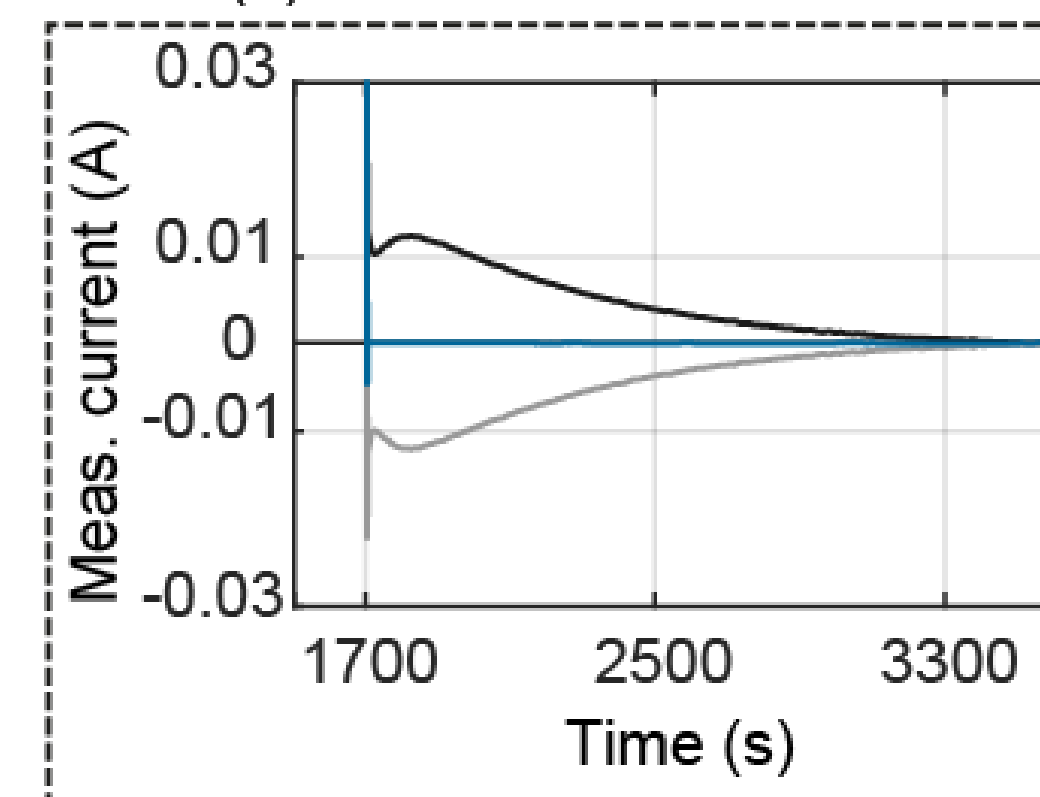
Long term Effect



Detail (a)



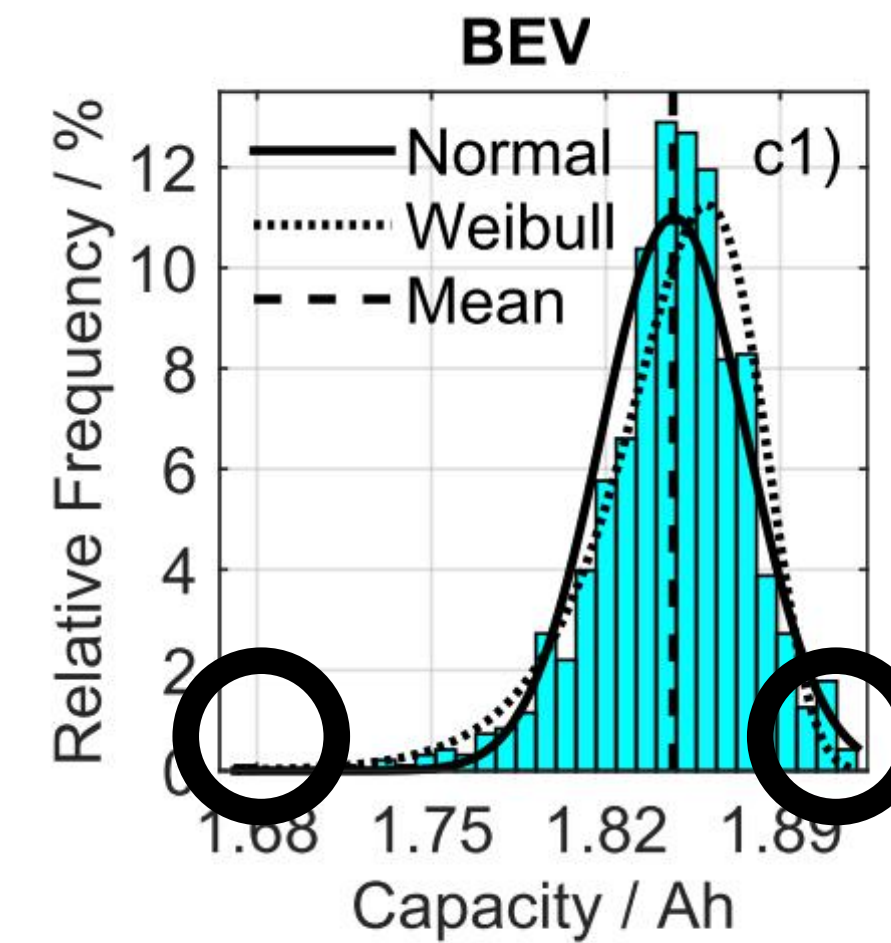
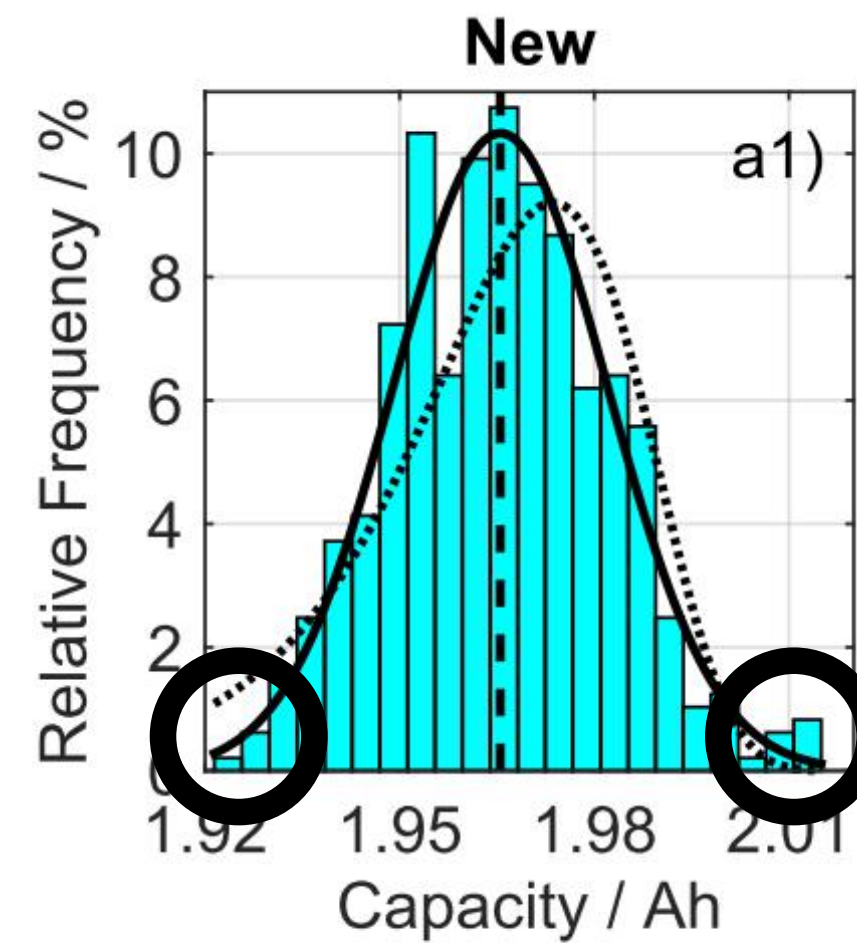
Detail (b)



	Cell 1	Cell 2
Capacity	2.00 Ah	1.92 Ah
Ohmic Resistance	96.0 mΩ	95.0 mΩ

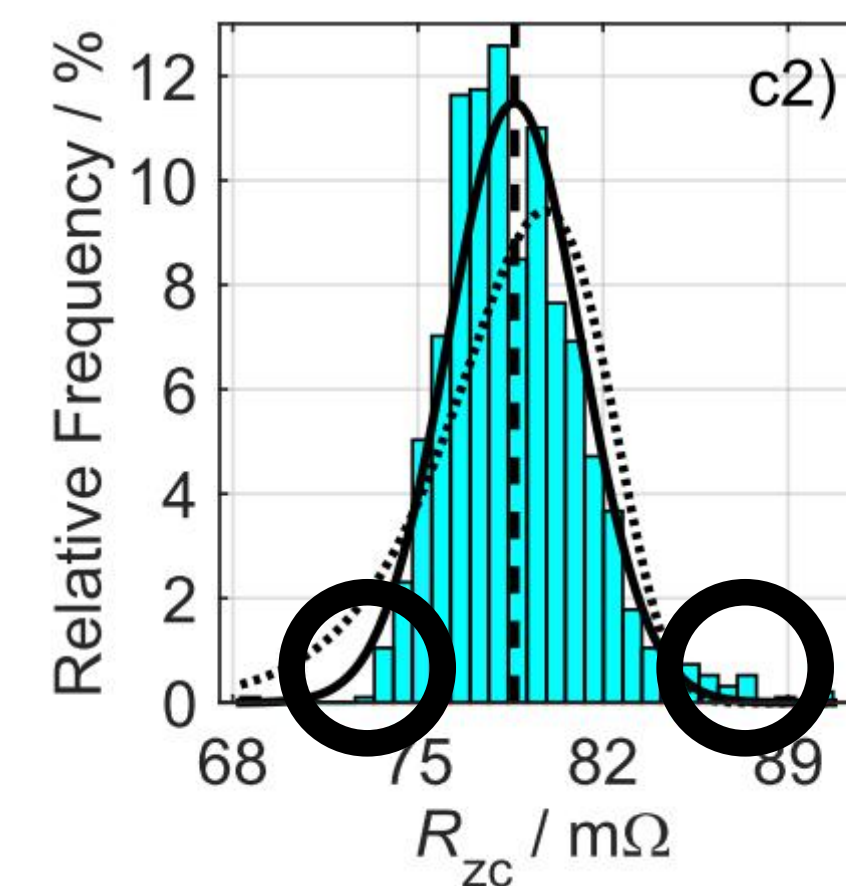
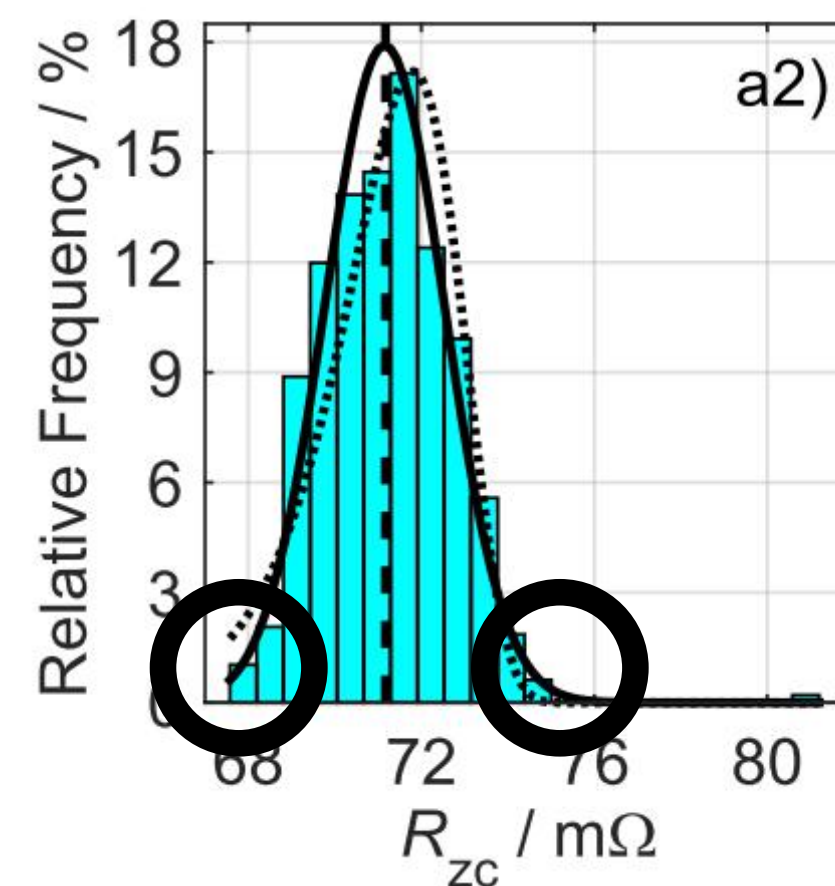
Effects on Battery Packs

$$\Delta C_n = 0.09 \text{ Ah}$$



$$\Delta C_n = 0.27 \text{ Ah}$$

$$\Delta R_{zc} = 8 \text{ m}\Omega$$

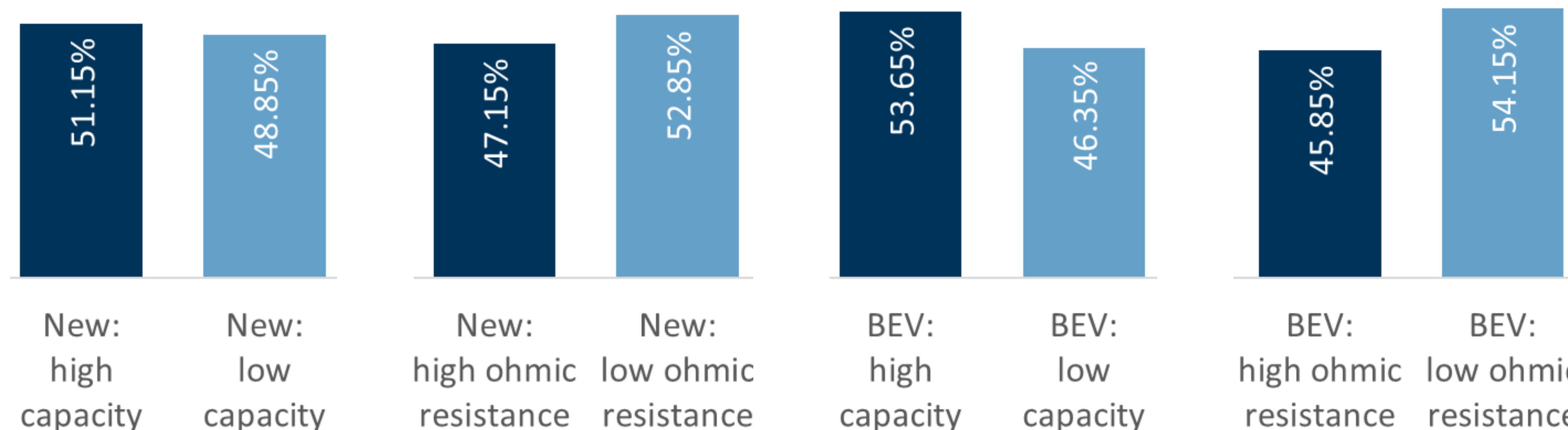


$$\Delta R_{zc} = 12 \text{ m}\Omega$$

[1]

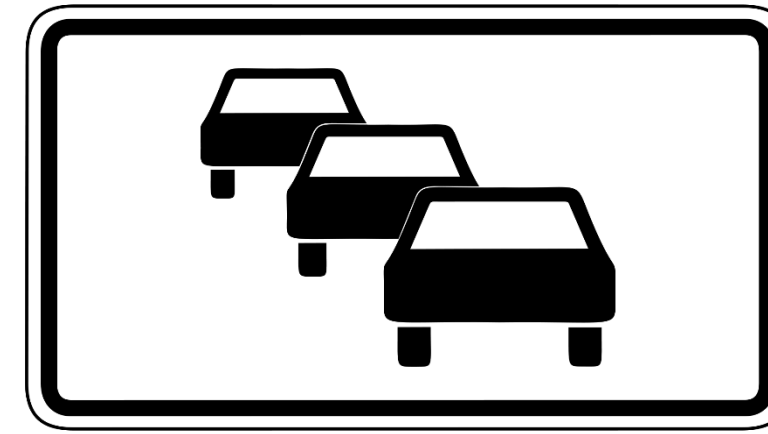
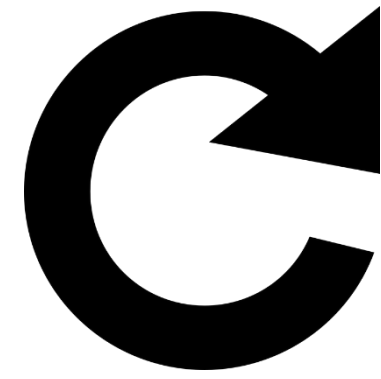
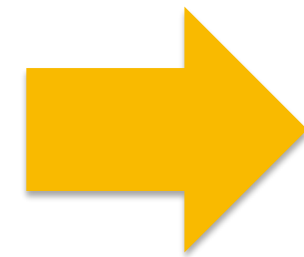
Effects on Battery Packs

	New	BEV
Maximum capacity difference	0.09 Ah	0.27 Ah
Maximum ohmic resistance difference	8 mΩ	12 mΩ
Long-term current distribution		
Cell with high capacity	1.023 A	1.073 A
Cell with low capacity	0.977 A	0.927 A
Short-term current distribution		
Cell with high ohmic resistance	0.943 A	0.917 A
Cell with low ohmic resistance	1.057 A	1.083 A

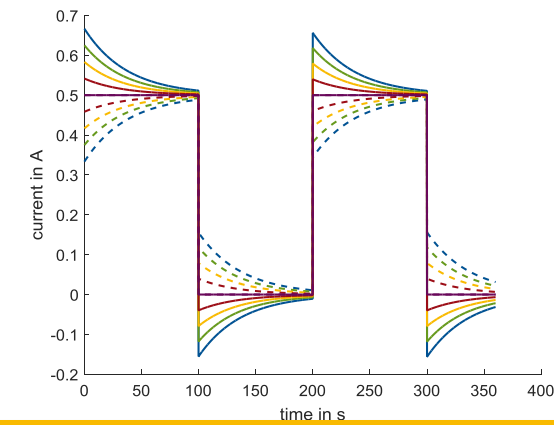
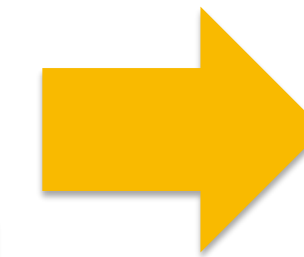


Conclusion

Different
Impedance

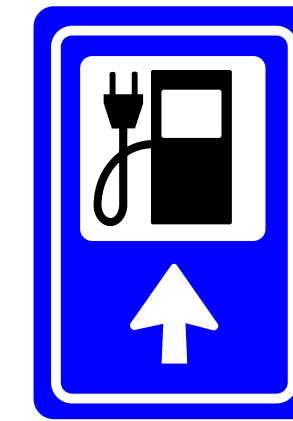
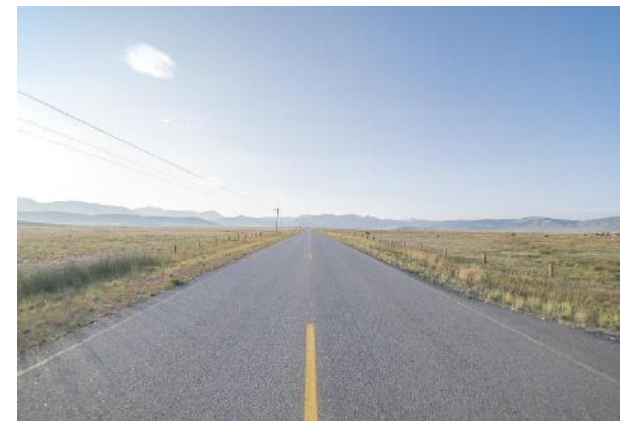
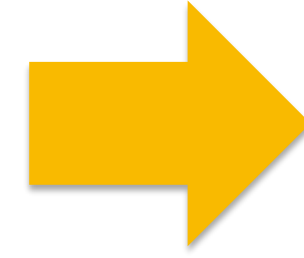


Recuperation / Stop and Go

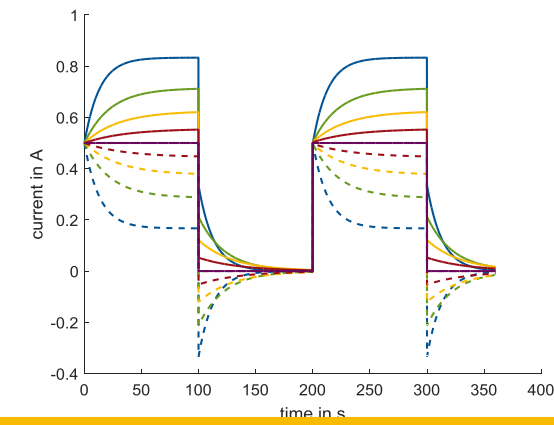
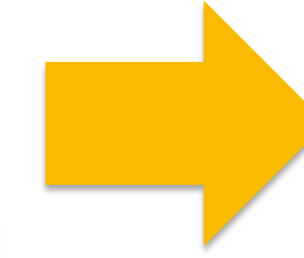


$$I_{max \text{ x short term}} = \frac{G_x}{G_{total}} \cdot I_{total}$$

Different
Capacity

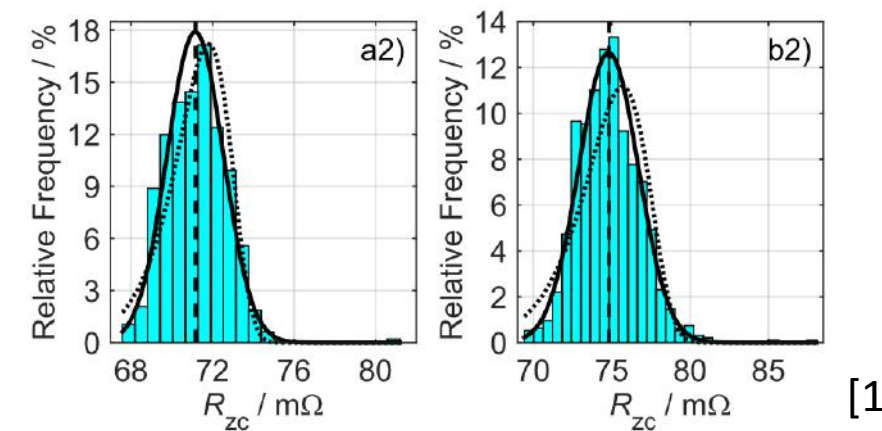
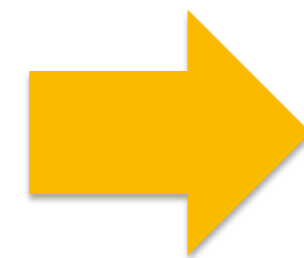


Motorway / Charging

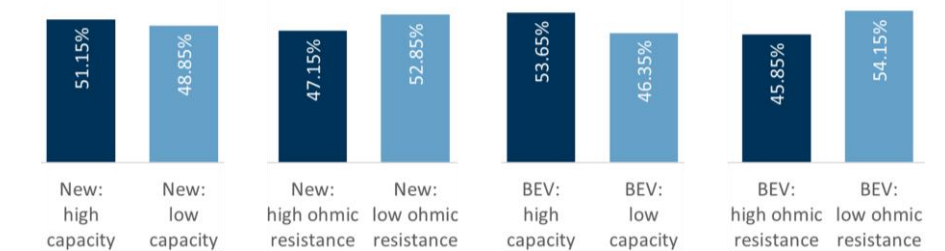


$$I_{max \text{ x long term}} = \frac{C_{n \text{ cell } x}}{C_{n \text{ total}}} \cdot I_{total}$$

Effects on
Battery
Packs



Parameter Variance



Current Distribution