Battery system technology

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for Solar Energy Systems

Workshop - Renewable energy concepts for SKA and its pathfinders

Berlin, 7th of April 2011

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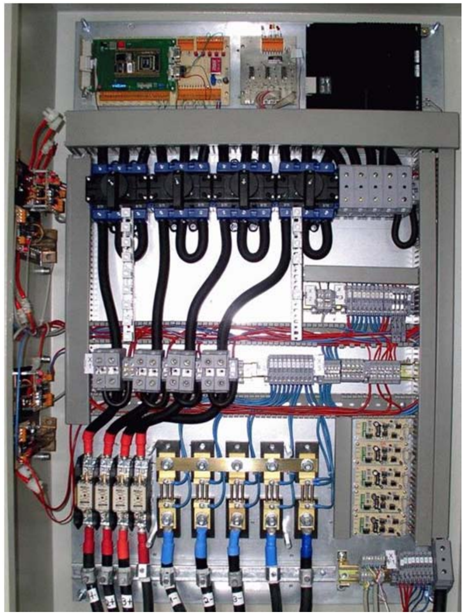
PV off-grid solutions and battery system technology



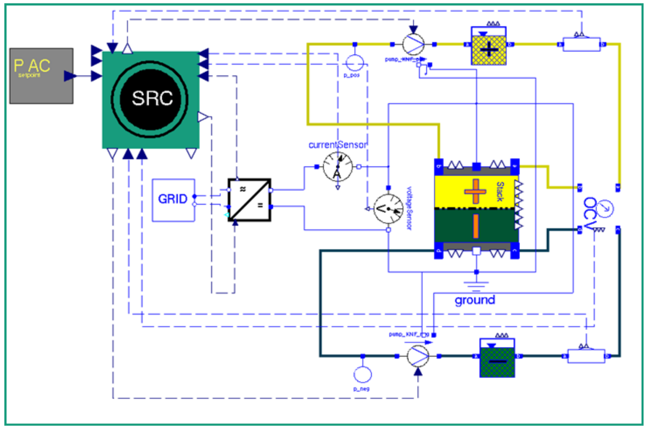
- Team “Autonomous systems and mini-grids”
- Team “Battery modules and systems”
- Team “Solar driven water supply and storage systems”

Agenda

- Introduction “battery system technology”
- Overview of battery technologies
- Lead acid batteries
- Lithium-ion batteries
- Vanadium redox-flow batteries
- Conclusions

Battery system technology

- Battery testing
- Development of battery modules and systems
- Battery monitoring
  - State of charge determination
  - State of health determination (capacity)
- Charging and operating control strategies
- Development of charge controllers and battery management systems
- Modeling and simulation
- Technical and economical system analyses (e.g. life cycle cost)



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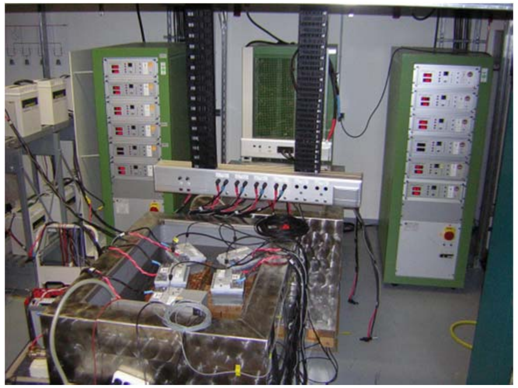
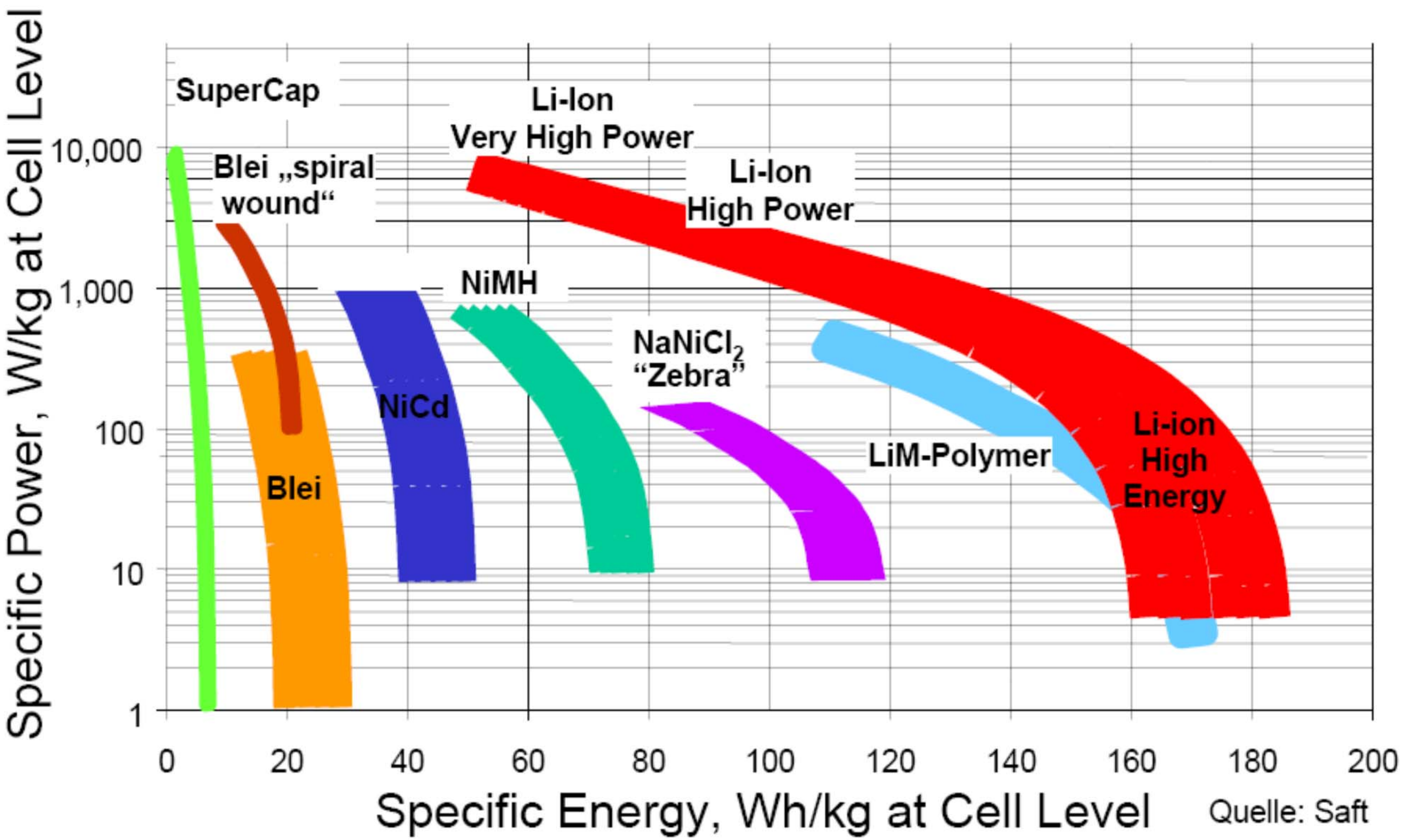
Battery laboratory at Fraunhofer ISE

- 1 x 250 kW, 1 kV, 600 A (Pack tester)
- 1 x 500 V, 100 A (Pack tester)
- 3 x 300 V, 5 A
- 32 x 6 V, 3 A (with reference electrode)
- 32 x 5 V, 5 A
- 18 x 12 V, 200 mA-10 A
- 8 x 18 V, 5A
- 32 x 5 V, 30 A (parallel switchable)
- 1 x 20V, 300 A
- 3 x 18 V, 100 A
- 12 x 70 V, 50 A
- 3 x 18 V, 100 A
- 4 channels impedance spectroscopy 1µHz – 4,5kHz
- 9 Climate and temperature chambers

→ 146 test circuits



Batteries: Ragone plot



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Storage solutions – batteries

V-redox-flow

NiMh

Source: www.saftbatteries.com

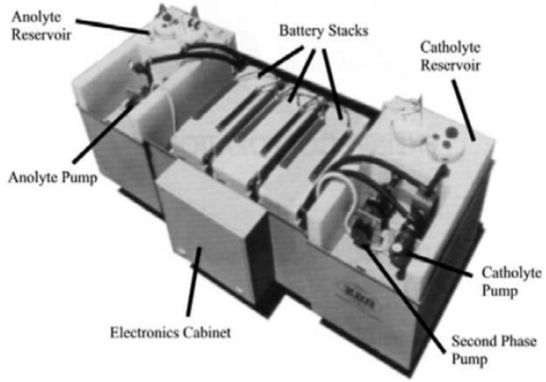
Lithium

NaS

Source: www.ngk.co.jp

Lead-acid

Zinc-bromine



Source: B.L. Norris

Storage solutions – batteries

V-redox-flow

kW / kWh

MW / MWh

NiMh

Source: www.saftbatteries.com

kW / kWh

MW

Lithium

NaS

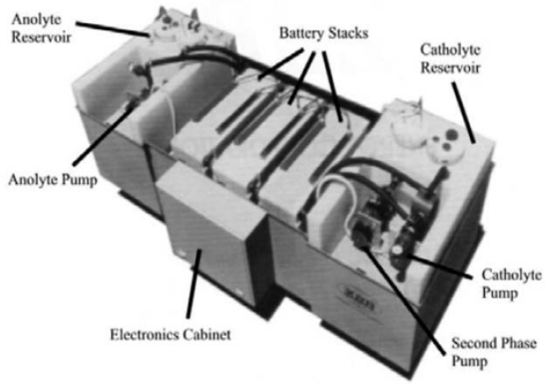
MW / MWh

Source: www.ngk.co.jp

Lead-acid

kW / kWh

Zinc-bromine



Source: B.L. Norris

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Storage solutions – batteries for MW PV power plants

V-redox-flow

MW / MWh

NiMh

Source: www.saftbatteries.com

Lithium

MW

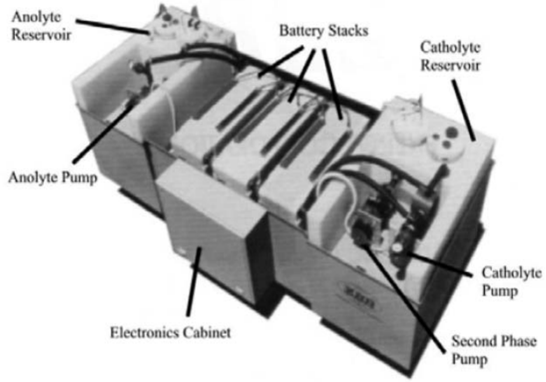
NaS

MW / MWh

Source: www.ngk.co.jp

Lead-acid

Zinc-bromine



Source: B.L. Norris

Lead-acid batteries

Advantages:

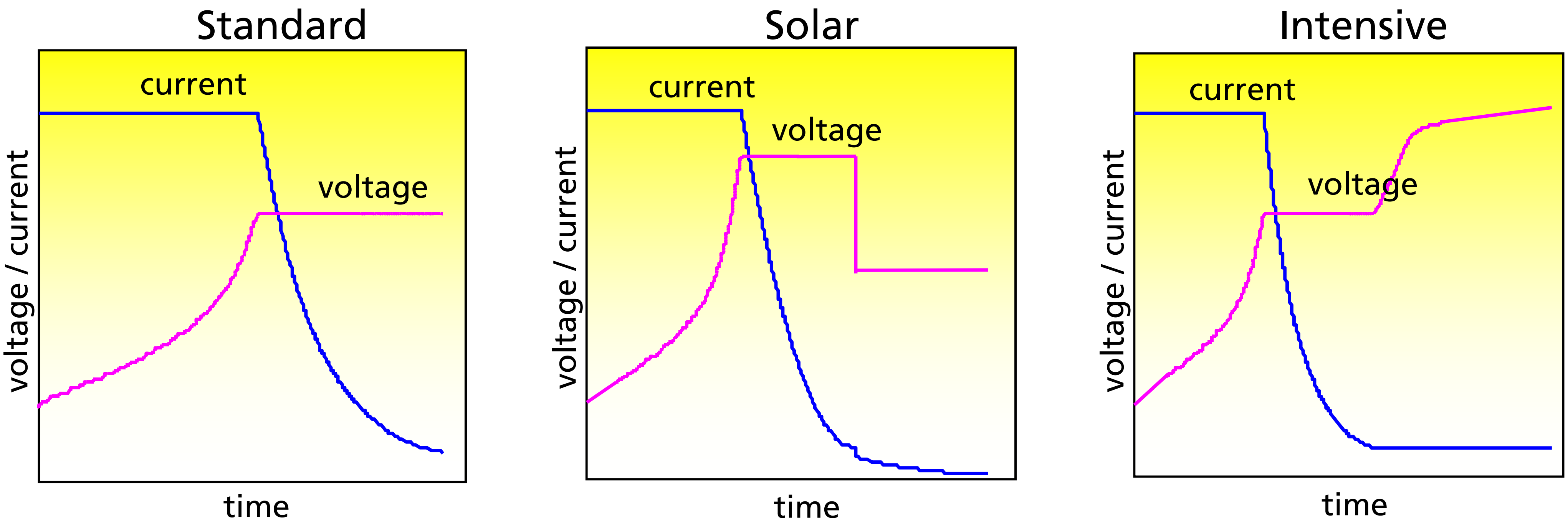
- Market leading battery type
- Available in large quantities
- Available in a variety of sizes and designs
- Relatively high efficiency
- Low specific costs

Disadvantages:

- Low life cycle
- Limited energy density
- Hydrogen evolution in some designs
- High maintenance costs

Schematics of different charging regimes

- **Standard:** constant current / constant voltage charge → **cc-cv**
- **Solar:** constant current / constant voltage charge with two end-of-charge voltage limits → **cc-cv-cv**
- **Intensive:** constant current / constant voltage charge followed by a limited constant current phase → **cc-cv-cc**



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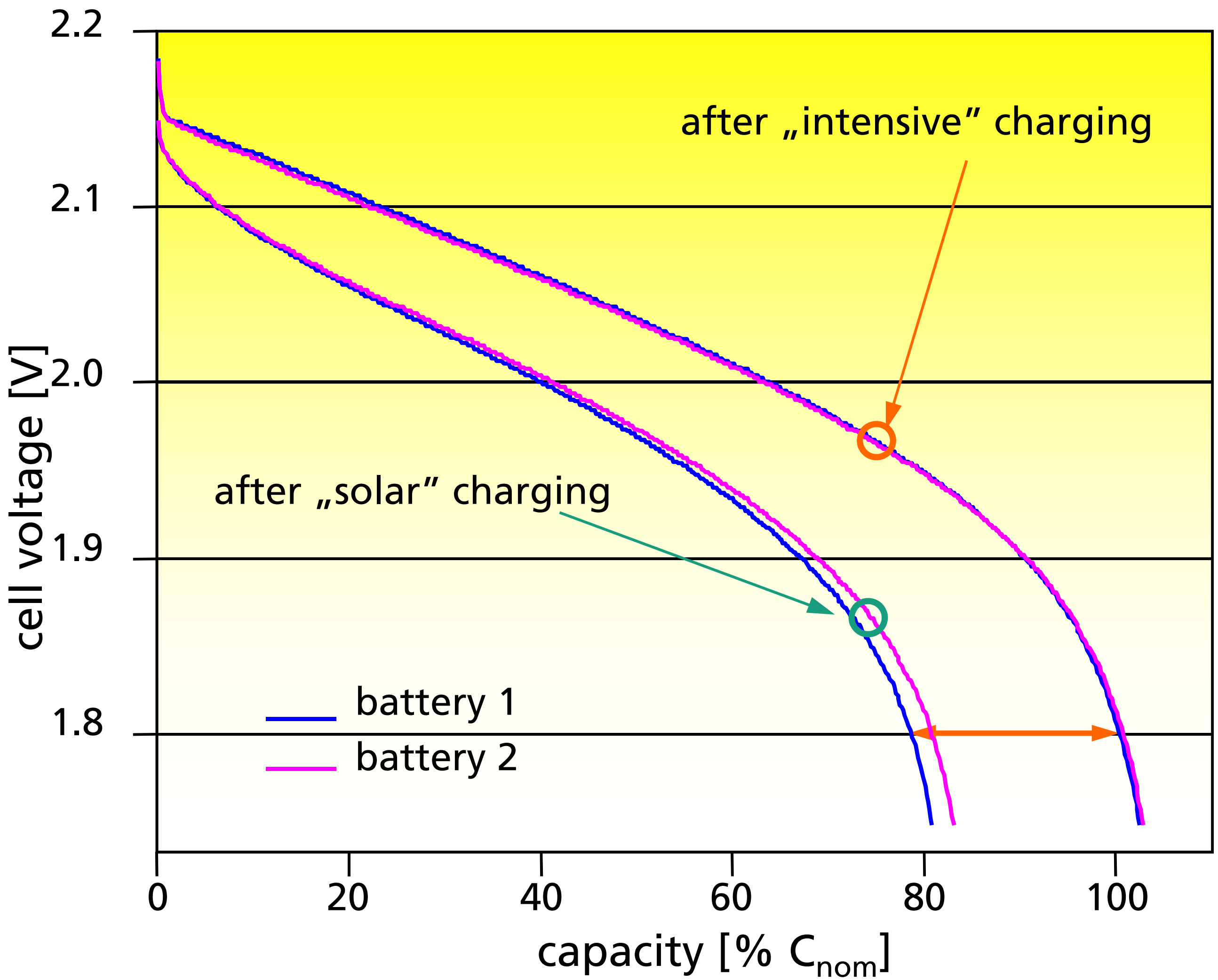
Capacity gain by intensive charging

VRLA gel battery operates in a hybrid PV system with solar charging regime. Each half year capacity test plus intensive charging (I_{80} up to total charge of 112% C_{nom})

- Capacity after solar charging: 80 % C_{nom}
- Capacity after intensive charging: 100 % C_{nom}



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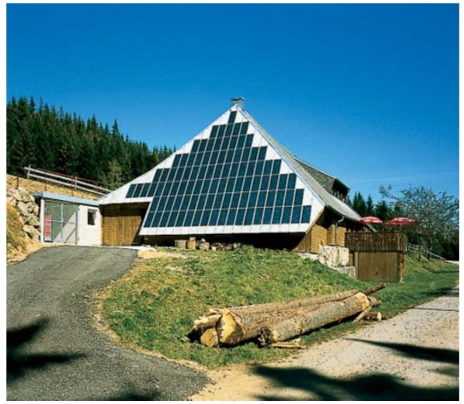
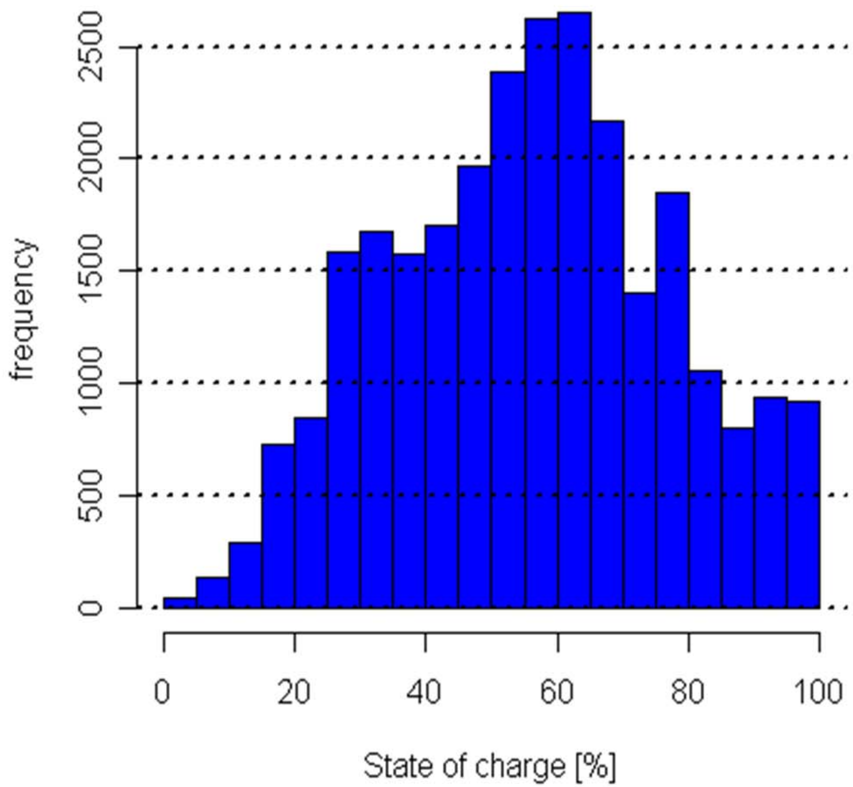
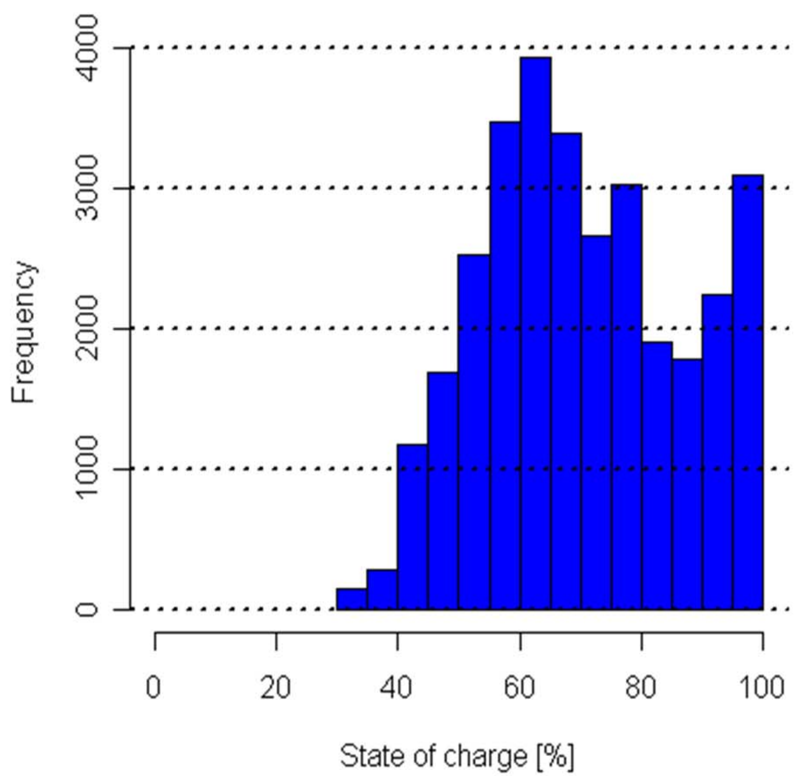
Battery management system – Results of field trial with lead acid batteries



2006: without BMS



2007: with BMS



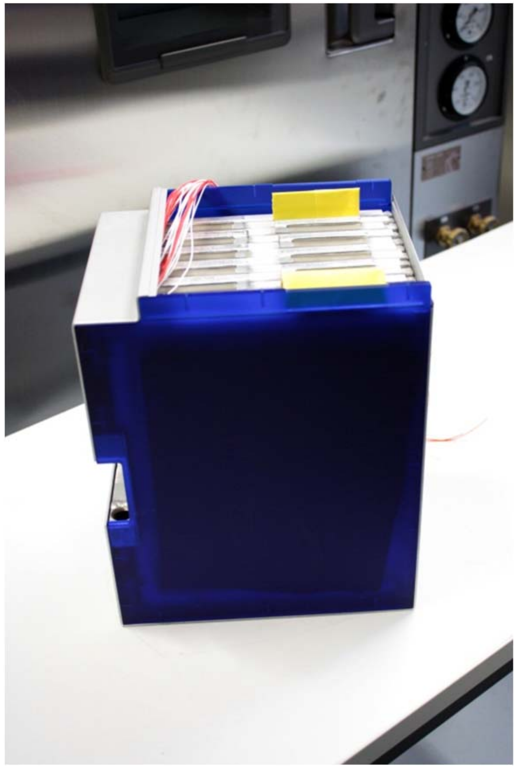
Lithium-ion batteries

Advantages:

- High energy density
- High power to capacity ratio
- Little or no maintenance
- Low self discharge
- High energy efficiency
- Long calendar life times
- Large number of cycles

Disadvantages:

- Safety – need for protective circuit
- High initial costs
- Thermal runaway possible when overcharged or crushed

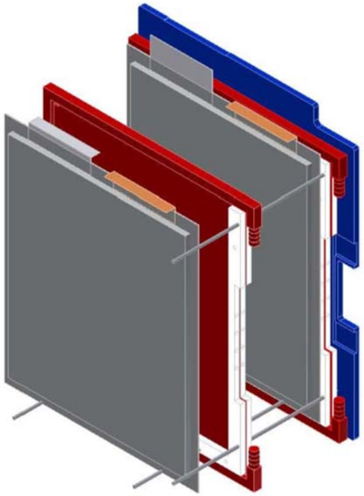


Lithium battery systems

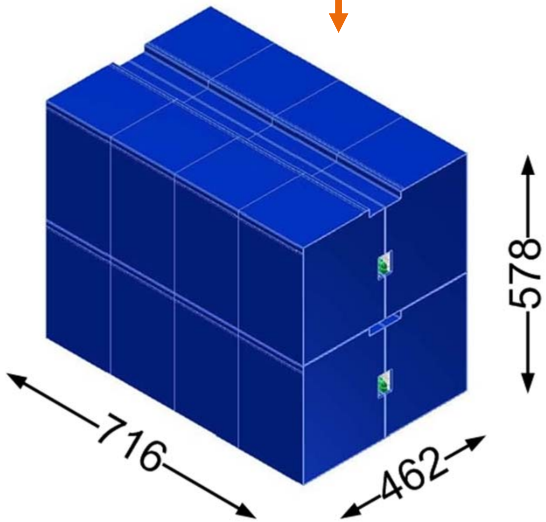
- From cell to module to system

EMS

BMS



231x179x289 mm



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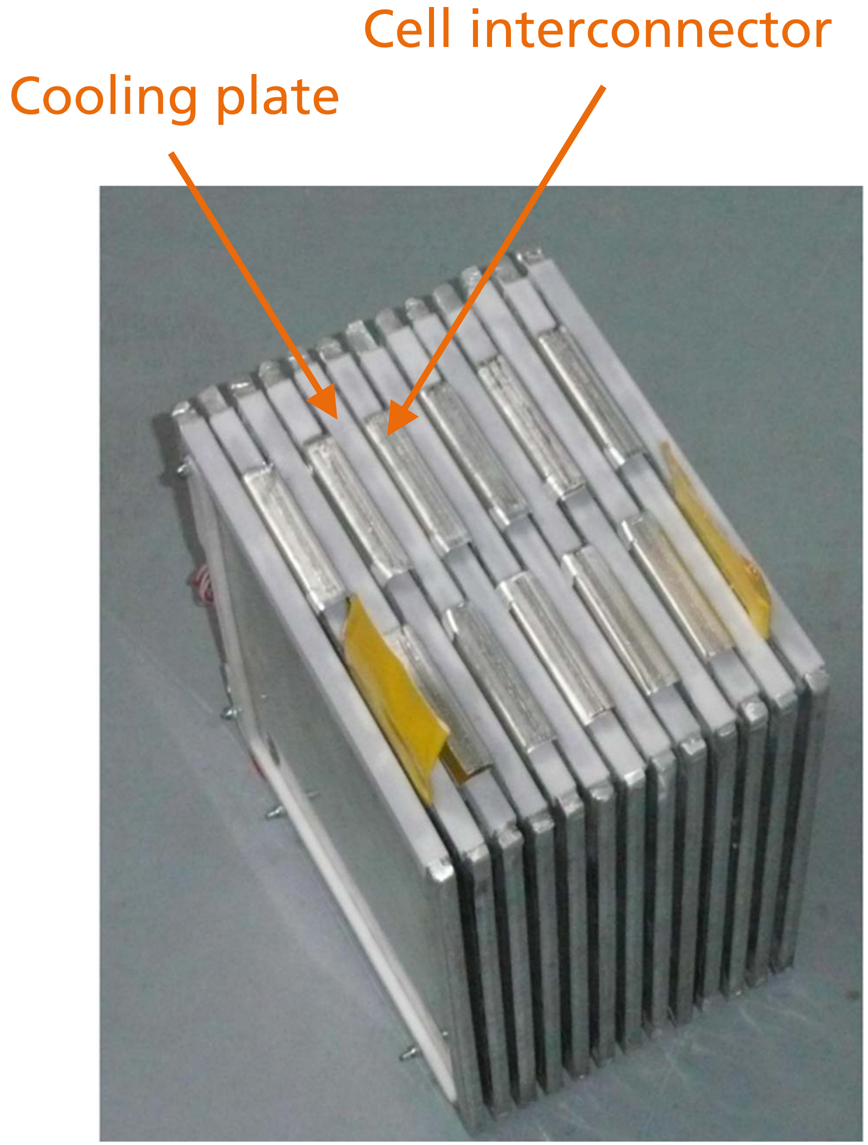
Battery module – Connection methods

- Cell interconnectors
  - ➢ Laser welding
  - ➢ Ultrasonic welding
  - ➢ Spot welding
  - ➢ Gluing
- Mechanical stability of cells within a battery module
- Thermal connection of cells (e.g. via cooling plates)



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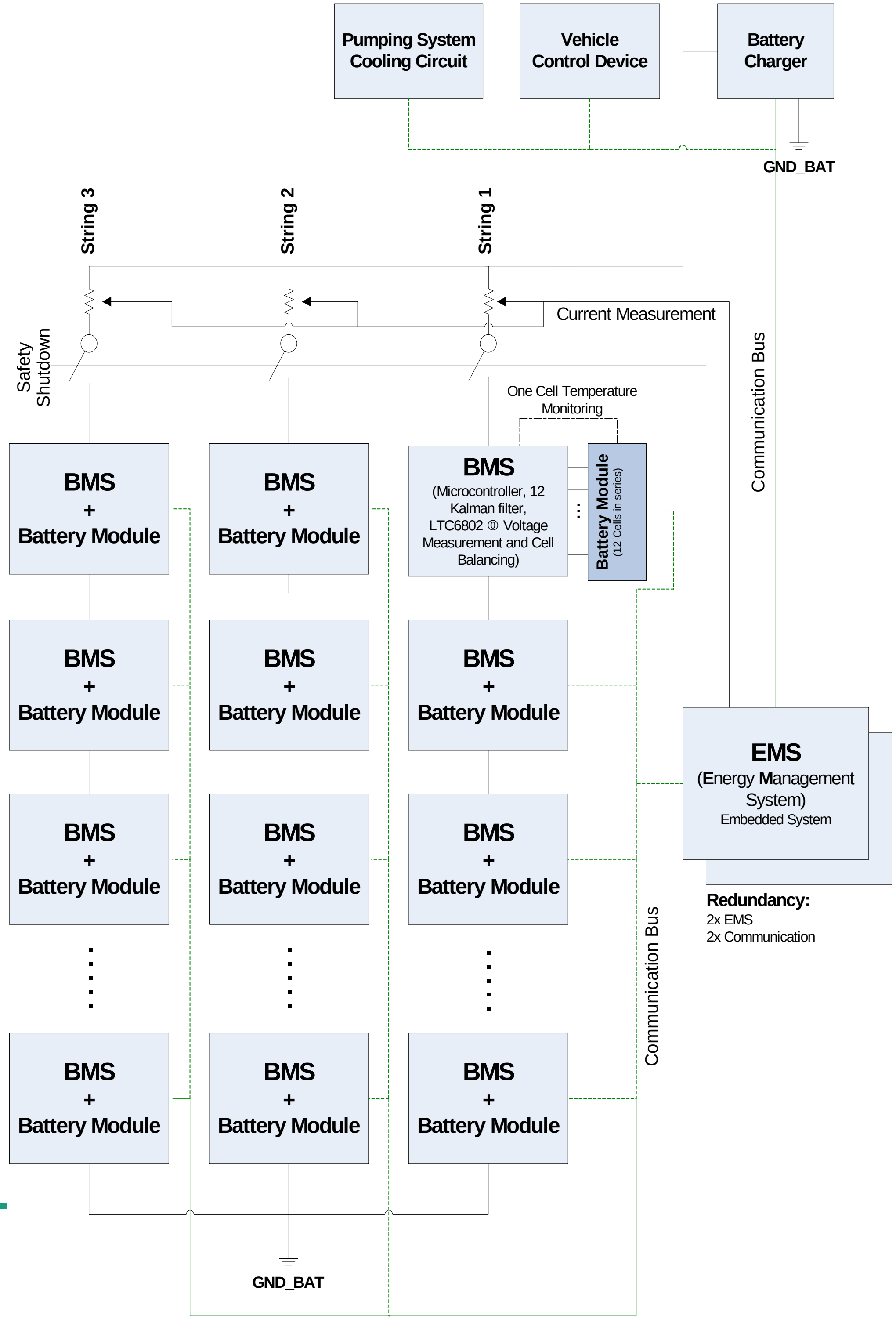
Energy and battery management – Architecture

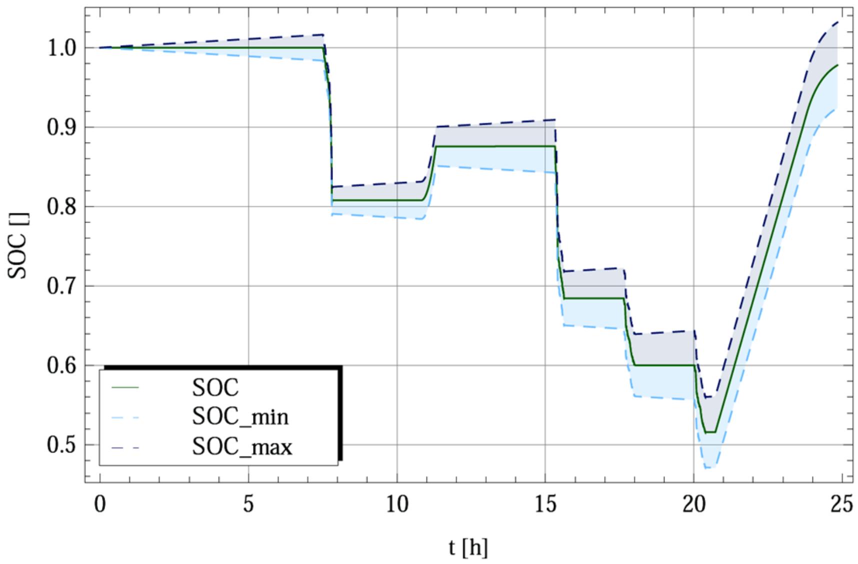
- Energy management system as central control unit
- Decentralized battery management system for each single battery module

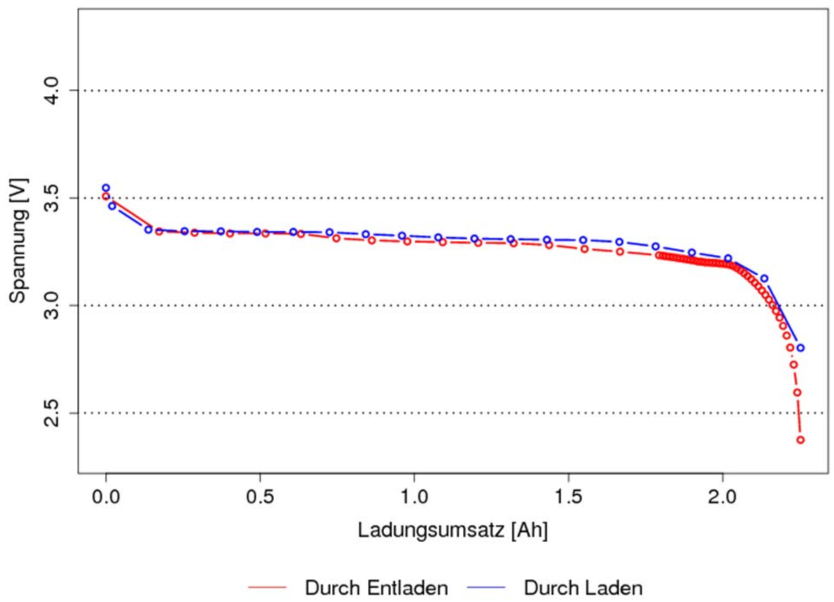
→ Determination of state of charge and state of health of each single cell possible



State of charge determination

- Ah counter: Integration of measurement errors
- Most conventional approaches:
  - ➢ Use of some kind of OCV correction in combination with Ah counting
    - → Recalibration of the SOC value via OCV consideration needs resting phases
- Flat OCV characteristic with hysteresis for $LiFePO_4$





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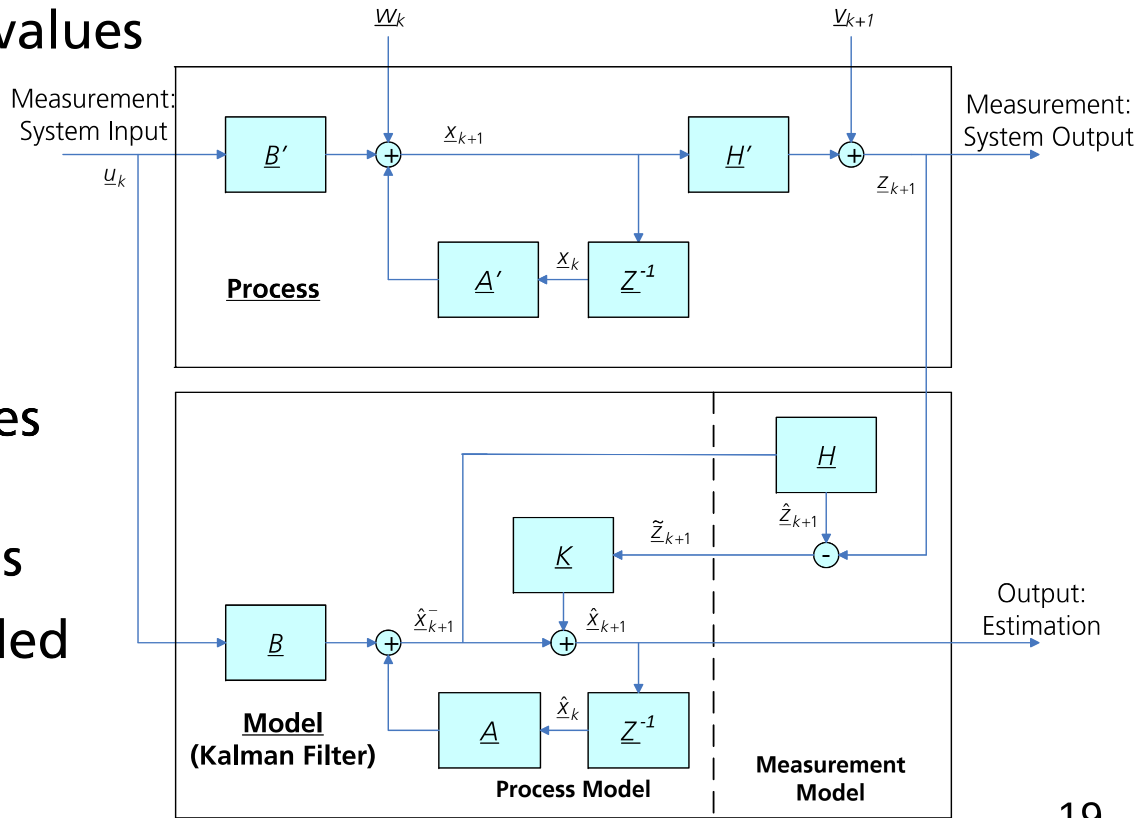
State of charge determination

→ Approach: Kalman Filter

- More insensitive against measurement errors
- No resting phases necessary for recalibration of SOC
- Fast identification of starting values
- Improved performance for aged batteries

- Recursive state estimator
- Optimal estimator for processes with Gaussian noises
- Suitable only for linear systems
- For non-linear systems: Extended or Unscented Kalman Filter



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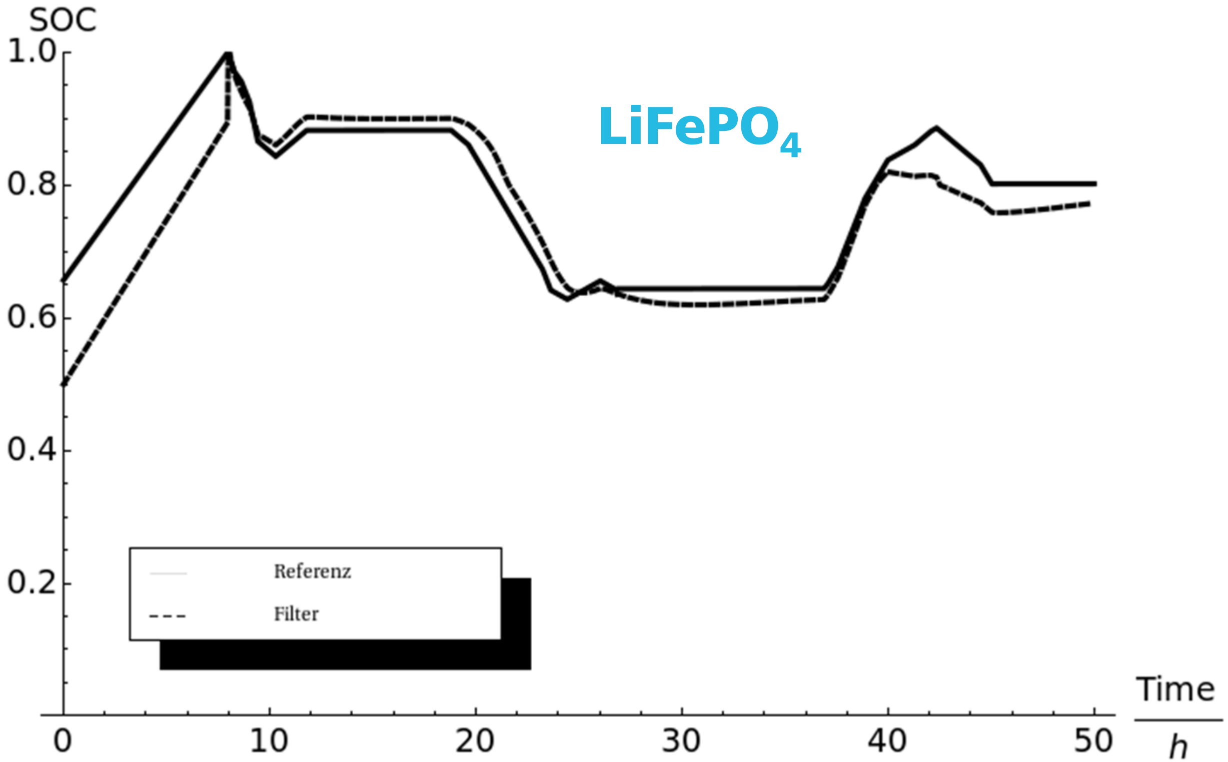
State of charge determination

Approach: Extended Kalman Filter (EKF)

- Extension of Kalman Filter approach for non-linear systems:
  - → Linearization within the operating point using first order Taylor series approximation



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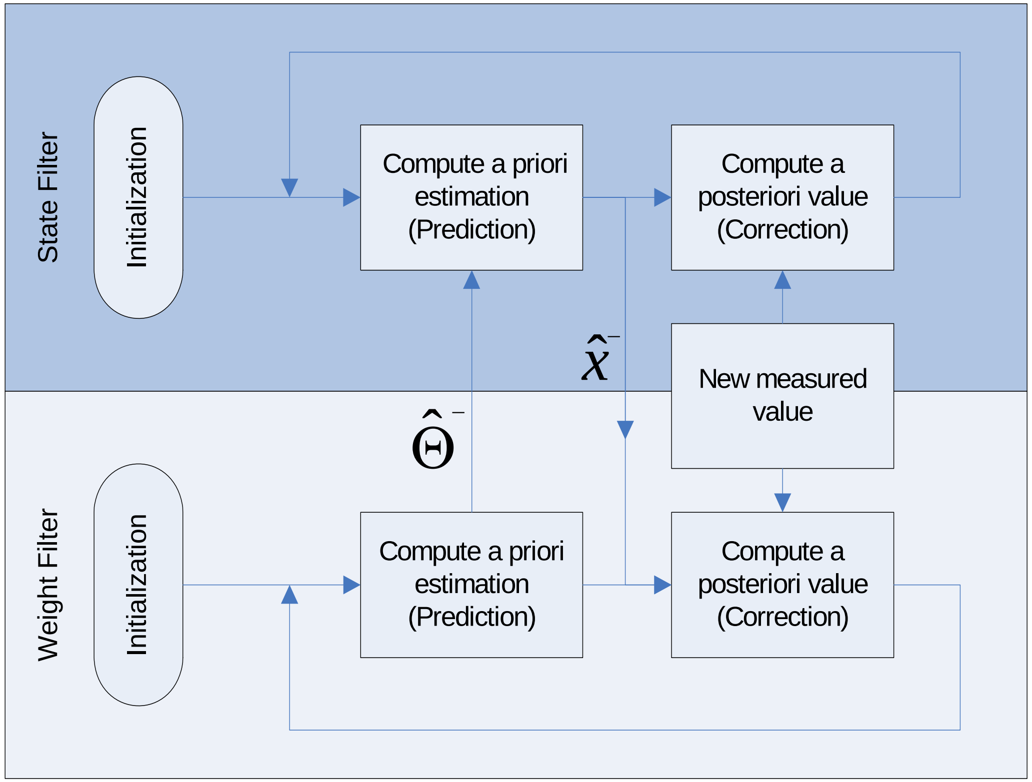
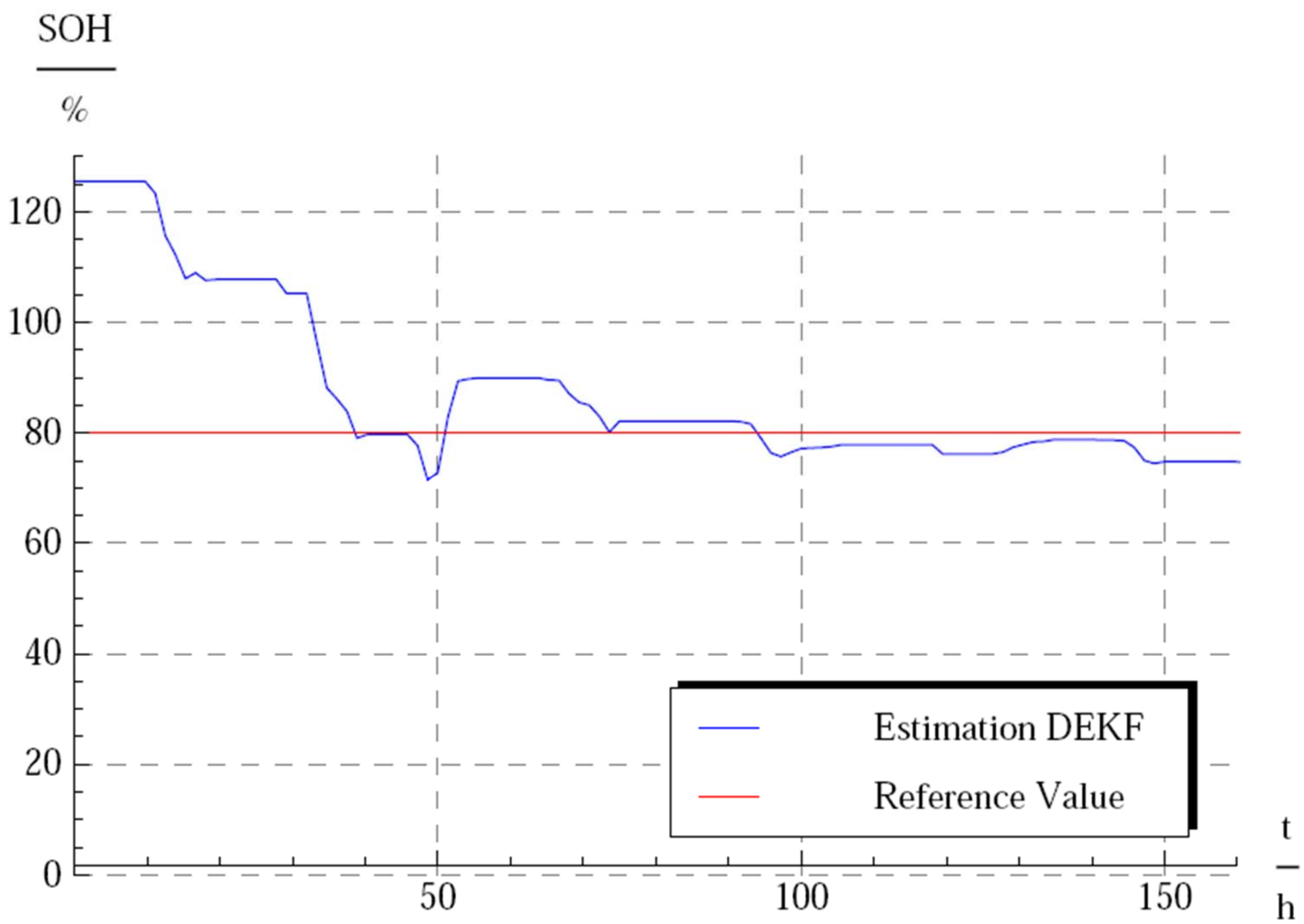
State of health determination

- Principle of Dual Extended Kalman Filter
  - Two decoupled parallel Kalman Filters
  - Exchange of computed states of state filter (state of charge) and of weight filter (state of health)



State of health determination

- Aged battery: 80 % SOH
  - ➢ Cathode: NMC
  - ➢ Anode: Carbon
- 2.45 Ah, 3.6 V



DEKF: Dual Extended Kalman Filter; MA: Mean Average

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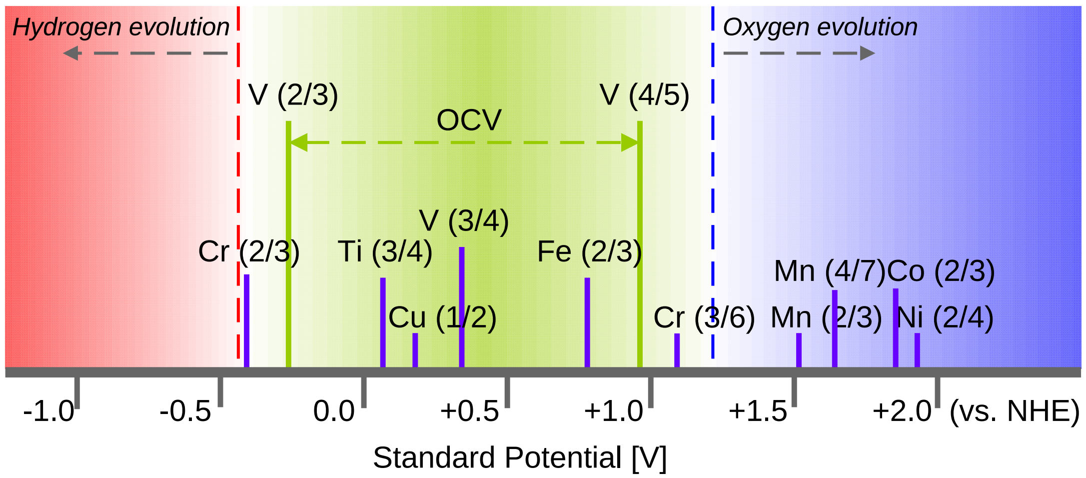
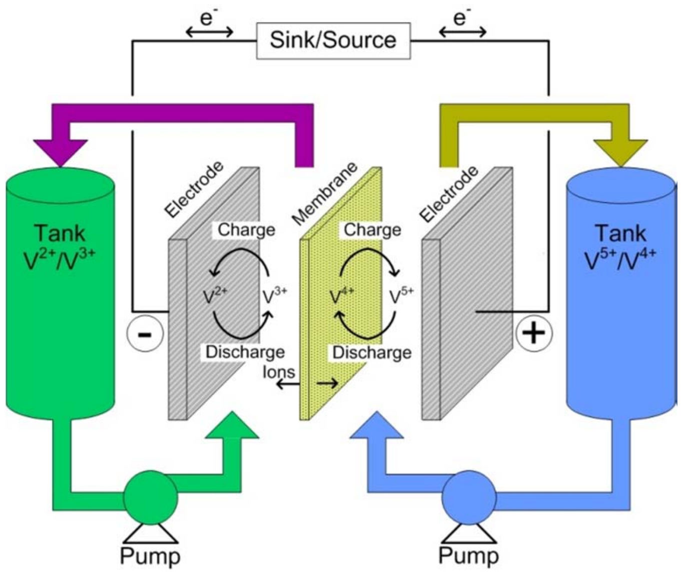
Redox-flow batteries

Flow batteries:

- Different redox couples possible
- Research focuses on Vanadium
- Power and capacity decoupled





Redox-flow batteries

Advantages:

- Decoupling of power and capacity
  → Modularity
- Only two manufacture worldwide (!?)
- High cycle stability
- Low self discharge

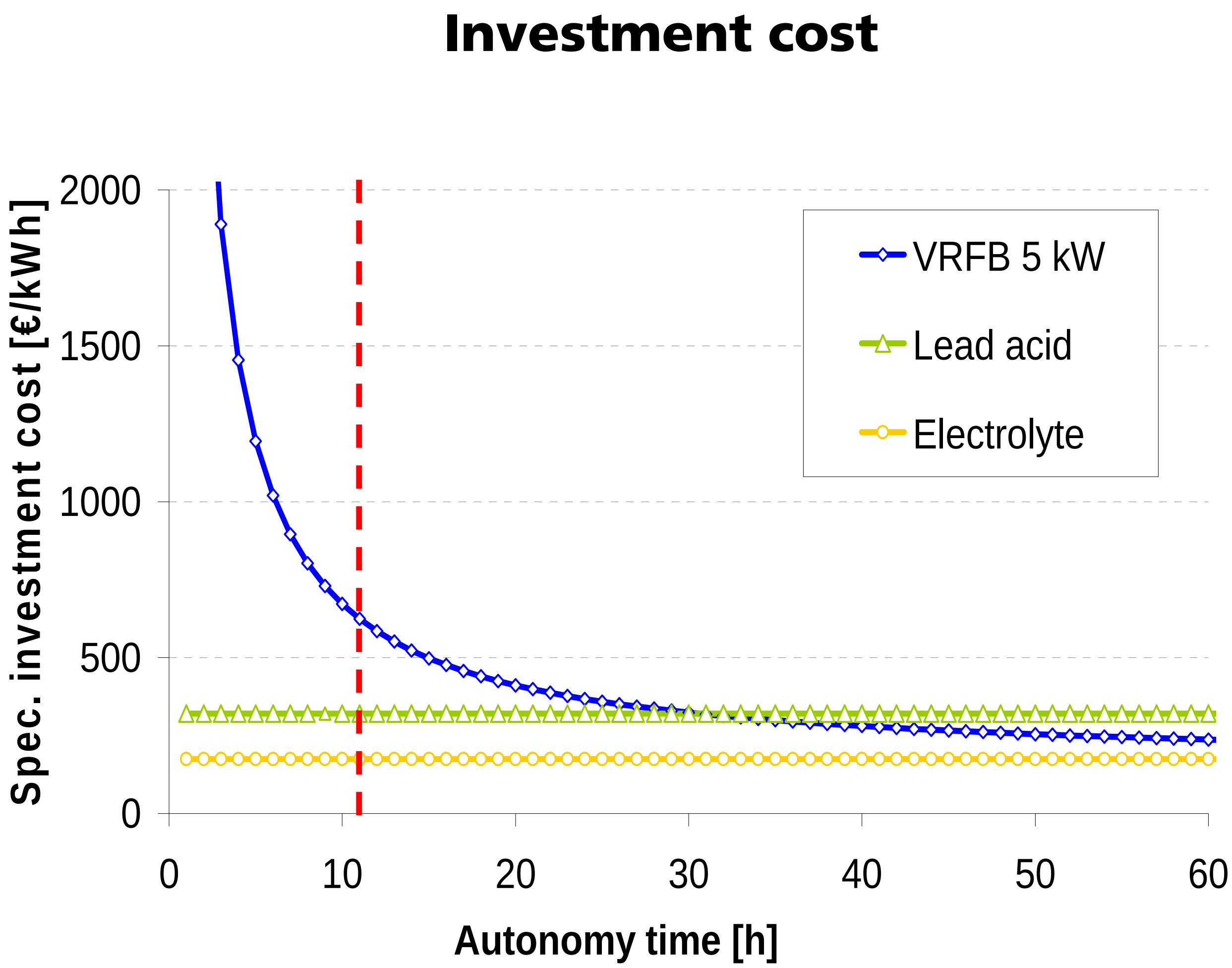
Disadvantages:

- Low energy density
- Complex control strategies
- Flow battery
  → Risk of leakages

Cost analyses

Case study
„Rappenecker Hof“:

- 5 kW / 57 kWh VRFB

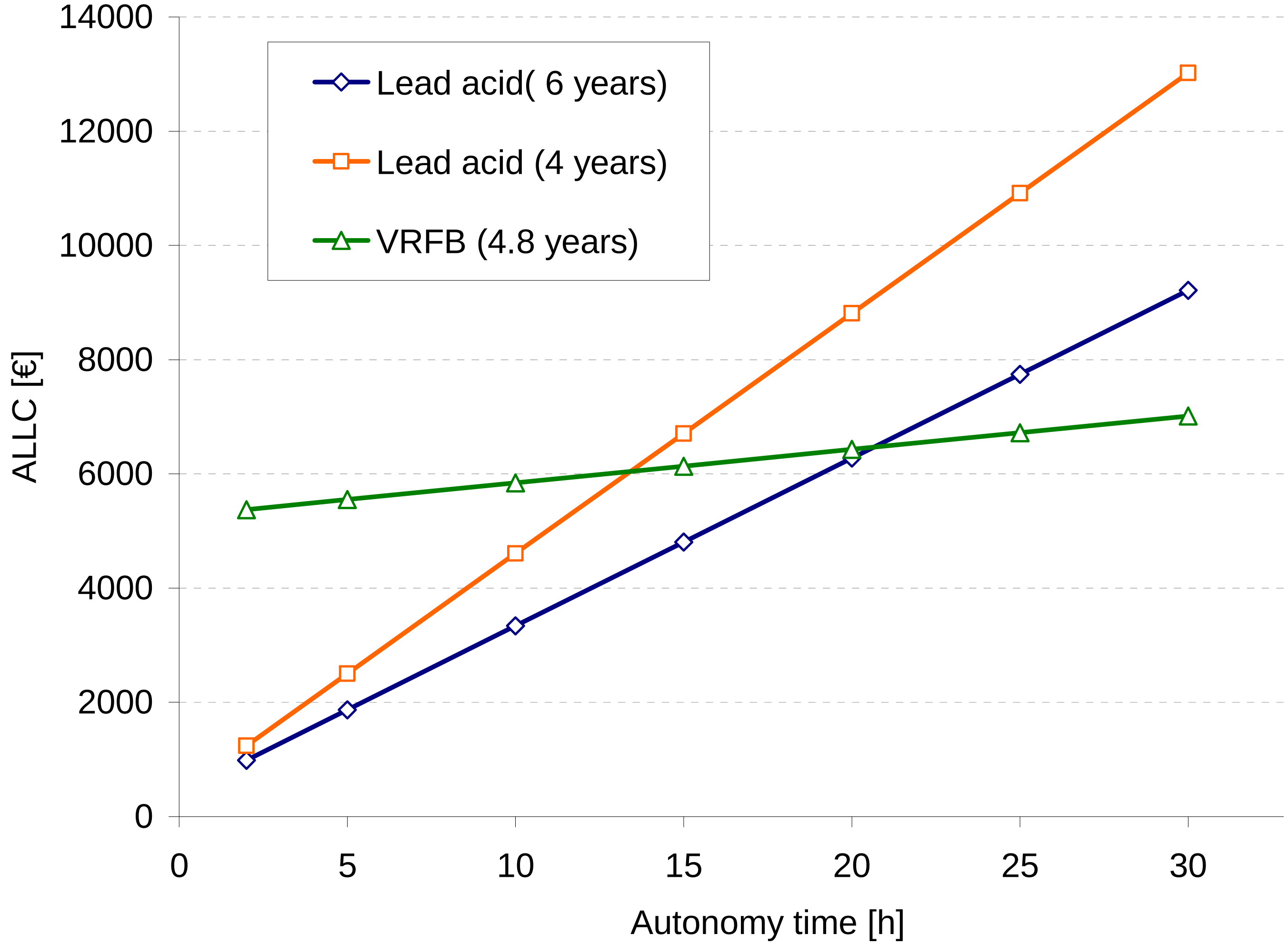


Cost analyses

Case study
„Rappenecker Hof“:

- 5 kW / 57 kWh VRFB
- ALCC including:
  - Investment
  - Maintenance
  - Replacement

Annualized life cycle cost



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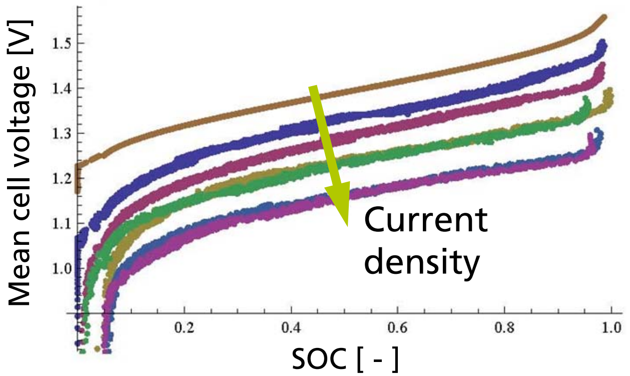
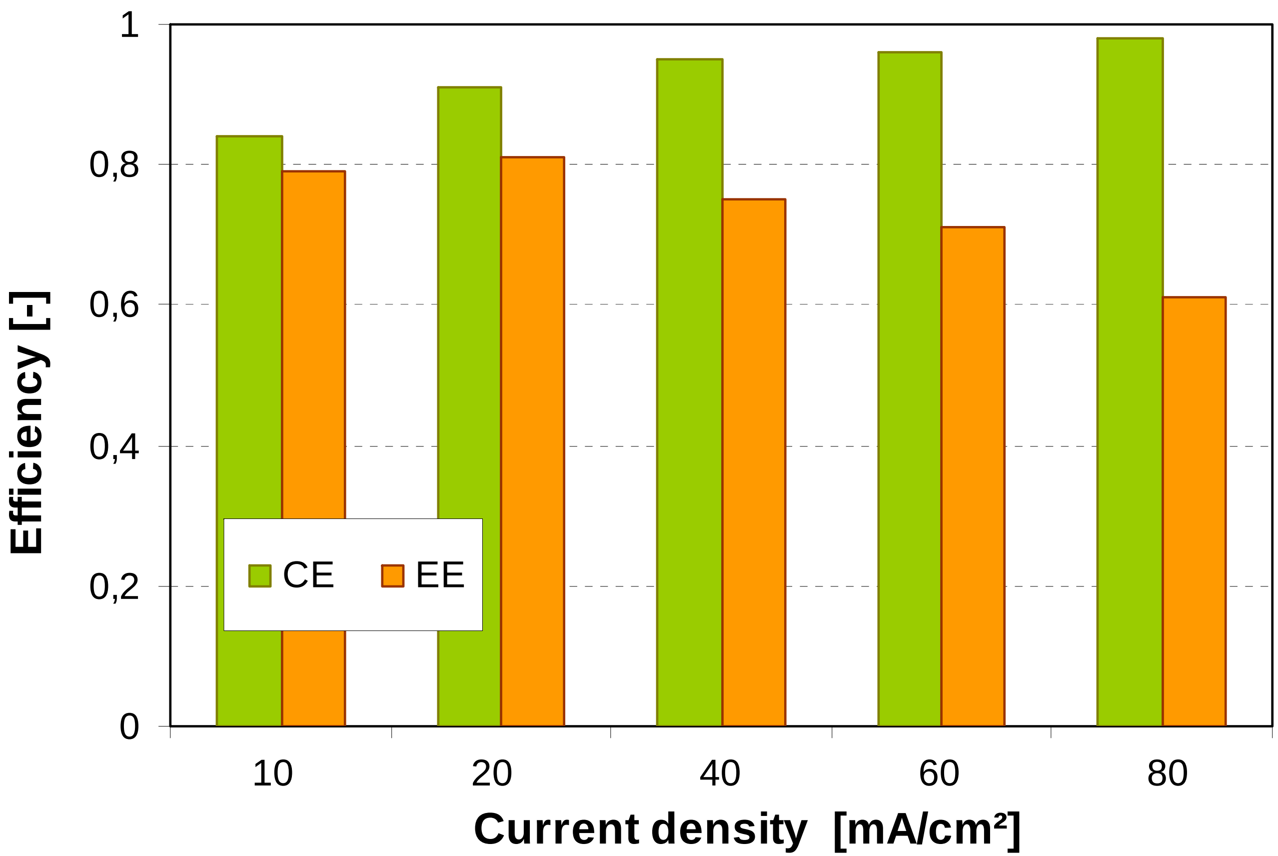
Efficiencies

- At different current densities
- Complete charging / discharging
- CE: Coulombic Efficiency
- EE: Energy Efficiency





5-cell stack à 250 cm²

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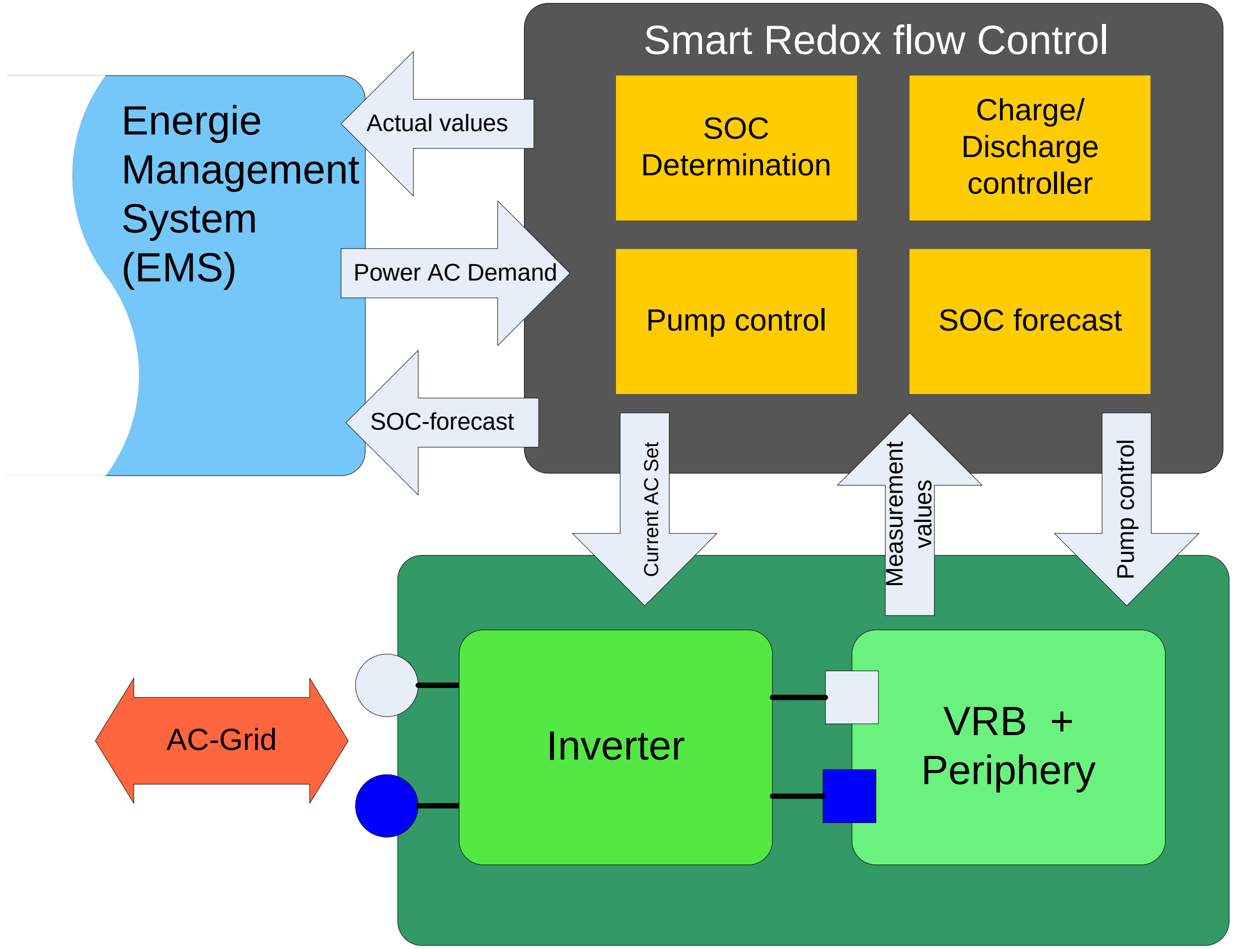
Development of a “Smart Redox-flow Control“

Smart Redox-flow Control:

- Control loops for devices of redox-flow battery
- Determination of set points (e.g. inverter, pumps)
- Optimization of the process cycle

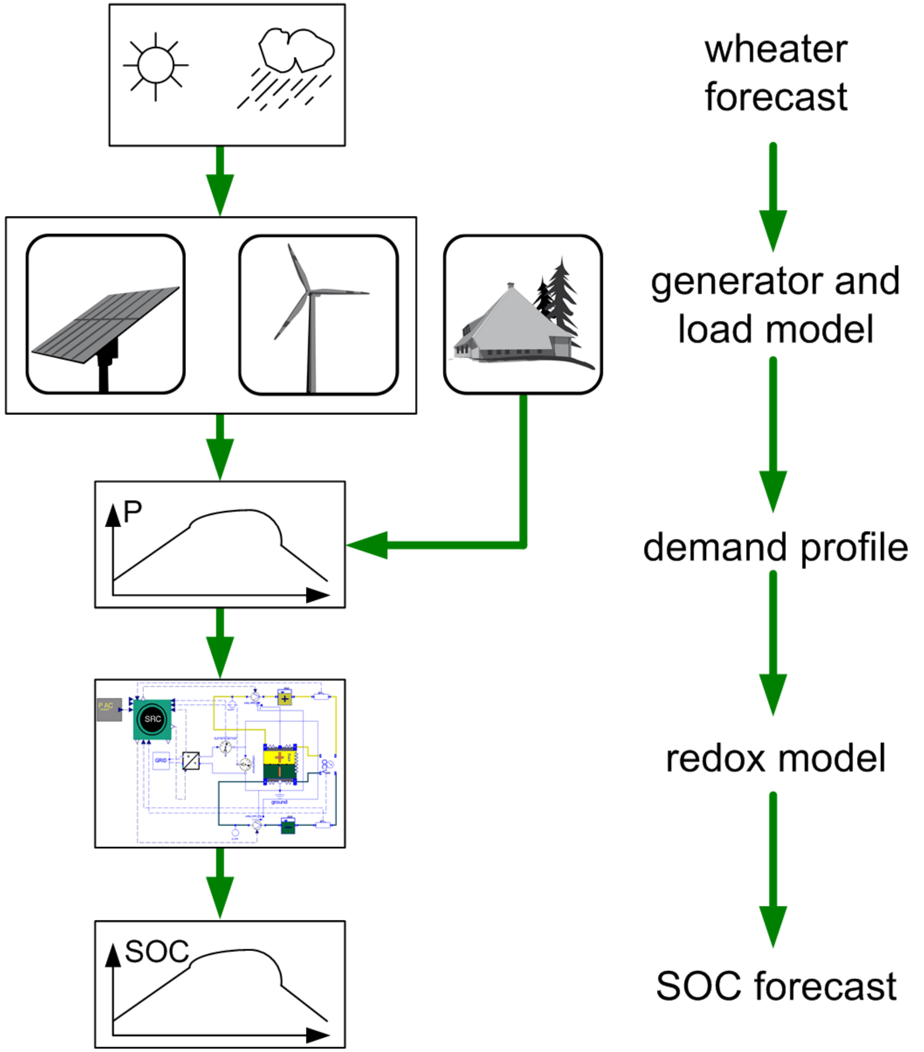
  → energy efficiency
- Interface with energy management system (e.g. UESP)



Smart Redox-flow Control: SOC forecast

SOC forecast:

- Simplified model of the VRFB system
- SOC calculation according to power demand
- Interface with energy management system
- Energy management system determines mode of operation for the VRFB



Batteries in PV applications
Classification of operating conditions

	class 1	class 2	class 3	class 4
typical application	parking meter	residential house	mountain hut or village supply small	big
solar fraction	100 %	70 - 90 %	about 50 %	< 50 %
storage size	> 10 days	3 -5 days	1 -3 days	about 1 day
charac-teristics for battery	• small currents • few cycles (mainly one yearly cycle)	• small currents • large number of partial cycles (at different states of charge)	• medium currents • large number of partial cycles (at good states of charge)	• high currents • deep cycles (0.5 to 1 cycles per day)

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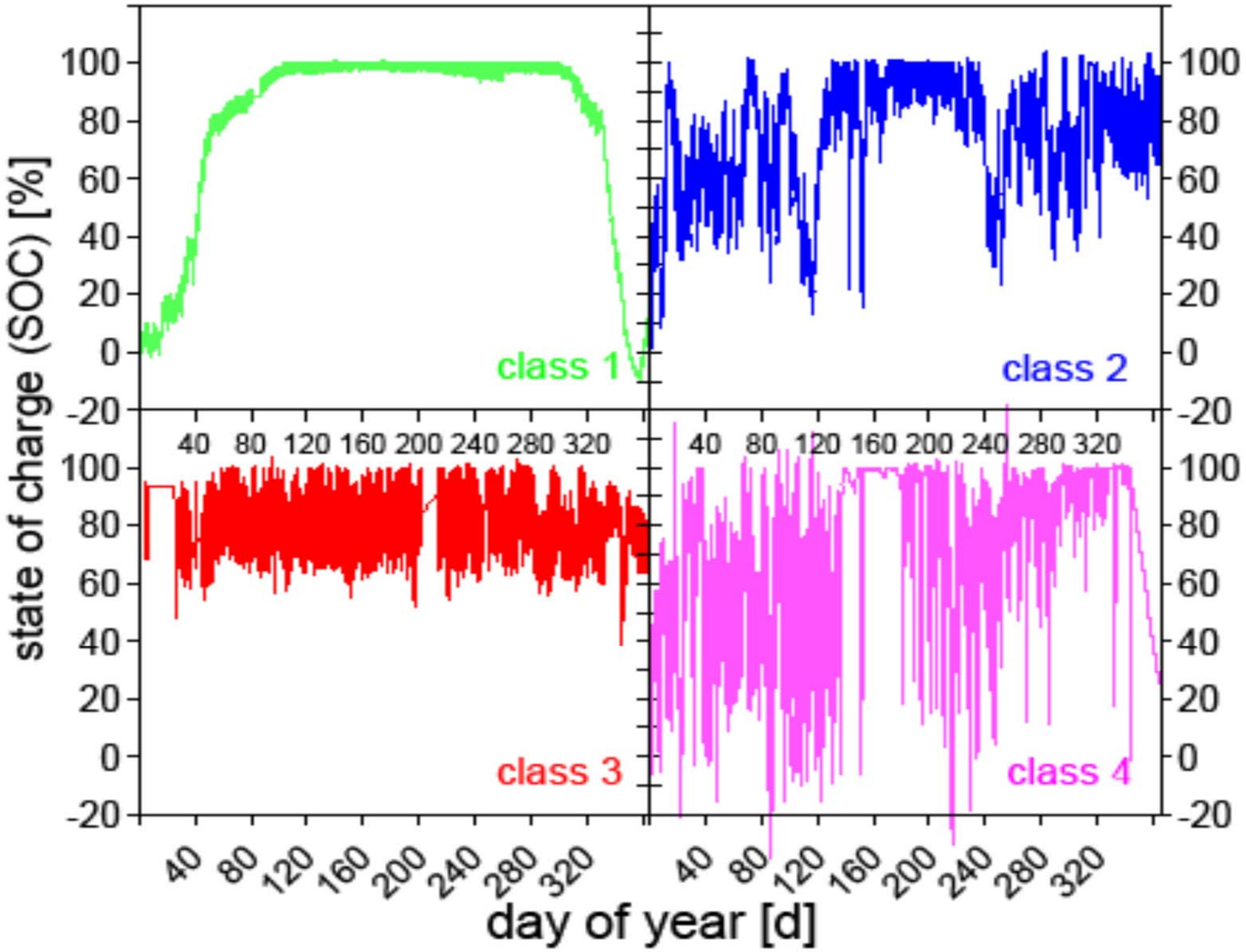
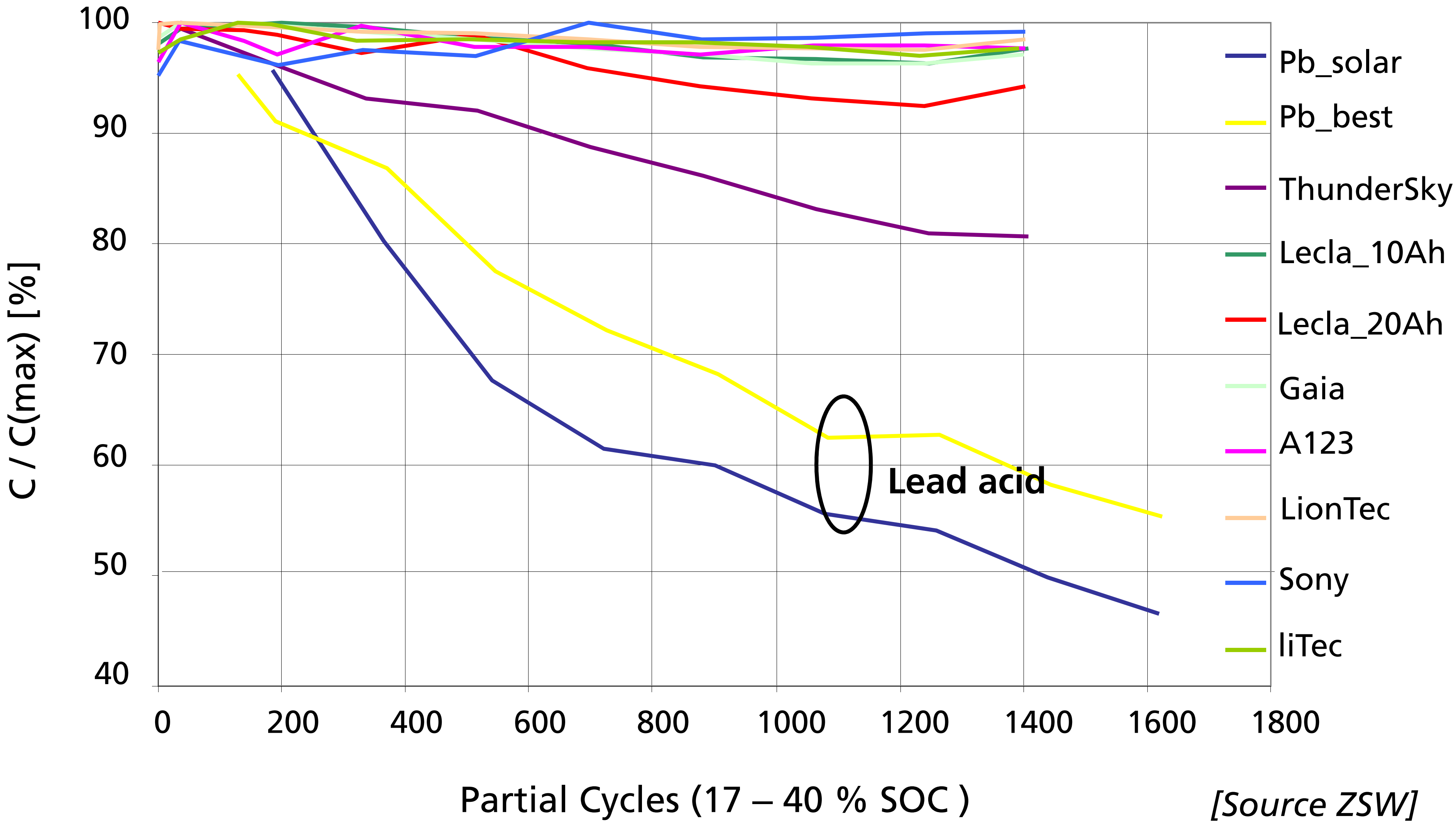
Batteries in PV applications
State of charge for different operating conditions



Batteries in PV applications

Partial cycling at low states of charge



[Source ZSW]

Conclusions

- Storages are the key component for 100 % renewables
  - In off-grid applications
  - **And** in on-grid applications
- Batteries have a huge potential to fulfil this task:
  - Modular design
  - Usable as decentralised and centralised storage systems
- For different purposes a variety of storages is available:
  - Lithium-ion for short term storages and residential use
  - Redox-flow for long term storages and in bigger stationary applications
  - Lead-acid battery as state of the art in today's off-grid applications and UPS
- Hybridisation of (battery) storages → Optimized system solutions

→ Presentation on energy concept for ASKAP / SKA

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Thanks for your attention!

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