
Battery management and energy management



Simon Schwunk, Matthias Vetter, Nils Armbruster

Fraunhofer Institute for
Solar Energy Systems ISE

FVEE-Workshop

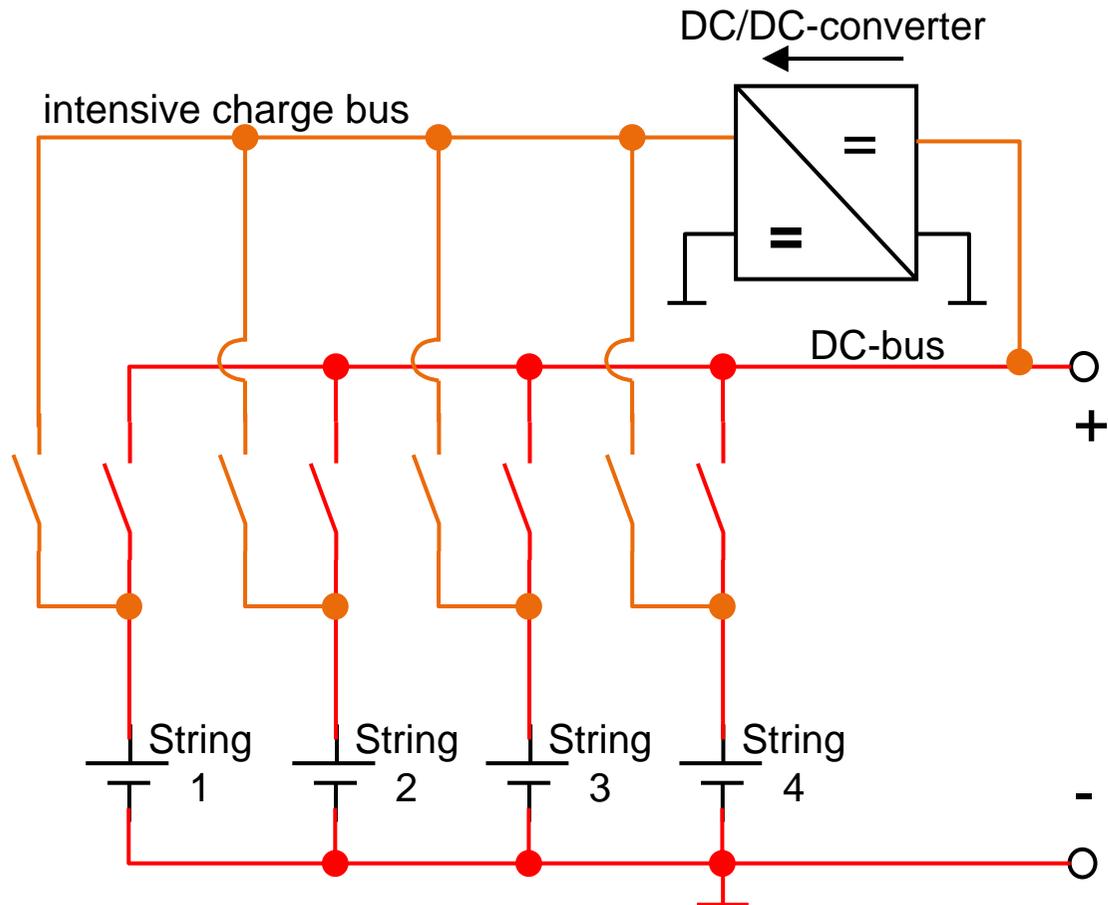
Ulm, 20. Januar 2010

Agenda

- Stationary applications
 - Battery management
 - Architecture
 - State determination for lead-acid batteries
 - Results
 - Energy management
 - Architecture
 - Results
- Automotive applications
 - Architecture
 - State determination for lithium-ion batteries

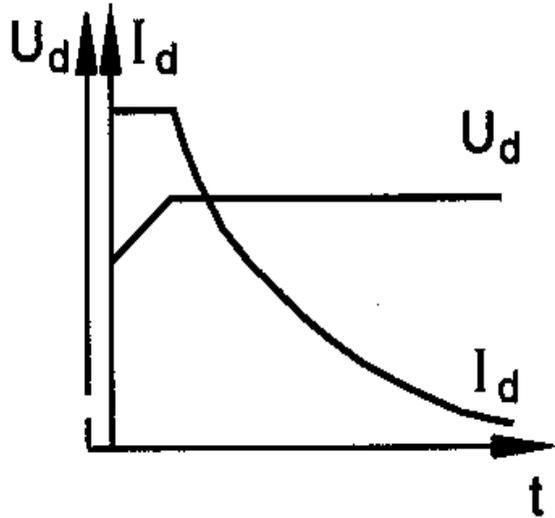
Stationary Battery Management

- Increased flexibility by splitting the battery into several strings
- DC/DC-converter for making intensive full charges
- Appears as a single battery for the connected system



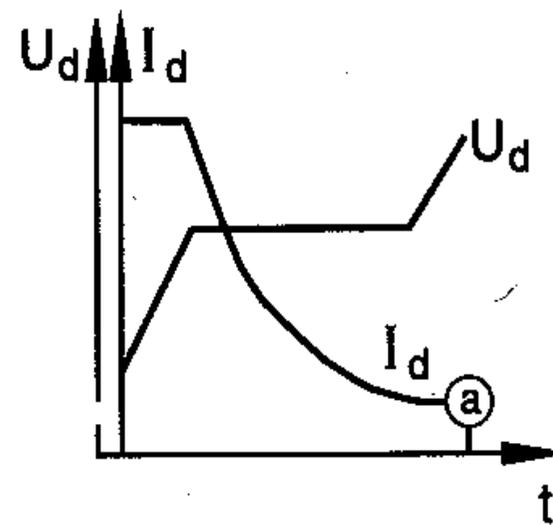
Charging strategies: Example lead-acid batteries

CCCV



- Standard procedure
- Often two constant voltage phases with different voltage levels

CCCVCC



- Besonders geeignet für verschlossene Bleibatterien
- Ia-Phase: Abstände von 1-2 Monaten

Charging strategies for lead-acid batteries

Discharge characteristics for a capacity test after

1. CCCV charge similar to a full charge in solar applications
 2. CCCVCC charge with intensive full charge (112% of capacity)
- Very good experiences with maintenance free lead-acid batteries in field tests

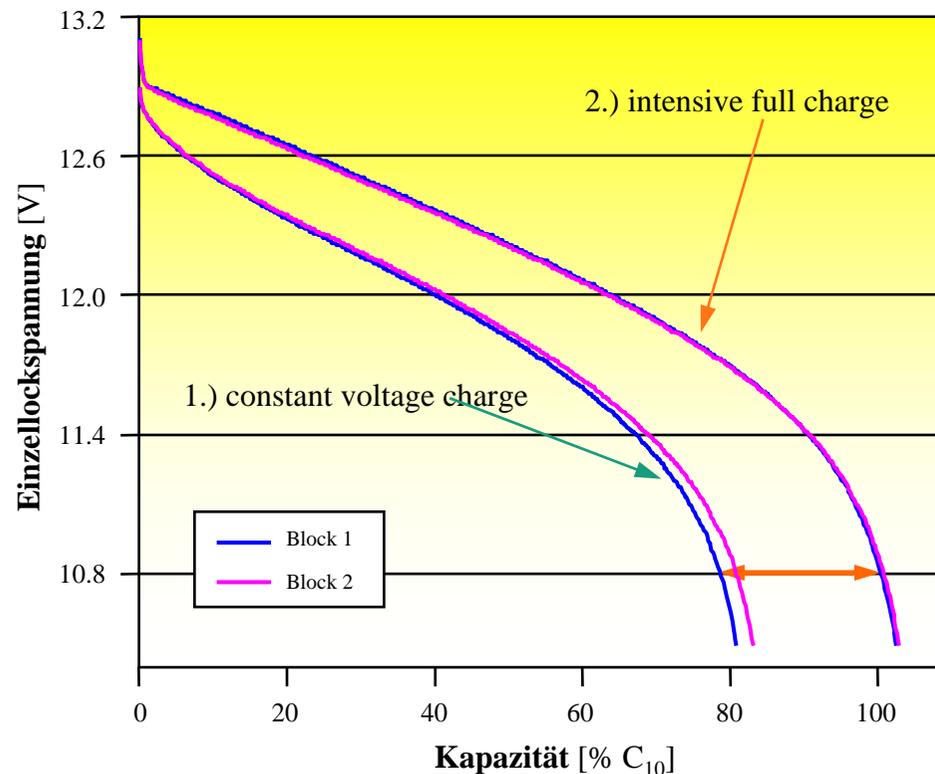
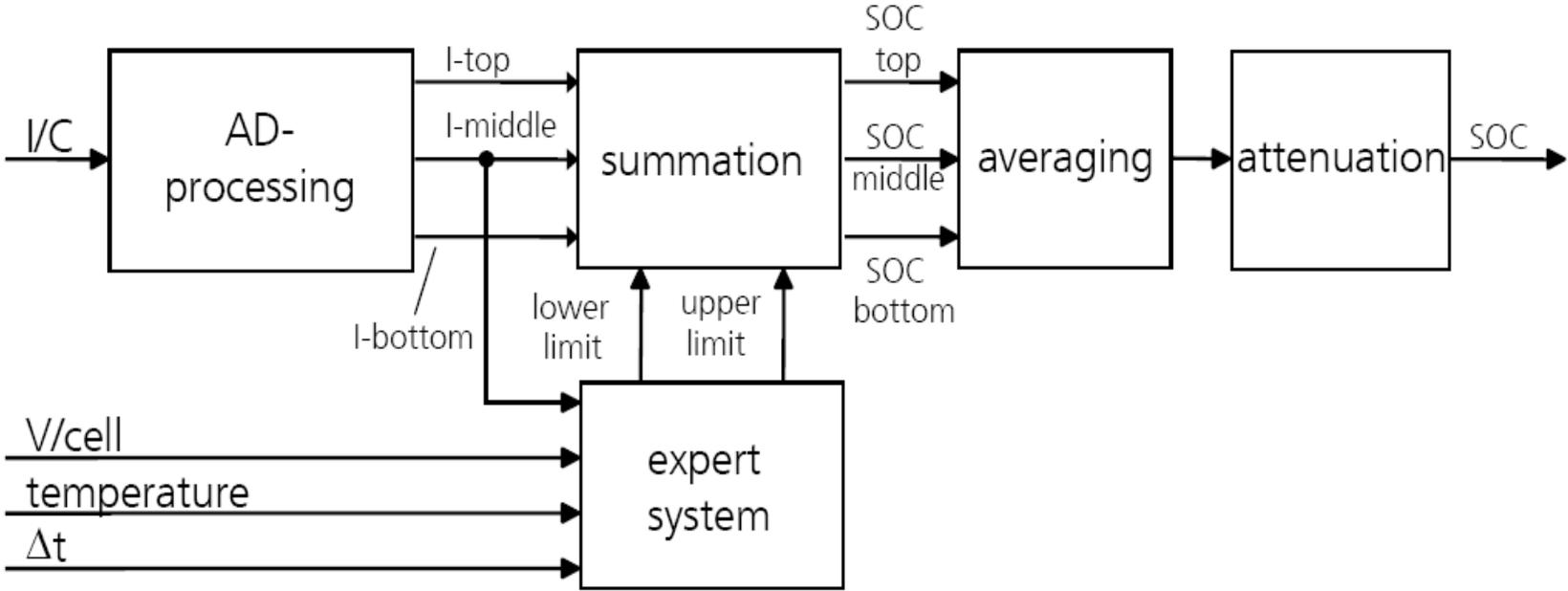


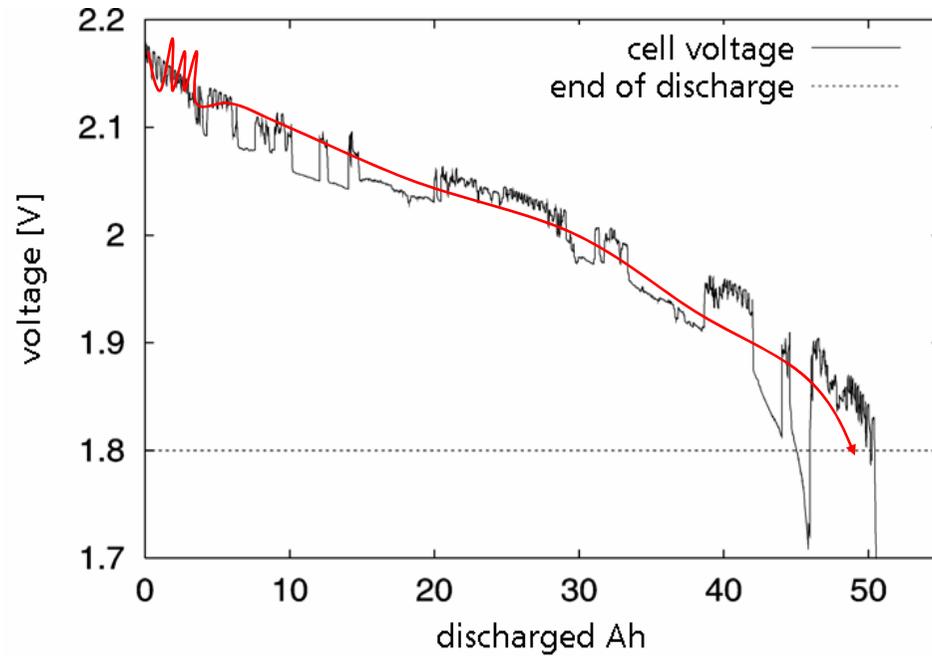
Bild: Fraunhofer ISE, Freiburg, Germany; Solarpraxis AG, Berlin, Germany

State of charge determination



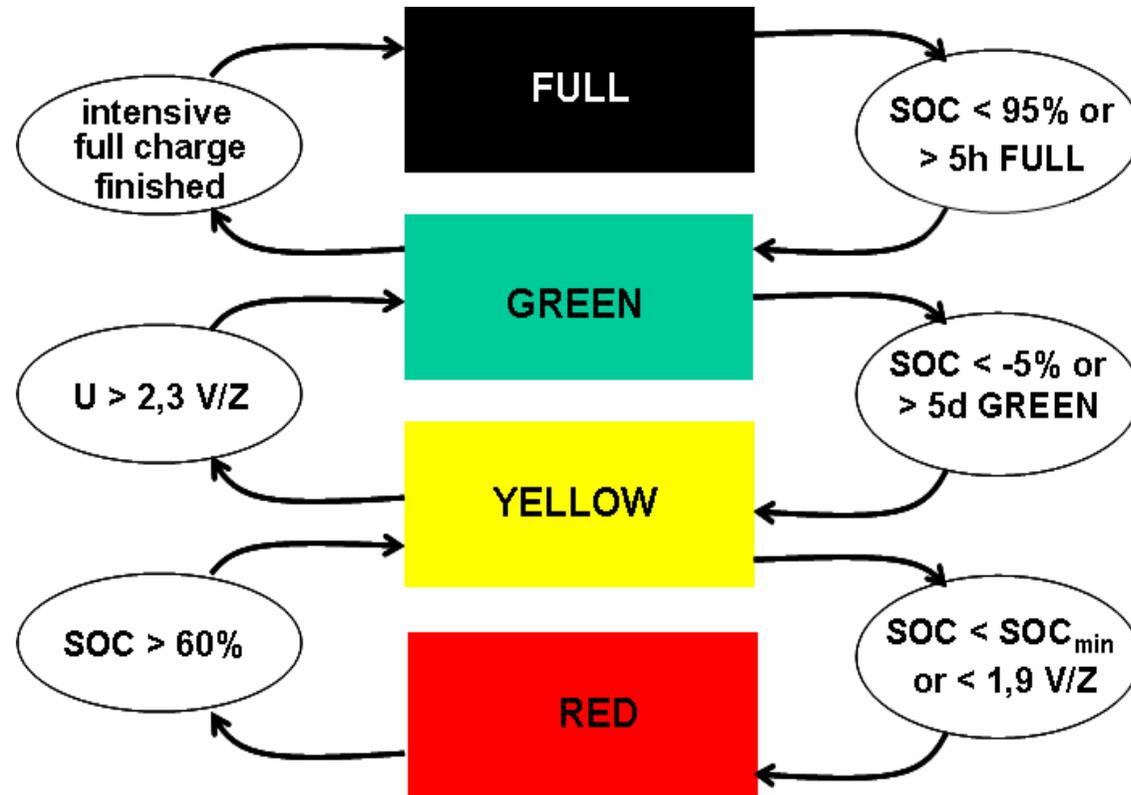
State of health

- Determination of battery capacity
- Complete discharge of the battery
- Calculation of $U_{10}=f(I_{10})$
- Attenuation of U_{10}
- Correction of Offset
- Correction by temperature

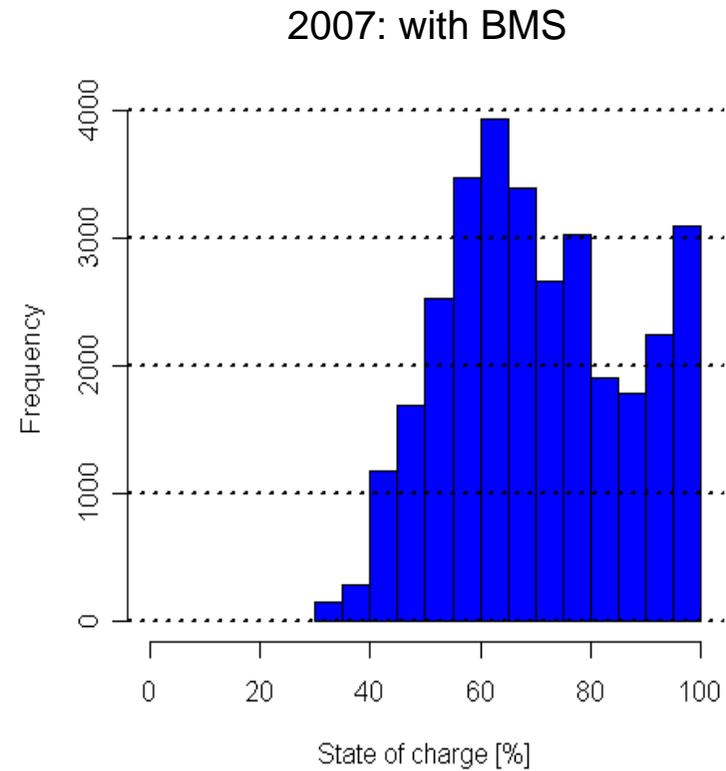
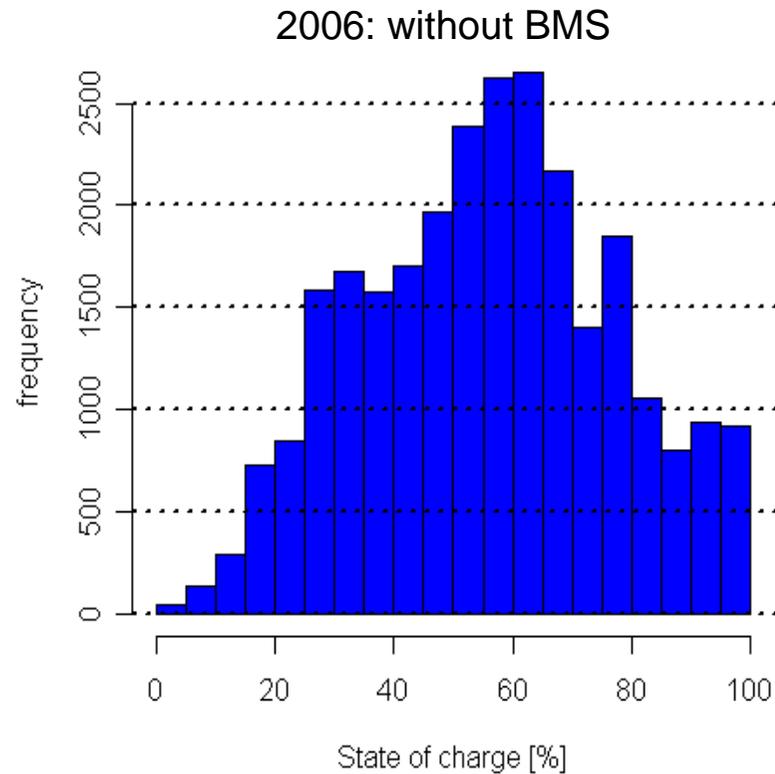


Battery management system

- Four battery states
- Charging and discharging priorities according to state
- Within a state priority given according to state of charge

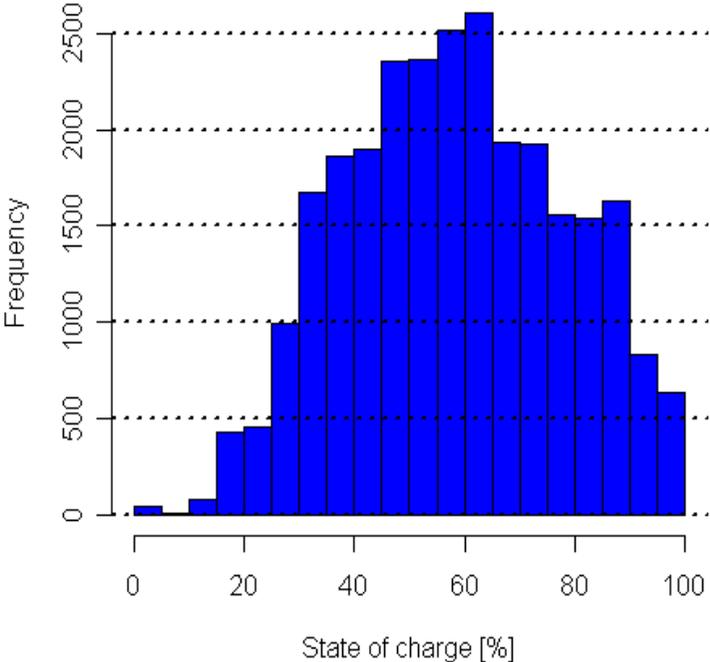


Results – Frequency of SOC for battery system

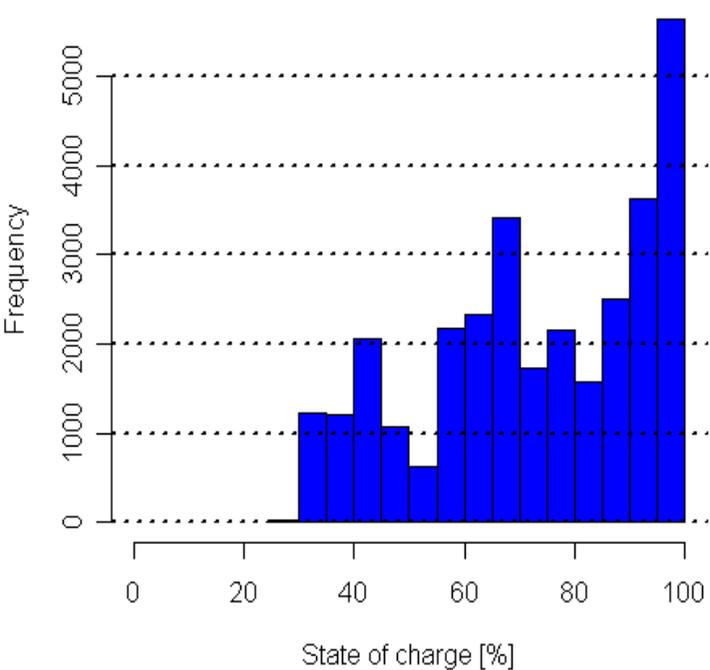


Results – Frequency of SOC for string 4

2006: without BMS



2007: with BMS



Energy management system

Objectives of the operation strategy



- Supplying the load with sufficient energy and power
- Optimized usage of photovoltaic energy
- Long battery life
- Minimized usage of auxiliary power generator (e.g. diesel) for low fuel consumption and long life times

Energy management system

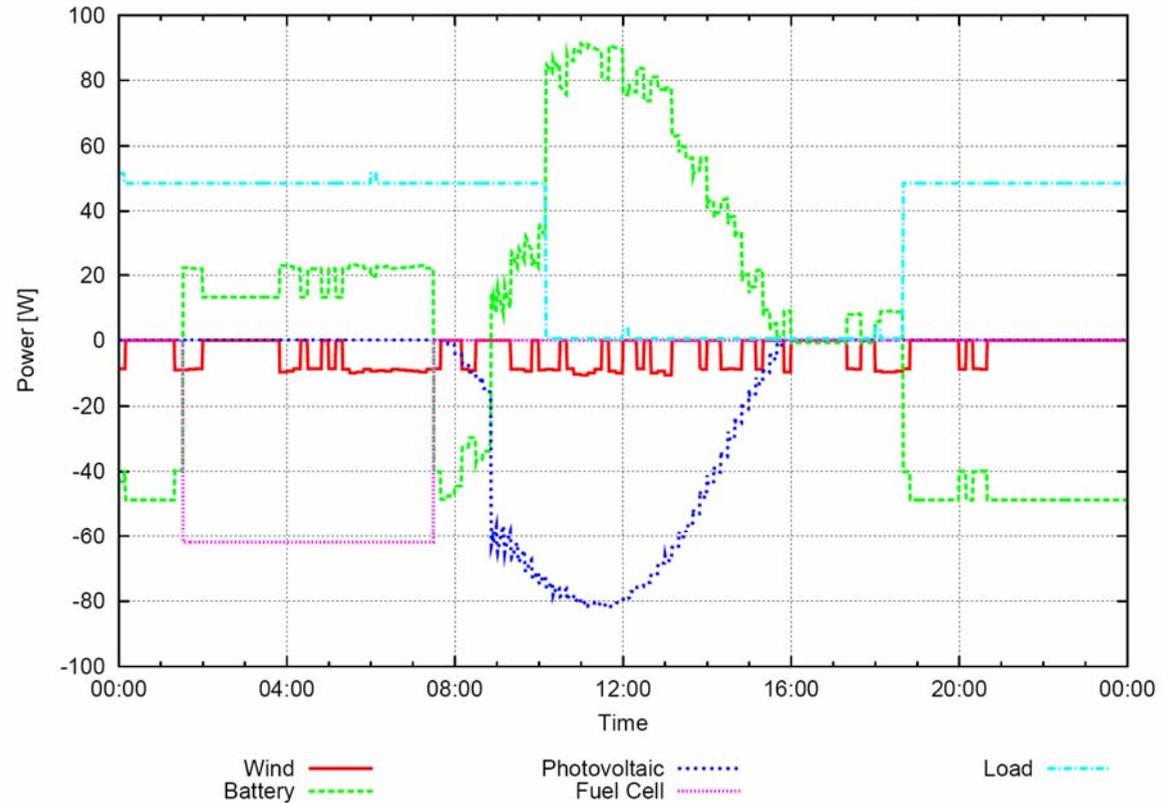
Characteristics of good operation



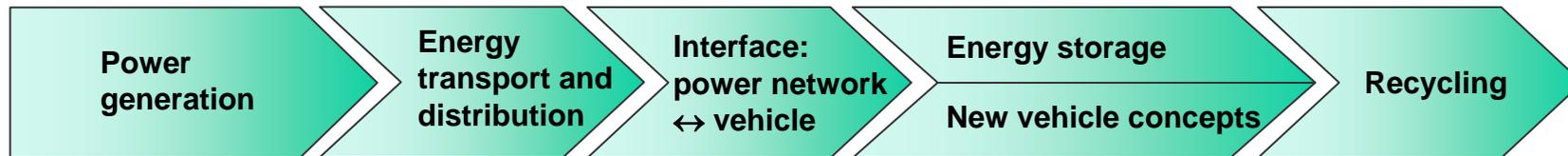
- Produced energy is preferably consumed directly and not stored within the battery
- For lead acid batteries the state of charge should not fall below 40 to 50 %
- Regular full charges in the case of lead-acid batteries
- No usage of auxiliary power if there is sufficient photovoltaic energy available
- Little start / stop cycles and minimum run times for auxiliary power generators

Energy management system – scheduling fuel cell

- Optimized use of the fuel cell because of limited lifetime
- Direct supply to avoid storage losses
- The schedule is determined for the next day



Fraunhofer System Research for Electromobility FSEM



- Funding: German Ministry for Education and Research BMBF (economic stimulus package II)
- Budget: 30 Mio. Euro, plus 14 Mio. Euro for Invests in economic stimulus package I
- Project head: Prof. Dr. Ulrich Buller (Senior Vice President Research Planning of the Fraunhofer-Gesellschaft)
- Main project coordinator: Prof. Dr.-Ing. Holger Hanselka (Director of Fraunhofer LBF)
- Duration: June 2011

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In sum: 33 Institutes at 22 locations



Demonstrator for Passenger Cars and Public Transport

Wheel-hub motor
(including power electronics) Battery

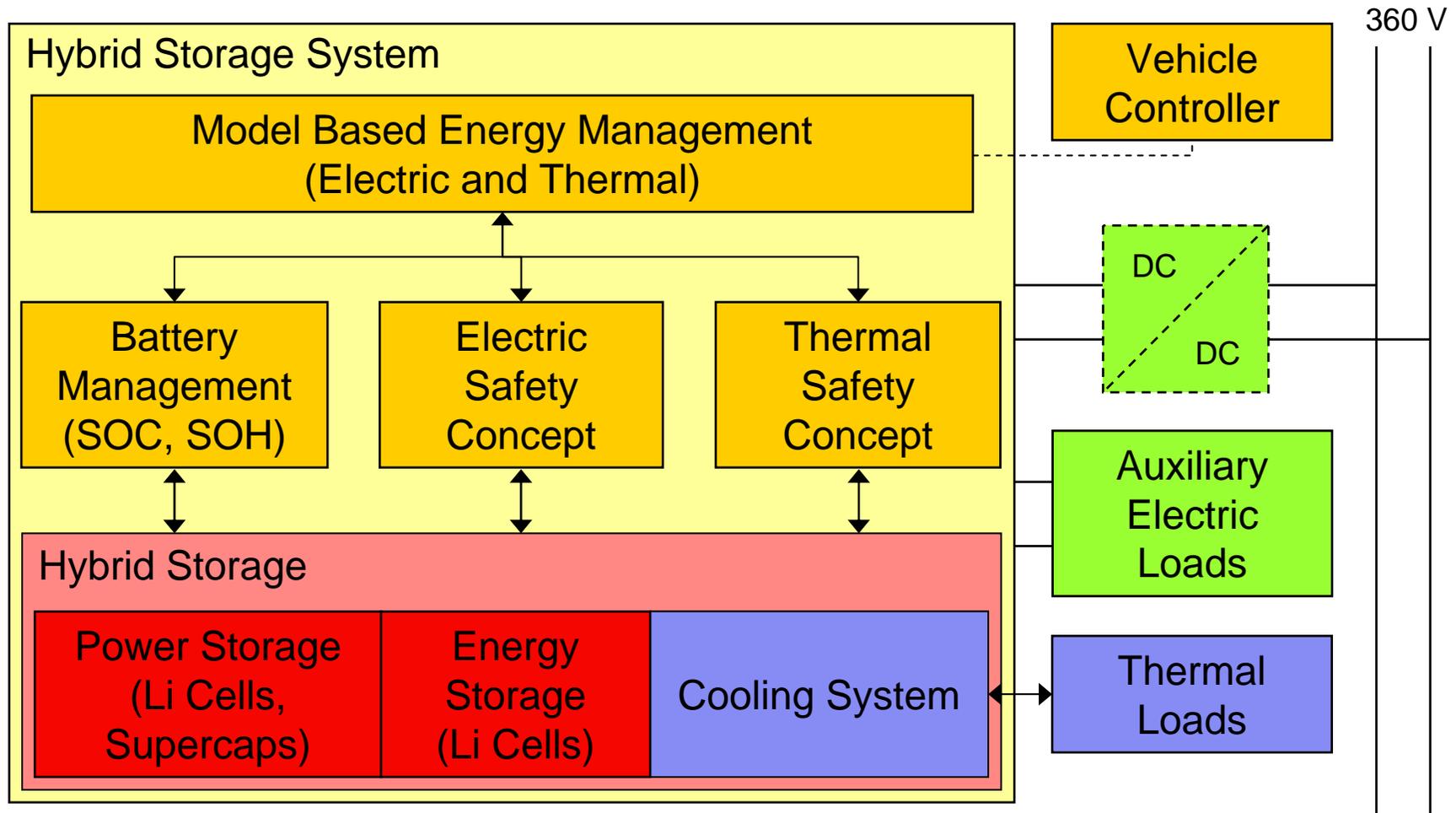


**Fraunhofer E-Concept Car Typ 0
FrECC0 (Photo Fraunhofer IFAM)**



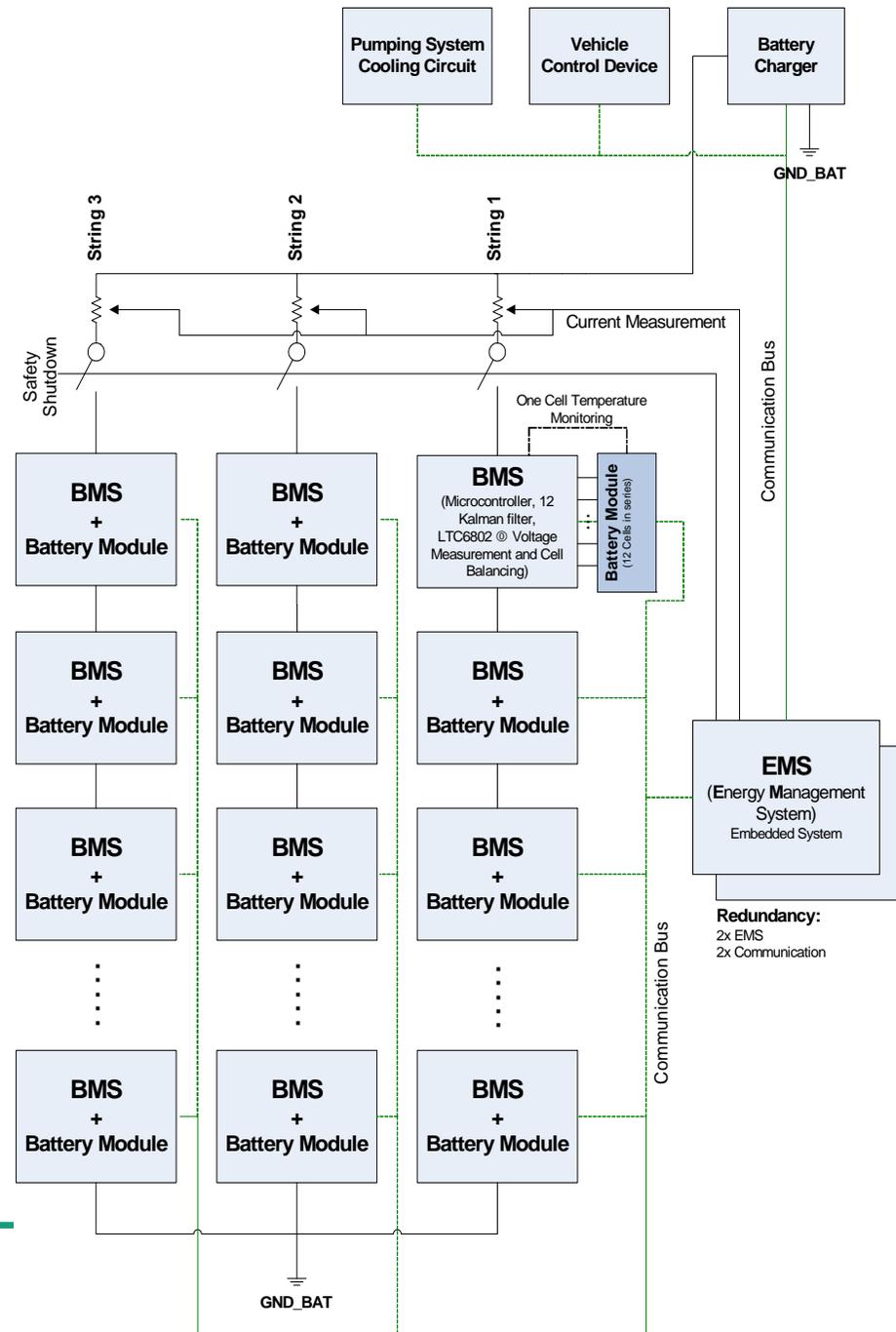
**AutoTram®
(Photo Fraunhofer IVI)**

Hybrid Storage System



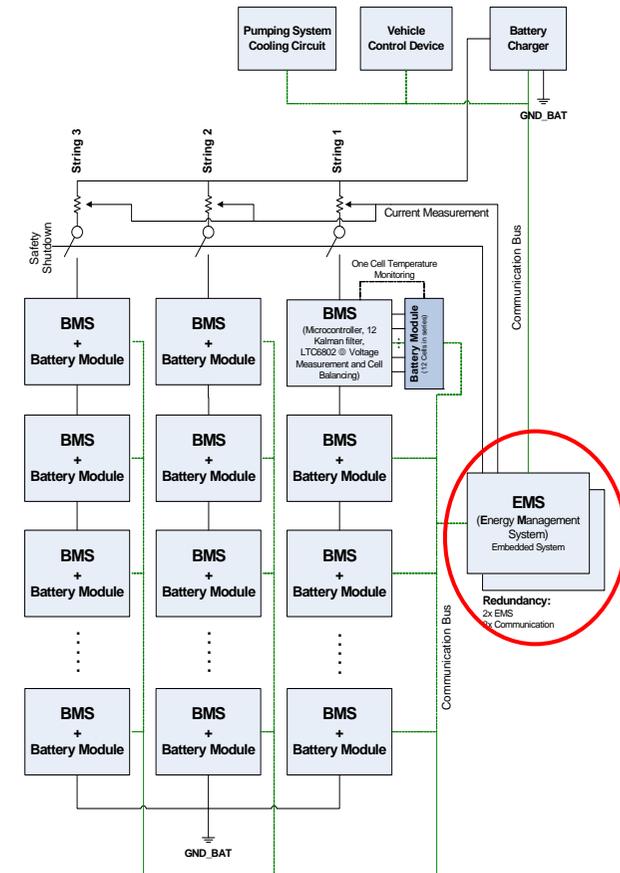
Energy and Battery Management – Architecture

- 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
- Slightly higher costs for processors, but some kind of frontend for acquiring measuring data is necessary anyway
- Additional energy demand for quick processor is negligible (decrease of efficiency of battery system by 0.05 %)



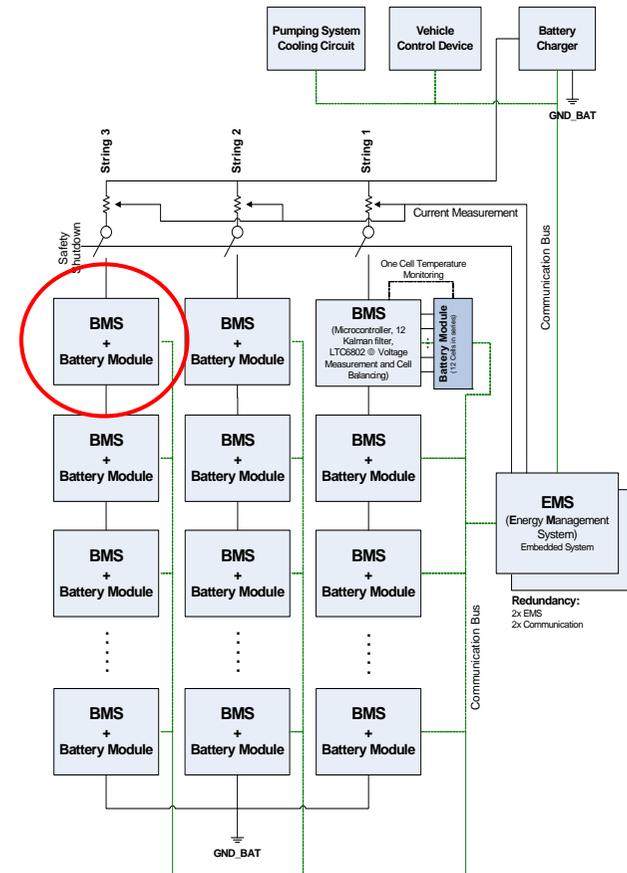
Main Tasks of Energy Management System

- Supervision of BMS modules
- Management of communication with BMS modules
- Data acquisition, logging and fault tracking
- Main tasks of model based electric and thermal management:
 - Reduction of motor power (via vehicle controller), e.g. in case of low SOC or critical temperatures
 - Distribution of energy fluxes of power and energy storage (in case of a hybrid storage)
 - Set values for on- and off-board chargers
 - Set values for cooling system
- User information: Cruising range estimation
- Diagnosis for pack or module exchange
- Safety of pack (Switches in +/- connections)



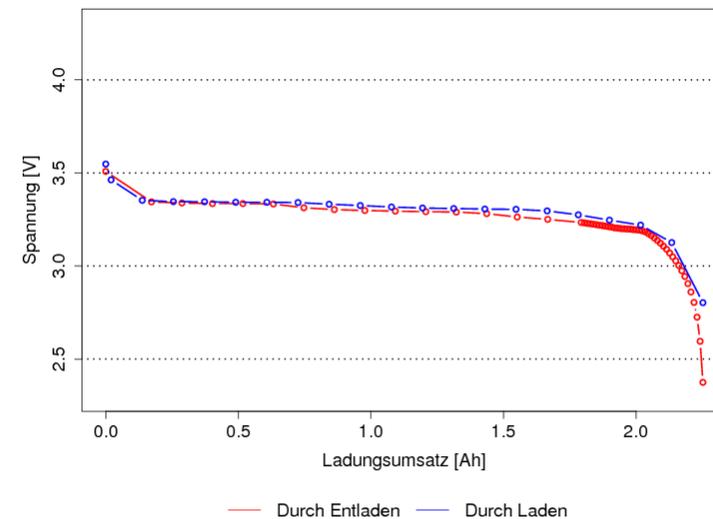
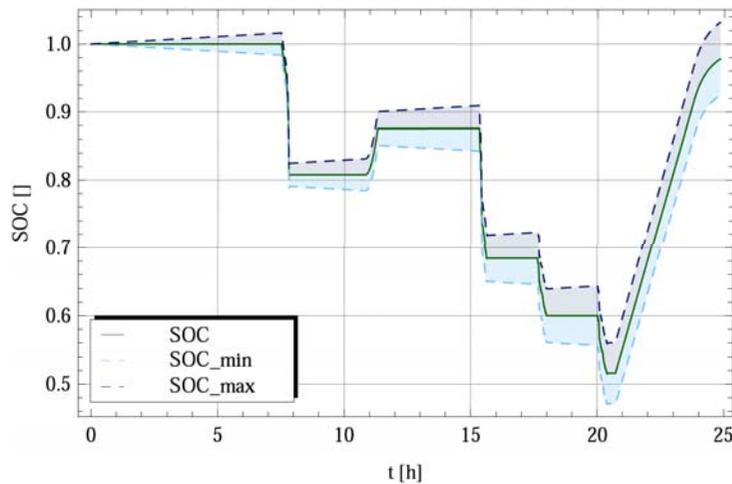
Tasks Battery Management System

- Module battery management system:
 - Battery module front end
 - Battery module controller
- Main tasks battery module front end:
 - Measurement of voltage and temperature
 - Switches for cell balancing
- Main tasks of battery module controller:
 - Preprocessing of measurement values
 - State of charge determination of single cells
 - State of health determination of single cells
 - Control of cell balancing
- Safety functions
 - Identification of critical values (e.g. voltage levels, temperatures) and communication to EMS



State of charge determination

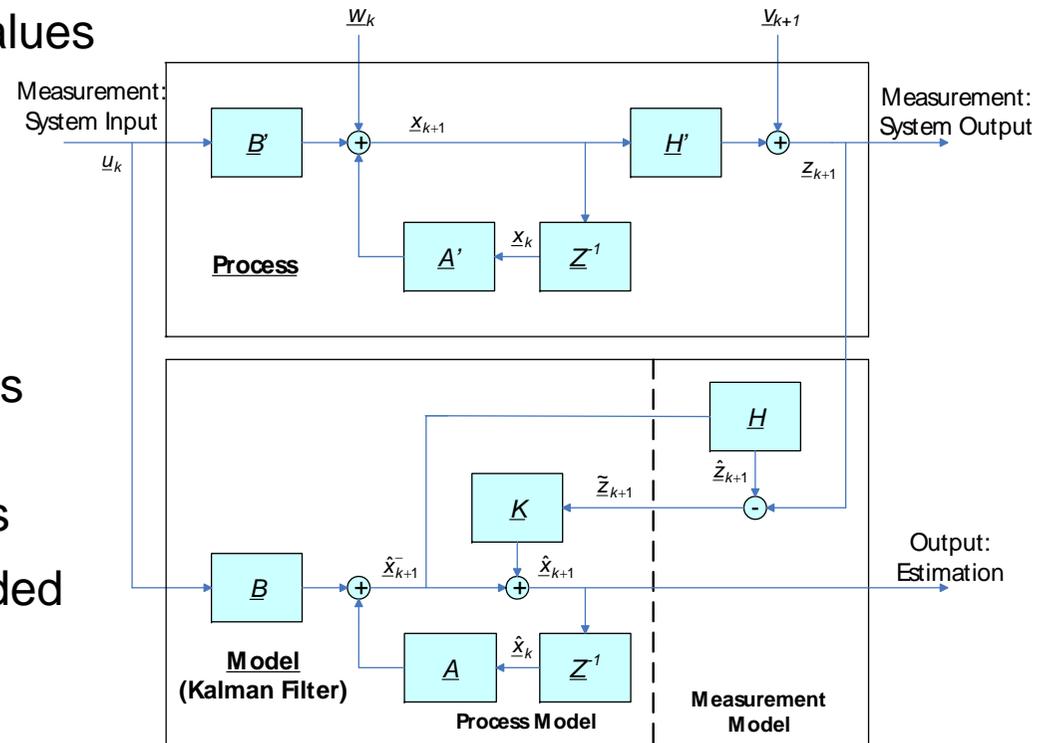
- Ah counter: Integration of measurement errors
- Most conventional approaches:
 - Use of some kind of OCV correction in combination with Ah counting
 - ➔ Recalibration of the SOC value via OCV consideration needs resting phases
- Flat OCV characteristic with hysteresis for LiFePO_4



State of charge determination

→ Approach: Kalman-Filter

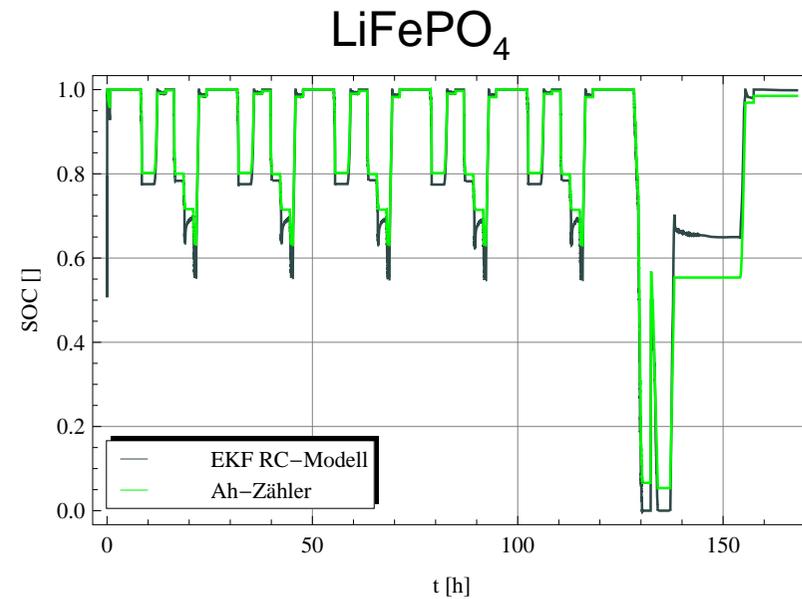
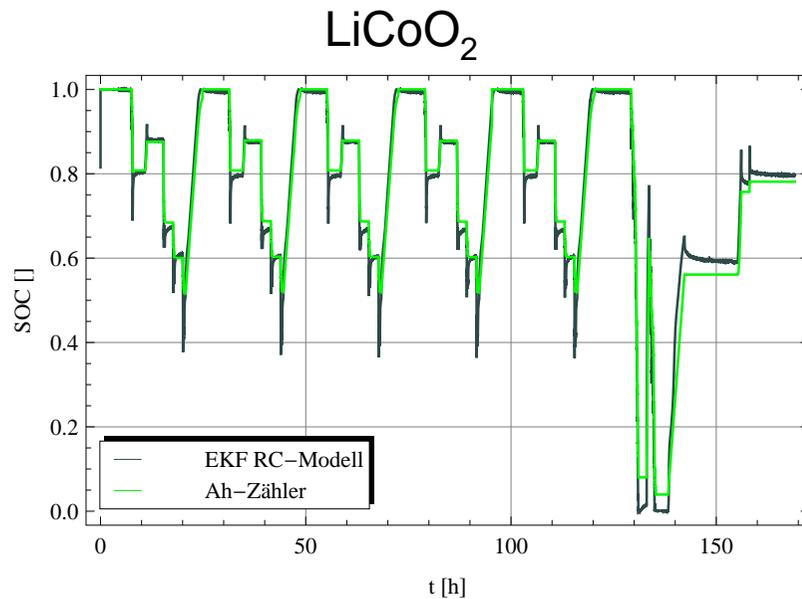
- More insensitive against measurement errors
- No resting phases necessary for recalibration of SOC
- Fast identification of starting values
- Improved performance for aged batteries
- Recursive state estimator
- Optimal estimator for processes with gaussian noises
- Suitable only for linear systems
- For non-linear systems: Extended or Unscented Kalman-Filter



State of charge determination

Approach: Extended Kalman-Filter (EKF)

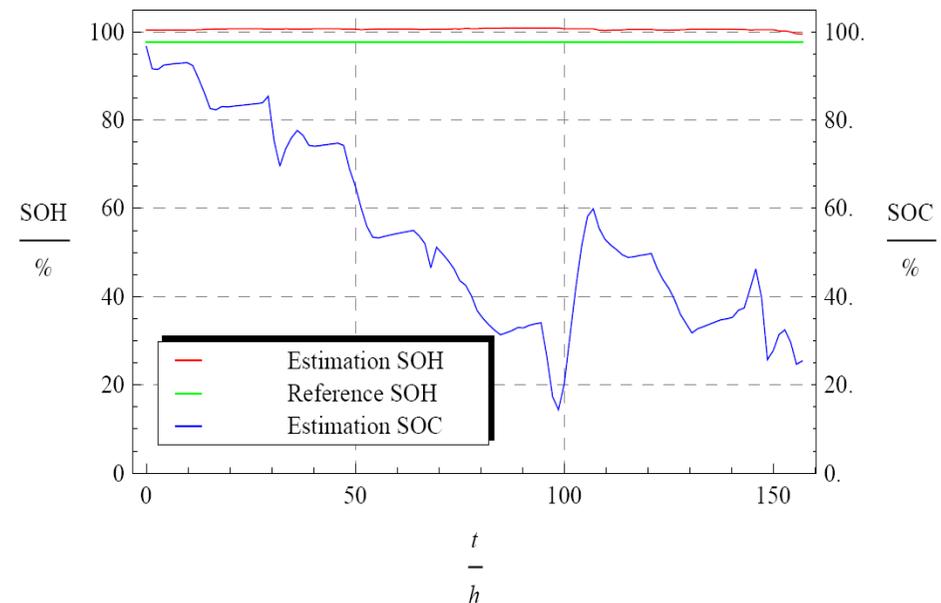
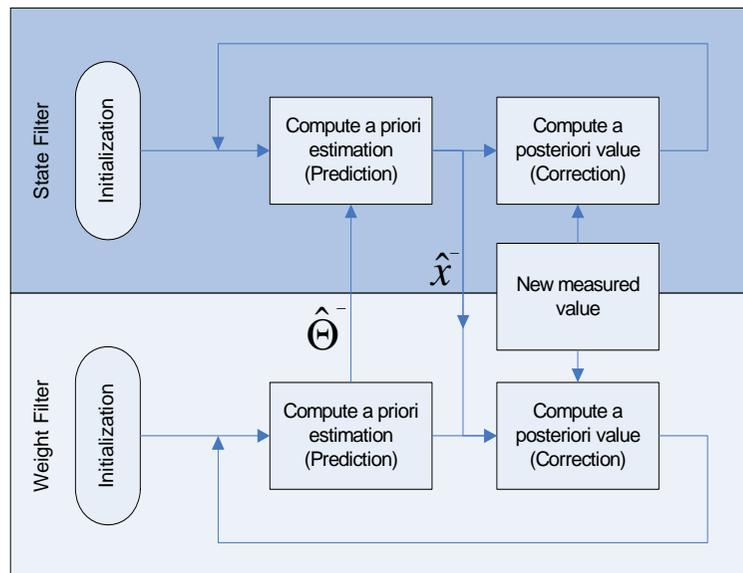
- Extension of Kalman Filter approach for non-linear systems:
 - Linearization within the operating point



State of health determination

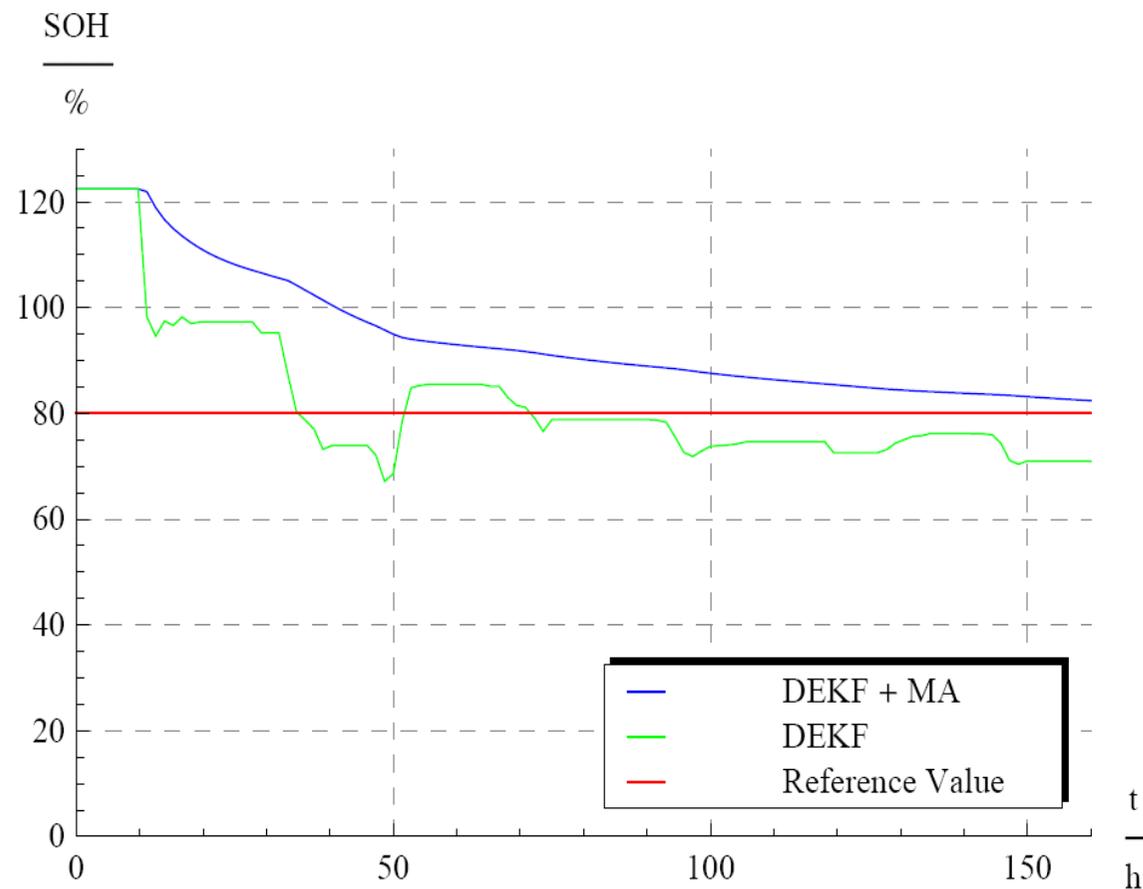
■ Principle of Dual Extended Kalman Filter

- 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



Conclusions

Battery systems for electric vehicles

- Energy and battery management systems are similar both in stationary and automotive applications in principal
- But specific boundary conditions must be taken into account:
 - Very specific properties of batteries in automotive applications make e.g. approaches for state determination based on rules difficult to implement → model based approaches are more straight forward to adapt to different battery types
 - Centralized BMS in stationary applications easier to handle since there are less dynamics and safety can be more easily assured → module BMS in automotive applications ensures safety, reliable state determination and long life times
 - Thermal management is more important in automotive applications than in stationary applications
 - In automotive applications there are not multiple power generators available at the same time

Thank you for your attention

Contact:

Simon Schwunk

simon.schwunk@ise.fraunhofer.de