Batteriespeicher-Optimierung für stationäre Anwendungen

Auslegung, Effizienz und Multi-Use Betrieb

Dr. Holger Hesse

Technische Universität München

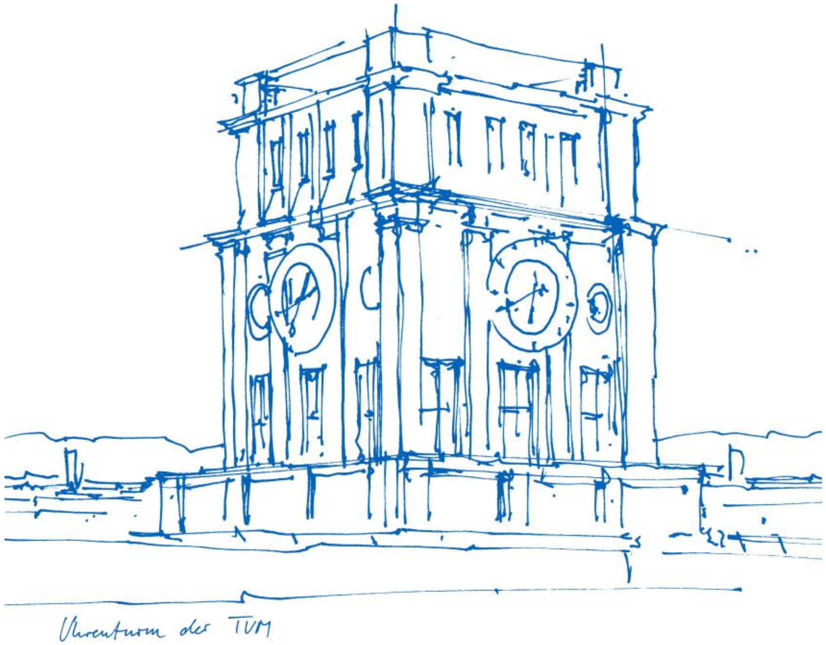
Lehrstuhl für Elektrische Energiespeichertechnik

2. Herbst-Workshop

„Dezentrale Sektorenkopplung und

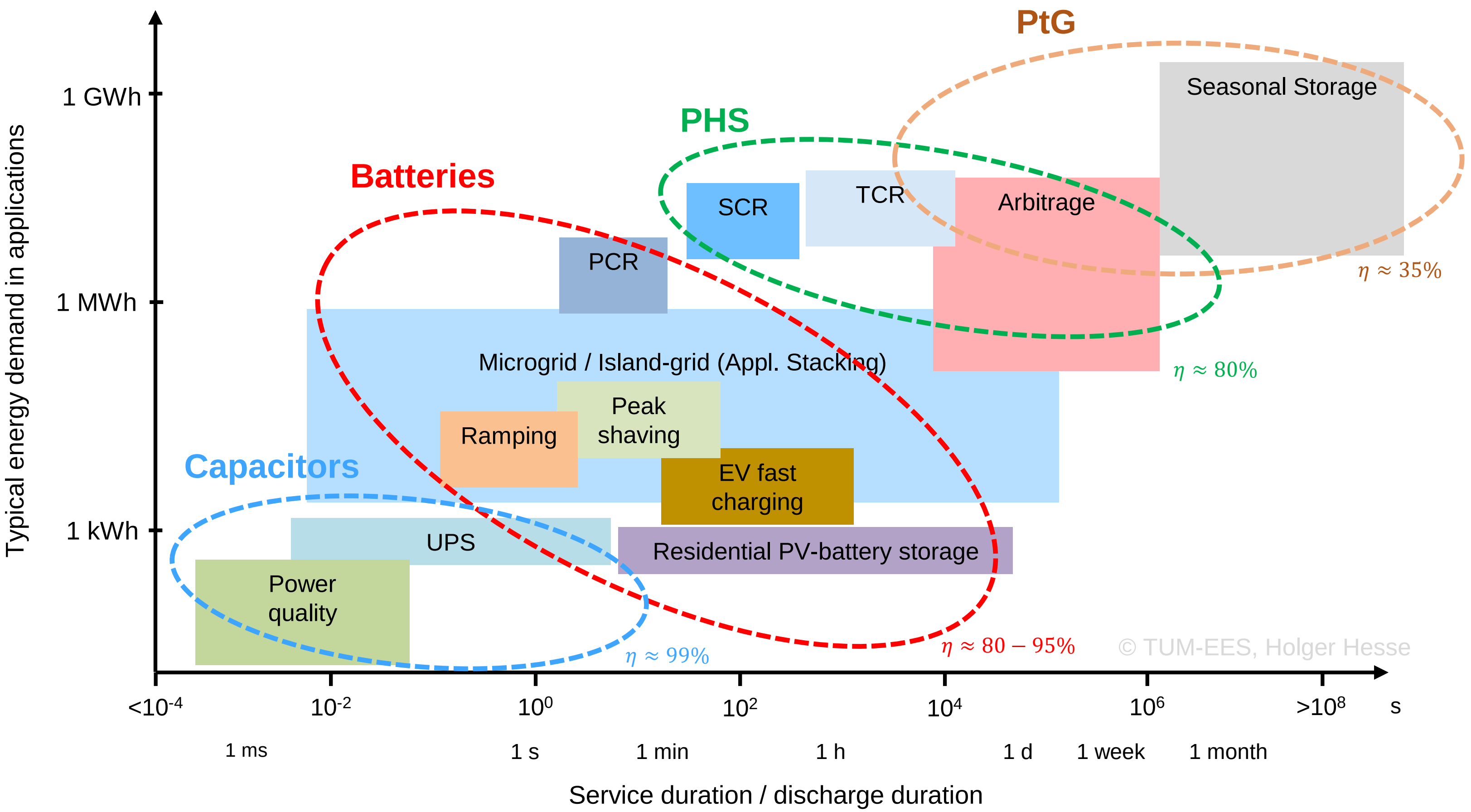
Hybride Energiespeichersysteme“

Dresden, 29.11.2017



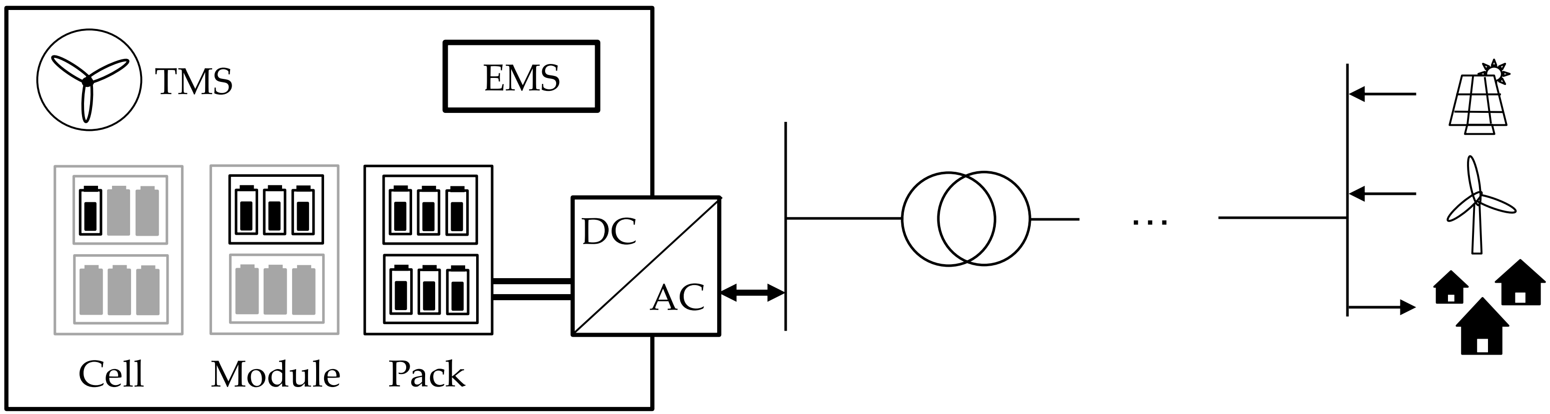
Einsatzgebiete stationärer Speicher

Technologien und Anwendungsfälle



Systemanalyse Batteriespeicher

Battery & Storage System | System Coupling | Grid Integration



Technical

- Battery System (Cell, Module, Pack)
- Thermal Management (TMS)
- Energy Management (EMS)

- Power Electronics (AC/DC) & Transformer
- Environmental Conditions

- Application Specific Profile
- Local Connection / Grid Level of Integration

Economic

- Investment (Batt., Periphery, Casing)
- Degradation and Efficiency
- Sizing & Operation Control

- Power Electronics Invest
- Conversion Efficiency
- Placement of System

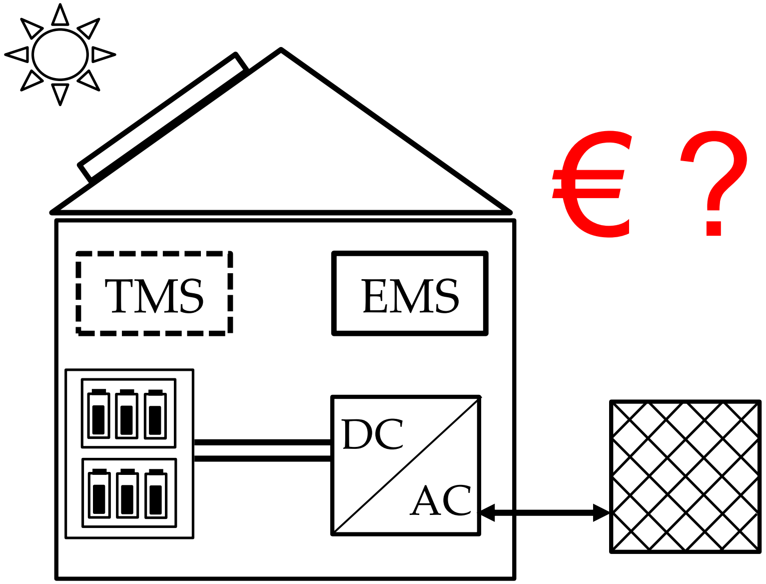
- Profit / Savings via Application
- Stakeholder Involvement
- Regulatory Framework

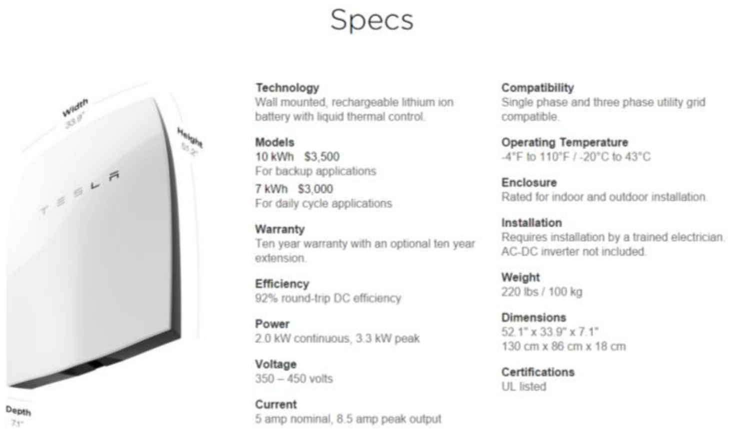
$$ROI = \frac{\mathbb{A}_{return} - \mathbb{C}_{inv}}{\mathbb{C}_{inv}} = \frac{(\mathbb{P}_{APL} - \mathbb{C}_{OPEX} - \mathbb{C}_{degrade}) - \mathbb{C}_{inv}}{\mathbb{C}_{inv}}$$

HC. Hesse, M. Schimpe, D. Kucevic, A. Jossen: “Lithium-Ion Battery Storage for the Grid – A Review to Stationary Battery Storage System Design Tailored for Applications in Modern Power Grids” accepted for publication in *MDPI Energies (Open Access review article)*

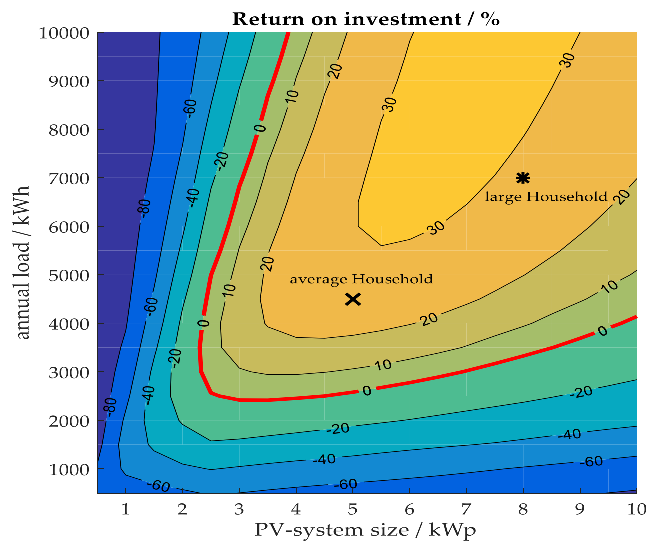
Auslegung von Speichersystemen

Wirtschaftliche Auslegung von Heimspeichersystemen (PV-BESS)





Source: www.tesla.com



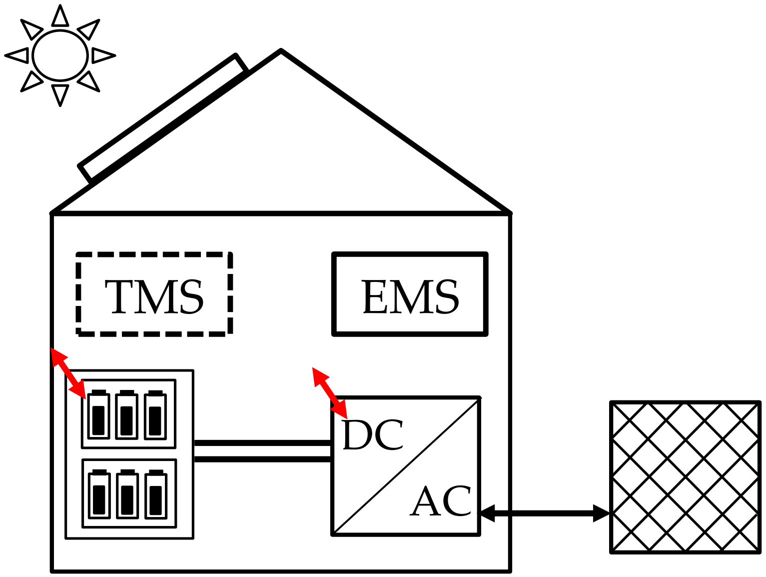
System ROI depends on several parameters:

- Load & generation profile
- Future of electricity tariffs
- Battery and periphery cost
- Technical parameters of storage system, i.e.
    - Battery and inverter size
    - LIB technology and storage degradation
    - Storage operation strategy

“Economics of residential photovoltaic battery systems in Germany: The case of Tesla’s Powerwall”
C.N. Truong, M. Naumann, R.C. Karl, M. Müller, A. Jossen, H.C. Hesse, Batteries 2016,2 (2)

Auslegung von Speichersystemen

Wirtschaftliche Auslegung von Heimspeichersystemen (PV-BESS)



Datasheet parameters

Parameter	Unit	Battery technology		
		PbA	LFP	NMC
η_{batt}: Battery round-trip efficiency	%	85	98	95
SD_{batt}: Self-discharge per day	%	0.17	0.02	0.02
(SOC_{min} - SOC_{max}): Usable SOC	%	50 - 100%	5 - 95%	5 - 95%
$Life_{Cal}^{80\%}$: Calendric life indicator in years	a	10	15	13
$Life_{Cyc}^{80\%}$: Cycle life indicator in FEC	-	1,500	10,000	4,500
$C_{var,bat}$: Variable battery price	€/kWh	271	752	982
C_{fix}: Fixed price for storage (price for housing, cooling, and periphery)	€	1182	1723	580

Linear optimization:

$$minimize\ C_{tot} = C_{buyE} - R_{sellE} + C_{deg}$$

s.t.: $P_{load_i} = P_{pv-load_i} + P_{batt-load_i} + P_{grid-load_i}$

$$P_{pv_i} = P_{pv-load_i} + P_{pv-batt_i} + P_{pv-grid_i} + P_{curtail_i}$$

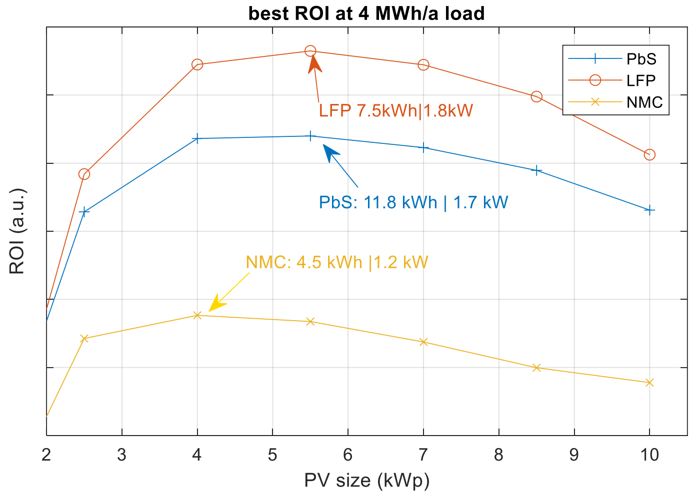
$$P_{pv-grid_i} + P_{curtail_i} \leq P_{feed-in}^{max}$$

$$a_{cal} \leftarrow f(tech)$$

$$a_{cyc} \leftarrow f(tech)$$

[12 additional constrains]

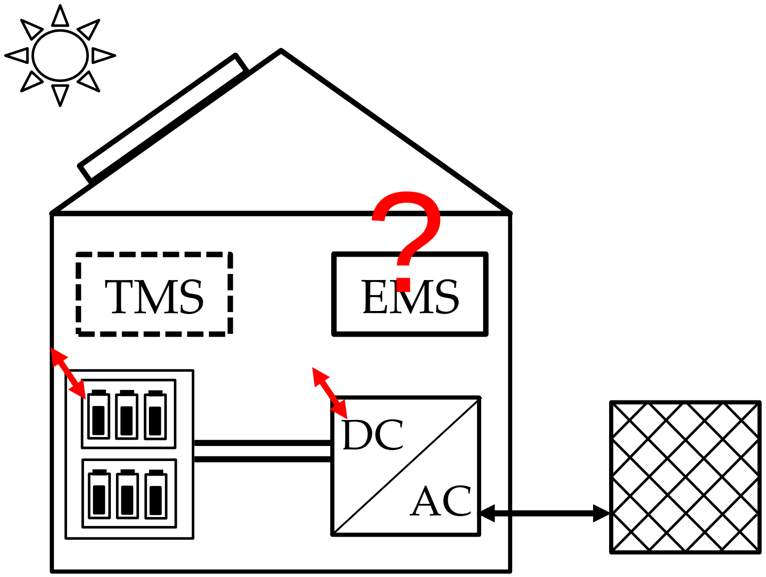
Optimization output:



"Economic optimization of component sizing for residential battery storage systems", HC Hesse, R Martins, P Musilek, M Naumann, CN Truong, A Jossen, Energies 10 (7), 835 (**2017**), DOI: 10.3390/en10070835

Betrieb von Speichersystemen

Wirtschaftliche Auslegung von Heimspeichersystemen (PV-BESS)



Linear optimization:

$$minimize \;\; C_{tot} = C_{buyE} - R_{sellE} + C_{deg}$$

s.t.: $P_{load_i} = P_{pv-load_i} + P_{batt-load_i} + P_{grid-load_i}$

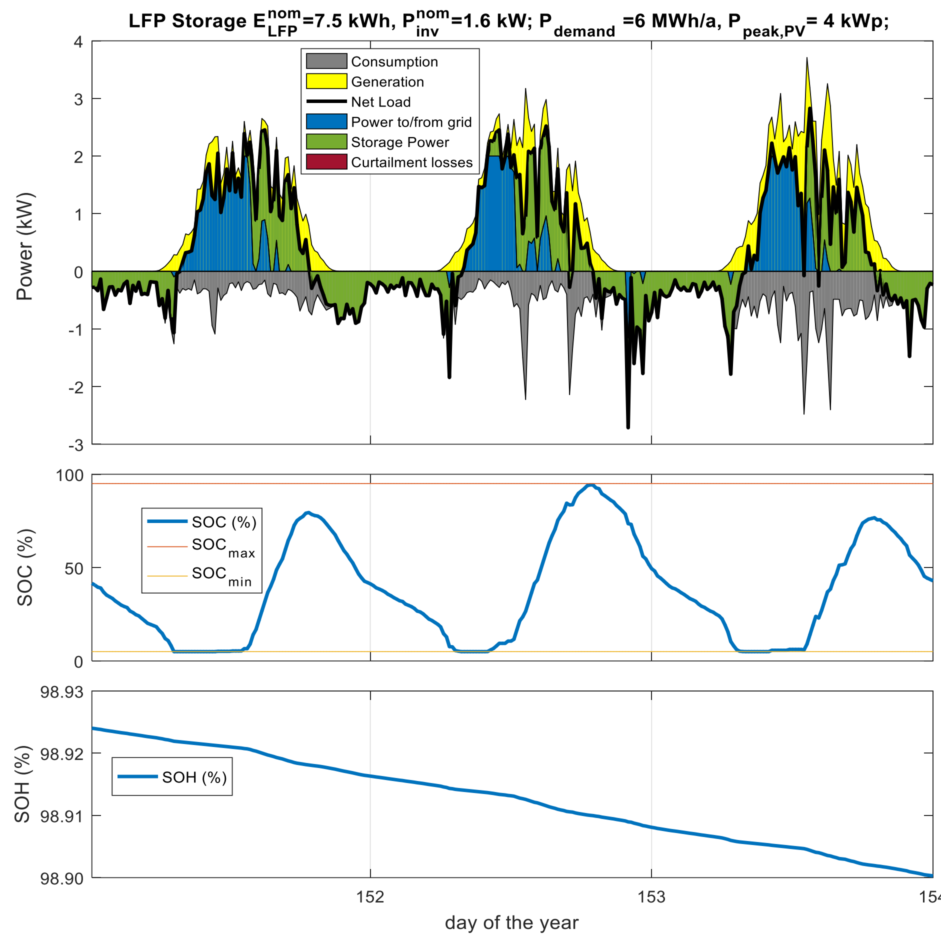
$$P_{pv_i} = P_{pv-load_i} + P_{pv-batt_i} + P_{pv-grid_i} + P_{curtail_i}$$

$$P_{pv-grid_i} + P_{curtail_i} \leq P^{max}_{feed-in}$$

$$a_{cal} \leftarrow f(tech)$$

$$a_{cyc} \leftarrow f(tech)$$

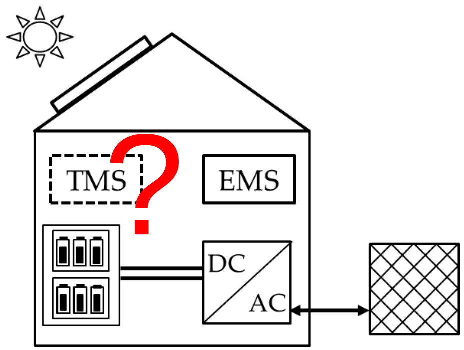
[12 additional constrains]



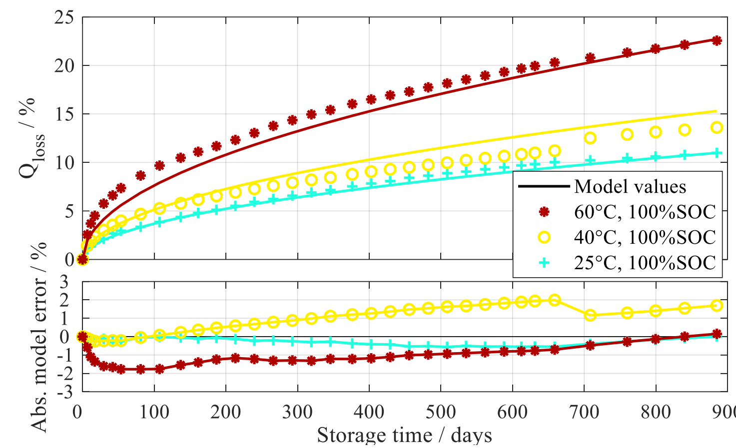
"Economic optimization of component sizing for residential battery storage systems", HC Hesse, R Martins, P Musilek, M Naumann, CN Truong, A Jossen, Energies 10 (7), 835 (**2017**), DOI: 10.3390/en10070835

Betrieb von Speichersystemen

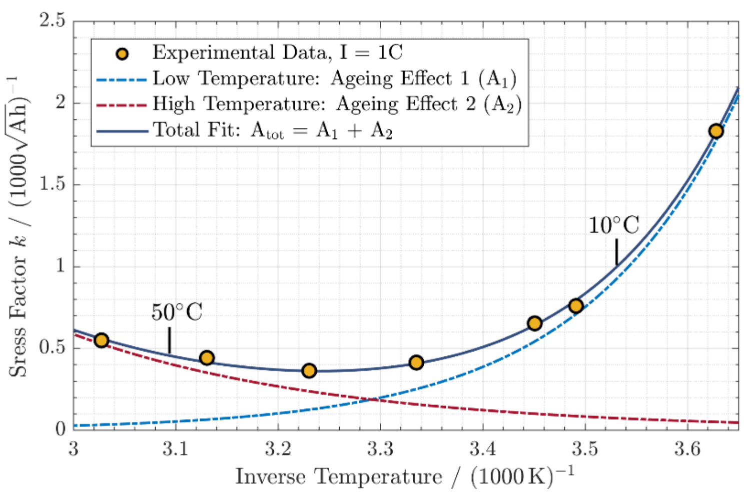
Alterung von Batterien: Einfluss Temperatur und Belastung (Beispiel: LFP:C Chemie)



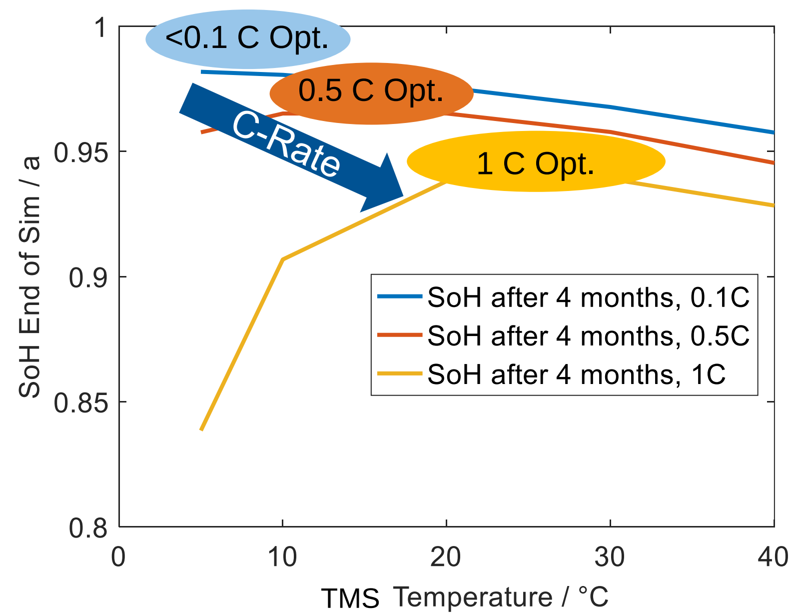
Kalendarisch Alterungsstudie an LFP Batterien



Semi-Empirische Modellierung LFP zykl. @ 1C



Simulation LFP Speicher unter typ. Belastung

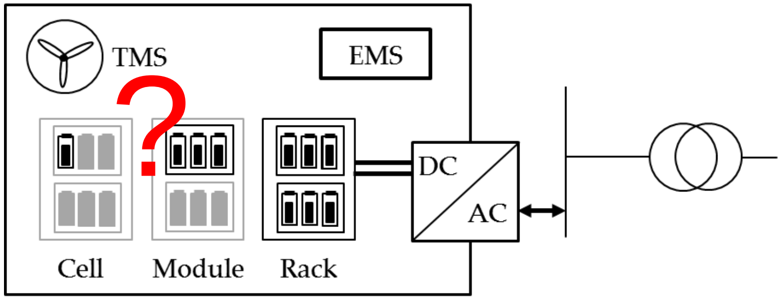


Semi-Empirical Modeling of Temperature-Dependent Degradation Mechanisms in LiFePO4 Batteries; M. Schimpe, M. E. von Kuepach, M. Naumann, H. C. Hesse, K. Smith, A. Jossen. (ECS Journal, accepted)

Analysis and modeling of calendar aging of a commercial LiFePO4/graphite cell; M. Naumann, M. Schimpe, P. Keil, H.C. Hesse, A. Jossen. (submitted)

Betrieb von Speichersystemen

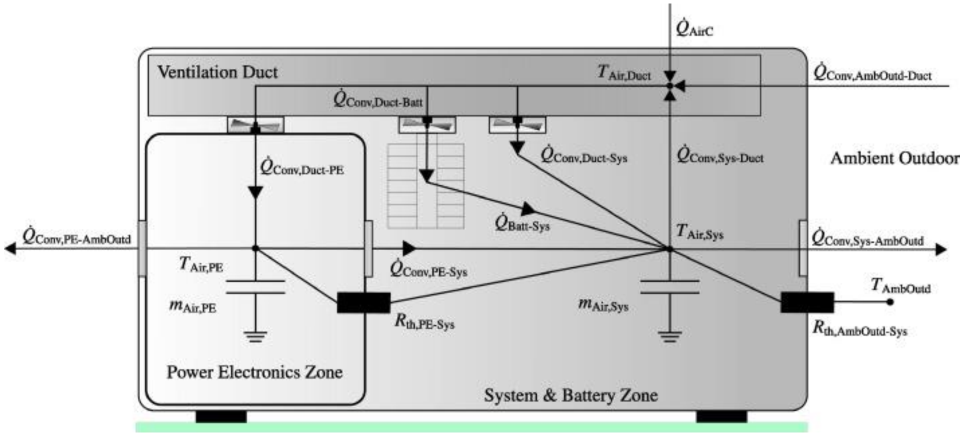
Systembetrachtung von Großspeicheranlagen: Thermisches Management

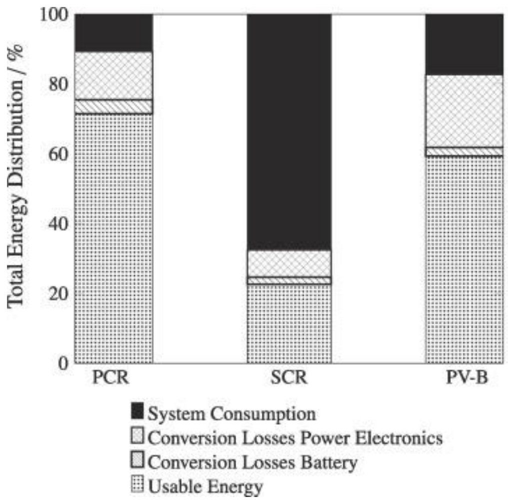


Energy neighbor Prototyp (240 kWh)

www.energyneighbor.de

Thermisch-elektrisches Systemmodell Speicher



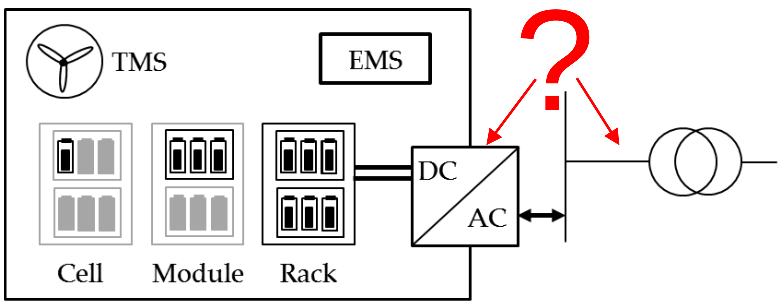


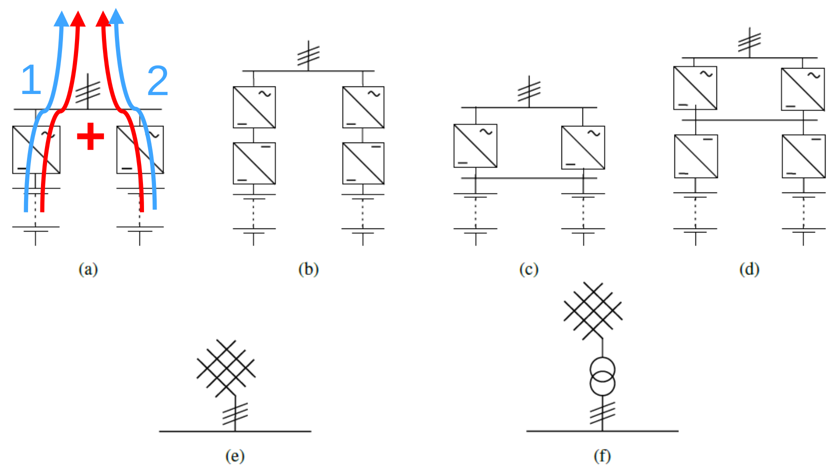
Appl. specific efficiency analysis	PCR	SCR	PV-B
Conversion efficiency $\eta_{Conversion}$	80.2%	69.6%	72.0%
Total efficiency η_{Total}	71.6%	22.6%	59.5%

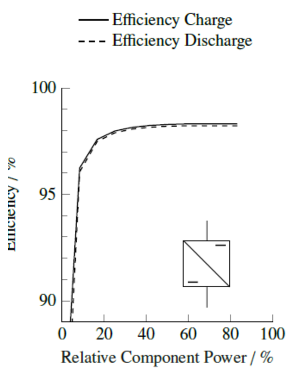
Energy efficiency evaluation of a stationary lithium-ion battery container storage system via electro-thermal modeling and detailed component analysis
M, Schimpe, M, Naumann, N Truong , HC Hesse , S. Santhanagopalan , A. Saxon , A. Jossen; *Applied Energy (2018)* 10.1016/j.apenergy.2017.10.129

Betreib von Speichersystemen

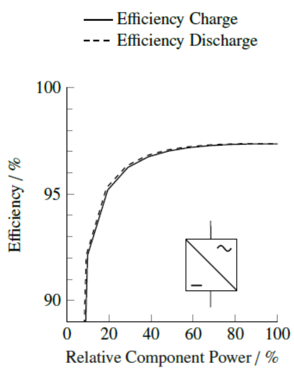
Systembetrachtung von Großspeicheranlagen: Leistungselektronik und Systemanbindung



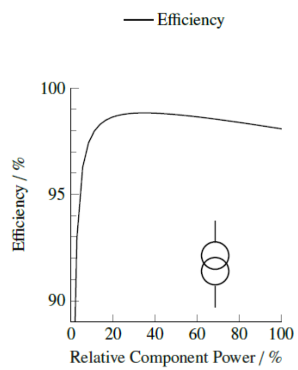




Siemens
DCP 30 kW

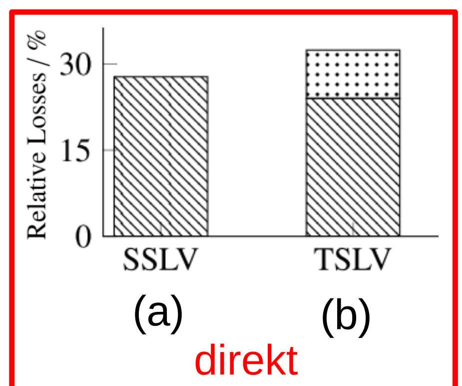


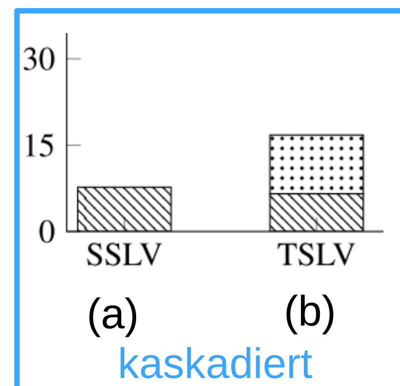
Siemens
S120 36 kW



Siemens
GEAFOL 250 kVA

Effizienzvergleich direkter und kaskadierter Speicherbetrieb

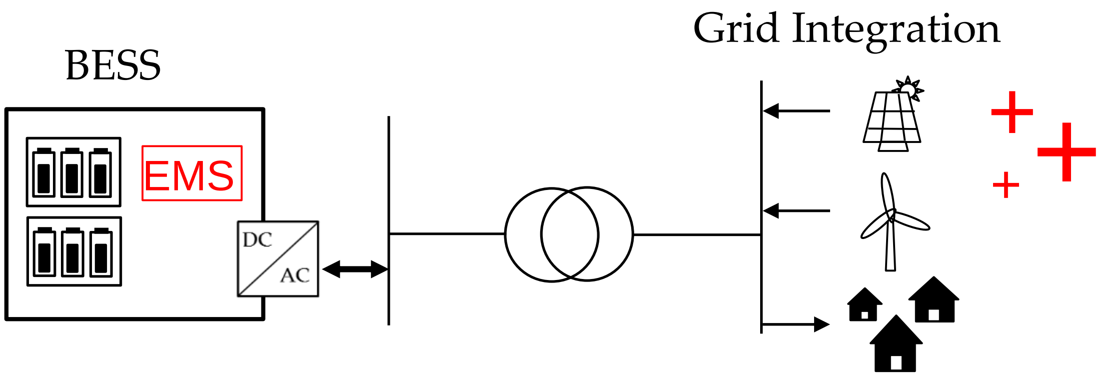




Energy efficiency evaluation of grid connection topologies for battery storage systems
M. Schimpe, N. Becker, T. Lahlou, HC Hesse, HG Herzog, A. Jossen, (submitted)

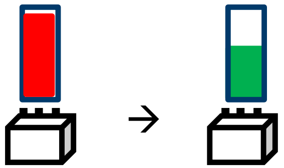
Multi-Use Betrieb von Speichersystemen

Konzept-Demo Multi-Use in EEBatt



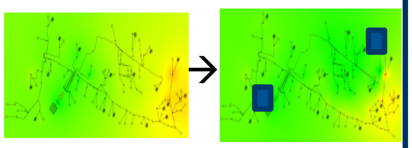
www.energyneighbor.de

Transformer load



98,5 % → 58,0 %

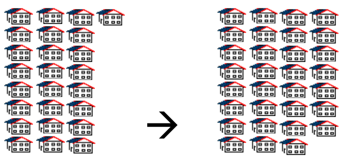
Voltage regualtion



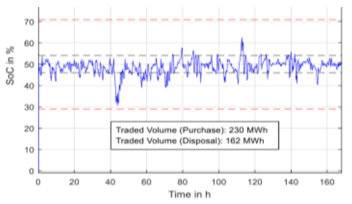
105 % → 102,0 %

PV-Integration

34,5 % → 43,0 %



Ancillary service (PCR)

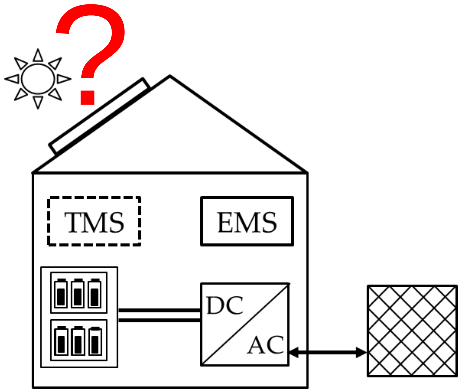


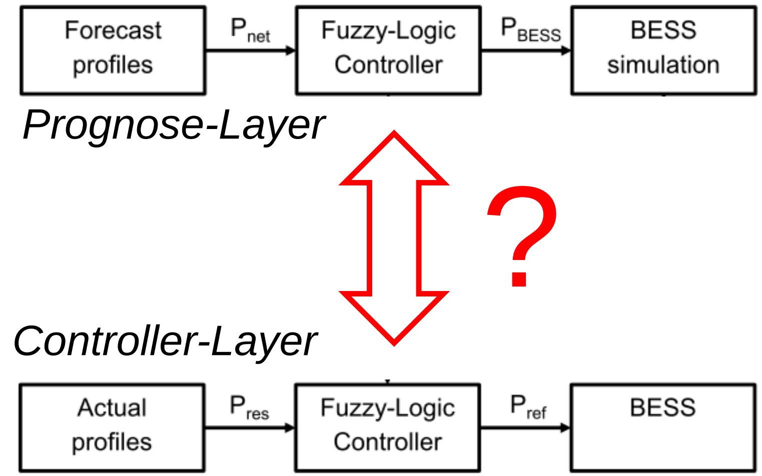
§

$$J_{opt} = f_{apl1}(\vec{x}) \dots f_{aplN}(\vec{x})$$

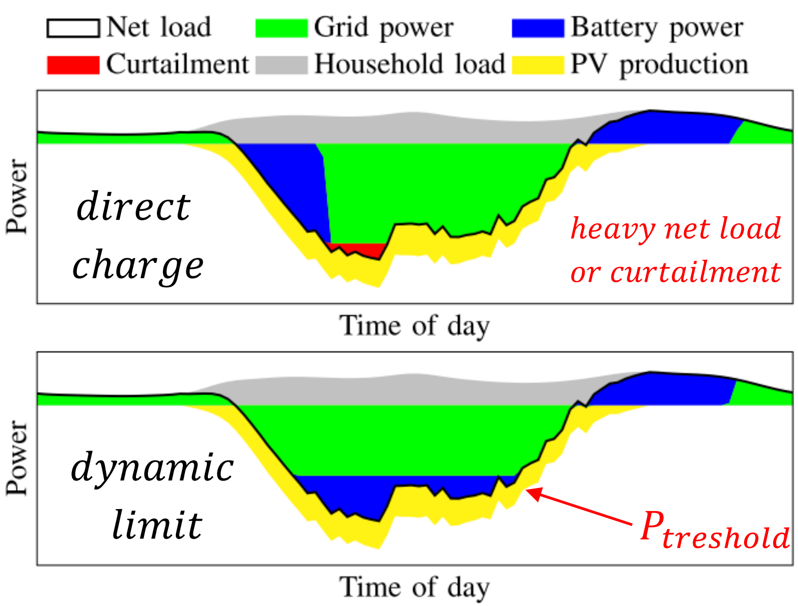
Multi-Use Betrieb von Speichersystemen

Betriebsoptimierung BESS bei Prognose-Unsicherheit durch FLC + Cuckoo search





Referenz-Strategien



FLC-Controller

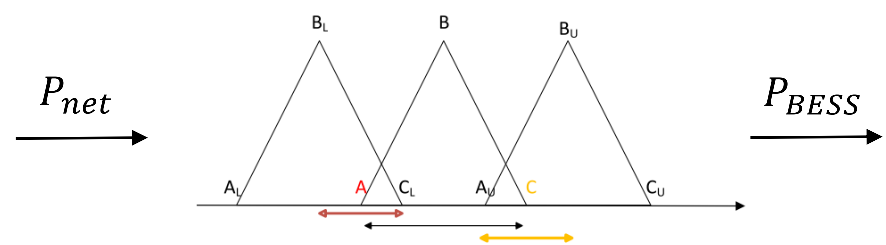


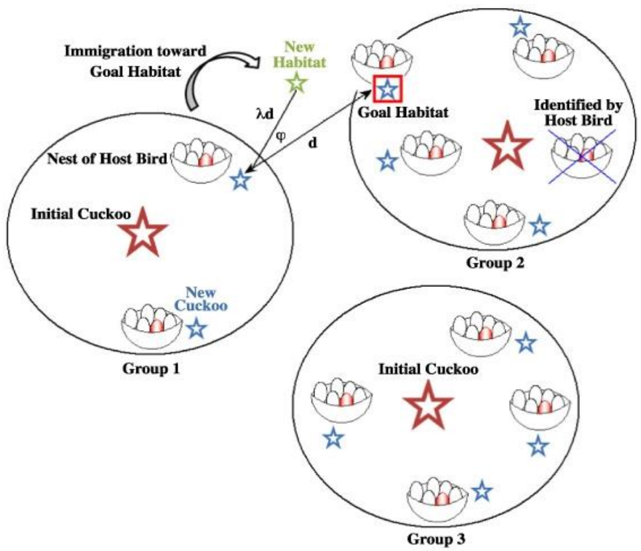
Fig. 4. Illustration of membership function constraints.

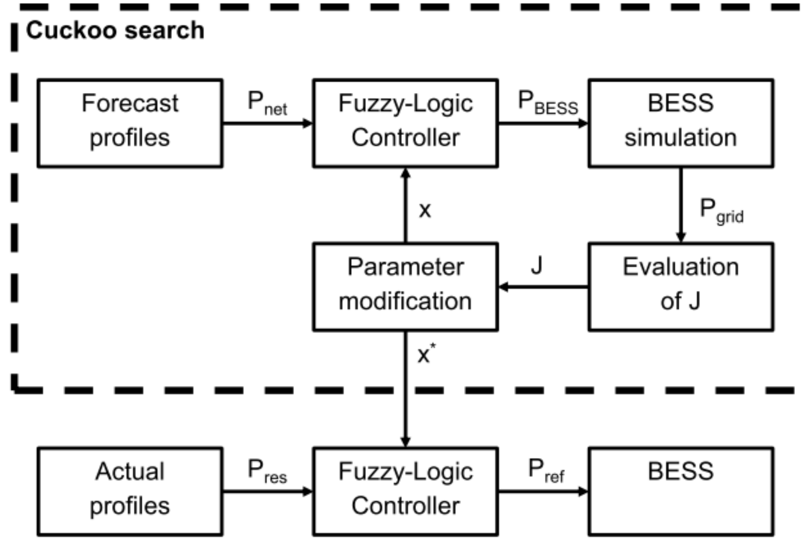
Cuckoo-Search Optimized Fuzzy-Logic Control of Stationary Battery Storage Systems, N Truong, D. May, R. Martins, P. Musilek, A. Jossen, H. Hesse, IEEE EPEC 2017

Multi-Use Betrieb von Speichersystemen

Betriebsoptimierung BESS bei Prognose-Unsicherheit durch FLC + Cuckoo search

Cuckcoo-Search





Cost function

$$\min_x J(x) = \min_x \left(-\hat{P}_{red}\right)$$

$$\hat{P}_{red} = \hat{P}_{net} - \hat{P}_{grid}$$

System constraints

$$SOC = [0;1]$$

$$P_{BESS} = [P_{CH}; P_{DCH}]$$

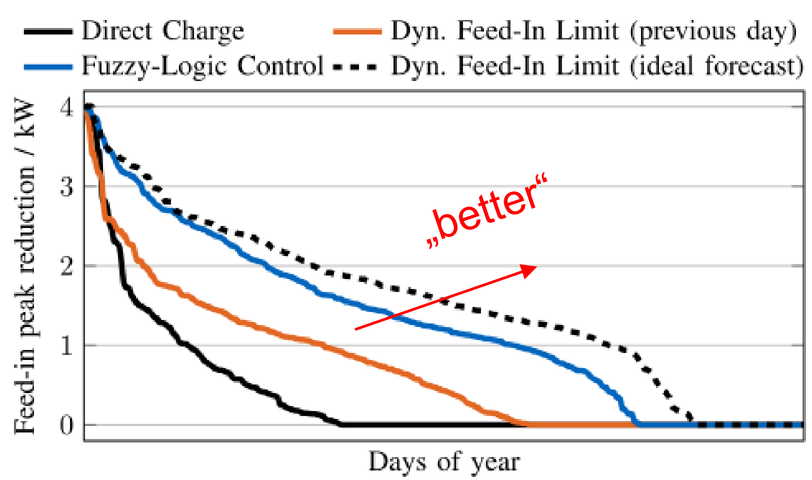


Image Source: Ali Zare Hosseinzadeh et al 2014
Smart Mater. Struct. 23 045019 doi:10.1088/0964-1726/23/4/045019

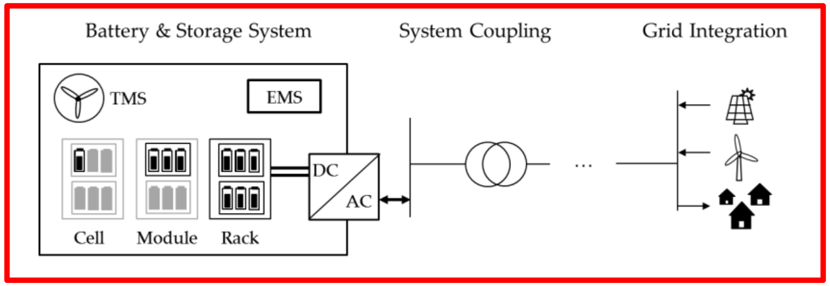
Cuckoo-Search Optimized Fuzzy-Logic Control of Stationary Battery Storage Systems,
N Truong, D. May, R. Martins, P. Musilek, A. Jossen, H. Hesse, IEEE EPEC 2017

Modellierung von Speichersystemen

SimSES Modellierungs-Toolkette

MATLAB

- Matlab skript (system objects)
- Simulink kompatible

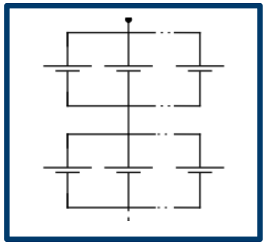


openmod
open energy
modelling initiative

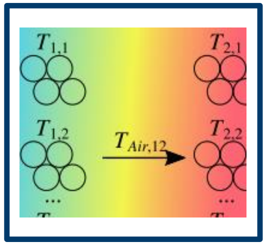
- Open source model
- GIT repository version control
- Online: www.simses.org

Input layer

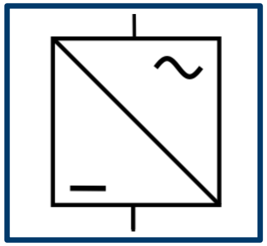
Cell



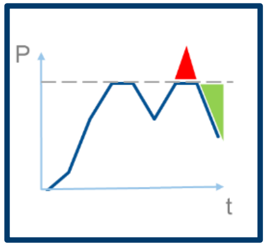
System



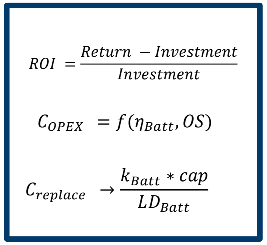
Thermal



Grid



Application



Evaluation

Cell
- Battery technology datasheet models
- OCV-R Model
- Aging model stress detection cal. / cyc.
- Empirical data based models

System
- Sclaing of cell serial-parallel Interconnection
- Contact resistance

Thermal
- Thermal loss model
- Ambient temperature
- Cooling concept

Grid
- Inverter model
- Transformer model

Application
- Pre-defined OS:
- PV-BESS
- Peak-Shave
- PCR /SCR
- User-defined OS

Evaluation
- Economics ROI / NPV
- CO_2 impact

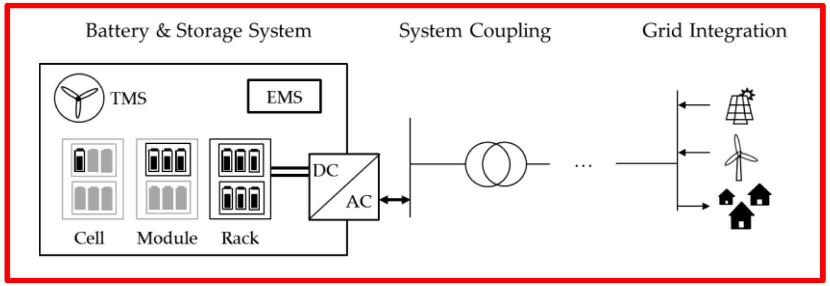
Download at: www.simses.org

Modellierung von Speichersystemen

SimSES Modellierungs-Toolkette

MATLAB

- Matlab skript (system objects)
- Simulink kompatibel

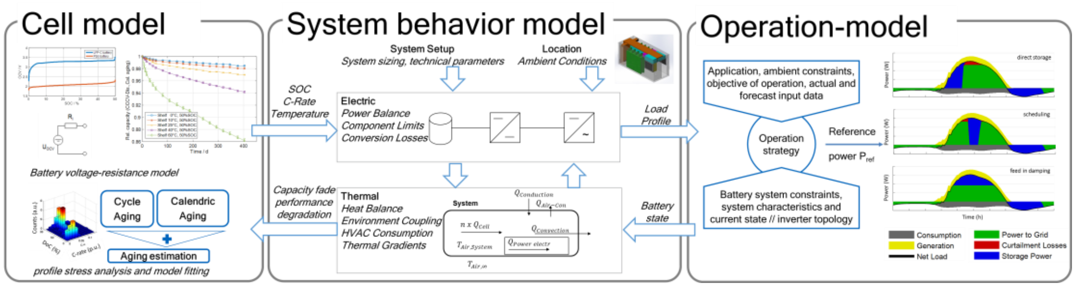


openmod

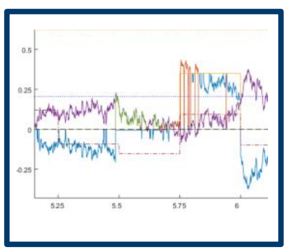
open energy modelling initiative

- Open source model
- GIT repository version control
- Online: www.simses.org

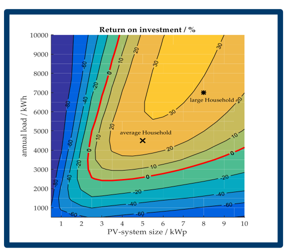
Internal models (objects)



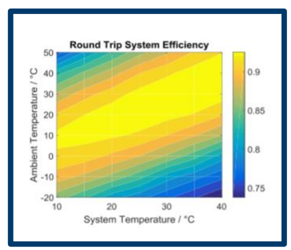
Output layers



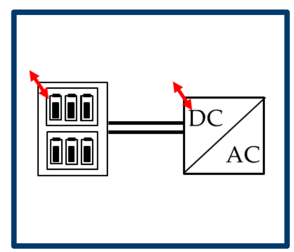
Time series analysis



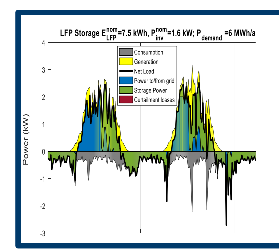
Economic assessment



Efficiency analysis



Optimized sizing

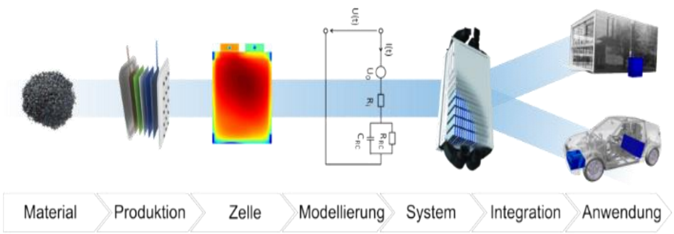


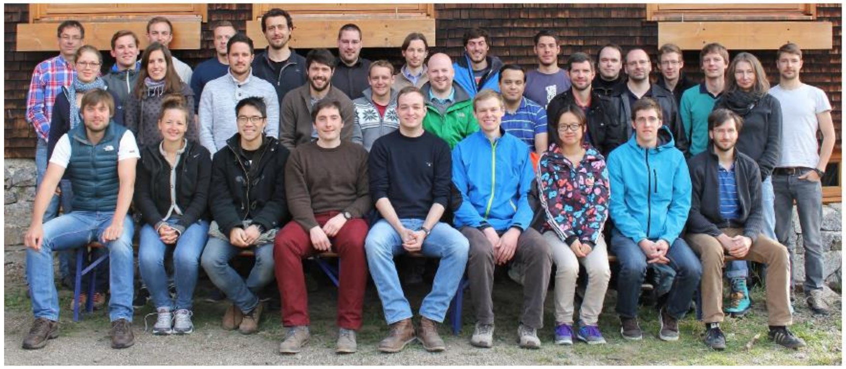
OS & controller

Download at: www.simses.org

Danke für Ihre Aufmerksamkeit!

Lehrstuhl für Elektrische Energiespeichertechnik
Fakultät für Elektrotechnik und Informationstechnik
Technische Universität München





Team Stationäre Energiespeicher

- Techno-ökonomische Bewertung und Optimierung von Speichersystemen in verschiedenen Anwendungen
- Test und Modellierung von Speichertechnologien: Lithium-Ionen, Blei, Redox-Flow, neue Technologien
- Alterungs- und Effizienzanalyse und -optimierung
- Simulation verteilter Energiespeicher und innovative Technologien zur Netzintegration
- Innovationsforschung: Smart-Grid, Smart Home, V2G, Blockchain, Sektorenkopplung

http://www.ees.ei.tum.de/mitarbeiter/team-ses/

Kontaktdaten:
Dr. Holger Hesse
+49 (0) 89 / 289 – 26964
holger.hesse@tum.de