SIMULATION-BASED ENERGY PERFORMANCE ANALYSIS AND ECONOMIC ASSESSMENT OF $Na/NiCl_2$ BATTERIES COMPARED TO LI-ION BATTERIES OPERATING IN A PV HOME STORAGE SYSTEM

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1. MOTIVATION AND APPROACH

Main Objective
Energetic and economic evaluation of a PV home storage system with a $Na/NiCl_2$ battery (SNB) compared to a system with a Li-ion battery (LIB)

Approach
- Experimental determination of $Na/NiCl_2$ battery characteristics
- Annual simulations of power flow models with Modelica in Dymola
- Parameter study for performance analysis
- Economic assessment

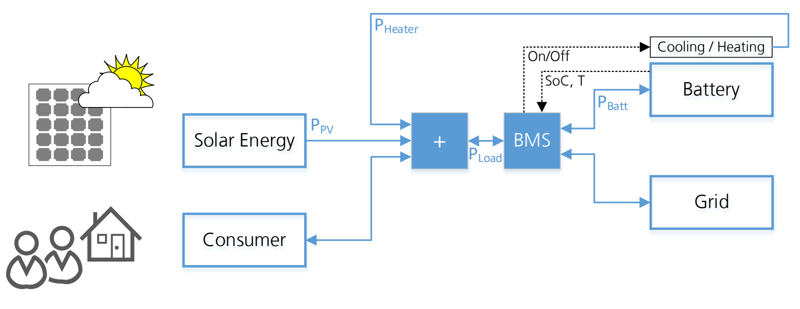

Figure 1: Simplified illustration of the PV home storage model.

$Na/NiCl_2$ battery model
Phenomenological thermo-electric model of $Na/NiCl_2$ battery, parametrization based on experimental and literature data, i.e.
- Charging/discharging rate limitations depending on state of charge (SOC)
- Self-heating depending on discharging rate
- Heat capacity
- Heat loss depending on battery temperature

Li-ion battery model
Simplified electric model with small constant cooling power demand, parametrization according to data sheets of currently available home storage systems [1][2], i.e.
- Round trip efficiency
- Maximum charging/discharging rates depending on SOC

PV home storage model
Power flow model consisting of
- PV power input
- Consumer demand input
- Battery model
- Grid power output
- Controller unit

Input data are standardized, synthetic consumer demand profiles and PV production profiles generated based on the VDI 4655 Sheet 1[3] standard.

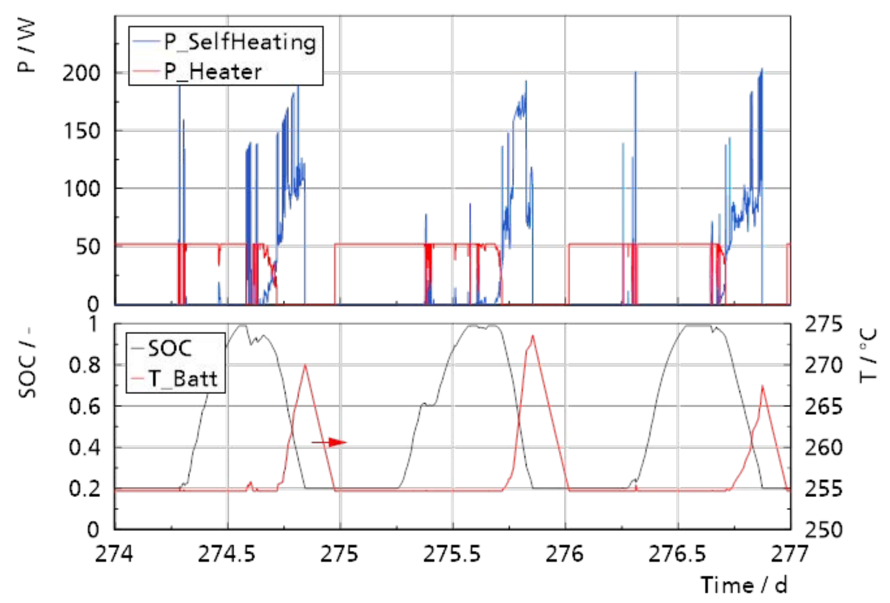

Figure 2: Simulation result for a 5 kWh $Na/NiCl_2$ battery, temperature-controlled heating power and self-heating due to discharge (upper panel), state of charge and battery temperature (lower panel).

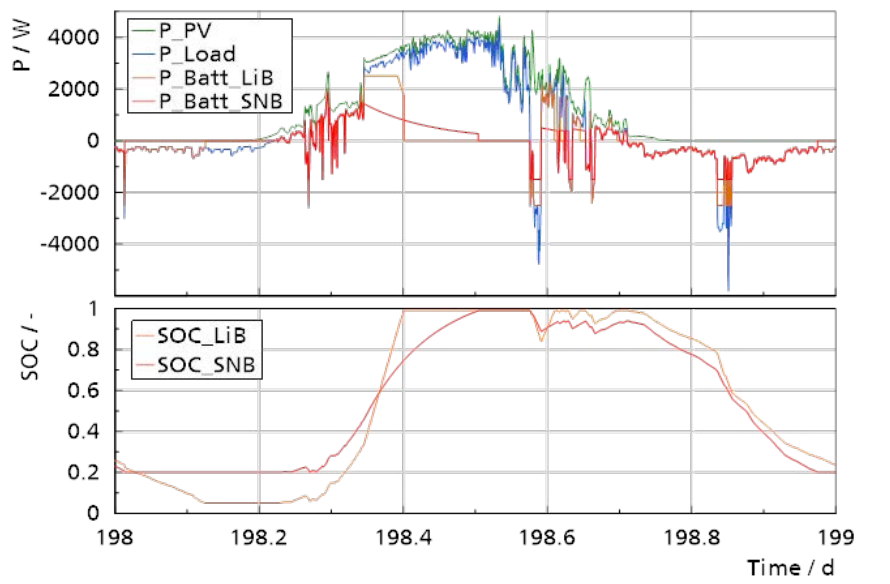

Figure 3: Simulation result for a 5 kWh $Na/NiCl_2$ battery compared to a 5 kWh Li-ion battery, showing different charging power (upper panel) depending on the state of charge (lower panel).

3. PERFORMANCE ANALYSIS

Parameter study with variation of:
- PV area from 3 m² to 42 m² (0.5 to 6 kW_p)
- Daily consumer demand of approx. 5, 10 and 15 kWh/day
- Battery capacity of 5, 10 and 15 kWh

Energetic evaluation based on system parameters such as self-sufficiency, self-consumption rate, battery module efficiency, battery utilization, number of equivalent charge/discharge cycles and idle times, i.e.:

Self-consumption rate $SCR = \frac{E_{Consumer,PV+Batt}}{E_{PV}}$ (1)

Battery utilization $\zeta_{Charge} = \frac{E_{Charge}}{E_{PV}}$ (2)

Table 1: Model parameters.

Parameter	$Na/NiCl_2$ battery	Li-ion battery
Usable capacity	80 %	95 %
Maximum charging rate	$r_{Ch,max} = f(SOC)$	$r_{Ch,max} = f(SOC)$
Maximum discharging rate	0.3 C	0.5 C
Round trip efficiency (el.)	≈ 88 % (internally calculated depending on self-heating)	95 %
Heating / Cooling system	≈ 12 W / kWh Temperature controlled heater power	1.2 W / kWh Constant cooling power

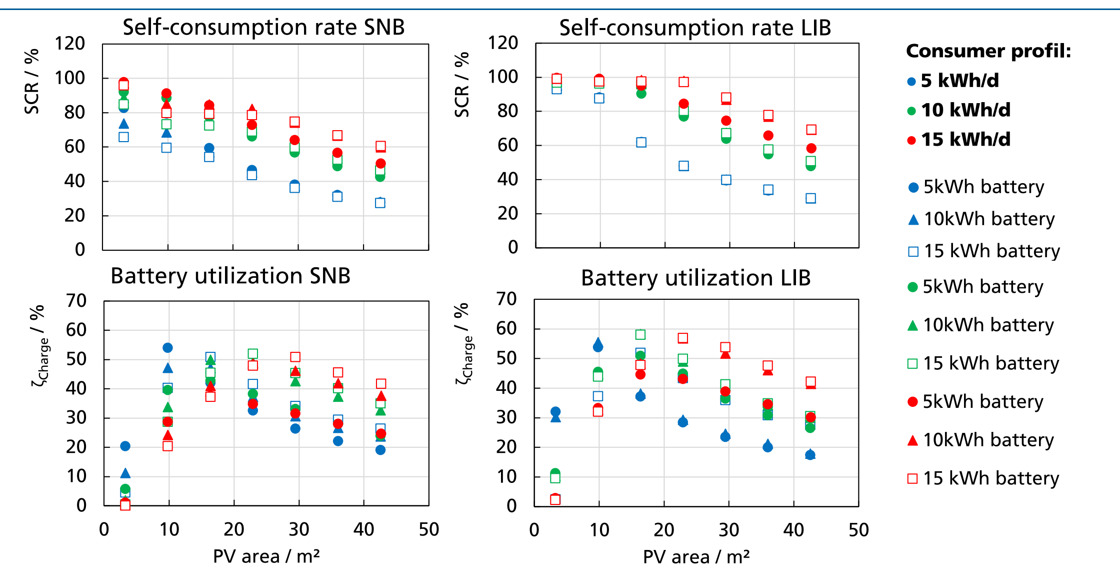

Figure 4: Performance analysis of $Na/NiCl_2$ battery and Li-ion battery home storage systems, self-consumption rate and battery utilization according equation (1) and (2).

4. COST ASSESSMENT

Comparison of annual electricity costs for home storage systems with SNB and LIB based on simulation results for all configuration of the parameter study

Cost assumptions according to literature data

Table 2: Basic electricity cost calculation assumptions

Electricity costs (mains supply)		31 ct./kWh
PV electricity production cost		8 ct./kWh
Feed-in remuneration		10 ct./kWh
LCOS $Na/NiCl_2$		
	CAPEX	100–400 € / kWh
	Lifetime	15 years
	LCOS	3.5–14.0 ct./kWh
LCOS Li-ion		
	CAPEX	700–1000 € / kWh
	Lifetime	10–15 years
	LCOS	20.5–39.0 ct./kWh

Calculation of Levelized Cost of Storage (LCOS)

$$LCOS = \frac{CAPEX + O\&M \cdot \sum_{y=1}^{Y} \frac{1}{(1+r)^n} - \frac{V_{residual}}{(1+r)^n}}{N \cdot DOD \cdot C_{rated} \cdot \sum_{y=1}^{Y} \frac{1-DEG \cdot n}{(1+r)^n}} + \frac{P_{elec-in}}{\eta(DOD)}$$

CAPEX	Investment costs
N	full charging/discharging cycles per year
DOD	Depth of discharge
C_{rated}	Rated capacity
DEG	Annual degradation rate
Y	Project lifetime in years
r	Discount rate
O&M	Operation and maintenance costs
$V_{residual}$	Residual value (after project lifetime)
$P_{elec-in}$	Charging electricity costs
$\eta(DOD)$	Round trip efficiency at DOD

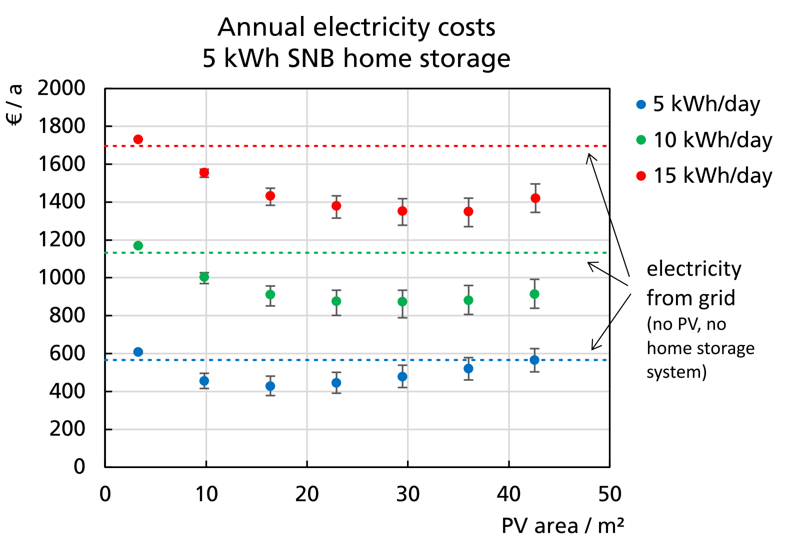

Figure 5: Annual electricity costs of a PV home storage system with a 5 kWh $Na/NiCl_2$ battery compared to full mains supply for different power demands.

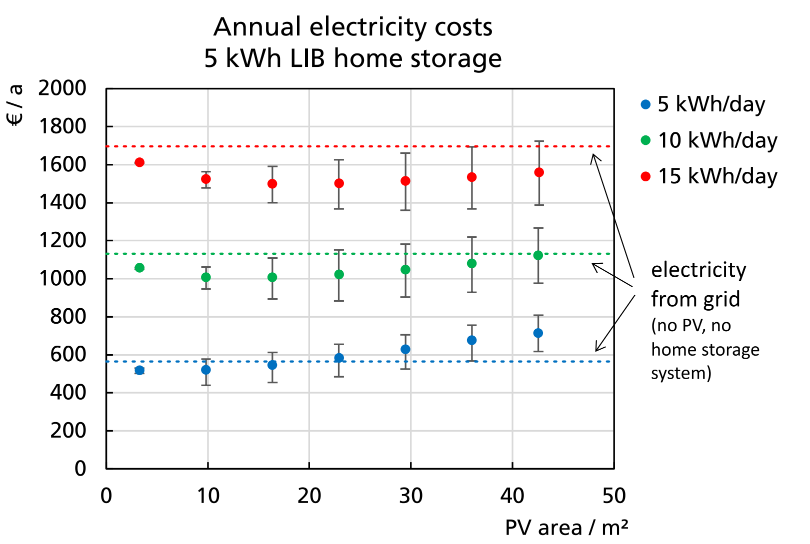

Figure 6: Annual electricity costs of a PV home storage system with a 5 kWh Li-ion battery compared to full mains supply for different power demands.

5. SUMMARY AND OUTLOOK

- $Na/NiCl_2$ battery and Li-ion battery technology was investigated in the application of a PV home storage system by annual simulations
- $Na/NiCl_2$ batteries are economically viable for home storage applications compared to Li-ion batteries at current prices
- Li-ion battery shows a slightly better energetic performance due to higher charge/discharge rates and no heating demand
- A holistic comparison requires the consideration of degradation rates and security issues where $Na/NiCl_2$ batteries are more favorable
- In future work degradation characteristics should be integrated in the battery models and effects on overall costs need to be investigated

REFERENCES

[1] https://www.pv-magazine.de/marktuebersichten/batteriespeicher/speicher-2020
[2] https://batterytestcentre.com.au/batteries/
[3] VDI 6455 Sheet 1: Reference load profiles of residential buildings for power, heat and domestic hot water as well reference generation profiles for photovoltaic plants, VDI-Gesellschaft Energie und Umwelt, 2019

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