Impact analysis of different operation strategies for battery energy storage systems (BESS) providing primary control reserve

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Research Topic

Primary control reserve (PCR) is required to balance the feed-in and use of electricity to/from the public grid, thereby ensuring safe and stable grid operation. Presently, PCR is predominantly provided by conventional power plants. However, when an energy system shifts towards fluctuating renewable electricity generation, new options to provide PCR will become necessary. BESS offer the opportunity of providing both positive and negative primary control.

In Germany, PCR is traded on a separate auction market with specific regulations. These regulations (minimum tender size of 1 MW, contract period of one week) offer the opportunity of a market entry for stationary battery systems and allow for a certain degree of flexibility regarding system configurations and operation strategies.

Methodology

If a tender on the PCR market is successful, the contractor must ensure both positive and negative primary control supply during the respective contract period. Consequently, the charge level of a BESS may not exceed or fall below certain limits to enable it to exchange the required amounts of primary control energy with the electric grid at all times.

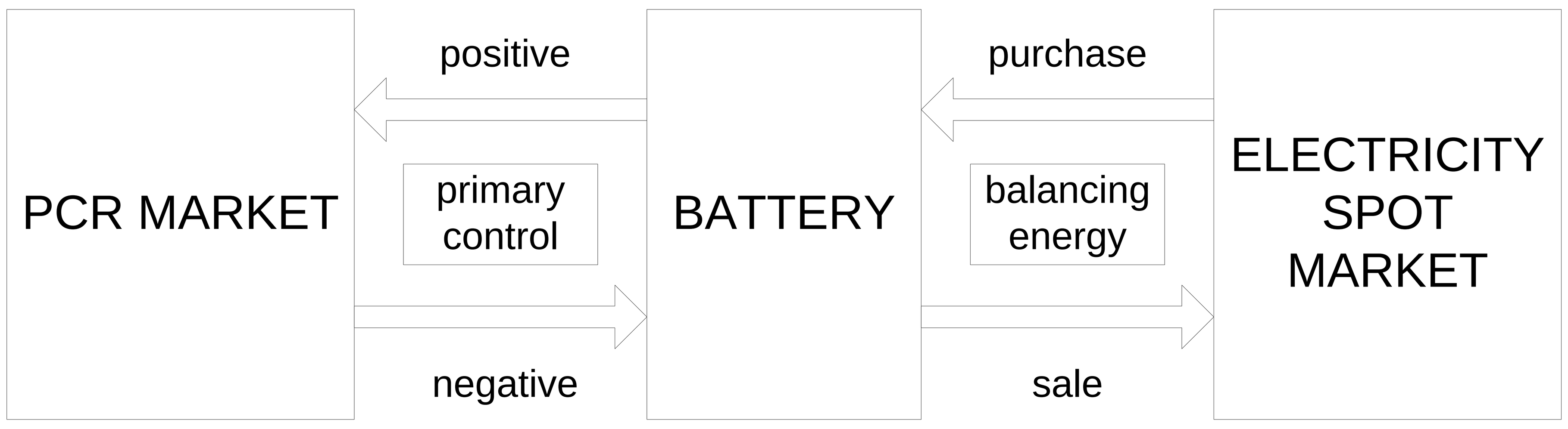

Fig. 1: Scheme of energy flows during primary control operation

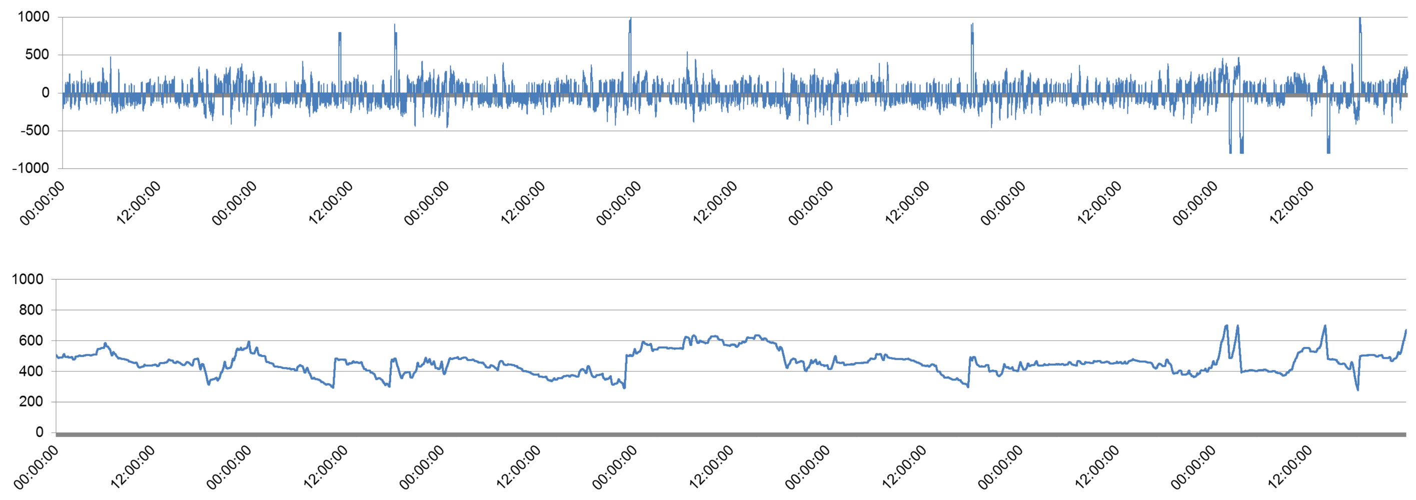

Fig. 2: Exemplary load profile and SoC profile of a battery system providing PCR (1 MW/1 MWh capacity, 30-70% SoC, 1 week operation)

In order to reduce the required battery capacity, and thus the overall system costs, balancing energy can be purchased or sold on the electricity spot market. A simulation model has been developed to analyse various battery designs, which are distinct in terms of capacity, as well as several operation strategies. Based on an energy balance for every time step, the model simulates battery operation and calculates the state of charge (SoC). If the SoC exceeds or falls below certain predefined limits, sale or purchase of balancing energy is simulated. The simulation results are statistically evaluated with a focus on parameters which affect battery lifetime.

The amount of energy exchanged with the public grid due to primary control operation is calculated from grid frequency data and PCR tendering results The energy balance takes into account this primary control energy and the energy purchased or sold on the spot market.

$$E(t+1) = E(t) + \eta_{BESS} \int_0^1 P_{PC}(t)dt + \eta_{BESS} \int_0^1 P_{spot}(t)dt$$

Six different simulations are conducted in a temporal resolution of one second.

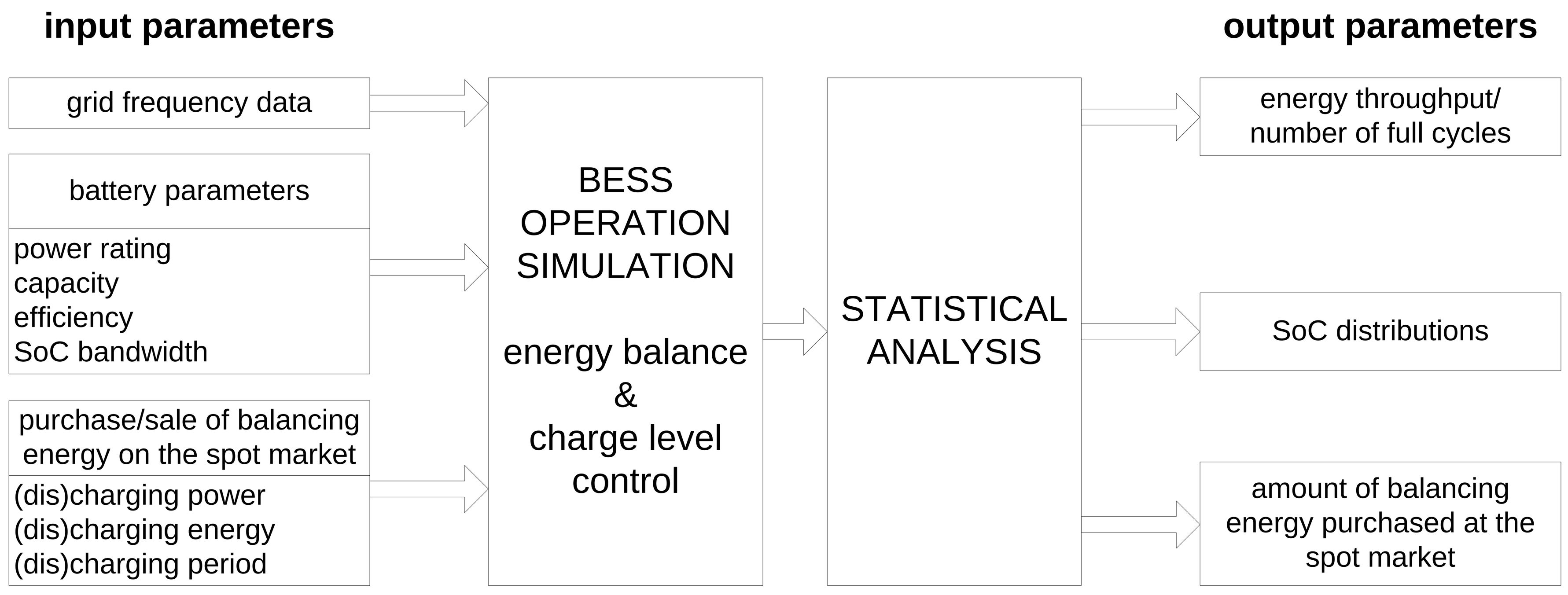

Fig. 3: Structure of the PCR simulation model

Tab. 1: Overview on conducted simulations and their respective input parameters

Simulation	Input parameters (battery)		Input parameters (electricity spot market)			General input parameters
	capacity [MWh]	SoC bandwidth [%]	(dis)charging power [MW]	(dis)charging energy [MWh]	(dis)charging period [h]	
0.5 MWh / 20-80% SoC	0.5	20-80	0.25	0.25	1	▪ BESS power rating: 1 MW ▪ BESS efficiency: 95% ▪ PCR tendering results (source: regelleistung.net) ▪ grid frequency data in 1s resolution (source: SWISSGRID AG)
0.5 MWh / 30-70% SoC	0.5	30-70	0.1	0.4	0.25	
1 MWh / 20-80% SoC	1	20-80	0.5	0.5	1	
1 MWh / 30-70% SoC	1	30-70	0.2	0.8	0.25	
2 MWh / 20-80% SoC	2	20-80	1	1	1	
2 MWh / 30-70% SoC	2	30-70	0.2	0.8	0.25	

Results

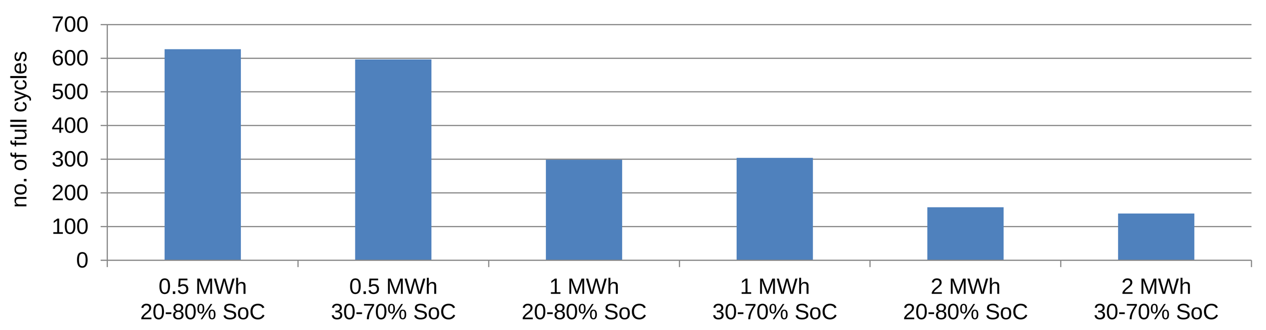

Fig. 4: Number of equivalent full cycles per year

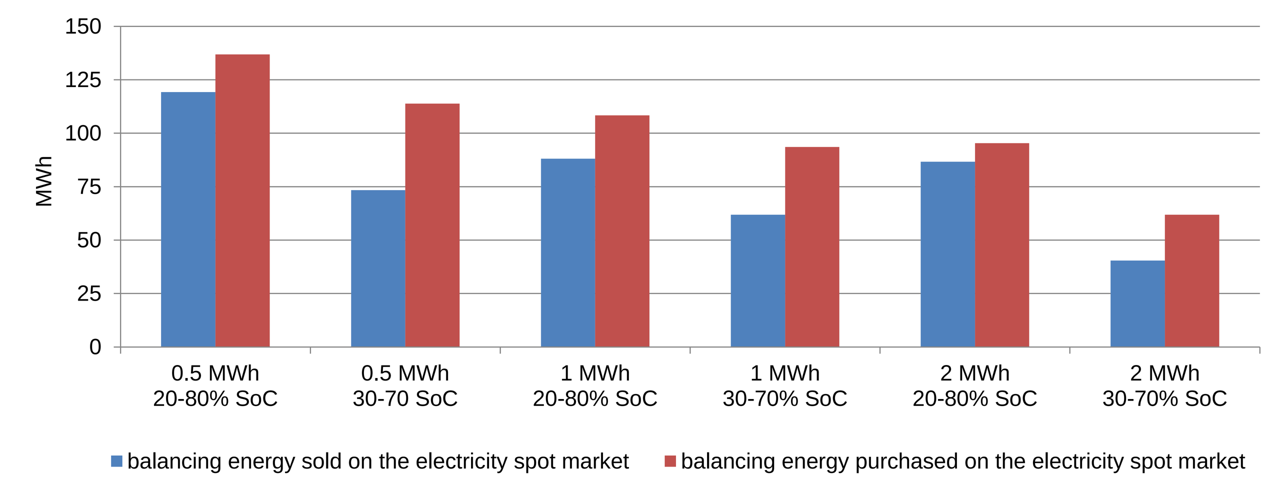

Fig. 5: Amount of required balancing energy per year

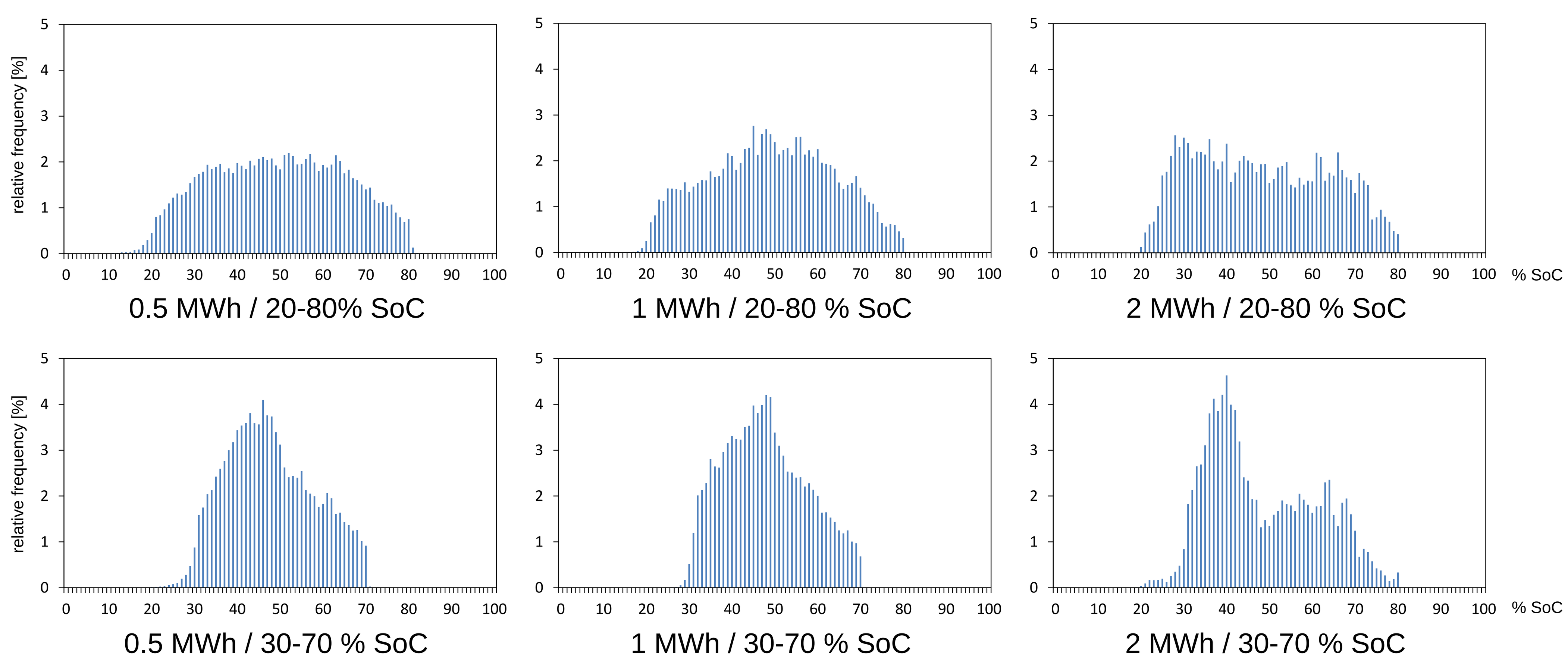

Fig. 6: SoC distributions

Conclusion

- The BESS operation strategy significantly affects the amount of required balancing energy and the SoC distribution profile of a battery, however, it has hardly any influence on the number of equivalent full cycles.
- Battery dimensioning has a major impact on the number of equivalent full cycles. Its influence on the amount of required balancing energy and the SoC distribution profile is less distinct.
- Coupling the simulation model with a battery ageing model could lead to substantial conclusions regarding lifetime expectancies of stationary BESS providing PCR.