Scaling management of distributed energy storage systems

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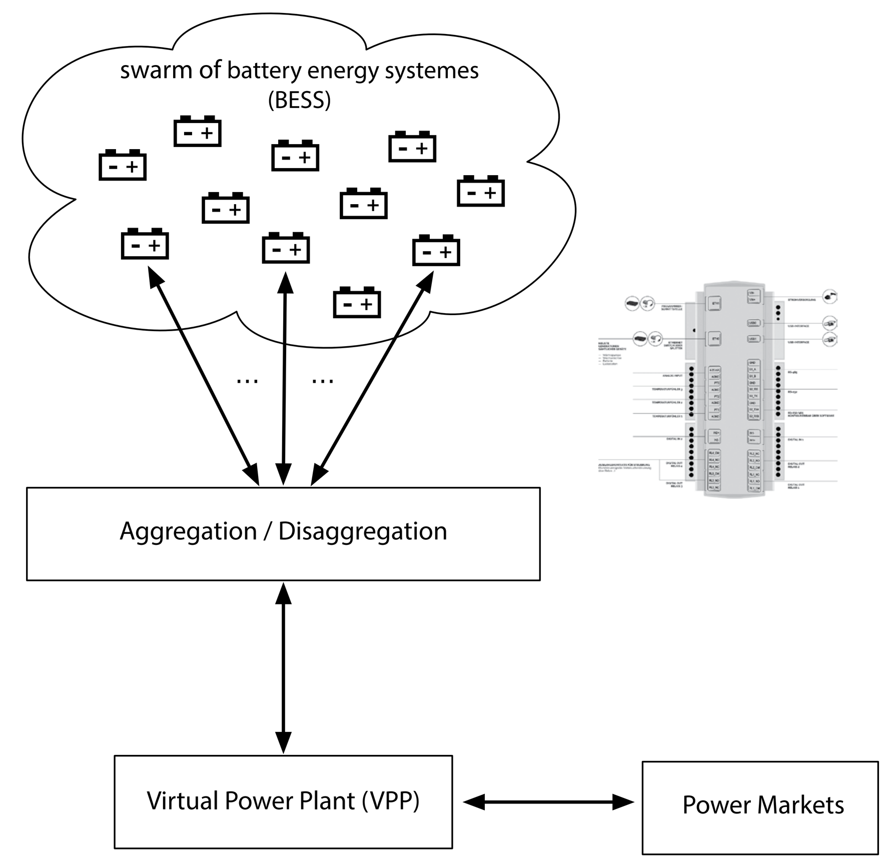
Introduction

The management of battery energy storage systems (BESS), in order to provide:

- energy market services, and
- electricity grid services,

comes into practice more and more.

One of the next research questions: how to apply such a management to a **larger number, like 100'000,** of interdependent BESS.



Optimization Problem

Case study: optimal deployment of BESS in day-ahead / intra-day market. Can be modeled as a LP:

$$\arg\max_{p} \sum_{t=1}^{T} \sum_{b=1}^{n_{bess}} \pi_t \left[p^b_{t,dischar} - p^b_{t,char}\right]$$

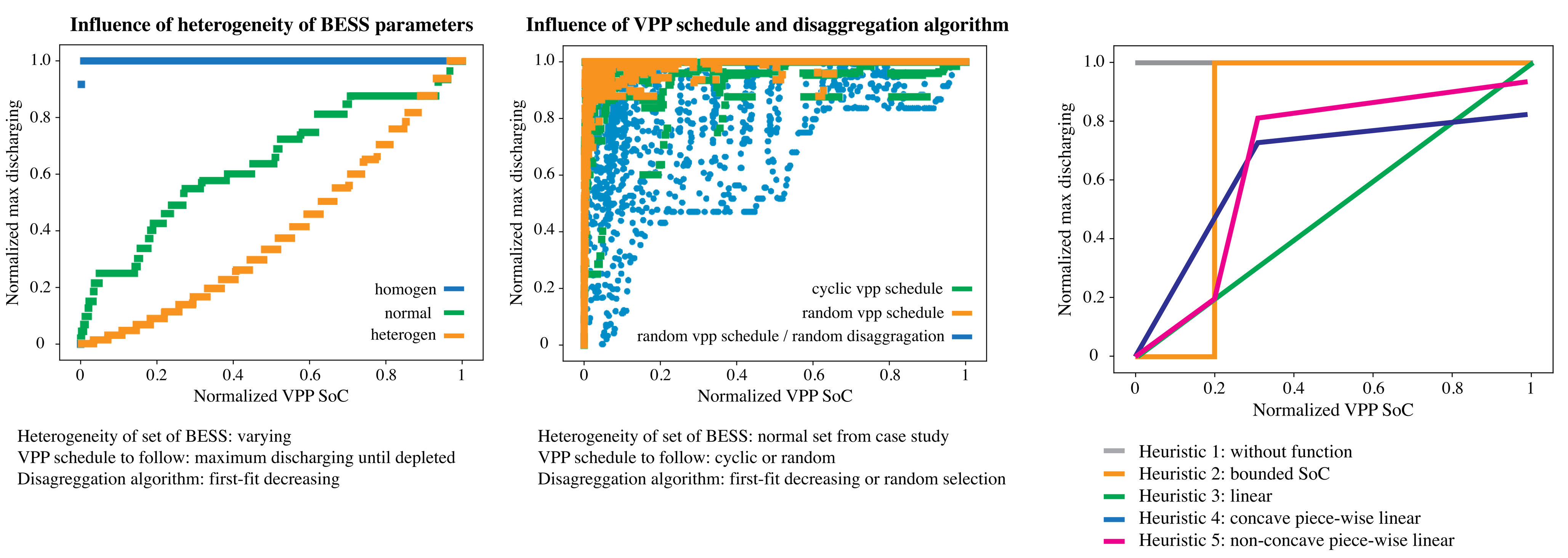
$$\text{s.t.:} \begin{cases} SoC^b_{t+1} = SoC^b_t + \Delta t \left(\eta^b_{char} p^b_{t,char} - \frac{1}{\eta^b_{dischar}} p^b_{t,dischar}\right), \ \forall t, \forall b \\ 0 \leq SoC^b_t \leq SoC^{b,max}, \ \forall t \in [1, T+1], \forall b \\ SoC^b_{t=1} = SoC^b_{start} \ , \ SoC^b_{t=T+1} = \frac{1}{2} SoC^{b,max}, \ \forall b \\ 0 \leq p^b_{t,char/dischar} \leq P^{b,max}_{char/dischar}, \ \forall t, \forall b \\ t \in [1, T], b \in [1, n_{bess}] \end{cases}$$

Proposed model and heuristic algorithm

Possible downsides of LP model & solver: 1. "too" optimal, 2. comp. complexity.

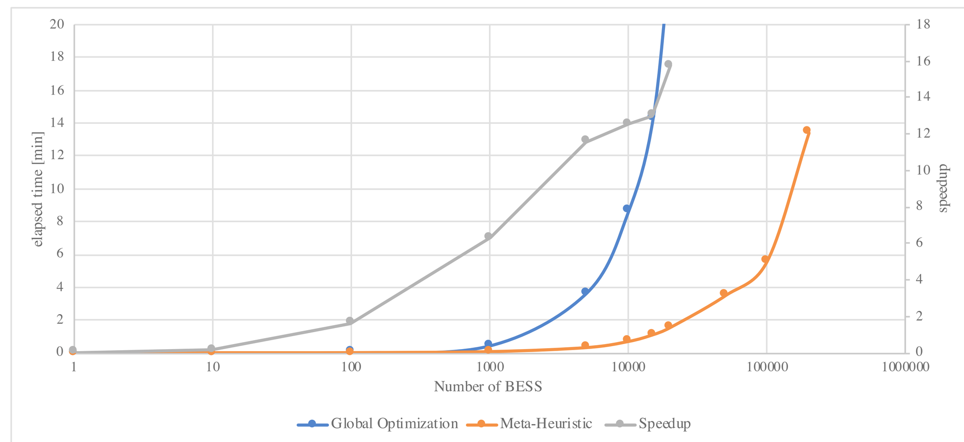
As an alternative: opportunistic heuristic:

- aggregation: behavior of fleet of BESS consider by simple VPP model
- disaggregation: applying policy by first-fit decreasing heuristic (based on SoC)



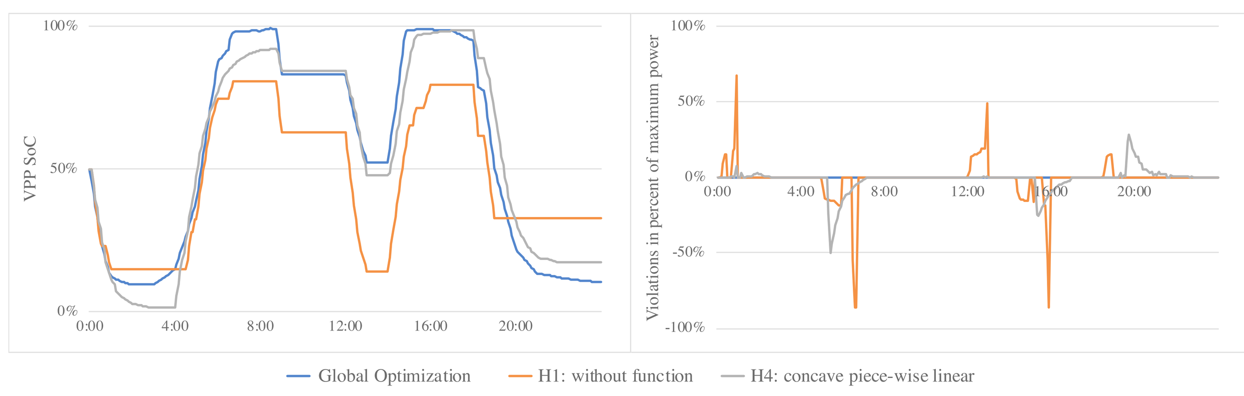
Results 1: Performance of heuristic

Both solving LPs and the proposed heuristic scale linearly with number of BESS. However, a speed-up of more than 10 is achieved with the heuristic:



The problem is well approximated by the heuristic:

Algorithms	Revenue [Euro]	average violations discharging
Global Optimization	7949	0 %
Heuristic 1: without function	4749	21.6 %
Heuristic 2: bounded SoC	2859	9.8 %
Heuristic 3: linear	6694	12.2 %
Heuristic 4: concave piece-wise linear	7311	13.2 %
Heuristic 5: non-concave piece-wise linear	7473	6.0 %



Results 2: Co-simulation framework

Applying the concepts to managing a fleet of BESS with:

- simulation for one week
- receding optimization horizon of 24h

Algorithm 1 Procedure of co-simulation framework

Require: Starting SoC for all BESS: $\mathcal{SOC}_{\tau=0} = \{SoC^1_{start}, \ldots, SoC^{n_{bess}}_{start}\}$

for all $\tau \in \{0, 15\text{min}, \ldots, \mathcal{T}\}$ **do**
aggregation: build VPP:
by using VPP model

perform optimization of VPP:
look ahead next 24 hours: $t \leftarrow \{\tau, \tau + 5\text{min}, \ldots, \tau + 24\text{h}\}$
find VPP schedule $p^{vpp}_{t,char/dischar}, \forall t$

disaggregation: find individual BESS schedules $p^b_{t,char/dischar}, \forall b, \forall t$
apply first-fit decreasing algorithm to VPP schedule $p^{vpp}_{t,char/dischar}, \ t = \tau$

perform simulation of individual BESS:
apply individual BESS schedules if possible
update SoC of BESS: $\mathcal{SOC}_{\tau, \tau+5\text{min}, \tau+10\text{min}}$
end for

Applying the concepts shows:

- trade-off: optimality <-> robustness
- too much modeling effort may not be needed

Algorithms	Revenue [TEuro]	average violations discharging
Global Optimization	34.60 (100 %)	0 %
Heuristic 1: without function	32.79 (95 %)	11.1 %
Heuristic 2: bounded SoC	24.53 (71 %)	3.7 %
Heuristic 3: linear	27.99 (81 %)	8.5 %
Heuristic 4: concave piece-wise linear	31.21 (90 %)	9.3 %
Heuristic 5: non-concave piece-wise linear	29.40 (85 %)	10.4 %

Conclusions

The proposed heuristic may be an interesting candidate to manage large number of BESS, offering:

- speed-up of > 10 compared to LP
- performance within 90% of optimality

Further Information

H. Abgottspon, R. Schumann, "Scaling: Managing a large number of distributed battery energy storage systems", submitted to Energieinformatik 2018.

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