Paper Review

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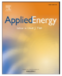

A storage degradation model of Li-ion batteries to integrate ageing effects in the optimal management and design of an isolated microgrid

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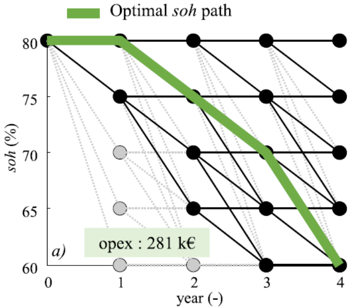
Abstract



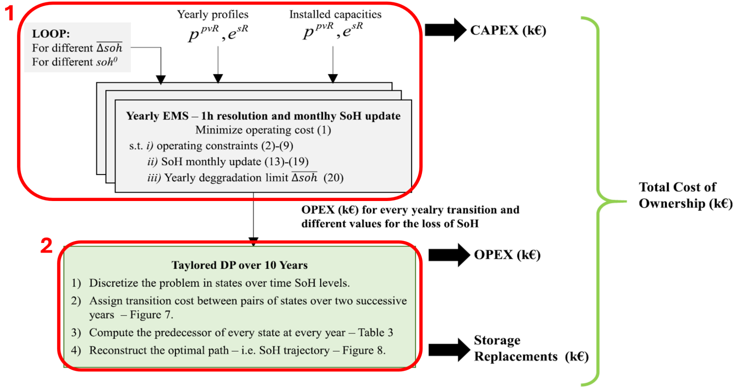
- **Simplified model for estimating battery degradation**
- **Optimal second life battery SoH** trajectory over 10 years is derived using dynamic programming

Motivation

- Existing degradation models are often complex and nonlinear, making their integration into optimization problems challenging
  - computational cost

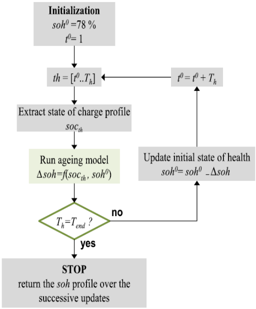
- Previous studies have not addressed the long-term optimal operation of energy systems
  - not considering battery replacement

Framework



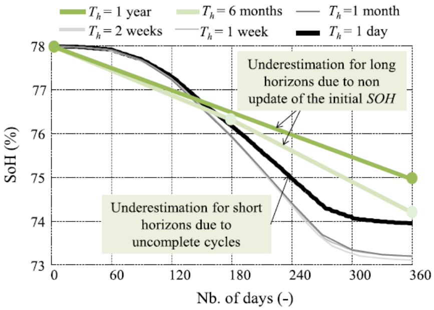
1. Simplified SoH Estimation
2. Dynamic Programming for Optimal SoH Trajectory

Traditional SoH Estimation



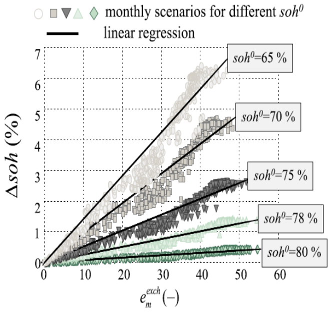
1. Energe Management System (EMS) outputs profile soc_{th} (SoC values, Cycle depth, Current, etc)
2. Degradation (Δsoh) over the period T_h is calculated using the degradation model (f)
3. The soh^0 is updated with the Δsoh

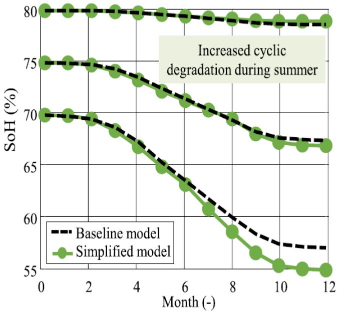
Determining the update period (T_h)



- When the update period T_h is set too large, degradation is underestimated
  - not adequately reflect the current state of soh
- If T_h is set too short, it underestimates
  - accumulated number of cycles is insufficient
- **Updating on a monthly basis (T_h = 1 months) is optimal**

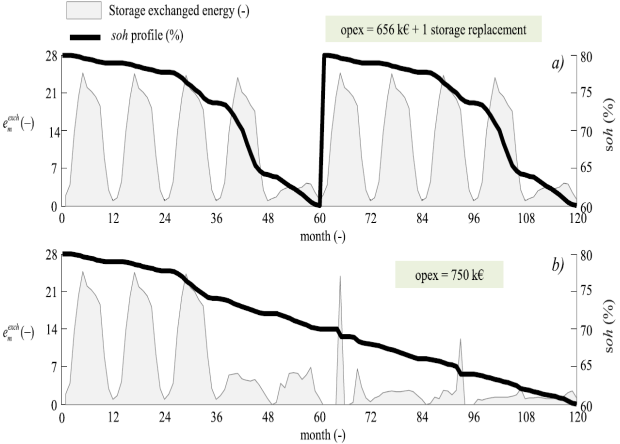
Simplified SoH Estimation





- estimates the degradation using Mixed Integer Linear Programming (MILP) with two variables
  - soh_m^0 : soh updated at each time point (m)
  - e_m^{exch} : the charged/discharged energy during the period (m-1 ~ m)
- The two variables and the degradation amount show a linear relationship

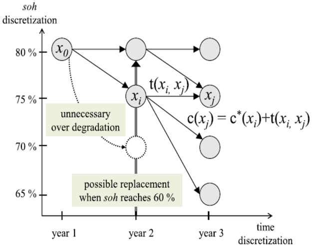
Long-term optimal SoH trajectory



- Considering battery replacement over a 10-year usage period (above) results in lower total operating costs

Dynamic Programming for Optimal SoH Trajectory

$$c^*(x_j) = \min_{i \in \text{predecessors}} \left(c^*(x_i) + t(x_i, x_j) \right)$$



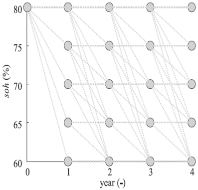
Pseudo code of the adapted dynamic programming.

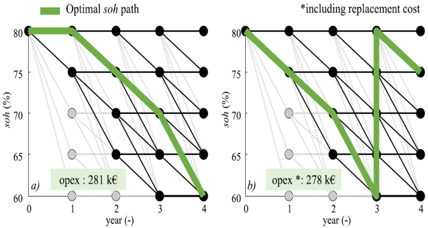
Algorithm

for year y in 1 to N^y:
 for all x_j at year y:
 initialize $c^*(x_j) = \infty$
  for all x_i at year y-1:
   if $c^*(x_i) + t(x_i, x_j) < c^*(x_j)$:
   $c^*(x_j) \leftarrow c^*(x_i) + t(x_i, x_j)$
   update optimal predecessor of x_j
  if SoH at $x_j = 60$ % - replacement opportunity
  x_k = state with SoH at 80 % at year y
   if $c^*(x_j) + c^{rep} < c^*(x_k)$
   $c^*(x_j) \leftarrow c^*(x_j) + t(x_i, x_j)$
   update optimal predecessor of x_k

- DP is used to calculate the optimal soh path over the 10-year period
  - x_i : SoH level at the end of the year i
  - $c^*(x_i)$: optimal cost of state x_i
  - $t(x_i, x_j)$: transition cost
  - c^{rep} : cost of replacing battery

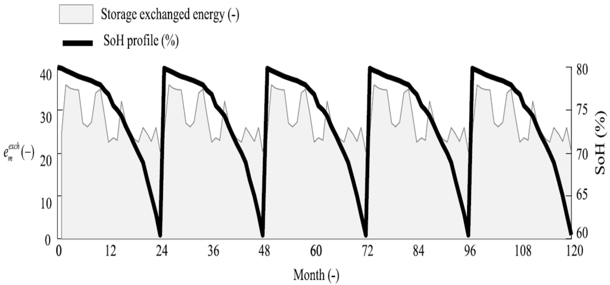
Optimal SoH Trajectory





- when the replacement cost is high, the SoH path is as shown on the left
- when the replacement cost is low, the SoH path is as shown on the right

Optimal SoH Trajectory of Isolated Microgrid



- optimal SoH path obtained using dynamic programming for a system with solar panels and batteries

Results

	Baseline	2nd life no degradation	2nd life degradation
p^{pvR} (kW)	0	200	200
e^{sR} (kW/kWh)	0	350	300
capex	0	575 k€	550 k€
opex	1,603 k€	211 k€	311 k€
replacement	N.A.	N.A.	90 k€
TOTAL	**1,603 k€**	**786 k€**	**951 k€**

- 50% reduction in costs compared to the baseline (power is supplied solely by a generator)
- prevents underestimating the total cost by 20%, where degradation is neglected

Limitations

- assumes the same power load and solar generation profiles every year
- does not consider time-varying electricity/battery prices

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"Thank you for listening"
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