Effect of tariff policy and battery degradation on optimal energy storage

SUPPORTING INFORMATION

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S1 Model supporting information

Figure S1 shows (in bullets) the fraction of capacity loss after one hour of operation at different C-rates. Data reported in Sarker et al. [12] was used to derive this plot. The procedure is explained in the same reference.

The solid line represents the second order fitting made in this contribution $x^{CL} = 1.06E - 5{C_{rate}}^2 + \alpha_2 = 1.44E - 4C_{rate}$. There is no constant term in the polynomial approximation because at $C_{rate,t} = 0$ there are no charge or discharge process, so there is no degradation induced by battery operation.

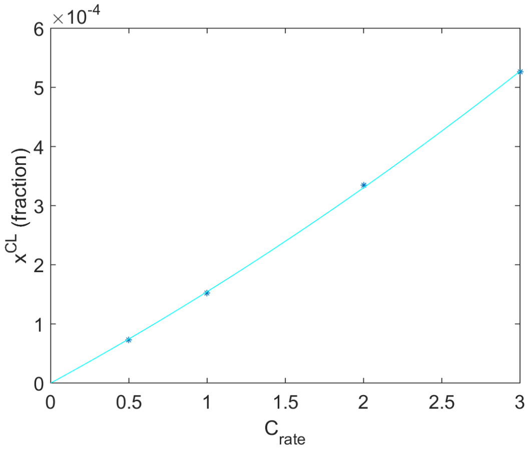

Figure S1: Second order polynomial approximation for capacity loss fraction as a function of C_{rate}

S2 Additional results for Case 1: Simple tariff, optimal scheduling for a 24 h period

Table S1 shows the value of the Kuhn-Tucker multipliers for constraint 21. As these values are all non-zero, it is verified that the constraint is always active.

Table S1: Kuhn-Tucker multipliers for different battery prices at each period of time.

C^{ES}	**300 (USD/kWh)**	**400 USD/kWh**	**500 USD/kWh**
t	$\mu_{21,300}$	$\mu_{21,400}$	$\mu_{21,500}$
1	3000	4000	4996
2	3000	4000	4994
3	3000	4000	4993
4	3000	4000	4992
5	3000	4000	4992
6	3000	4000	4991
7	3000	4000	4990
8	3000	4000	4990
9	3000	4000	4990
10	3000	4000	4989
11	3000	4000	4989
12	3000	4000	4988
13	3000	4000	4988
14	3000	4000	4988
15	3000	4000	4987
16	3000	4000	4987
17	3000	4000	4987
18	3000	4000	4986
19	3000	4000	4995
20	3000	4000	4995
21	3000	4000	4996
22	3000	4000	4996
23	3000	4000	4997
24	3000	4000	4998

S3 Additional results for Case 2: Complex tariff, optimal scheduling for a 24 h period

Figures S2 and S3 show the state of charge and fraction of capacity loss during one day for a 300 USD/kWh battery.

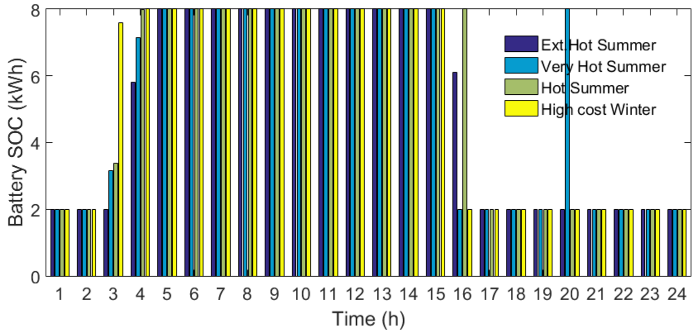

Figure S2: soc_t for most variable days in the complex tariff example.

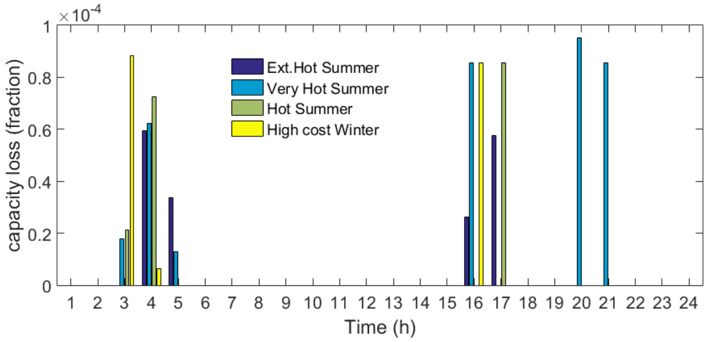

Figure S3: x_t^{CL} for most variable days in the complex tariff example.

Figure S4 shows that as battery price decreases, more days of the TOU become active (example shown here is for a moderated price day).

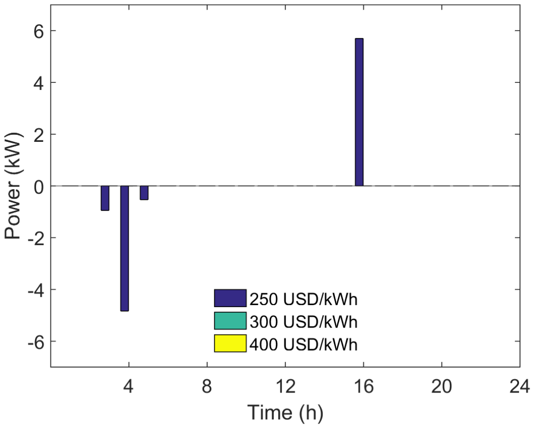

Figure S4: p_t^C (negative) and p_t^D (positive) for Moderate Summer Weekday in the complex tariff example and different battery costs.

S4 Additional results for optimal scheduling for long-term periods - Complex tariff

S4.1 Relevance of restricted time span between charge and discharge periods

Figure S5 shows the results for the complex tariff case in one year optimization, not considering time span limitations between charge and discharge processes (i.e., Equation 29 is not considered). As seen, the optimal operation strategy implies extremely slow partial charge through the first winter season (during cheapest weekend hours), to finally discharge the battery on a High Cost Winter Day. The first charging processes lasts more than 100 d. Note the difference with Figure 7, where the additional restriction (Equation 29) is considered.

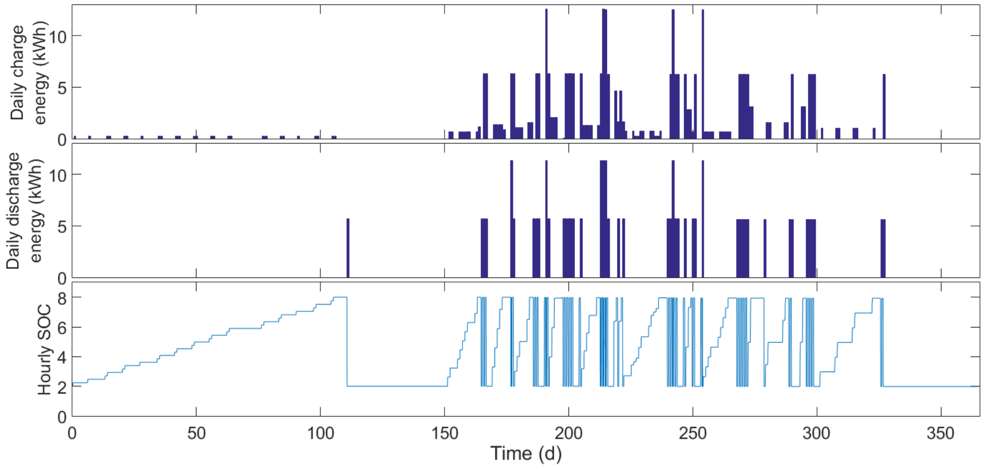

Figure S5: One year results for the complex tariff example.

S4.2 Avoiding battery use at the beginning of the optimization period

Figures S6 and S7 show the optimization strategy for a 5 year period at a 300 USD/kWh battery price and 200 USD/kWh battery price respectively. At 300USD/kWh the battery is only used the days where the is a large variation in prices. In all possible days falling in this category the battery is effectively turned on. On the other hand at lower battery prices, more days might be used. This can be seen comparing the amount of bars for the same period in Figs. S6 and S7. However, notice that in Fig. S7 the density of bars become thicker towards the end of the simulation period. This can be interpreted as the battery in the cheap case was not used as much as it could have been at the beginning of the period, "waiting" for a more profitable future day. Towards the end of the simulation, as there are no more future days the battery is used as much as it can be.

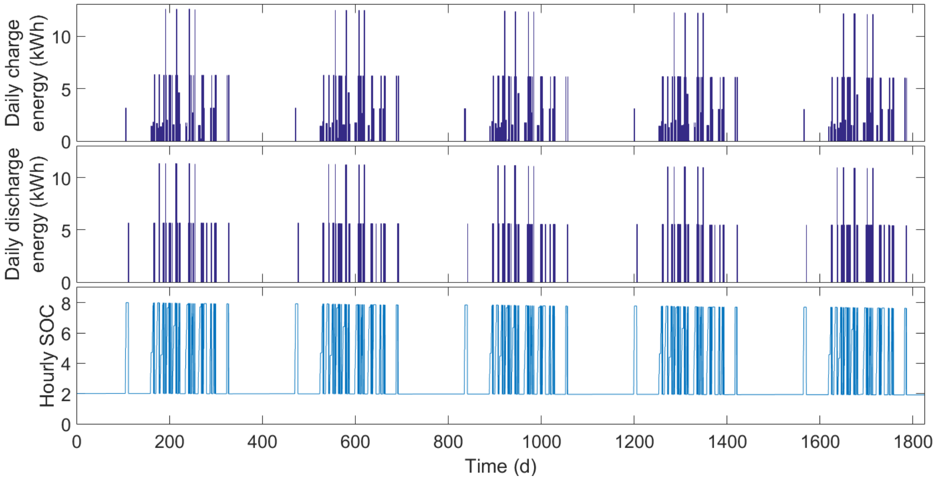

Figure S6: 5 year results for the complex tariff example with battery price of 300 USD/kWh.

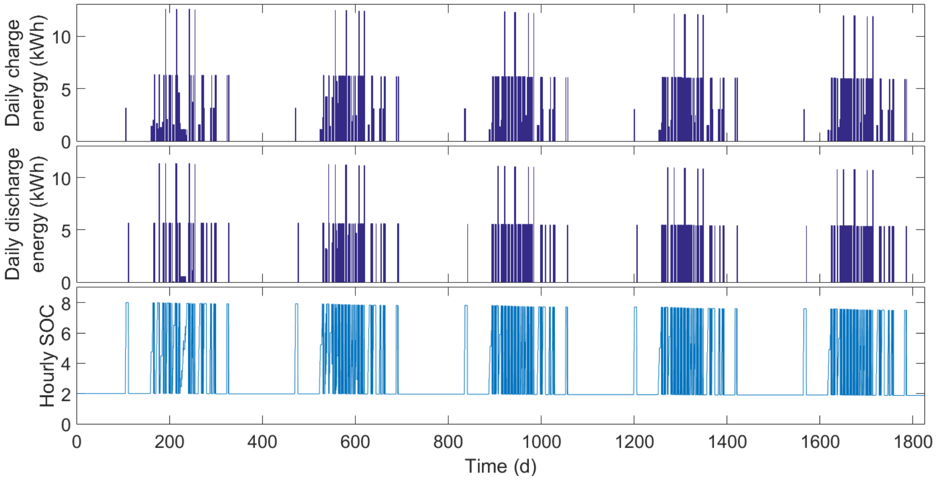

Figure S7: 5 year results for the complex tariff example with battery price of 200 USD/kWh.

Figure S8 shows the optimization strategy for a one-year period at a 250 USD/kWh battery price. Notice that the pattern has an active day density similar to the last year of simulation in Figure 8 from the manuscript.

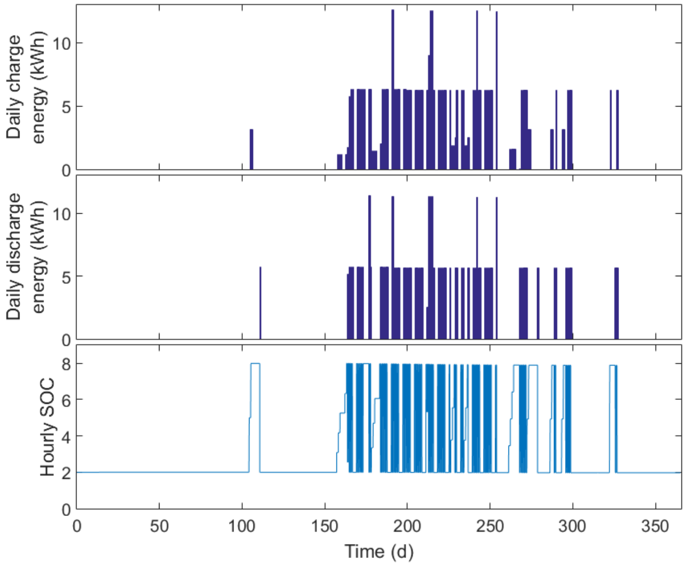

Figure S8: One-year results for the complex tariff example with battery price of 250 USD/kWh.

Figure S9 shows the number of days the battery is charged or discharged depending on battery price. Days added to the count only if the amount of energy charged or discharged was at least 1 kWh.

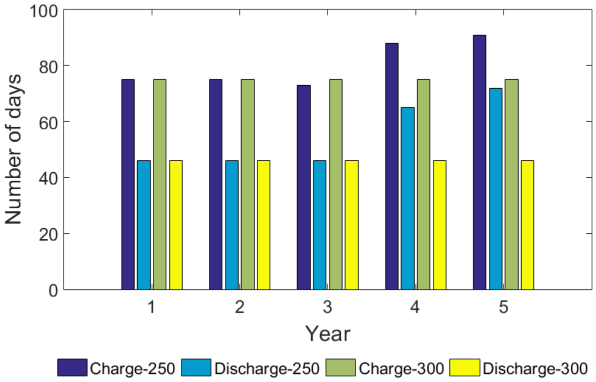

Figure S9: Comparison of annual number of days with significant charge/discharge for different battery cost.