Offering multiple grid services in parallel while minimising battery degradation

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1. Battery degradation

Battery degradation is the result of multiple degradation mechanisms. Each mechanism is influenced by different factors, implying that battery degradation is highly dependent on how the battery is used.

Empirical models try to capture this by curve-fitting on a large data set. However, extrapolation to realistic grid-applications is not justified. Furthermore, empirical models aren't accurate enough to make detailed decisions on battery operation. Therefore, electrochemical methods are used.

A Single Particle Model is extended to model a growing passivation layer on the graphite electrode and an increasing surface area as cracks grow due to mechanical fatigue. **Fig. 1** compares measured capacity fade with the simulation during calendar ageing at different temperatures and state of charge (SoC).

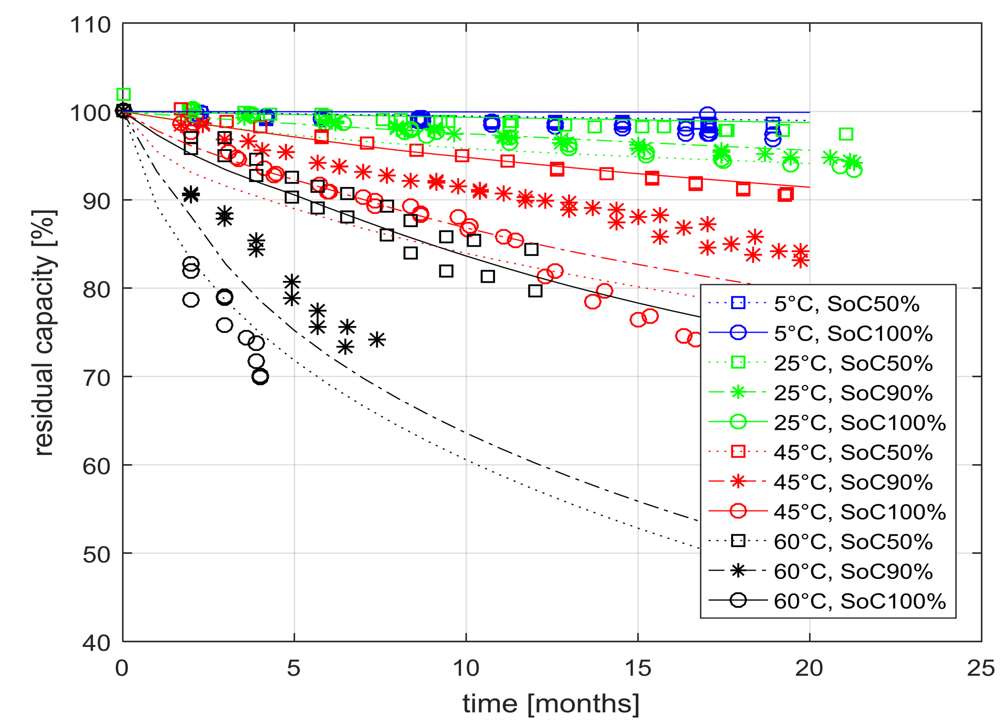


Fig. 1 Experimental (marker) and simulated (lines) calendar ageing at various temperatures and state of charge (SoC)

2. Co-optimising for degradation

Load management is a traditional application for distributed storage. A consumer faces a real-time tariff and can use a battery to shift the load to times with lower prices. Minimising the retail cost for the consumer results in using the battery to store large amounts of energy for longer periods to take advantage of large swings in price (**Fig. 2 A**). Minimising for total cost, including degradation cost of the battery, results in a usage pattern where the battery is often cycled at low power to take advantage of every small change in price (**Fig. 2 B**). This increases the total retail cost by 9% but decreases the battery degradation cost by 86% (**Fig. 2 C**). The total cost is decreased by 18% by co-optimising for degradation.

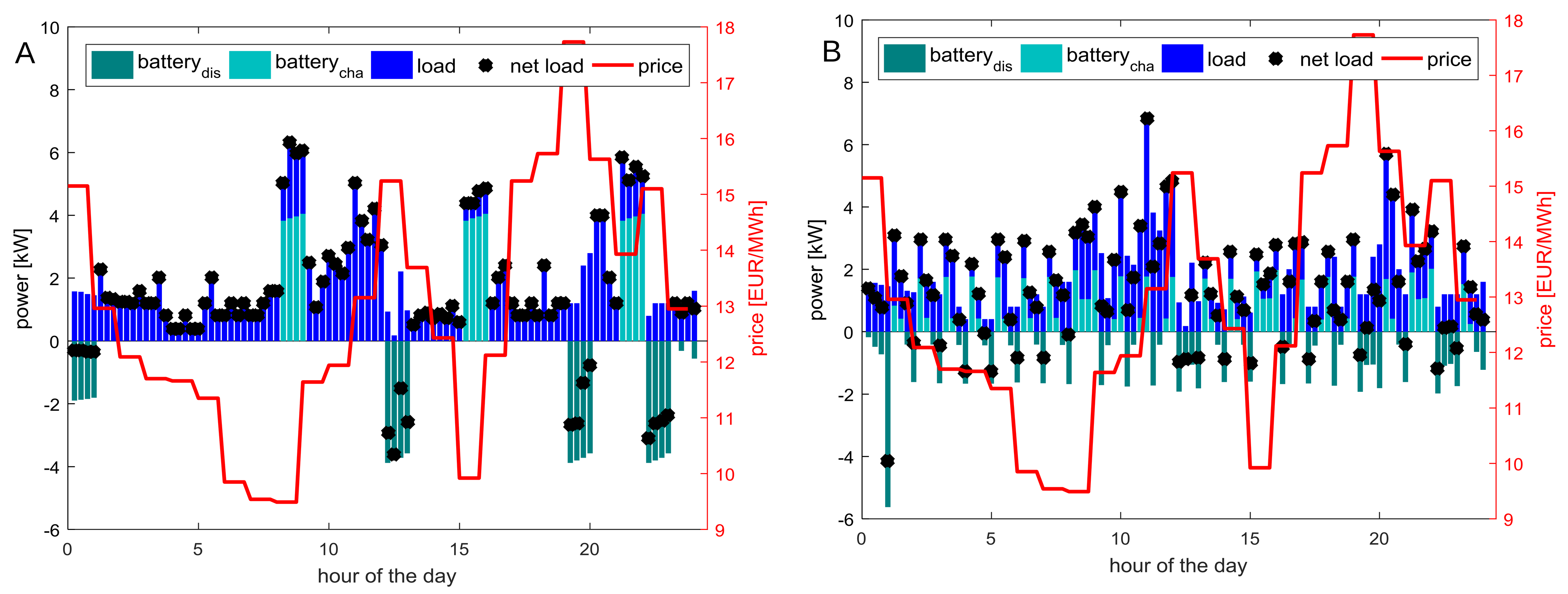
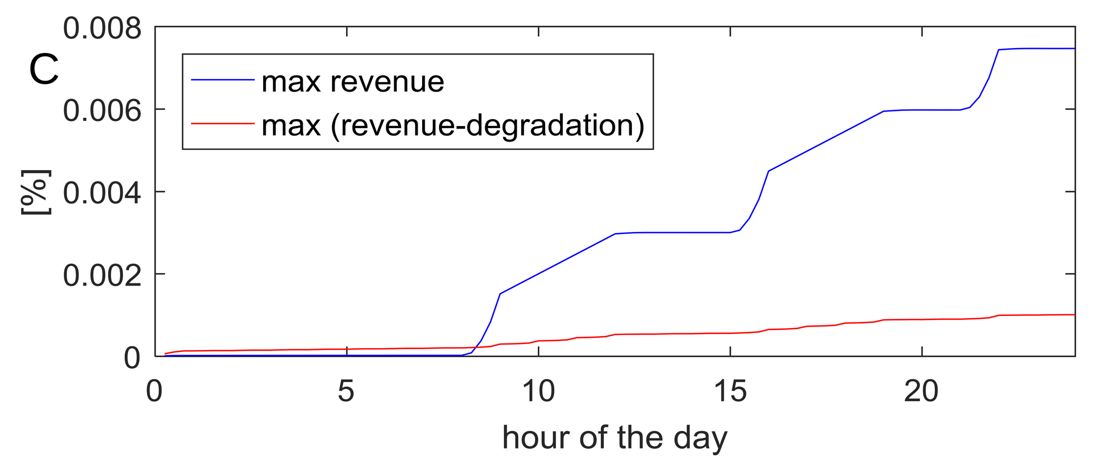


Fig. 2 Optimisation outcome: per period of 15 minutes, the graph shows the load, the charge and discharge battery power and the total net load (left axis). The real-time tariff is overlaid (right axis). **A** minimising retail cost (ignoring degradation). **B** minimising total cost (retail + degradation). **C** comparison of cumulative relative battery degradation in both cases.



3. Stacking applications

Stacking applications refers to the situation when a battery is being used for multiple applications at the same time. Four categories can be identified (**Fig. 3**)

- Using a battery for different applications at different points in time. **(A)**
- Using a battery for one physical action that creates value for different applications. E.g. peak-shaving reduces grid congestion, avoids triad-periods, reduces the electricity bill if a real-time tariff is used etc. **(B)**
- Statically divide the battery capacity between multiple applications. E.g. use 50% for each application. **(C)**
- Dynamically divide the battery capacity between multiple applications. At each time step, the battery control will determine how much battery capacity to use for which applications.**(D)**

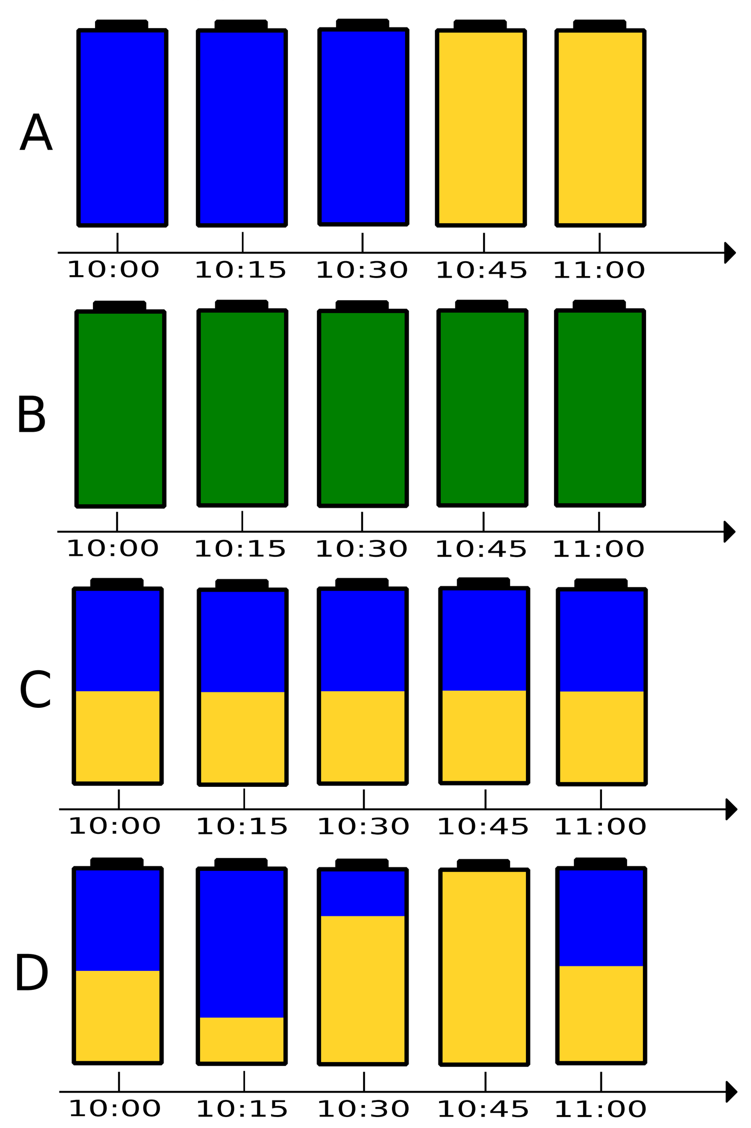


Fig. 3 Four categories of stacking applications

4. Results

The simulation was performed with data for the Belgian power system on the 1st of January 2014. The battery could be used for load management (with a real-time retail tariff), trading on the wholesale market, offering reserves for frequency control and trading on the real-time market. The optimisation was done once to maximise revenue (not shown) and once to maximise revenue and minimise degradation (**Fig. 4 A**). In the latter case, the battery is used at a lower power and lower state of charge, decreasing degradation (**Fig. 4 B**). If degradation is accounted for in the optimisation, the revenue is reduced by 43% and the degradation is reduced by 92%, almost doubling the total profit.

Different simulations were performed, experimenting with different market rules, different days and different economic situations (prices). In all cases, the degradation was dramatically reduced by accounting for it in the optimisation. The revenue decreased as well, the amount depending on the market rules and the economic situation (prices for different applications). The profit increased in all simulations, the exact number also depending on the simulation setup.

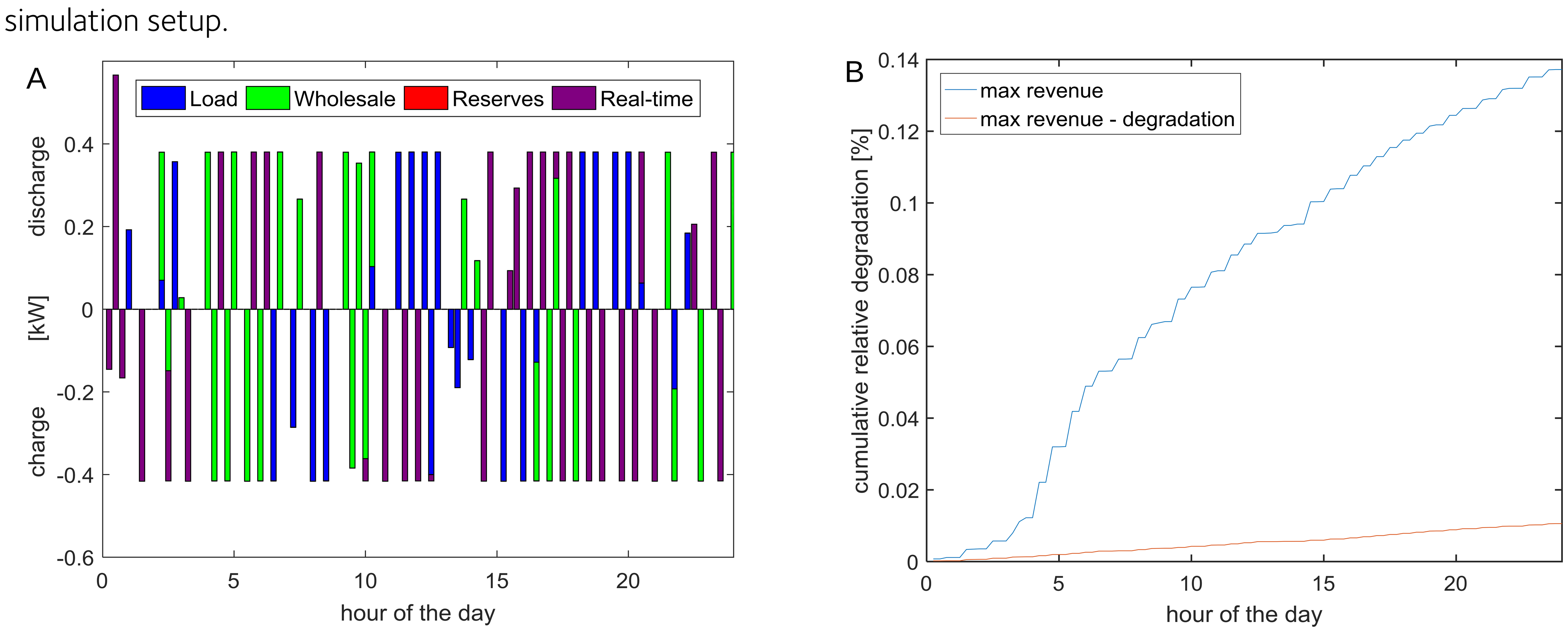


Fig. 4 Optimisation outcome: **A** per period of 15 minutes, the bars indicate how much power the battery should deliver to the different applications for maximising profit (revenue – cost of degradation). **B** comparison of cumulative relative battery degradation for maximising revenue and profit

5. Conclusions

- Co-optimising for degradation decreases it by 80% to 90% with only a modest decrease in revenue.
- Stacking applications increases the battery freedom and utilisation.
- Market rules and harmonisation of different markets are essential for stacking applications.

Acknowledgements

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