Increasing the value of VRFBs behind the meter using dynamic efficiency optimisation

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Introduction
Optimising the operation of a grid-tied battery is highly important to maximise the revenue or avoided cost and hence minimise the payback period. We recently demonstrated that a mixed integer quadratic programming (MIQP) schedule optimisation allows additional revenue to be realised when performing electricity price arbitrage using a VRFB [1]. The quadratic component captures the relationship between ohmic losses and current density. The integer component allows losses with a fixed component such as coulombic or pumping losses to be included, with the binary variable allowing idling to avoid these. This is in contrast to a simple linear programming (LP) model where the efficiency is assumed to be constant.

The representation of efficiency in each case is shown in Figure 1:

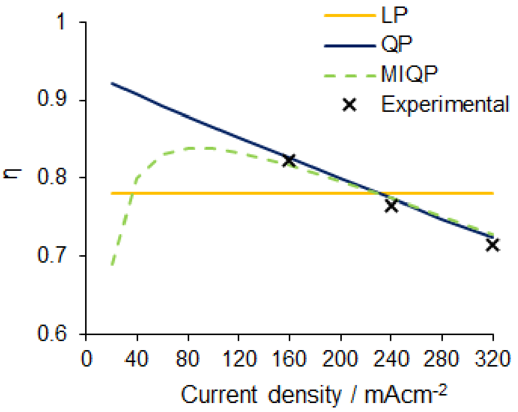

Figure 1: representation of VRFB stack efficiency under different optimisation approaches, with experimental data from [2].

Here, we adapt our formulation to a case study of a behind-the-meter VRFB performing peak shaving to avoid peak demand charges and arbitrage to reduce retail and wholesale energy costs. In this application the majority of the benefit comes from peak-demand charge avoidance [3].

Method
In this work, the objective to be minimised is the bill cost of an industrial facility (site 767 in [4]), consisting of unit charges and peak demand charges from the supplier Southern California Edison, and wholesale unit charges from the CAISO day-ahead market.

The formulation applied in [3] has been adapted to accommodate the MIQP model described in [1]. The key modification is the redefinition of the facility net load (kW) by:

$$\begin{aligned} nl_t = l_t - A\big(I_{D,t}(OCV_{50\%} - V_a) \\ - I_{C,t}(OCV_{50\%} + V_a) \\ - \big(I_{D,t}^2 + I_{C,t}^2\big)ASR\big)/1000 \end{aligned}$$

Where l_t is the load (kW), A the cell area (m^2), $OCV_{50\%}$ the open cell voltage at 50% SOC, V_a the faradaic over-potential (V), and ASR the area specific resistance (Ω m^2). These parameters were derived from a 1 kW mixed acid system demonstrated at PNNL [2], as described in [1]. $I_{D,t}$ and $I_{C,t}$ are continuous variables representing discharge and charge current density (Am^{-2}). The active/idle binary variable is included in the expression for SOC as in eqn. 13 in [1].

The maximum current density is set at 320 mAcm^{-2}, although this may not be possible for prolonged periods in practice.

The operation is optimised across a 36 h sliding window, with the first 24h implemented. The time resolution is set at 15 min, the resolution of import metering for peak demand charges.

The VRFB is specified with an A value such that the power rating is 300 kW at 75% stack efficiency. The duration is set at 4h. In this case study we ignore inverter losses, and balance of plant losses.

Results
The turnout from the optimal current density schedules determined by LP and MIQP approaches are shown in figures 2 and 3 for a weekday in July.

Charging of the VRFB is spread out in the MIQP case to minimise losses, while in the LP case it is concentrated in localised wholesale price troughs (see figure 4) as much as possible without increasing the green zone peak demand charge.

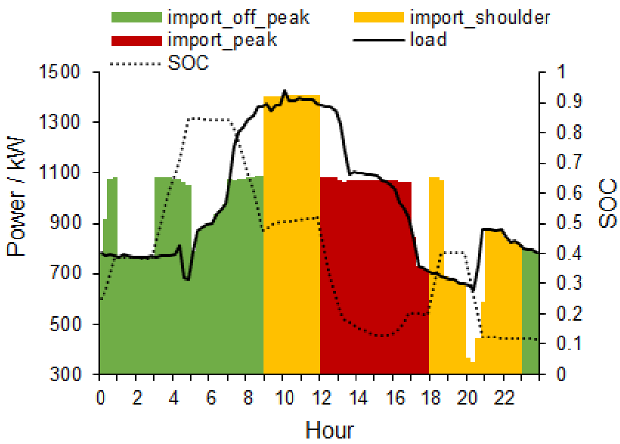

Figure 2: LP schedule turnout for 11th August

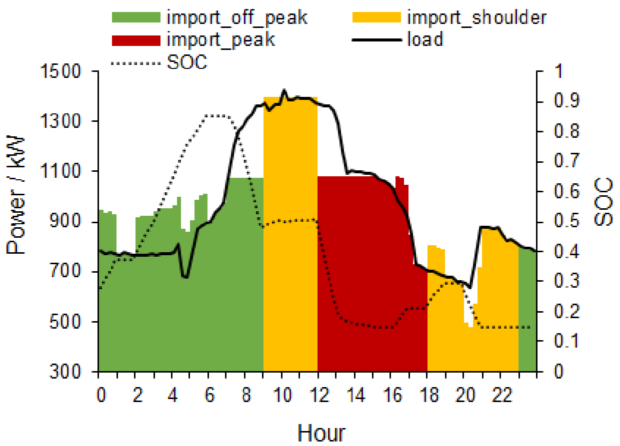

Figure 3: MIQP schedule turnout for 11th August

The MIQP approach targets less peak shaving in the red zone, as the increasing losses at high power output make shaving in the yellow zone more profitable. The LP model aims for greater red zone shaving (plateau at 14:00 to 16:00) but is unable to achieve this between 12:00 and 13:00 once the actual losses are considered.

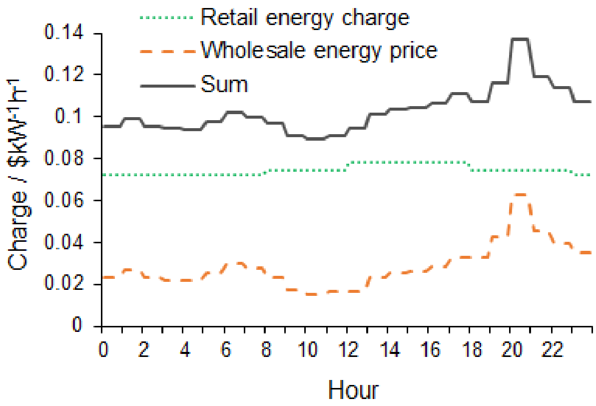

Figure 4: Electricity unit charges for 11th July

In August the LP schedule saves USD 10918 on peak demand charges and USD 62 on unit charges. The MIQP schedule saves USD 11296 and USD 105 respectively, giving a saving improvement of 3.8%.

Conclusion

We have expanded on previous work to show that a dynamic efficiency method can increase peak shaving revenue as well as unit charge arbitrage in a simultaneous optimisation.

The findings of this work are to be incorporated into a fuller techno-economic analysis including system cost at various durations and published in the near future.

Given the profitability of peak charge avoidance, the sustainability of operation at high power is a subject that merits further investigation.

Acknowledgements

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