Flexible operation of a neighbourhood battery to align with community priorities.

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Summary:

We introduce a novel incentive structure to encourage flexible operation of a neighbourhood battery (NB) and to capture non-market benefits of these battery systems such as increased energy self-sufficiency and solar resource utilisation. The approach is based on flexible battery optimisation which adapts to the seasonality exhibited by renewable solar energy systems. Self-consumption of solar energy tends to be higher during the winter months, indicating lower solar exports to a neighbourhood battery. This observation suggests an opportunity to leverage energy arbitrage as a revenue generating strategy in winter and maximising for solar soaking in summer.

Background:

Neighbourhood batteries are medium-scale batteries in the 0.1-5MW range that are typically connected to the low-voltage network [1]. They have been receiving significant investment by both government and industry [2][3]. The goal of these batteries is to aid in the regulation of grid voltage and local demand/generation, thereby reducing solar curtailment, helping to facilitate the increasing electrification of households, integration of electrical vehicles and increasing rooftop PV generation. Spare capacity can be used to generate revenue on the arbitrage and FCAS markets. Recent work in the Battery Storage and Grid Integration Group (BSGIP) has shown that shared energy storage reduces total storage requirements by around half, compared to household batteries [4].

Considering that this is a new and shared energy resource, there can be some conflicting expectations and requirements between community stakeholders and battery owners/ operators. The Battery Storage and Grid Integration Program (BSGIP) at the ANU has conducted significant social research into what these may be. A summary of some of these are in Table 1 below, further detail can be found in other BSGIP publications and the neighbourhood battery knowledge hub.

Table 1 Summary of stakeholder expectations and requirements

Communities	Energy Networks
Cost Reduction	Grid Stability
Emissions Reduction	Grid Reliability
Self-Sufficiency	Integration of DER
Autonomy	Innovation

We propose that there exists a seasonal operating structure that more accurately reflects the benefit of appropriate utilisation of solar resources, which can allow for neighbourhood batteries to operate at a pareto optimal level between profit maximising and solar soaking. For the purposes of this project, we define this pareto optimal level to be any point that is feasible and performs better than the case where the battery uses the same operating algorithm throughout the year. The idea behind this modelling was that solar generation profiles vary throughout seasons. A study by Li et al. found that solar self-consumption was generally higher in winter, which implies that solar exports to a battery would be lower [5]. This could present a potential opportunity to leverage more energy arbitrage as a revenue generation measure compared to more solar soaking and emissions reduction goals in summer months.

Methodology

A structured, quantitative experimental research methodology was undertaken for this analysis. Using an in-house power flow modelling tool and a battery modelling tool, we systematically modified a network under different conditions to observe battery behaviour and consequent economic outcomes. The battery optimisation tool determines optimal electricity import and export decisions based on a given electricity tariff, renewable generation profiles, load demands and objective weightings. The objective function is summarised in Eq. 1 below. The power flow modelling tool then takes this battery scheduling behaviour and simulates the consequent electrical flows at different household nodes in the system.

$$\min Z = w_1 * L^{peak} + w_2 * C^{imports} + w_3 * C^{exports}$$

Equation 1. Optimisation objective function where L^{peak} is the maximum import-export across a study time interval T. $C^{imports}$ and $C^{exports}$ is the sum over every timestep of import and export respectively from the grid. w_1, w_2, w_3 are the weightings for each objective.

The objective weightings in the optimisation were altered to explore the impact of different operation modes. The outcomes were evaluated by comparing local voltages, cost, and local solar generation and utilisation. For this analysis, system costs and battery revenue are an aggregated sum of network costs and energy import and/or export costs over time. Network costs refers to the kWh cost charged by a network operator for each kWh unit of electricity that is delivered. The fixed service charge is the fixed daily charge that is imposed by the network operator for access to their network infrastructure. The additional reference price that is included in the Battery revenue is the market ‘spot price’ that the battery can also trade with.

$$Battery\ Revenue = \sum kWh * (Spot\ Price + Battery\ Network\ costs) + Fixed\ Service\ Charge$$

$$Household\ costs = \sum kWh * Network\ costs + Fixed\ Service\ Charge$$

$$System\ Cost = Battery\ Revenue + Household\ costs$$

One method to assess solar utilisation is comparing the Solar Self Consumption (SSC) and Solar Self Sufficiency (SSS) rate which are defined below.

$$SSS = 1 - \frac{community\ imports}{community\ load}$$

$$SSC = 1 - \frac{community\ exports}{community\ solar\ generation}$$

Higher SSS and SSC can indicate greater local solar utilisation. Higher SSS indicates less energy imported to the community from the grid, while higher SSC indicates less locally generated solar exported into the grid. The community size in this exercise was kept consistent with 55 households modelled after the IEEE906 network, 25 with hypothetical 100% solar penetration. A single 100kW/200kWh community battery was used with maximum 1 cycle/day.

Results

The results of this analysis show that there are indeed strong differences between seasons with respect to the impacts of a NB on the system. The below figures show that NB can have a strong impact on local voltages. Notably, we observe that a NB operating in cost minimisation mode in summer with high PV penetration has worse outcomes for local voltage management. However, when operating in a solar soaking mode, instances of over voltage are reduced. In winter months there does not seem to be this same phenomenon. As such, this suggests that operating a NB with a solar soaking algorithm in summer is beneficial and in winter operating in arbitrage mode does not have any negative consequences.

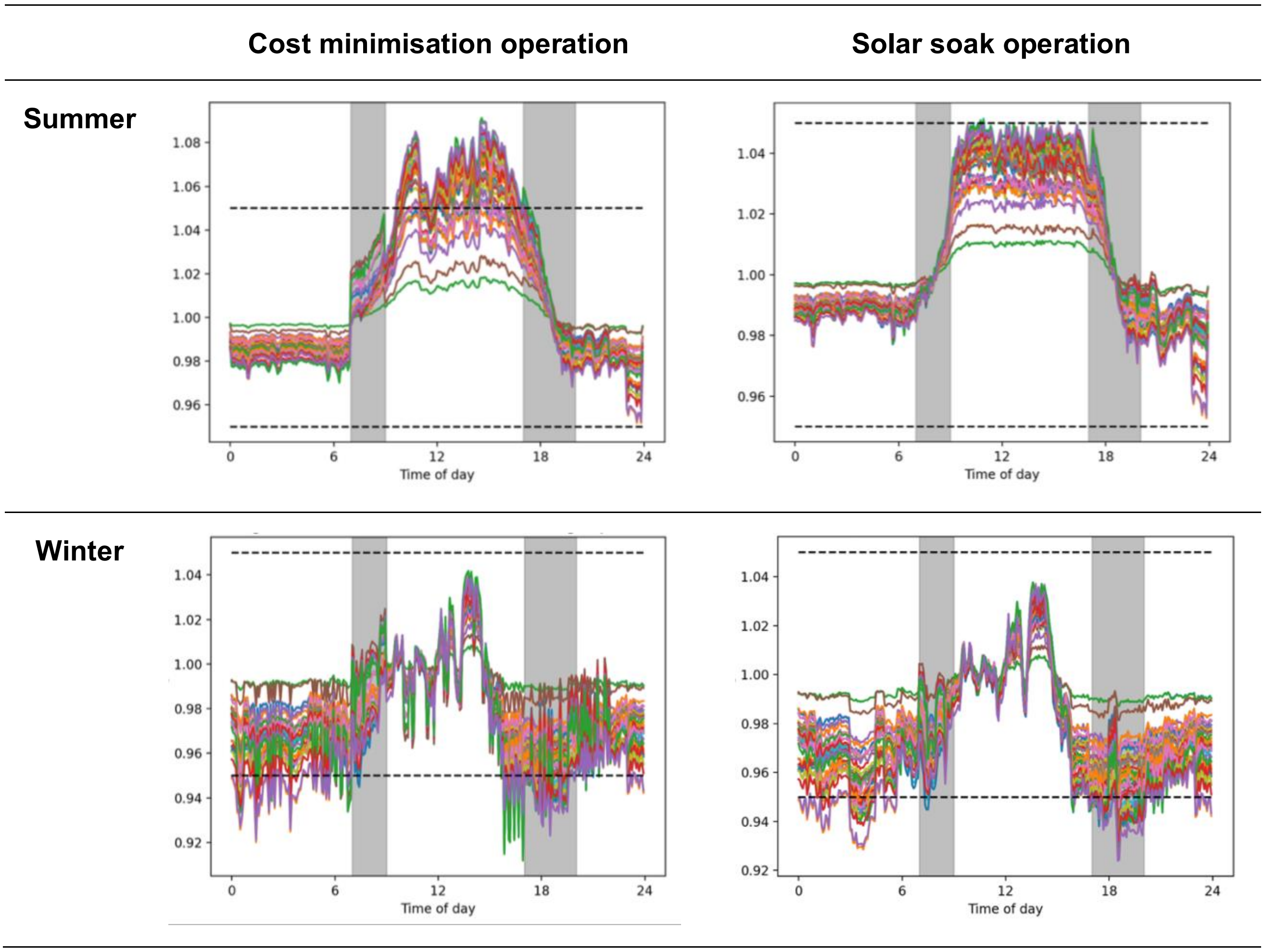

Figure 1. Voltages across the network for one day in summer and one day in winter with the NB operating in cost minimisation or arbitrage algorithm mode and in solar soaking mode.

This is supported by the plot in Figure 2 which demonstrates that a solar soaking algorithm can be more favourable for meeting goals such as increased self-reliance and solar utilisation. It does, however, lose out on financial gains which is particularly evident in winter months where the solar soaking algorithm does not respond as dynamically to electricity demand in the absence of excess local solar generation. Conversely, aggressively conducting energy arbitrage with the battery under existing tariff structures nets the most profit for a battery. This is however, at the expense of reduced Solar Self Sufficiency (SSS) and Solar Self Consumption (SSC) rate. This indicates that benefits of neighbourhood batteries such as increased hosting capacity or decreased energy emissions, have not been taken advantage of. Table 2 summarises the aggregate performance over the year and compares a seasonal hybrid scenario where the NB spends 6 months utilising a solar soak algorithm and the other 6 months focused on cost minimisation or performing arbitrage.

Table 2 Summary of algorithm operational outcomes after one year. The system cost is generated using Ausgrid FY22/23 trial tariffs

Algorithm	**System Cost ($AUD)**	**Battery Revenue ($AUD)**	**SSC**	**SSS**
Arbitrage Only	43706.2	17587.56	0.61	0.44

Solar Soak Only	46535.2	11480.8	0.7	0.55
Seasonal Hybrid	45188.47	12828.32	0.67	0.50

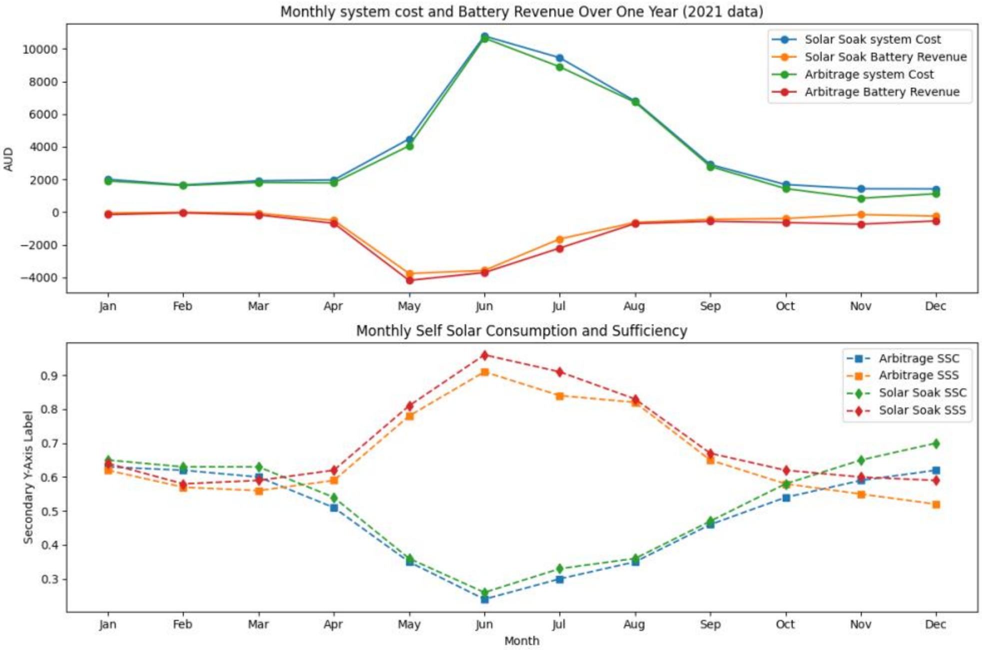

Figure 2. Monthly System costs and Battery revenue over one calendar year using Ausgrid's FY22/23 trial tariffs. The shape of this plot is consistent despite the contrasting algorithms. This indicates that winter months are an optimal time to maximise arbitrage profits as solar demand management does not provide significant utility maximisations for either households or the battery. This is supported by the plot of SSS and SSC which follows a similar trend through the year with higher SSS in winter and lower in summer and vice versa.

This work introduces the idea of a varying the operating algorithm that a NB uses according to winter and summer seasons. We show that this could result in a battery operation structure that aligns potentially different priorities and expectations from different stakeholders.

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