How neighbourhood batteries can unlock network capacity for consumer energy resources

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Acknowledgements

We acknowledge, respect and celebrate the Ngunnawal and Ngambri people, on whose land this research was conducted, and pay our respects to Elders, past, present and emerging.

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Image: Tarneit battery

Executive summary

Neighbourhood batteries (NBs)[1] have captured the imagination of the Australian public with the idea that this form of mid-size storage could provide a host of benefits. Government-funded trials are underway to investigate whether neighbourhood batteries can be operated in a way that aligns with what has been promised of this technology i.e. to support decarbonisation, allow more renewables to enter the grid, make energy cheaper and more local, and provide local economic value and employment.

This report summarises work conducted by the ANU Battery Storage and Grid Integration Program to quantify the extent to which neighbourhood batteries can be designed and operated to increase the network's capacity and integrate more consumer energy resources (CER) e.g. rooftop solar and electric vehicles, into the grid. Importantly, we identify what factors need to be considered to maximise how much neighbourhood batteries increase this 'hosting capacity'.

We found that NBs do have the potential to increase the network's capacity to integrate more CER. For example, for one scenario with 86 houses, 70% with rooftop solar, the battery reduced the number of voltage violations by 20% and eliminated thermal violations. Over all our simulations, we observed that the ability of a NB to increase network hosting capacity depends on (a) the size and location of the battery, as well as (b) how it is operated and (c) the network tariffs that apply to that operation.

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[1] Also known as community batteries however we reserve the term community batteries for those that are owned and/or governed by community.

For example, we found that operating the battery only according to price signals (see Figs 1 and 2, below) can impact how much the battery can increase hosting capacity and can even result in decreased hosting capacity. However, network tariffs can help here. Two-way network tariffs help batteries achieve increased hosting capacity even when the battery is in 'profit maximisation' mode. Further work will investigate how neighbourhood batteries can be operated with emerging smart network controls (e.g. dynamic operating envelopes) to maximise revenue while not breaching network constraints and not impacting customer access to network capacity.

For our simulations where the percentage of households with rooftop solar was very high (90%), the NB had an even more sizeable impact on reducing voltage and thermal violations. This suggests that NBs may be particularly helpful in unlocking network capacity in regions with a high density of distributed energy resources or significant reverse power flows and voltage issues. With the anticipated increase in electric vehicle (EV) charging demand potentially pushing network thermal and voltage limits, NBs could offer a strategic solution. This study suggests neighbourhood battery policies should focus on network position, battery operation modes and distribution network tariffs, to ensure batteries are being operated to unlock network capacity for the benefit of energy consumers.

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Background

Neighbourhood batteries (NBs) offer capacities from 0.1–5MW, and therefore sit between household and grid scale batteries (Ransan-Cooper, Shaw et al. 2022). These batteries are typically located on the distribution network to provide shared storage for households and businesses. Several government-backed trials are underway which seek to investigate the technology's ability to allow for more renewables in the grid, to make energy cheaper, to support decarbonisation and to provide local economic benefits.

Hosting capacity is defined as the integration of consumer energy resources (CER) into the grid without causing adverse effects on voltage profiles, ampacity, power quality and reliability (Sahu and Ghosh 2019). Once the limit of a network's hosting capacity has been passed, the grid no longer acts in accordance with its prescribed standards. To ensure this does not occur, distributed network service providers (DNSPs) may use smart control methods and peak shaving to reduce the load on the network, ensuring that the grid's capacities are not exceeded.

Where this is not achievable, costly network element upgrades must be implemented. The rapid projected increase in CER will result in a doubling of the solar energy curtailed by 2029 (Zepben 2022), with low voltage (LV) networks becoming more sensitive to increased loadings such as electric vehicle (EV) charging by 2030.

In the Australian Capital Territory, Evoenergy found that increased CER penetration was resulting in seasonal impacts on the operating voltage range (LV) (Evoenergy 2022). As such, the voltage envelope on the LV network will continue to broaden, resulting in increased overvoltage and undervoltage events. LV appliances underperform and can be damaged from such under and overvoltage events, and increased voltage directly increases energy consumption which means higher energy bills for consumers and increased carbon emissions.

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There are a range of solutions that are already being used to increase network hosting capacity. Network operators can adjust network voltage settings when required, for example by adjusting transformer ratios or using on-load tap changers. These solutions can create more headroom for CER generation; however, they can be costly and can result in transferring low-voltage network issues into the high-voltage network. This is a growing concern with the increasing prevalence of CERs and reverse power flows. On-load tap changers are also constrained by tap range limitations and minimum voltage requirements, which can limit the efficacy of this approach (The State of Victoria Department of Environment 2022). Although these network solutions are being utilised to effectively increase hosting capacity of our distribution networks, we will increasing require other technologies to support our changing network requirements.

Smart inverter settings offer an efficient and cost-effective mitigation technique to manage voltage levels, even in areas with up to 100% PV penetration. For this reason, new inverter standards (NZ/AS4777.2) were introduced in 2020, mandating smart voltage controls be installed by default. However, CitiPower, PowerCor, and United Energy noted a high level of non-compliance with smart inverter settings for solar systems and other CER (The State of Victoria Department of Energy 2023).

These settings, known as 'power quality response modes' (PQRMs), include tripping, volt-var, and volt-watt modes, refer to reactive and active power being exported by inverters to help manage voltage on the distribution grid. In this way, PQRMs effectively increase the hosting capacity of the network and exemplify how modern control methods can be utilised to manage network and grid elements.

In addition to the solutions listed above, neighbourhood batteries also promise to increase hosting capacity, although the degree to which this can be achieved in practice is unknown. In an ideal scenario, neighbourhood batteries would charge using locally produced solar energy and discharge during peak demand in the evenings. In practice, battery operation will often be directed by price signals i.e. charging when electricity is cheapest and discharging when prices peak. As electricity prices are typically lower during solar production hours and higher during evening peaks, this results in a charging-discharging pattern that aligns with ideal usage. However, market dynamics can vary, and this pattern does not always hold true. The goal of the analysis presented in this report was to investigate whether neighbourhood batteries can increase network hosting capacity, and to gain insight into the conditions under which this might occur.

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Methodology

This report is based on simulations of a neighbourhood battery operating in realistic Australian low-voltage networks under a range of scenarios. The scenarios included: how the battery was operated (3 modes), where the battery was located (3 positions), the network charges applied to the battery (5 tariffs) and the battery size (100-300 kWh, 50-150 kW).

The three battery operation modes were (1) profit maximisation, (2) solar soaking and (3) balanced. Profit maximisation meant that the battery only operated according to price signals. Solar soaking meant that the battery only operated to charge during solar hours and discharge during the evening peak. Balanced mode meant that the battery operated to generate revenue according to price signals but within the bounds of still soaking up solar generation.

We ran the simulations in four different low-voltage networks from the CSIRO taxonomy study of typical Australian LV networks (Heidarihaei 2022). We used a range of PV penetration levels (50-100%). Hosting capacity was evaluated based on the number of thermal and voltage violations per day. More detailed methodology is given here.

It should be noted that the battery capacity available for increasing hosting capacity is smaller than modelled in this study. The battery will reserve capacity for FCAS co-optimisation, network reservicing and battery health. We have controlled the depth of discharge in our modelling but have not considered reserves for FCAS or network reservicing. These would impact our calculations for the number of thermal and voltage violations.

Results

We found that neighbourhood batteries can increase hosting capacity. As shown in example results (Figure 1, below), operating the battery in solar soaking mode always resulted in reduced voltage and thermal violations, which indicates increased hosting capacity.

By reducing the impact on network constraints, the potential for further CER integration is increased, thereby increasing the hosting capacity. In practice, this would bring direct benefits for consumers through increased network capacity for their energy resources (e.g. they could export more rooftop solar power or charge/discharge electric vehicles).

The impact of the battery on hosting capacity was highly dependent on the network, with significant impacts in only two of the four networks studied. In those two networks, hosting capacity could be significantly increased by three main factors:

1. where the battery is placed on the network
2. how the battery is being operated, and
3. the network tariffs applied to the battery operation.

In one network (network J) the battery reduced thermal violations by 74% in solar soaking mode (see Fig 1) and in another network (network Q) the battery reduced under and over voltage violations by 100% and 28% respectively.

Our results also found that the neighbourhood battery does not always increase hosting capacity. In profit maximisation mode, the battery did reduce hosting capacity in certain scenarios e.g. when situated downstream of the transformer and when the tariff was a one-way flat rate (with one exception). However, we found that network tariffs can help here. A two-way time-of-use tariff resulted in the battery positively impacting on increasing hosting capacity through reduced voltage and thermal violations, even when the battery was operating in profit maximisation mode.

In practice, we assume that scenarios where the batteries result in reduced hosting capacity are unlikely, as DNSPs would typically not allow network batteries to be placed in such locations. However, it will be important to further investigate whether these scenarios do arise in the real-life neighbourhood battery trials currently underway. The worst-case outcome would be if consumers were unfairly burdened by potential costs associated with decreases in hosting capacity caused by neighbourhood batteries.

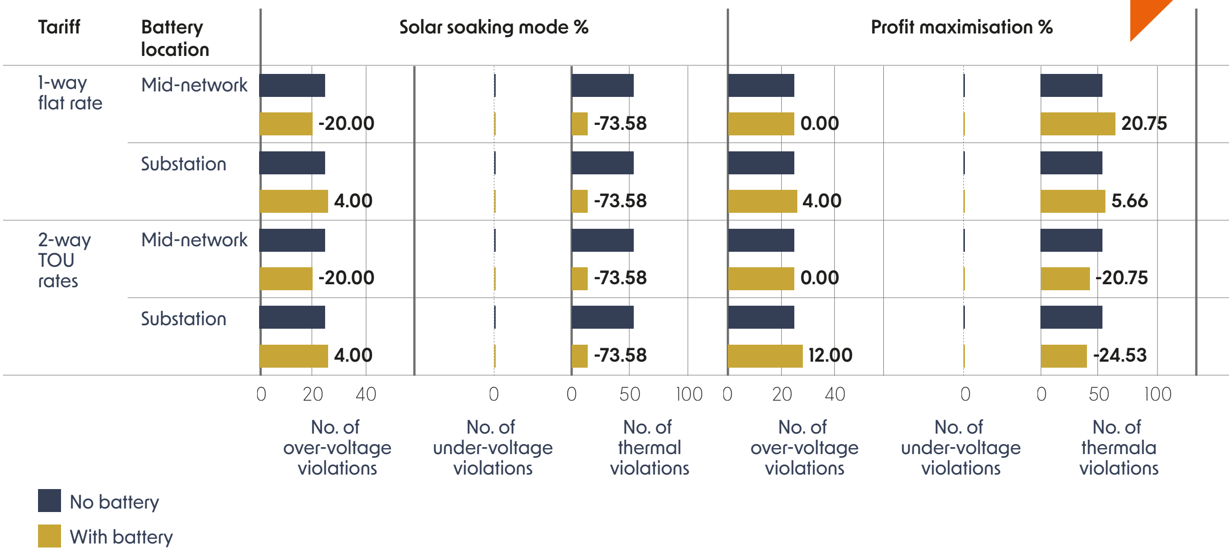

Figure 1 Impact of neighbourhood battery on hosting capacity in one of the four networks studied (network J) with an example scenario with 200kWh battery where 70% of households had rooftop solar. Note that the neighbourhood battery mostly decreased voltage and thermal violations which indicates increased hosting capacity, with the exception of a few scenarios when the battery was operating in profit maximisation mode. The simulation day corresponds to 15 Feb 2021 (the hottest day in 2021).

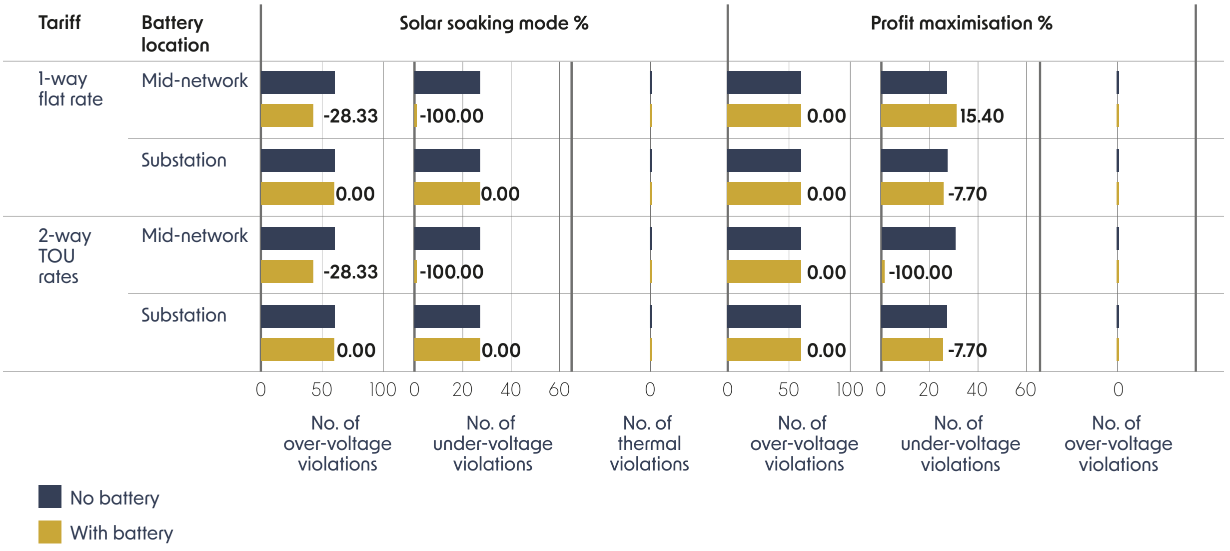

Figure 2 Impact of neighbourhood battery on hosting capacity in a different network (Q). Results are shown for an example day for a scenario with 200kWh battery where 70% of households had rooftop solar. Note that the neighbourhood battery reduced or eliminated voltage violations when positioned mid-network and operating in solar soaking mode. Network Q did not have any thermal violations with or without a battery.

Conclusion, next steps, and recommendations

For some low-voltage networks, a neighbourhood battery could help 'unlock' network hosting capacity.

However, the impact will depend on several factors:

1. How the battery is operated – following price signals alone will lead to less opportunity to increase hosting capacity compared to operating the battery primarily to 'solar soak'.
2. The network tariffs that apply, with two-way time-of-use tariffs more likely to increase hosting capacity, even when the battery is following price signals.
3. The battery location. Two of the four networks we studied had no issues with voltage or thermal violations such that the battery could be of no benefit. For the other two networks, the battery had more impact on reducing voltage violations if it was located downstream of the transformer.

These results are simulations and need to be verified with real-life data. We have assumed perfect foresight of price, load and generation, which could result in an over-estimate of impacts. As mentioned, the battery capacity available for increasing hosting capacity will be smaller than modelled in this study given that, in practice, the battery will typically reserve capacity for FCAS co-optimisation, network services and battery health.

These results are simulations and need to be verified with real-life data. We have assumed perfect foresight of price, load and generation, which could result in an over-estimate of impacts.

Further work should investigate how our results change when considering smart network controls like dynamic operating envelopes, which we expect will both increase the ability of battery storage to generate more revenue as well as unlock more network capacity for consumers, while not breaching network constraints. Comparative analyses between the effects of neighbourhood and equivalent household batteries on hosting capacity should also be pursued in future work.

We have identified several factors that impact how much neighbourhood batteries could increase network capacity for consumers, and these factors warrant thorough examination in the ongoing government-funded rollouts of neighbourhood batteries. Taken together, our results indicate that the impact of neighbourhood batteries on unlocking hosting capacity for consumers will depend on battery configurations and topology of the local network, as well as the tariffs that apply. Our recommendations are to:

Recommendation 1

Ensure batteries are installed in parts of the network where they will provide a benefit. We only saw significant impacts in two of the four LV networks studied. Recent efforts to increase the visibility of LV network constraints for both DNSPs and third parties will help here.

Recommendation 2

Introduce a NEM-wide optimised network tariff, with a two-way time-of-use (TOU) structure (see our recent report on neighbourhood battery network tariffs).

Recommendation 3

Investigate how a battery responding to price signals (arbitrage, FCAS) can be achieved while still improving hosting capacity e.g. with network tariffs and smart controls (dynamic operating envelopes).

Taken together, these recommendations will support collective goals to better understand how neighbourhood batteries can be implemented to bring maximum benefits for consumers.

Yarra Energy Foundation battery

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