Agents of change
Making batteries go the extra mile

Taking distributed generation a step further, household battery systems will become active network agents in a world-first trial happening now on Bruny Island in Tasmania. ANU's Evan Franklin explains.

THE buzz surrounding on-grid residential battery storage systems has been deafening of late. In fact some market analysts, notably among them Bloomberg New Energy Finance (BNEF), predict Australia to become a global leader in battery storage deployment. BNEF forecasts the majority market-share to be residential 'behind-the-meter' storage, with an installed storage capacity of about 20 GWh expected by 2040. This will equate to around 2.5 million homes—about one in five—being equipped with batteries. Battery deployment is very much in its infancy, but there seems little doubt that battery storage is set to become a key feature of our energy system.

Battery storage, if deployed and managed appropriately, can present a win-win scenario for battery system owners (householders), network service providers (the 'poles and wires' guys), renewable energy developers, power system operators and the Australian community at large.

This is because batteries can take on many important roles—time-shifting to balance behind-the-meter generation and demand being just the tip of the iceberg. Batteries can help network operators to do their job by providing improved network visibility, improved reliability and up-time, and managing voltage levels and load flows across the network—and by doing so deferring or avoiding costly network upgrades. Batteries can also help power system operators (in Australia this is AEMO) and transmission network operators by strategically charging or discharging to help regulate system frequency, rapidly responding to system disturbances and helping guarantee stability given increasing generation from renewables.

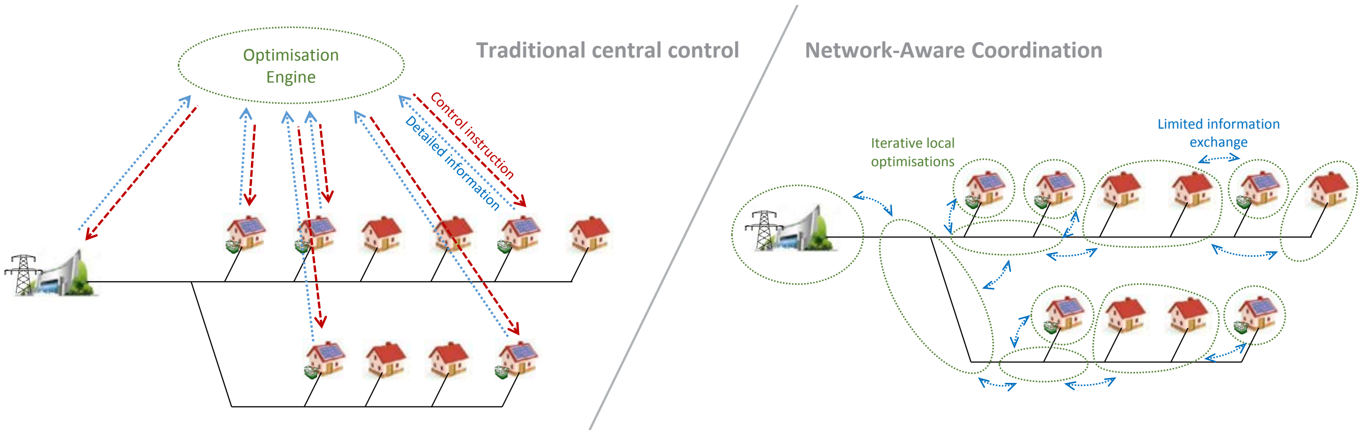
Image: www.flickr.com/photos/gun254

↑ Bruny Island's undersea cable connection to Tasmania's main grid gets overloaded at peak times, such as summer holidays, leading to a reliance on diesel generation. In a world-first trial, household battery systems will be used as mini power stations to reduce diesel use and avoid costly cable upgrades. The project uses sophisticated distributed optimisation software to balance household and network benefits.

Optimal ways to deploy batteries

To date, the different services that battery systems can offer have largely been viewed separately and independently—homeowners install batteries for time-shifting and self-consumption only, while utilities install them for a specific network or power system purpose (South Korea for example is installing 500 MW for the express purpose of frequency regulation). But they can and should be viewed together. Understanding how to optimally coordinate the various roles across thousands or millions of battery installations in the grid will be challenging to say the least. However, this will be the key to unlocking the full potential of battery storage.

This challenge, coordinating millions of small on-grid battery systems to achieve optimal outcomes, points us then to where the next wave of innovation is required and where research and development dollars can yield the 'best bang for the buck'. And this is precisely where part of a recent ARENA funding announcement has been directed. The Australian National University, along with TasNetworks (the network operator in Tasmania), Canberra-based Reposit Power, University of Tasmania and The University of Sydney, has been awarded $2.9 m for a research project which will address how batteries can be used by householders to manage their energy while simultaneously being used to help manage the network. The project also aims to work out exactly how best to reward battery



↑ Instead of traditional centralised network control, the Bruny Island trial will use distributed optimisation software to control power flows and pricing. Network-aware Coordination (NAC) uses negotiation between the local network and neighbouring household battery systems to reach an optimal price/power flow result.

system owners for doing this, thus enabling the batteries to realise extra value for the owner. This will pave the way for maximising the benefits from mass deployment of battery systems Australia-wide.

The Bruny Island trial: householders become mini power stations

Under the ANU-led project, up to 40 battery systems will be installed in homes on Bruny Island in Tasmania's south-east. Bruny Island is connected to Tasmania's main grid via an undersea power cable which, at times of peak demand (typically during summer and holiday periods), becomes overloaded. The only solution at present is to generate power on the island using diesel generators at times when demand exceeds supply capacity; business-as-usual would see an ever-increasing reliance on diesel generation or otherwise the replacement of the sub-sea cable—both expensive and undesirable options. The installation of battery systems on the other hand, if appropriately managed, will reduce the reliance on diesel generation and eliminate the need to replace the cable. The batteries will also address another problem faced by the network operator—maintaining acceptable voltage at the far ends of the network—thus saving the operator from employing costly alternatives.

Let's consider then how battery owners and the network operator might actually benefit from working together on Bruny Island. At present TasNetworks spends around $15,000 to $25,000 per annum on diesel generation for the sole purpose of relieving cable overloading. With an undersea cable costing in the order of a million dollars per kilometre, the alternative of replacing the constrained feeder cable would equate to a cost of well over $100,000 per year. But things really needn't pan out like this: a large fraction of these costs could be avoided by intelligent, automated operation of distributed battery systems.

Allowing part of these network cost savings to be available as an additional income stream, via time-varying price signals, will enable each battery system to decide upon the most cost-beneficial course of action for both the battery system owner and the network. For example, for a particular set of network pricing signals, electricity pricing, anticipated PV generation and household demand, a battery system might decide to store all excess solar generation during the middle of the day, and may even decide to import additional electricity from the grid to charge batteries completely, so that at critical times later in the day it can be paid a premium to export to the grid and reduce load on the island's feeder cable. Add to this mix the possibility, via Reposit's GridCredits platform, of being rewarded for exporting at times when wholesale electricity prices are high and you're starting to get close to unlocking the full value of distributed battery systems.

At the centre of the project is the sophisticated, distributed 'Network-Aware Coordination' (NAC) software developed by researchers at ANU (see next page for more on NAC). Each battery system receives forward pricing and demand signals from this control software, continuously optimised according to the conditions on the grid and based on electricity demand/pricing information.

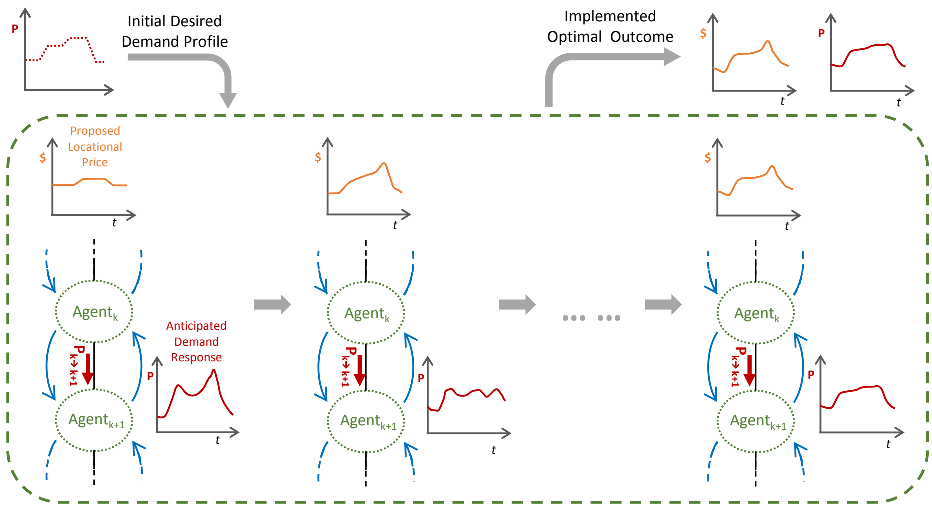
At the heart of each battery system will sit the innovative battery control hardware and software developed by Reposit Power. The Reposit system monitors live data on customer energy usage, household PV generation and weather forecasts, using that data to predict how much energy will be generated and consumed by the household over the next 24 hours. Based on the external pricing signals provided by NAC, each battery control system then determines how to manage that energy to maximise economic benefit to the customer.

For the example described previously, each battery system decides first to charge and then later discharge based on the high future export prices supplied by the NAC algorithm. The NAC algorithm meanwhile has determined the best price signals for all systems across the network so as to ensure the undersea cable capacity constraints and network voltage requirements are met at minimum net cost.

The approach taken by this project—distributed but coordinated control of multiple, customer-owned battery systems which allows customers to optimise their own energy use while also rewarding them for participating in 'the bigger picture'—is a world-first and a great example of Australian innovation and collaboration. The development of innovative reward mechanisms for customers plus the assessment of their responses to and interactions with the technology—research being led by the University of Sydney and the University of Tasmania respectively—add critical dimensions to the project that will ensure the outcomes are transferrable to the wider Australian context. ✱

The Bruny Island battery storage trial will commence with community consultation in the second half of 2016. Interested parties can contact TasNetworks on 1300 13 7008.

"Initial price signals are based on the cost of delivering power to and around the island for each time interval in a particular period (say 24 hours). The NAC negotiation process is iterative to yield final prices/power flows to ensure charge/discharge behaviour of battery systems is coordinated—with the aim being to avoid feeder constraints, minimise on-island diesel generation and manage voltages within acceptable levels across the network."



↑ A closer look at the NAC algorithm for distributed optimisation of network power flows and prices. Agents (generators, controllable loads and battery storage systems) negotiate iteratively with neighbouring agents to determine price and the final demand profile based on initial proposed pricing and a desired demand profile.

The NAC algorithm for distributed optimisation of price and power flow

The coordination of multiple market-participating agents (for example, generators, controllable loads such as controllable air conditioners and battery storage systems) distributed throughout a large electrical network in a way that provides energy services at lowest economic cost is a complex and challenging task. This is especially complicated by the numerous physical and financial constraints in the network which must be respected by any solution.

Traditionally power systems have taken a centralised control approach where decisions for all controllable agents are made based on a single optimisation engine that has access to all relevant system information. However, as the number of agents in the system grows (increasing numbers of battery systems, for example), the complexity of the problem increases rapidly and the ability to centrally find an optimal power flow solution in a reasonable timeframe becomes extremely challenging. In addition, the centralised approach fails to cater well to agents wishing to participate in the market while also maintaining a high degree of autonomy and privacy.

An alternative is a distributed optimisation algorithm, such as the Network-Aware Coordination (NAC) software that Paul Scott and Professor Sylvie Thiebaux from ANU have developed, which offers a scalable optimisation process and retains the independence and privacy of each individual agent in the system.

The NAC approach decomposes the very large and complex 'centralised problem' into a number of much smaller and simpler 'distributed sub-problems', each representing a particular agent or small section of the network.

By iteratively solving the local optimisation sub-problems, agents essentially 'negotiate' the amount and price of power that they exchange with each of their immediately connected neighbours (for example, between a battery storage system and a section of the network).

The local optimisation sub-problem calculates the best response of agents (each acting in its own best interest), to the currently standing prices, which are updated between iterations until connected agents agree on the amount of power that they exchange.

These sub-problems are solved in parallel to speed up the computation and, once the negotiated power and prices converge, an optimal power flow solution for the entire network has been reached. The solution includes network status (power flow and voltage at each node), power/energy produced or consumed by each agent in the network and power/energy prices charged or paid for by each element in the network.

Because of the iterative nature of the distributed optimisation technique, the NAC software provides a market mechanism for ensuring lowest overall cost of meeting energy demands within constraints while also ensuring, via the creation of locational pricing, that individual agents are fairly compensated for their role in meeting those constraints.

For a multiple time-step distributed optimisation, which is certainly required to satisfy the time-dependent behaviour of electrical loads, an optimal solution is computed for every time-step (for example, five minutes) over a defined forward period (for example 24 hours). Optimal solutions for the entire forward period are re-computed in real time as every time-step passes.

On Bruny Island the price signals will be based initially on the cost of delivering power to and around the island for each time interval, with the NAC negotiation process yielding final locational prices that will ensure charge/discharge behaviour of all battery systems is coordinated to avoid feeder constraints, to minimise on-island diesel generation and to manage voltages within acceptable levels across the network.