Demand Management Case Study

Residential Battery Storage Trial

Introduction

Home energy storage based on battery systems has recently emerged as a technology of interest to both electricity customers and electricity distribution networks. Although the market for grid-connected residential battery storage can still be considered to be at an early-adopter stage, it is maturing rapidly. Storage systems are becoming more readily available through suppliers such as solar installers and electricity retailers, and prices have been declining.

Figure 1: Residential battery storage unit, with solar inverter in foreground

Recognising the potential opportunities of home energy storage, AusNet Services initiated a Residential Battery Storage Trial in 2011, with regulatory funding from the Demand Management Innovation Allowance (DMIA). The trial was one of the first of its kind in Australia and aimed primarily to investigate the potential of residential battery storage to:

- flatten residential customer demand profiles,
- manage the peaks in network demand that are driven by residential customers,
- improve the integration of residential solar power into the network, and
- assess the financial benefits of battery storage to the network and to customers.

Potential Value

Network Value

For Distribution Network Service Providers (DNSPs) such as AusNet Services, battery storage has the potential to help the network run more efficiently by reducing peaks in demand, and managing the impact of solar PV.

Reducing customers' use of electricity at peak times or shifting the usage to off-peak times is desirable because it reduces the risk of the network becoming overloaded with the associated asset risks. In the long term this can also reduce or defer the need for networks to invest in new capacity that may only rarely be used (i.e. during periods of peak demand), and that would be paid for by customers through their electricity bills.

By storing excess solar power that would otherwise be exported to the grid, battery storage systems can also mitigate the technical issues for the network such as voltage-rise that can be caused by high penetration levels of solar power. In this way, battery storage may help facilitate a higher uptake of solar power whilst maintaining network power quality and reliability for all customers.

Customer Value

For customers, energy storage offers a potential means to reduce electricity bills and to better utilise their solar PV generation. Storage can also be used to provide a backup power supply during times of network outage, however backup functionality was not part of this trial.

Participant Selection

Ten participating customers were selected to form a *diverse* demographic base with different consumption levels ranging from 7 kWh (below average) to 51 kWh (above average) per day. Nine of the customers were located in the AusNet Services distribution network and were on a two-part network tariff with peak and off-peak components.

Technical Set-up and Data Capture

The Residential Energy Storage System (RESS) units were built by MPower to an AusNet Services specification.

Figure 2: Inside view of an RESS. The inverter and control system are located in the upper compartment and the batteries in the lower compartment.

The systems comprised a 6.6 kWh lithium-ion battery (Kokam cells), a 3 kW inverter/charger (Selectronic SP Pro), a programmable PLC controller, and a communications system. Each RESS was teamed with either a 1.2 kW or 3 kW solar PV system.

In order to capture sufficient data for control system operation and for analysis of system performance, power flows measurements (designated M in the schematic below) were taken at the:

- output of solar PV system
- output of the battery
- customer net import/export at the household meter board.

These data points fed into the energy management control system and were logged and sent to AusNet Services daily.

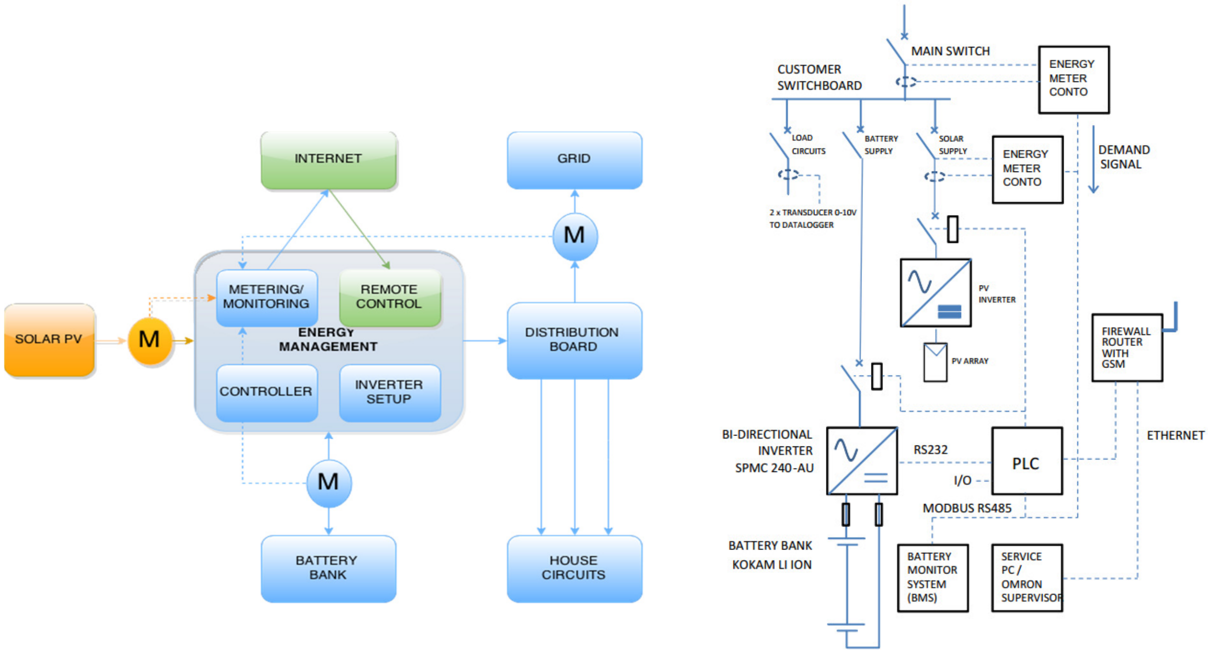

Figure 3: Conceptual and technical schematics of RESS setup

Operating Modes

The trial focussed on the two summer periods of 2013/14 and 2014/15 and involved testing the performance of the RESS under a series of operational modes that determined the charge and discharge behaviour of the RESS. The different operational modes were designed by AusNet Services to either prioritise benefits to the network, the customer, or balance these benefits, with the aim of determining an optimum operational profile. A version of each operating mode was implemented for at least one week across the summer peak period and detailed performance data was collected at one second intervals. The five operating modes implemented and investigated by AusNet Services are described below.

Peak Lopping with Fixed Setpoint

Peak Lopping mode limits the customer's grid demand at any time to a set power level (setpoint). The battery was fully charged from the grid overnight during the off-peak tariff period. The peak lopping mode can be summarised as follows:

Battery charge: From the grid only, during off-peak times.
Battery discharge: To bring grid demand down to setpoint (e.g.: 2000 W).
Advantages: Provides certainty of customer load on network energy price arbitrage between charge & discharge.
Disadvantages: Often results in under or over-utilised battery and sub-optimal demand reduction

The following chart is an example of the basic Peak Lopping operation of the RESS. The orange line is the fixed demand setpoint, which is 2000 W in this case. Initially when customer demand (black line) is less than the demand setpoint, the battery inverter is inactive and there is no battery output (green line). When the customer increases load above the demand setpoint, the battery inverter ramps up and brings the net customer demand (blue line) back to the demand setpoint. Based on this operation, the RESS is able to directly cap the peaks in customer demand.

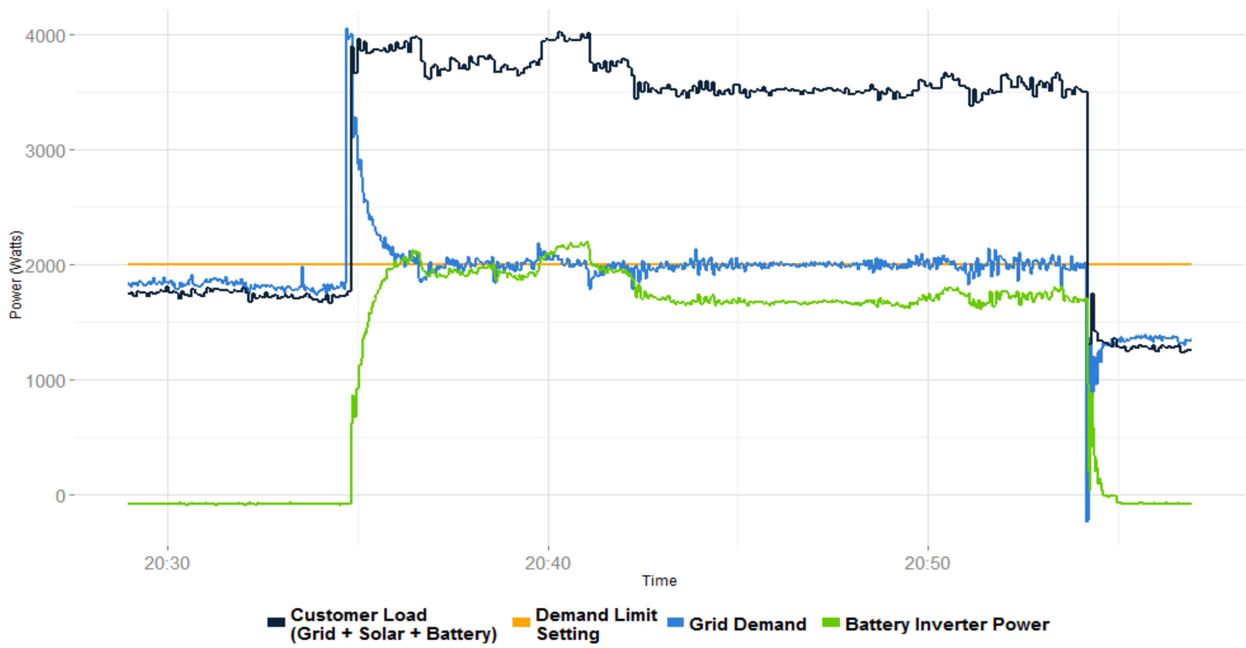

Figure 4: Example of the system outputs under Peak Lopping mode with a demand setpoint of 2000 W

Peak Lopping with Dynamic Setpoint

The fixed setpoint Peak Lopping mode evolved to a dynamic approach where the setpoint was calculated daily with the aim to use 80% energy stored in battery by the end of a day when it is fully charged in the morning.

Battery charge: Fully charge from the grid during off peak times

Battery discharge: To bring grid demand to customised setpoint during rest time of the day. The calculation aims to maximise demand reduction by minimising the set-point based on previous 7 days of customer data. The set-point is minimised within the constraint of battery capacity.

Advantages: Allows the RESS to follow the changing patterns of consumer demand throughout the year.

Disadvantages: Rolling average does not include a predictive element

The following chart shows an example of the RESS outputs under Dynamic Peak Lopping mode over three days with a demand setpoint that is dynamically calculated. The dynamic demand setpoint (purple line) was initially too high and results in little of the battery capacity being used. On the second and third day, the demand setpoint was recalculated and lowered. As a result, more of the battery was utilised to offset the customer's demand. Thus the calculated setpoint was able to track any variation in customer consumption to improve the level of demand reduction within the available battery capacity.

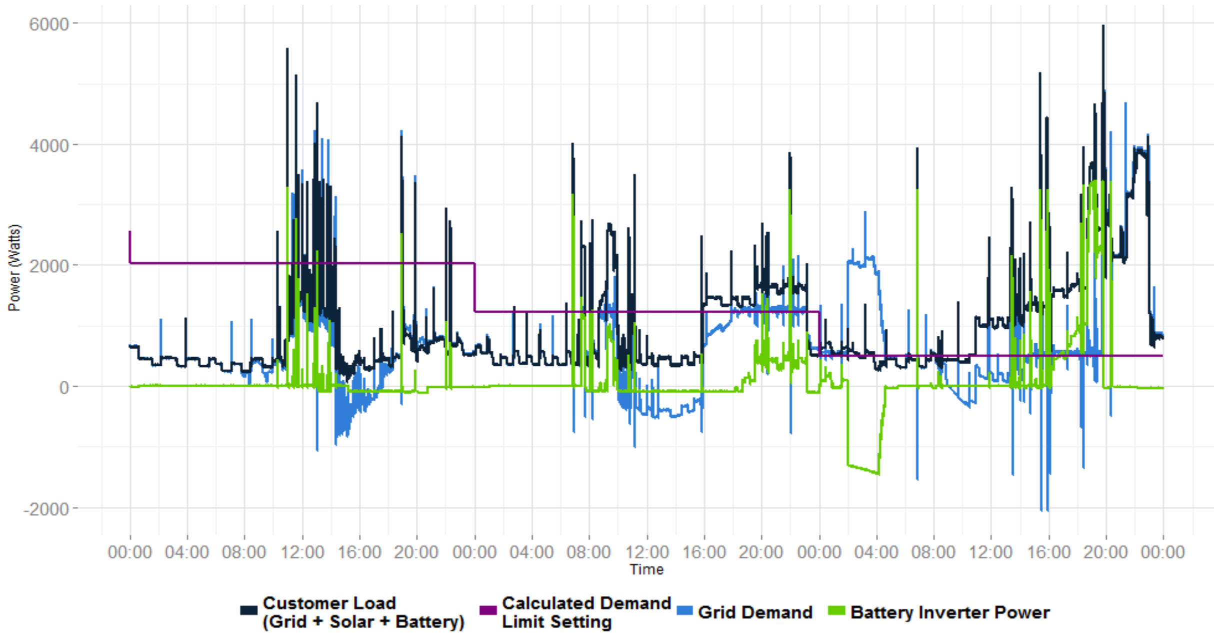

Figure 5: Example of the system outputs under Peak Lopping mode over three days

Solar Charging

This operating mode also applied peak lopping, but only charged the battery with the customer's excess solar power that would have otherwise been exported to the grid.

Battery charge: Only charged by excess solar power during the day.

Battery discharge: Bring the customer net demand down to a customised set-point at all times.

Advantages: Reduced solar exports, 100% renewable energy used to charge the battery.

Disadvantages: Battery often not full due to lack of PV, leading to less peak demand reduction.

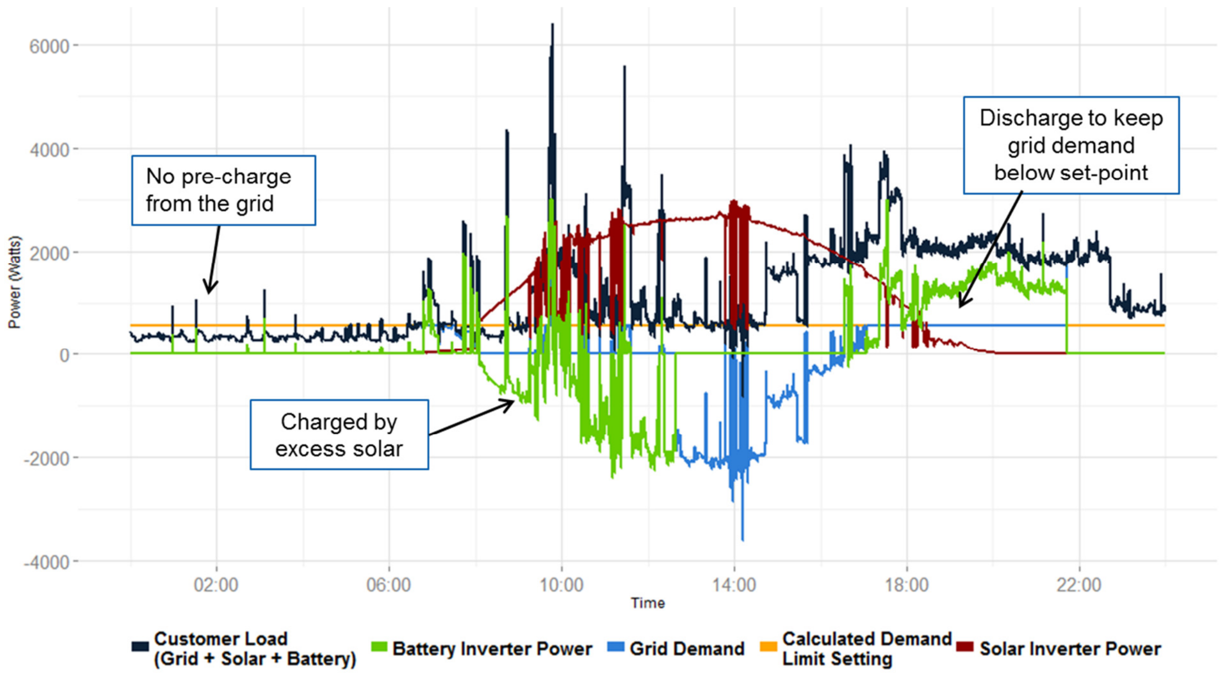

Figure 6: Example of the system outputs in Solar Charge mode over one day

Tariff Optimisation

For this operating mode the aim was to maximise customer bill reduction by charging preferentially from surplus solar power, with additional off-peak grid charging if required, and discharging to wholly support the customer's demand during the peak tariff period until the battery was exhausted.

Battery charge: Aims to use cheapest power to charge, but still have a full battery. Pre-charges an amount of off-peak power based on expected PV production the following day.

Battery discharge: Supports all load (peak lopping to zero W) from 2:00 pm to 11:00 pm (peak time).

Advantages: Maximises value of energy price arbitrage. Allows support of all load, not just that above a setpoint.

Disadvantages: Complex to program.

The following chart shows an example of the RESS operation under Tariff Optimisation mode. The RESS offsets the full customer load during the afternoon in peak tariff times until the battery capacity is exhausted. The battery is charged from surplus solar power during the day. If it is forecast that the customer will not have sufficient surplus solar power to fully charge the battery, a portion of the battery will charge overnight during off-peak tariff times as can be seen at 2:00am in the example below.

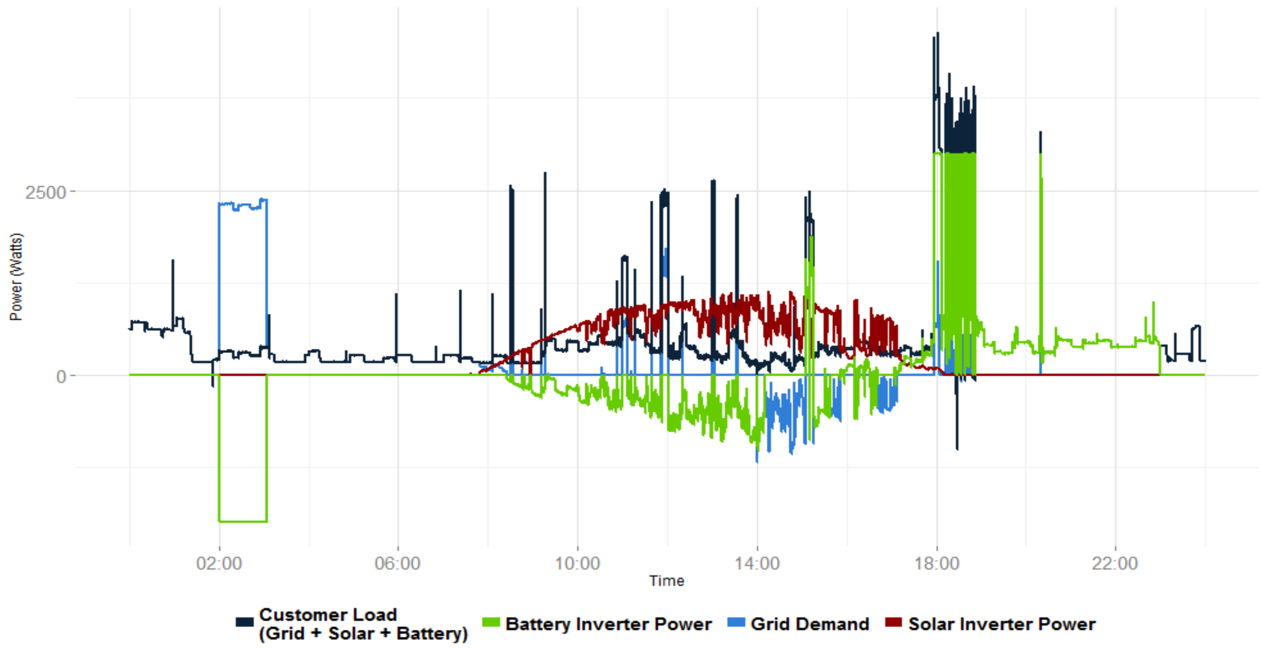

Figure 7: Example of the system outputs under Tariff Optimisation mode over one day

Scheduled Operation

This mode maximised network support by discharging 100% of the battery capacity during network peak times. This would first offset customer consumption, with any excess power exported to the grid.

Battery charge: Fully charge from the grid during off-peak time.

Battery discharge: Discharge at high power (2000W) across the three hour evening peak. Discharge time frame set to match local distribution substation peak, or feeder peak

Advantages: Provides maximum support to local network to reduce network loads

Disadvantages: Can creates costs to the customer due to low price paid for exports

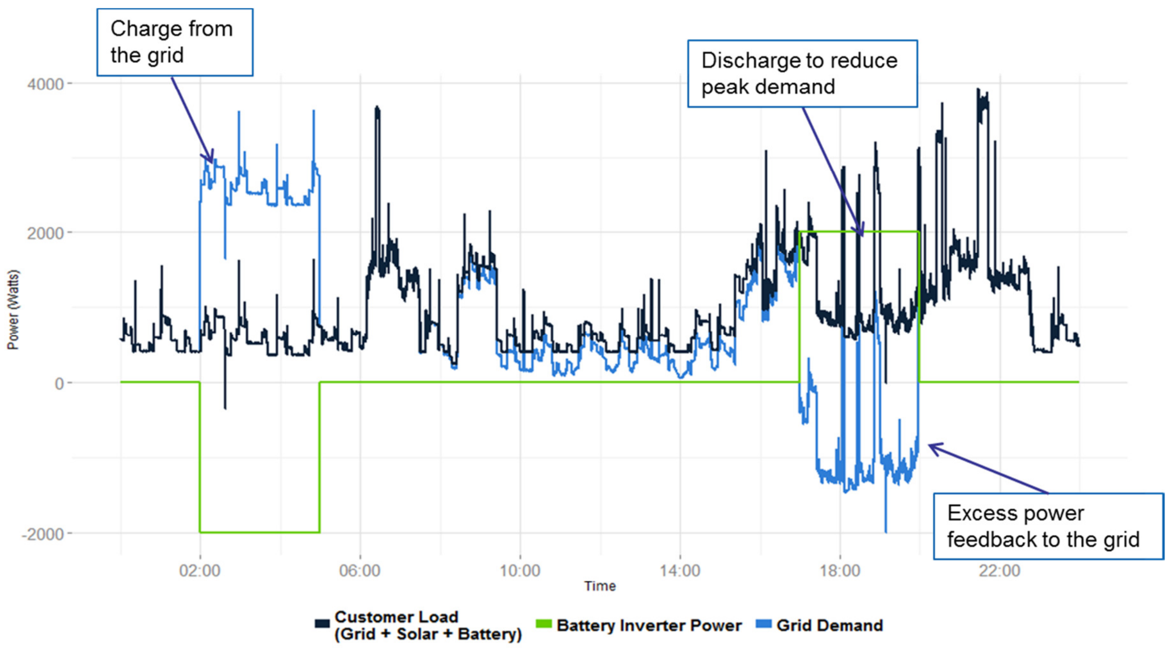

Figure 8: Load profile for Scheduled Operation

The above figure shows the RESS fully charging the battery at night, remaining on standby during day and then being scheduled to discharge at 2000 W from 17:00 to 20:00. During that time, the RESS not only reduced the customer load significantly, but also exported to the grid to further reduce demand on the local distribution network.

Computational model

In order to extrapolate the short-term tests into comprehensive data sets for further analysis, a computational model was developed which used real data at 1 second resolution for customer net demand and solar power generation over 12 months to calculate/simulate detailed system behaviour and power flows for each operational mode. These extrapolated 12 month data sets were then analysed to determine the technical performance of the RESS and economic performance under a typical two-part retail tariff (Table 1). Reported results focus on the Tariff Optimisation and Scheduled Operation modes as they were found to be the most financially promising.

	Peak Period	Rate (Incl. GST)	Off-peak Period	Rate (Incl. GST)
Weekdays	7am to 11pm	36.415 c/kWh	11pm to 7am	19.788 c/kWh
Weekends	Not Applicable		All Days	19.788 c/kWh
Vic Feed-In Tariff	6.20c/kWh any time (2015)			
Standing charge	135.98c/day ($496p.a.)			

Table 1: Two-part retail tariff for 2015 as used for financial analysis

Technical Performance

Key technical performance indicators investigated included the:

- impact on customer demand profiles
- reduction in a customer's peak demand during network peak times
- reduction in solar exports

Overall the RESS were found to perform well against all indicators, although there was a significant level of variability in performance between individual customers. Representative results across the trial sample are discussed below.

Impact on customer demand profile

The following charts show the average impact of the different operating modes for one customer across a summer period. Compared to the customer's underlying demand profile (**red line**), the addition of solar PV (**green line**) results in a highly variable demand profile across the day, and the addition of battery storage (**blue line**) helps to reduce this variability and flatten the load profile when operating in Peak Lopping, Solar Charging or Tariff Optimisation modes. A more consistent load profile represents a more efficient use of the electricity network. The Scheduled Operation mode shows the RESS exporting at the time of local network peak demand (in this case 6pm to 9pm) to support the network.

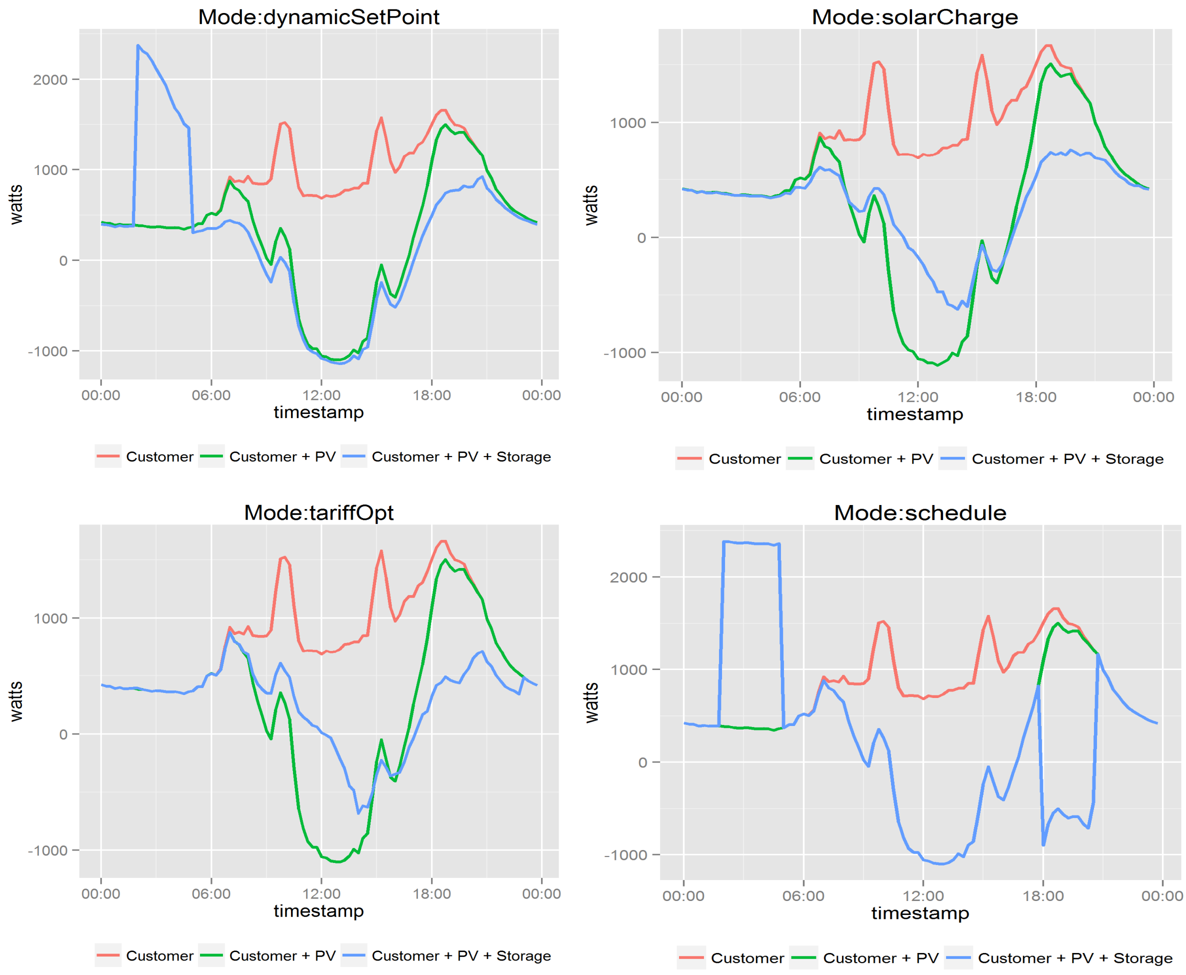

Figure 9: The effect of different operational modes on a customer's average summer demand profile with a 3 kW solar PV system

Network peak demand reduction

Across all trial sites, the local network peak demand was typically found to occur between 5pm to 8pm. On the five days of highest network demand across the 2014/15 summer, the maximum customer half-hour demand during this time period was typically 2.4 kW.

Overall, the RESS was found to be able to reduce this contribution to network peak demand by 1.1 kW when operating the customer-focussed Tariff Optimisation mode. If controlled centrally under a network-focussed Scheduled Operation mode, this reduction in peak demand could be increased to 1.9 kW, although this resulted in several customers exporting power from the RESS to the network. The PV systems alone were found to reduce coincident peak demand by around 0.5 kW for the 3 kW systems, or 15% of rated output.

The following chart shows the impact of the RESS on the contribution of two different customers to network peak demand. In these examples, the demand reduction due to the solar PV system is relatively small for the larger power user, but the demand reduction due to the RESS is significant.

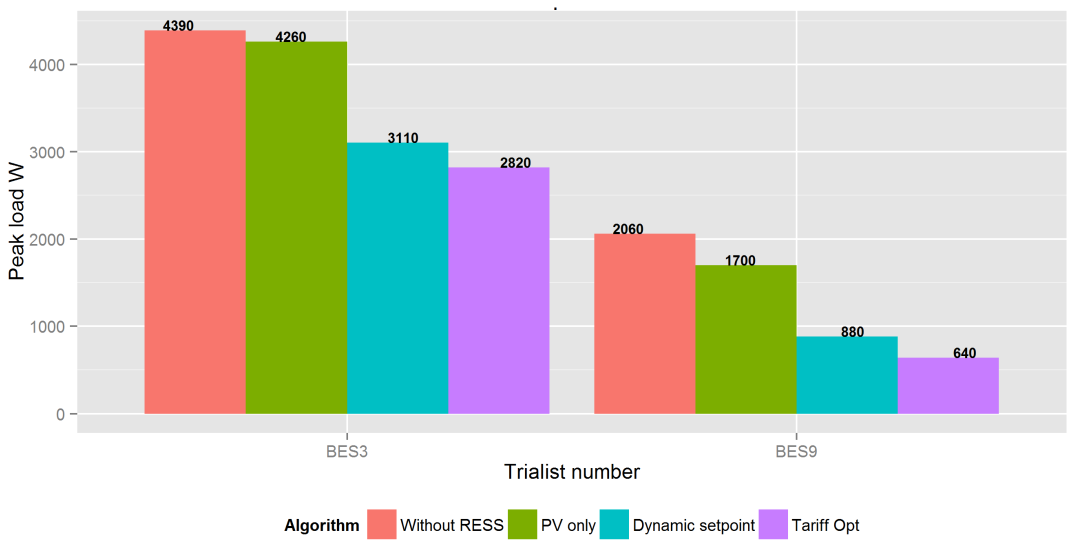

Figure 10: Customer 30-min peak demand at the time of network peak demand for two different customers under the Dynamic Setpoint and Tariff Optimisation modes

Solar export reduction

The RESS were also able to significantly reduce the amount of solar power that was exported to the grid. High levels of solar power export can create technical issues for the network such as voltage-rise that can impact power quality for all surrounding customers. The 3 kW PV systems exported an average of 6.3 kWh per day across the summer period. Under Tariff Optimisation, exports were reduced by between 56% and 74%, suggesting that battery storage can facilitate an increased PV penetration of two to three times for a given voltage limit constraint.

The chart below shows how the RESS systems were successful in reducing solar exports by a significant amount. The level of reduction varied widely between different customers depending on their usage patterns.

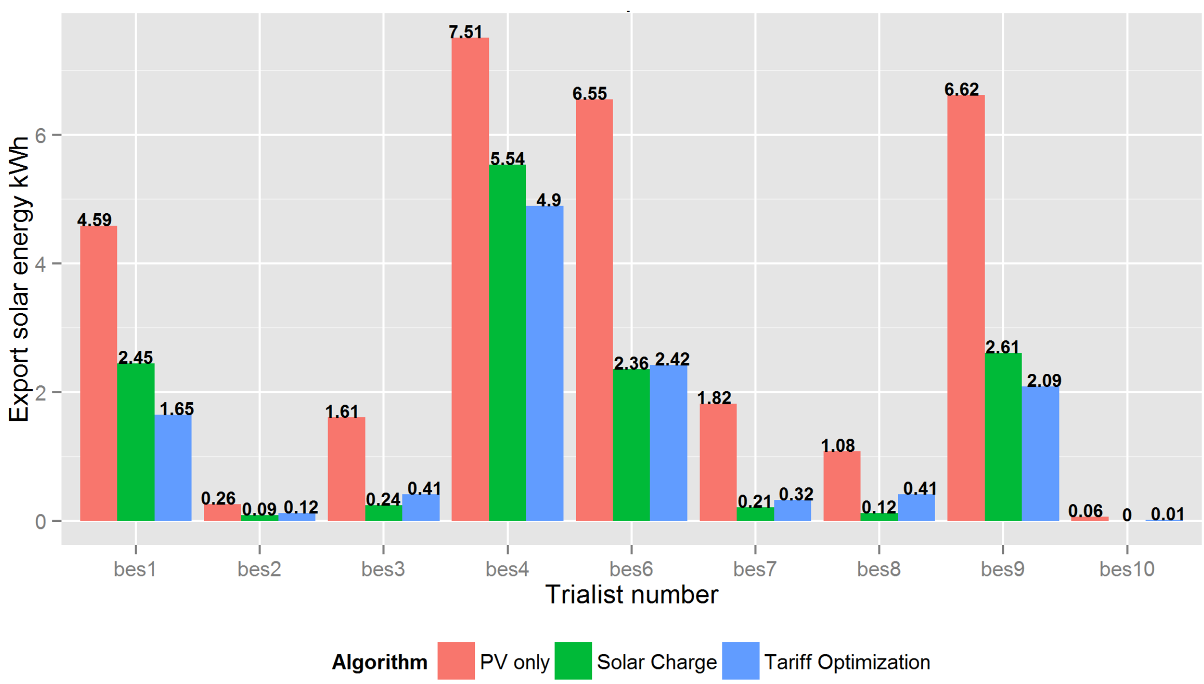

Figure 11: Average summer solar exports to the grid for each trial customer without the RESS, and under the Solar Charge and Tariff Optimisation modes of operation

Financial Analysis

Costs and benefits were analysed to evaluate the financial viability of residential battery storage deployed in a network context.

Storage Costs

The table below summarises the cost estimates over time for a residential storage system that is equivalent in capacity and performance to that used in the Trial. The table shows an expectation of significant reductions in cost, however it should be noted that there is a high level of uncertainty around whether the current rate of cost reduction can be maintained beyond the next few years.

Year	Capital cost estimate	Description
2011	$20,000	Approximate cost of systems used in the trial[1]
2015	$12,900	Benchmark for current system costs[2]
2018	$9,800	Short-term forecast of system costs
2023	$6,100	Long-term estimate of potential system costs

Table 2: Real and predicted decline in RESS capital costs 2011-2023

The 2018 costs were taken as representative of a point in time at which the market for storage is likely to have matured to exhibit a strong level of competition between suppliers. On top of the initial capital outlay of approximately $9,800 in 2018, operating costs were also estimated to include a minor service every 5 years and major repairs after 10 years. These operating costs are estimated to have a present value of $900, giving a total present cost for the storage system of $10,700, assuming a 15 year asset life.

Customer benefits

By storing excess solar power for later use, and using cheaper off-peak power for additional charging where required, the RESS were proven successful in being able to reduce customer electricity bills. The following chart shows for a sample of customers with 3kW PV systems, the estimated impact on their annual bills from adding solar PV and then an RESS.

Under the most common 2-part solar PV tariff, a typical customer could save $342 p.a. with the RESS operating in Tariff Optimisation mode. This annual saving is equivalent to a present value of around $1,500 over 5 years and $3,500 over the lifetime of the system[3]. Under a 3-part flexible pricing tariff the savings could increase to $455 p.a., but the take-up of these tariffs remains very low. By comparison, the savings purely from solar PV were typically over $600 p.a. for the 3kW systems, and over $300 p.a. for the 1.2kW systems.

Non-financial customer benefits also exist, such as increased energy independence and backup power supply provision. The value to customers of these benefits may be significant, but is not yet known with sufficient certainty to include in an analysis.

[1] As an innovation trial, a very high level of functionality, flexibility and robustness was specified, and that this was delivered by bespoke design and integration of components to form the RESS solution. This approach resulted in a higher price than would be achievable for a bulk business as usual procurement.

[2] A cost benchmark was developed, but the market is not yet mature enough for this to have a high level of certainty.

[3] Discount rate of 5% over a 15 year timeframe

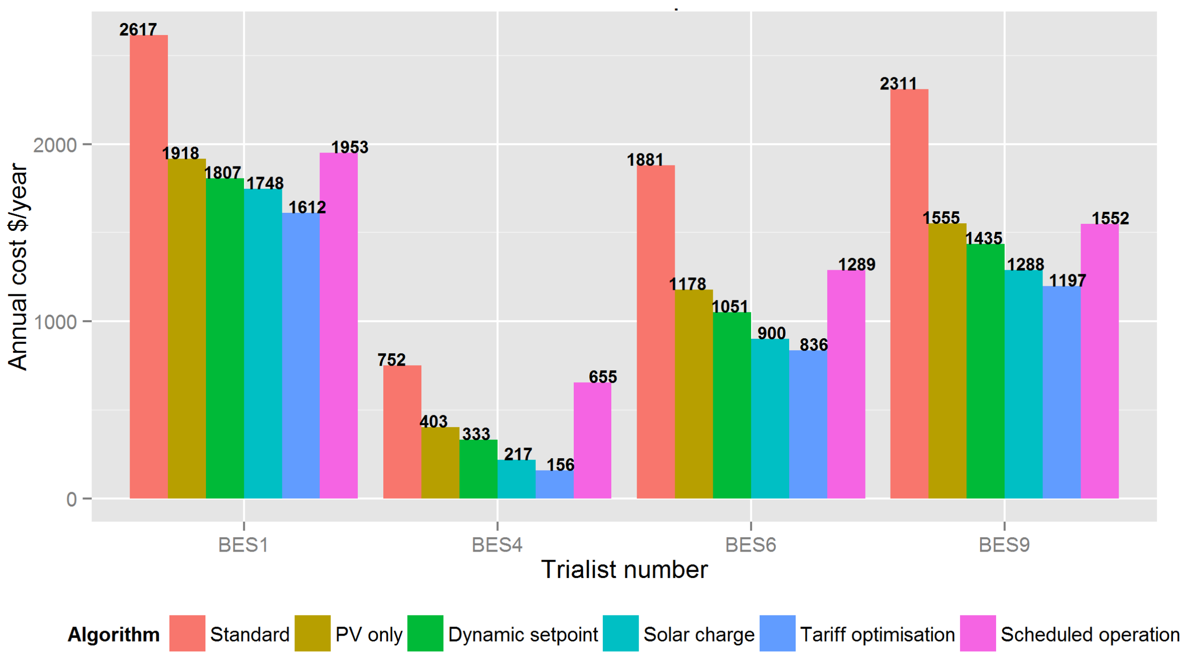

Figure 12: Annual electricity bill estimates under each operating mode for customers with 3 kW solar PV systems

Network benefits

The main quantifiable benefit of storage to the network is in peak demand management. A typical application would be for identified capacity constraints in the network, where demand is forecast to be greater than the capacity of the network assets. In these situations, battery storage may be able to support the network and defer the point at which an upgrade to network capacity is required. To model a situation where battery storage could provide maximum benefits and be an attractive solution, the following scenario for a hypothetical capacity constraint was developed:

- The network would be overloaded for 3 days each summer for a period of 3 hours each day. These parameters form the performance requirements of the battery storage solution and it is assumed that the DNSP has sufficient remote control of the RESS to ensure that the batteries provide their full level of output at times of network peak demand.
- The network upgrade solution can be deferred for 5 years. In areas of very high demand growth, it may not be possible to defer an upgrade for very long, so this scenario assumes an area of more moderate demand growth.
- The network upgrade solution to the constraint is high-cost. In practice this can be the case for long rural power lines where an upgrade would require the replacement of many kilometres of line, or where capacity is limited by underground cables that are expensive to replace. In other cases however, a low-cost network solution may exist which would reduce the attractiveness of the battery storage option.
- A sufficient number of residential battery storage systems within the constrained part of the network can be controlled to act in concert on days of peak demand.

Under the above scenario, each residential battery storage system could provide up to $700 of value per annum if optimally controlled to keep the network from becoming overloaded, thereby avoiding the risk of customers losing supply. Over the 5 year period that the network upgrade is assumed to be deferred, the value to the network can be up to $3,000.[4] Including the ongoing value of load levelling for the remainder of the system lifetime could increase the total value to $3,300.

[4] Loss of supply valued at a nominal Value of Customer Reliability of $40,000 per MWh, discount rate of 5%.

The financial value of voltage-rise management through reducing solar exports was assessed to be small in most cases given that low-cost alternative responses such as transformer tap changing can often alleviate the issues. As solar PV penetration increases over time, traditional responses such as this may be less effective, and the relative value of alternative approaches such as battery storage may increase.

Combined value proposition

Combining the maximum customer benefits of $3,500 with the potential network peak demand benefits of $3,300 yields a combined present benefit of $6,800. This falls some way short of the 2018 forecast total cost of $10,700. However, the shortfall could feasibly be made up through either non-financial customer benefits, benefits that vest with other parties such as energy retailers, or further technology cost reductions over a period of around 5 years.

The rapidly evolving business model around storage will be a key factor in facilitating uptake and there remain a number of uncertainties around the rate of technology cost reductions and customer appetite.

Trial conclusions and future research

The Residential Battery Storage Trial was successful in proving the technical performance of residential energy storage. The Trial also identified that the financial performance, while not currently economic, is sufficient to warrant a further ongoing work stream aimed at realising the benefits of storage and managing customer uptake.

Next steps in terms of innovation work around battery storage include:

- further development of new operating modes for the RESS, including investigation of potential new tariff structures that include a demand-based component.
- design of a larger scale trial of residential battery storage where the storage systems are concentrated in a local network area, and their operation is controlled in a coordinated fashion by an aggregation system.
- investigation of business models and partnerships that could facilitate the deployment of storage to address network issues.
- testing of backup power supply capability that could maintain supply to customers in the event of a network outage.

These innovation trials will be complemented by ongoing market research in order to facilitate the provision of non-network solutions to system planners where network constraints are identified, and to feed into ongoing asset strategy development regarding the application of energy storage in a network context.