Ausgrid Demand Management
Newington Grid Battery Trial

April 2016

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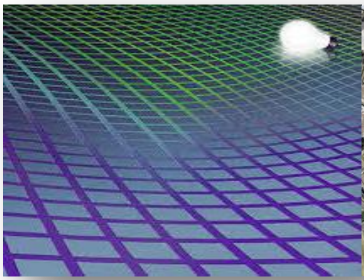
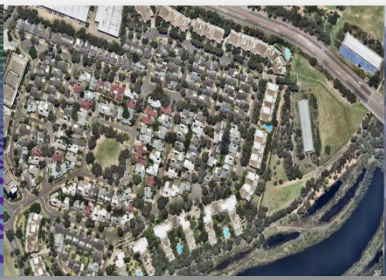


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1 Executive Summary

When the demand for electricity at peak times approaches the capacity of network infrastructure, network service providers such as Ausgrid must act to maintain reliable electricity supply to customers. Reliable electricity supply to customers can be maintained by either increasing the network capacity or reducing the peak electricity demand on the network (demand management).

Cost effective and reliable demand management solutions used recently by Ausgrid include:

- customer demand response (voluntary reduction of customer electricity demand)
- customer power factor correction
- supply of electricity from generators connected at customer's premises or to the network

The recent emergence of lower cost integrated battery storage systems may offer networks a new demand management solution which could help lower costs for networks and lower bills for customers.

The main objective of the Newington grid battery project was to investigate the potential from using a grid-connected battery storage system to reduce peak demand as an alternative solution for addressing a network need.

Secondary objectives included investigating power quality benefits and impacts and customer benefits from installing a battery storage system of this size.

Trial results have shown that grid based energy storage can be a viable solution to managing network demand once the product matures and energy storage prices lower . In addition to a lower cost per Megawatt-hour of storage capacity, improvements to system reliability will be required to compete with existing alternative demand management solutions.

Following completion of the Newington grid battery trial, Ausgrid has now assessed the reliability, performance and implementation issues for both grid and customer based battery storage. While the outcomes from both trials highlighted a performance gap in reliability compared with more mature demand management solutions, we expect that these issues will be resolved in the near future. And with battery costs forecast to decline significantly in the near term, cost competitiveness may not be far off.

Next steps for Ausgrid will be to better understand customer attitudes towards investment in battery storage systems and the willingness of customers to partner with networks to reduce peak demand. Depending upon the outcomes from this research and battery system costs, a trial to measure the customer response to a commercial offer for network support might be a logical next step. Such a trial would explore the costs, performance and issues associated with using customer owned and operated battery storage systems to defer network investment.

Details on the battery system, connection arrangement and trial objectives are found in Section 2 of the report. Results from the network peak reduction trials are detailed in Section 3, battery reliability and efficiency performance results are discussed in Section 4, power quality issues in Section 5 and customer benefits in Section 6. Trial conclusions and next steps are described in Sections 7 and 8.

2 Project Background

2.1 Introduction

There has been considerable interest in battery energy storage systems by customers and networks in recent years. Declining prices for battery storage systems offers networks the opportunity to utilise this technology to cost-effectively manage power supply and demand. For Ausgrid, batteries potentially offer a new alternative solution for the deferral of investments to meet network needs by reducing peak demand experienced by network assets.

The installation of batteries behind the meter by customers in order to benefit from reduced electricity bills is also a growing application of battery systems. In 2015, the global research group IHS predicted that within three years, 10% of US homes that currently have solar PV installed, are expected to also have energy storage[1]. More recently in early 2016, electricity retailer Origin Energy and Tesla announced a residential energy storage product which includes a 6.4kWh Tesla Powerwall battery, solar PV panels and an inverter, with AGL announcing their own offering shortly after. There are a variety of other companies offering a combination of battery and solar packages, demonstrating an emerging market for residential and commercial battery systems.

There are a number of Australian electricity utilities exploring the potential offered by battery storage. These projects include installing batteries at residential sites to facilitate innovative tariff trials, renewable generation support, grid support, peak demand reduction and islanding. Below is a summary of some of the battery trials conducted by Australian networks.

Table 1 - Battery trials throughout Australia[2]

Utility	Project Name and Aims
Ausgrid	**Smart Grid Smart City – Distributed Generation and Storage trials** Sixty 5kW/10kWh Zinc Bromide battery systems installed at residential homes.
AusNet Services	**Grid Energy Storage system trial** Network peak demand reduction, power quality and islanded supply.
Citipower	**Battery in Buninyong** A 2MW grid battery installed in Buninyong to trial peak reduction and islanding.
Ergon Energy	**Integrating Network Tariffs and Customer Owned Distributed Energy Resources** Install batteries at customer sites to facilitate innovative tariff trials. **Centralised Energy Storage System (CESS)** 200kWh of energy storage installed to allow trialling of network grid support, renewable energy management. **Effective Market Reform CSIRO tariff and DER Uptake Modelling** A study to determine the potential uptake of further increases in photovoltaic PV systems and Bess given various possible future tariff scenarios.
Transgrid	**iDemand** Facilitating demand management related research with a 400kWh battery, 99kWp of solar, energy efficient lighting, and a control system at the Transgrid's Wallgrove site.

[1] Australian Financial Review, Utility-scale batteries bring extra power to the grid, 1/4/2015, URL http://www.afr.com/news/special-reports/energy-and-infrastructure/utilityscale-batteries-bring-extra-power-to-the-grid-20150401-1mcw8s#ixzz3uvXkeJC5

[2] ENA, the Great Energy Quest; case studies in Australian Electricity Storage, September 2015

2.2 Project objectives

The project was focused on exploring the benefits of batteries to networks for reducing peak demand as a potential demand management solution to a network need. The primary objectives were:

1.) Summer peak reduction network benefits: To trial the control and scheduling methodology of a grid battery during the hotter summer months to reduce summer peak demand in a local area

2.) Summer battery performance and reliability: To test the grid battery performance during the hotter summer months when battery performance and reliability of operation may be more adversely affected by temperature

There were also a set of secondary objectives investigating other impacts and benefits of battery systems for customers and networks.

3.) Solar PV smoothing: Using the battery to store energy generation from local solar power systems to decrease potential impacts on the network or customers of intermittent solar generation

4.) Power quality issues: To test the power quality benefits and impacts of installing a grid battery in an urban network

5.) Customer benefits: To test the potential customer benefits of installing a larger battery system to reduce customer energy bills for a non-residential customer

2.3 Project history

The Newington grid battery was proposed as part of the Smart Grid Smart City (SGSC) project which ended in September 2013. Due to difficulties in securing a location to site the battery, the grid battery component of the project was not implemented before the end of the SGSC project.

The Newington suburb was originally chosen for the battery location because of the high penetration of solar power systems. Newington was the site of the Athletes Village for the Sydney 2000 Olympic Games and has housing stock that was built to high energy efficiency standards and features the installation of solar panels on almost every home. The Newington suburb includes an estimated 1,104 photovoltaic installations of mainly 500W and 1kW systems on residential rooftops, with some larger systems also located in the area.

The density of solar power systems presented an opportunity to examine the potential impact on the network of a high density of solar photovoltaic systems and whether a battery storage system could address any power issues which might arise. As part of the Smart Grid Smart City project, the 11kV electrical network was reconfigured in order to have the majority of the solar power systems connected to the same 11kV feeder (panel 13) from the Homebush Bay zone substation. In this configuration the 11kV feeder supplied electricity to nine low voltage distribution centres with around 1,800 customers comprised mainly of residential apartments and townhouses with solar power systems. There was a total of about 1 MW of customer installed solar system capacity connected to the feeder in this configuration. For further details refer to the Smart Grid Smart City – Distribution Generation and Storage Technical Compendium available on the Ausgrid website.

The original location for the battery was proposed to be adjacent to a ground-mounted low voltage distribution centre towards the end of the reconfigured 11kV feeder where there was a high penetration of townhouses with solar power systems. However, due to difficulties and delays in securing an agreement with the local strata of the townhouse community, it was not possible to locate the battery in this location within the time frame of the SGSC project. Alternative locations near the same network connection point were found to be not viable. Community concerns included visual impact, EMF radiation and the impact on the common area park landscape where the battery was proposed to be located.

In October 2013, Ausgrid resumed the trial, funded under the Australian Energy Regulator's Demand Management Innovation Allowance (DMIA) scheme.

2.4 Trial area and battery location

As the grid battery could not be located at the preferred location identified for the SGSC project an alternative location needed to be found that could meet the project objectives. It was preferable that the location would be in close proximity to customer solar generation in the low voltage network as well as a site that would satisfy community concerns about the location of the battery. A range of possible locations were identified and investigated and once a preferred alternative location was identified an agreement was negotiated with the land owners. In May 2014, the grid battery was commissioned at a site within the Sydney Olympic Park managed by the Sydney Olympic Park Authority (SOPA).

The grid battery was connected on the supply-side of the customer's meter with customer loads at the site consisting of irrigation pumps for the local parkland and the SOPA Building 46 facility within the Newington Armoury precinct. Building 46 is an ex-munitions storage facility now used as an education centre and which includes a 64kWp solar system with 10 inverters. The final location for the battery was under a road bridge adjacent to a pedestrian and cycle path. This location was selected so as to reduce the visual impact on the park.

The SOPA Building 46 facility, 64kWp solar system and irrigation pumps were the only loads connected to the low voltage distribution centre (Holker Street Jamieson No 2, S7637) to which the battery was connected. This location allowed trials to be conducted with a focus on some of the secondary trial objectives such as testing solar smoothing and storage that might benefit the customer. The Holker Jamieson No 2 distribution centre was the first low voltage transformer supplied from 11kV feeder 13 from Homebush Bay zone substation.

The maximum peak output of the battery was 60kW which is significantly smaller than the demand on a typical 11kV feeder. The maximum demand for 11kV feeder 13 was around 3.5MVA during summer 2012/13. As the 60kW peak output of the battery would only be 1.7% of maximum feeder demand, its impact would not be noticeable outside of the standard variation of network demand.

To ensure that the smaller battery system met the primary trial objectives of testing the network peak reduction potential, the 11kV feeder was temporarily reconfigured for the trial so that only two low voltage distribution centres were connected to the 11kV feeder (see Figure 1). This reduced the maximum peak load of the feeder to around 400kW; thereby increasing the potential impact of the battery to about 15% of the peak load. Note that due to unavoidable network operation requirements, for part of the trial the 11kV feeder configuration was switched from the preferred trial configuration of two distribution centres to one where the feeder supplied six distribution centres. During this period testing focused on secondary objectives that were not impacted by the feeder change. The second distribution centre included in the trial was Blaxland Plover (S4595) which supplies power to a predominantly residential area consisting of apartments and townhouses with solar power systems.

The 11kV and low voltage distribution networks in the Newington area are comprised of underground cables that are relatively new (constructed in 1999). This network area is typical of Ausgrid's suburban Sydney network which is a very dense network, with high capacity, low impedance cables. This type of network is typically resistant to power quality issues.

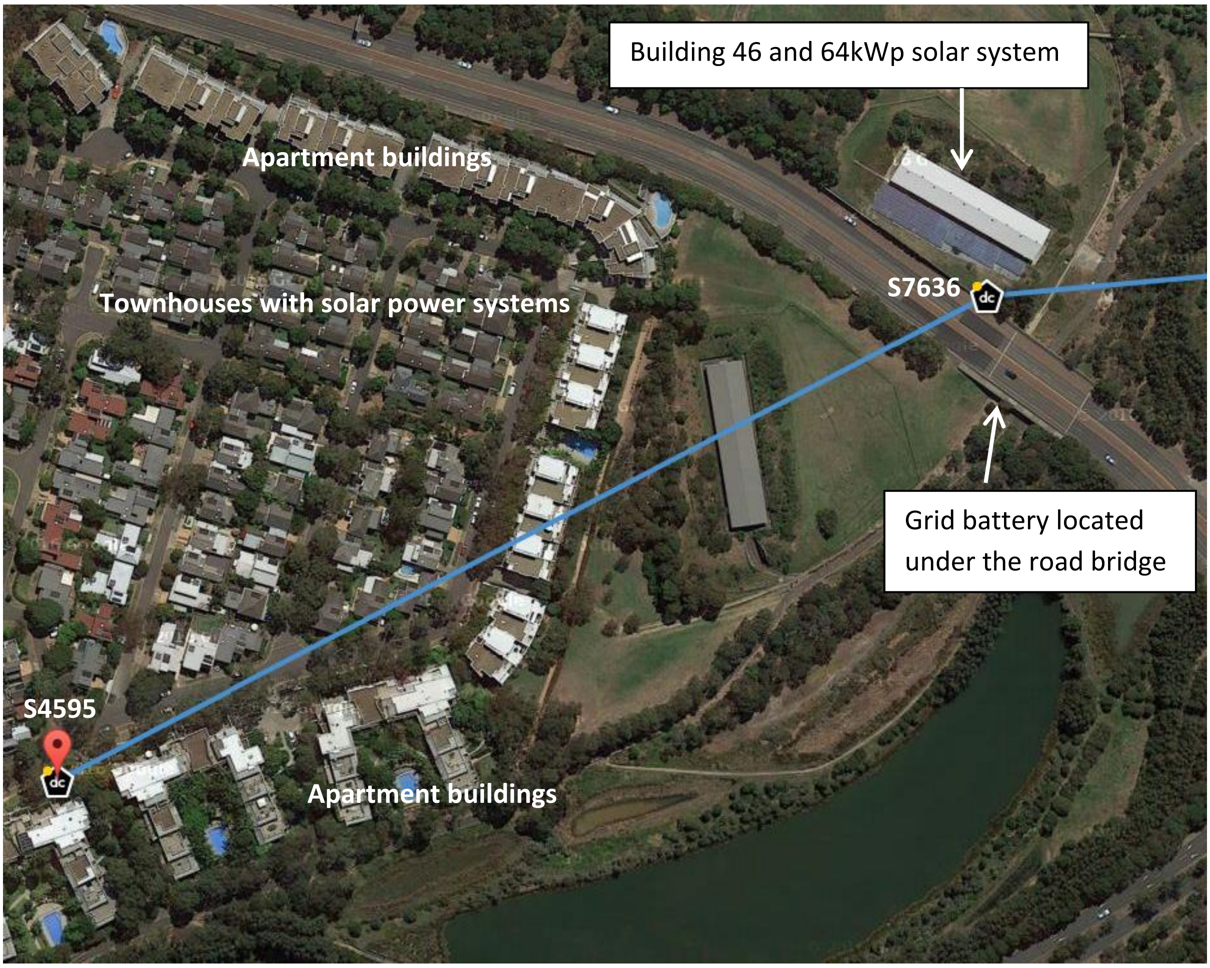

Figure 1 – Aerial imagery of 11kV feeder configuration for trial

Table 2 summarises the number of customers and loads connected to the two distribution centres for the summer peak reduction trials.

	1st DC	2nd DC	Total feeder
Distribution Center Name	Holker Jamieson No 2	Blaxland Plover	
Distribution Centre No.	S7637	S4595	
Total customers	1	322	323
Total solar power systems	1	90	91
Total solar system capacity (kWp)	64	90	154
Apartments	0	210	210
Townhouses	0	91	91
Other customers	1	21	22
Other customer loads	Grid battery, Building 46 and irrigation pumps	Residential strata, small businesses	

Table 2 – Summary of customers in the project trial area

2.5 Battery storage system

The battery system was leased for the period of the trial and consisted of 120kWh of Lithium Ion batteries and three 20kW inverters (one per phase) giving a total power output capacity of 60kW, contained within a standard 20 ft shipping container.

Battery Specifications

Container Dimensions – 2.9m (H) x 2.43m (W) x 6.09m (L)
Weight - 11.34 tons
Cooling System - Inbuilt air-conditioning unit to ensure ambient temperature remains at 25 degrees Celsius.
Inverter type – Three 20kW four quadrant inverters
Battery Technology – Lithium Ion (120kWh)

The battery had its own dedicated isolation equipment and metering equipment inside the shipping container. In addition to the meter measuring the battery input and output (LV Meter 2), two additional metering devices were installed that were integrated with the Battery Management System (BMS) to enable some of the automated battery functions used for the network peak reduction, solar smoothing and customer benefit trials. A schematic is shown in Figure 2.

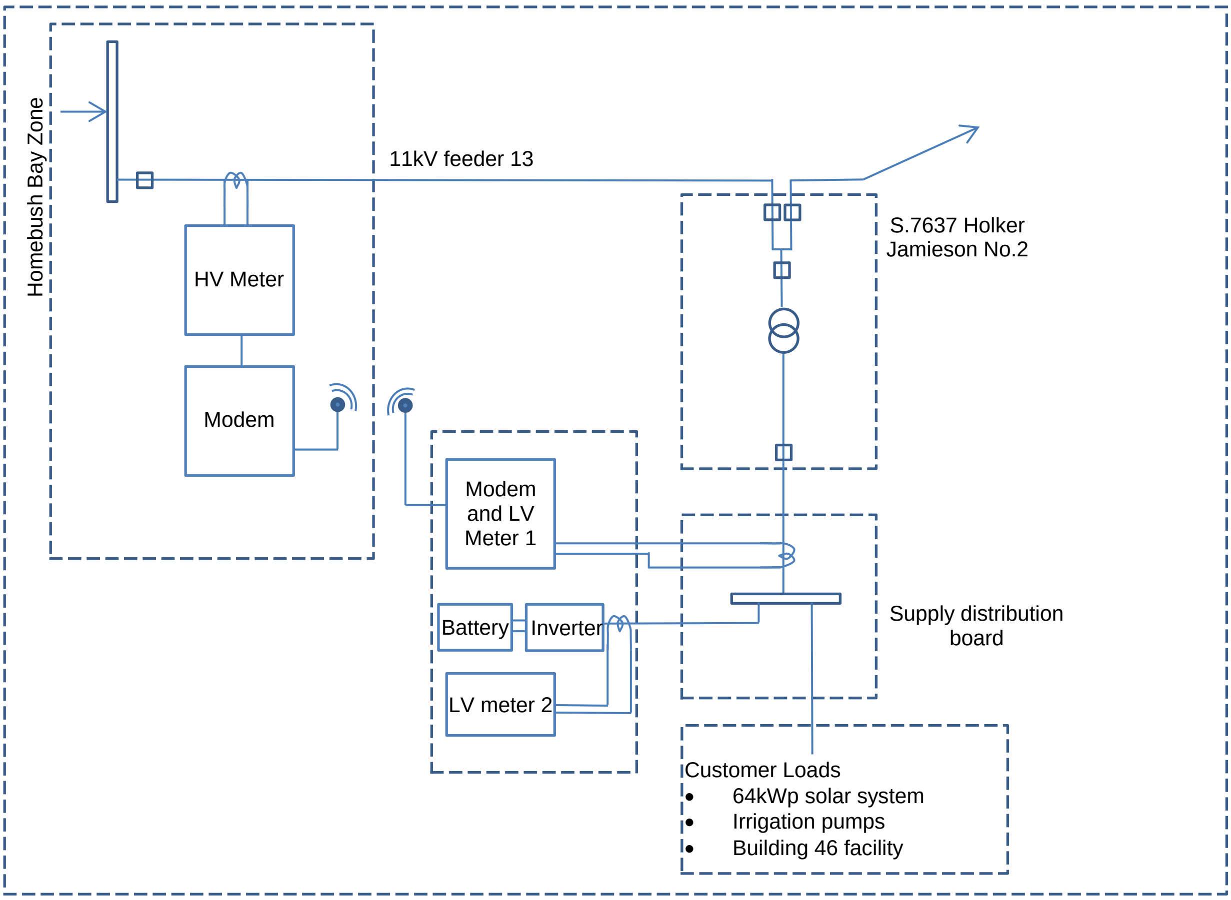

Figure 2 - Schematic of battery connection and metering arrangement for the BMS

A brief description of the two additional meters is as follows:

1) Low Voltage Meter 1 (LV Meter 1) measured the total low voltage distributor load from the S7637 transformer, both the SOPA customer loads and the battery. This meter was located inside the battery with current sensors and sensor wiring directly connected between the meter and load measurement point. This meter was used by the battery management system for automatic operation of the battery according to the low voltage loads on the S7637 distribution centre.

2) High Voltage Meter (HV meter) located within Ausgrid's Homebush Bay zone substation measured the total load on the 11kV feeder (panel 13). The meter had remote communications via a modem. This remote network measurement device of the feeder load was used by the battery management system for automatic operation of the battery according to the 11kV feeder load.

An important part of the trial was testing the reliability of the battery to automatically operate based on a separate remote measurement point of the network load (HV meter).

There were four main operating modes offered by the battery management system that were used for the trials. These were:

1) **Constant Power** – charge and discharge the battery at a constant kW and kVAr level set by the user until the energy in the battery can no longer support it.

2) **Load Management** – battery aims to maintain the net demand or generation on the network to a level set by the user until the battery is either full or empty. This function could be used to limit the level of load on a feeder or distributor by discharging the battery or to absorb the output of distributed generation by charging the battery.

3) **Target state of charge** – the user sets a target state of charge, and a time frame to achieve it. If the target state of charge is higher than the current state of charge, the battery will charge. If the target state of charge is lower than the current state of charge, the battery will discharge. The battery will regulate the charging or discharging of the battery to achieve the required state of charge by the time specified.

4) **Ramp rate control** – the user sets a bandwidth which if the battery exceeds within a set timeframe, the battery will charge (if the net load falls below the bandwidth) or discharges (if the net load exceeds the upper limit). This function can be used to smooth out the variation of load or intermittent generation sources such as solar or wind generation.

In addition to the meters installed as part of the battery management system, there were additional measurement equipment installed by Ausgrid to measure power quality impacts. These included

- Power quality measurement equipment on the high voltage feeder at the zone substation
- Power quality measurement equipment on the low voltage network at the S7637 distribution centre and at the battery connection point
- A standard Ausgrid interval meter installed at the battery connection point to measure total battery system import and export values

2.6 Project timeline

<table>
<tr><td rowspan="8">Project development and setup</td><td rowspan="3">2013</td><td>October</td><td colspan="2">Investigation of battery location options
Council Approval – 14th of October 2013
Formal Letter of Request to SOPA – 23rd of October 2013</td></tr>
<tr><td>November</td><td colspan="2" rowspan="3">Development of detailed trial design
Detailed network connection design
Licence Agreement drafting - 30th of January 2014</td></tr>
<tr><td>December</td></tr>
<tr><td rowspan="12">2014</td><td>January</td></tr>
<tr><td>February</td><td colspan="2">Environmental Impact Statement – 17th of February</td></tr>
<tr><td>March</td><td colspan="2">Licence Agreement Signed – 14th of March 2014
Site Layout Design – 18th of March 2014</td></tr>
<tr><td>April</td><td colspan="2">Protection Design – 14th of April 2014
Site preparation</td></tr>
<tr><td>May</td><td colspan="2">Site preparation
Battery Commissioned on 24th May</td></tr>
<tr><td rowspan="11">Trial Period</td><td>June</td><td rowspan="10">Feeder configuration

1. May 24th to Oct 22nd (Original SGSC configuration: 9 low voltage DCs)

2. Oct 22nd to Nov 25th (Trial configuration: 2 low voltage DCs)

3. Nov 25th to Dec 30th (Temporary configuration: 6 low voltage DCs)

4. Dec 30th to Mar 29th (Trial configuration: 2 low voltage DCs)</td><td rowspan="10">Trials conducted

Various trials were performed throughout the whole trial period, alternating to achieve the project objectives:
• Peak demand reduction
• System reliability
• Round trip efficiency
• Power quality
• Solar PV smoothing
• Customer benefits
• Customer benefits with network control</td></tr>
<tr><td>July</td></tr>
<tr><td>August</td></tr>
<tr><td>September</td></tr>
<tr><td>October</td></tr>
<tr><td>November</td></tr>
<tr><td>December</td></tr>
<tr><td rowspan="4">2015</td><td>January</td></tr>
<tr><td>February</td></tr>
<tr><td>March</td></tr>
<tr><td>April</td><td colspan="2">Battery decommissioning and make good of site</td></tr>
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Table 3 – Project timeline and overview

3 Network Peak Reduction

The trial objective with the highest potential value to Ausgrid was the opportunity to use grid connected battery systems for peak reduction. Reducing the peak demand on an asset can enable significant savings for networks by facilitating the avoidance or deferral of network investments to build additional network assets. These savings are ultimately passed on to customers in the form of lower bills.

For example, if the load on an 11kV feeder was predicted to exceed the rating of the feeder by a certain amount for 5 to 10 days of the year, the preferred network solution might be to expand the 11kV network to cater for the additional load. A demand management alternative considered would be to reduce the load on the 11kV feeder by the excess amount on these days such that we could defer the need to invest in network assets.

The objective of this component of the trial was to test the ability of the battery system to reliably reduce the peak demand on an 11kV feeder.

3.1 Battery operation modes for peak reduction

There are two different battery operation modes which were available to reduce peak demand; the load management function and the constant power output function.

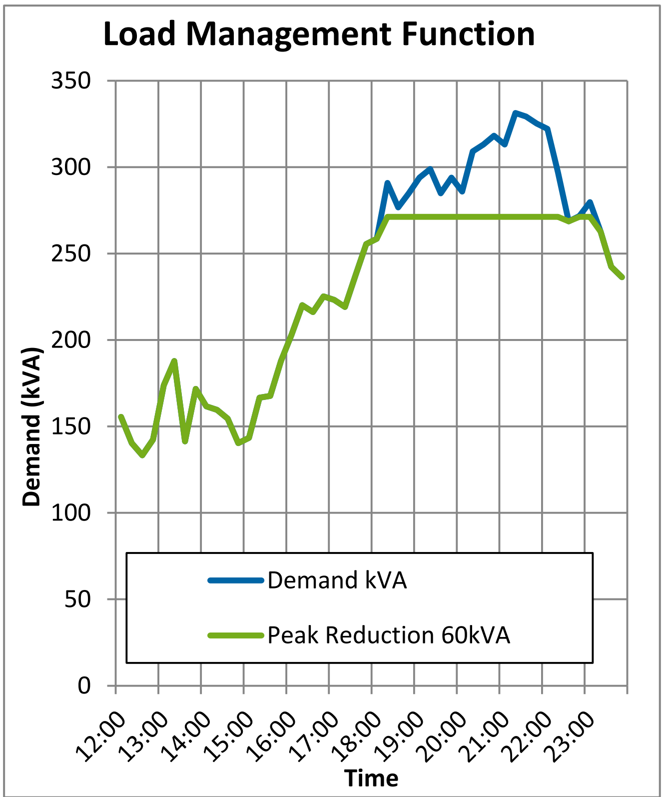
The **load management** function limits the net load to a specified level for the time specified, or until the battery is exhausted. The benefit of using the load management function is that the energy discharged from the battery only occurs if the load exceeds the set threshold. A possible application of this function would be to set a threshold to keep an asset loading below an equipment rating. This function allows a better utilisation of the available battery storage capacity as the battery system only discharges at a power above the set threshold. However, one important consideration when using this functionality is that the installation of a measurement device on the asset load of interest is required. This device must work reliably as an input into the battery management system.

The **constant power output** function, as the name suggests, discharges a set output for the specified time, and would guarantee a set reduction during that time. One of the considerations for using this type of operation is that the battery only has a certain amount of storage capacity at full power output. For this battery, there was only a nominal 2 hours of storage capacity at full power output, so the peak load would need to be predicted within a 2 hour window to reduce the peak by the full power output of the battery. Alternatively, a bigger time window could be specified at a reduced rate of power output.

Using a typical load profile, the two different methods of peak reduction are compared in Figure 3. For the load management function the load threshold was set to 270kW. For the constant power output function, the full power discharge time was from 20:15pm to 22:15pm. For this illustrative example, the load management function would have been more effective at reducing the network peak load.

For the peak reduction trials the load management function was the main battery operation mode used. Rather than choosing a single threshold value for the whole duration of the summer peak reduction trials which would only be reached on a handful of days, the threshold value was selected for each trial day so that the battery functionality could be extensively tested. The threshold value set for each day involved predicting the maximum feeder load and setting the load management function to start operating at 60kW below this predicted feeder peak load.

In order to predict the feeder load, a short term load forecasting tool was developed in order to predict the peak load of the feeder (consisting of the two distribution centres) on each summer day during the trial period. The peak prediction model developed for the trial was based on a neural network, and the inputs were the previous days load profiles and the forecast temperature for the predicted day. Overall, the short-term load forecasting tool, tended to under-predict the maximum peak feeder load with an average prediction of 93% of actual, ranging from 78% to 128%.



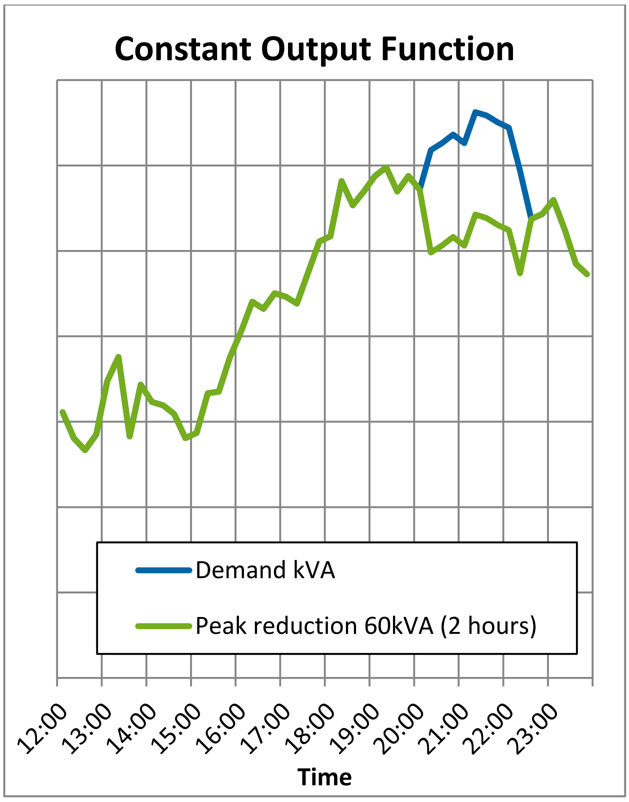


Figure 3 – Comparison of battery operation modes for peak reduction

To compare the two different battery operation modes, the constant power output peak reduction mode was also tested during the summer peak demand period.

3.2 Summer peak reduction trial results

Figure 4 shows a successful peak reduction trial result using the load management function. On January the 14th 2015 a peak reduction trial was run where the load management function was set to a limit of 340kW resulting in reducing the peak demand on the feeder by 43kW. The short term load forecasting tool predicted a peak load of 400kW and the threshold was set at 60kW below this value. This represents utilisation of around 72% of the peak power output of the battery.

Alternately, Figure 5 shows the results from a test dispatch on the 9th of January 2015 where operation of the battery failed to reduce the peak demand. The peak prediction for the 9th of January of 390kW led to a load limit of 330kW being set. The actual peak demand on the day was 415kW. The result of the under-estimation, the longer peak period and the later time for the peak demand on this day meant that the energy of the battery was exhausted before the maximum demand was reached at about 10:30pm. Due to the battery being exhausted before the peak demand period finished, the load experienced by the network from the feeder was the full peak load, therefore making the battery discharge of no value in reducing the maximum demand.

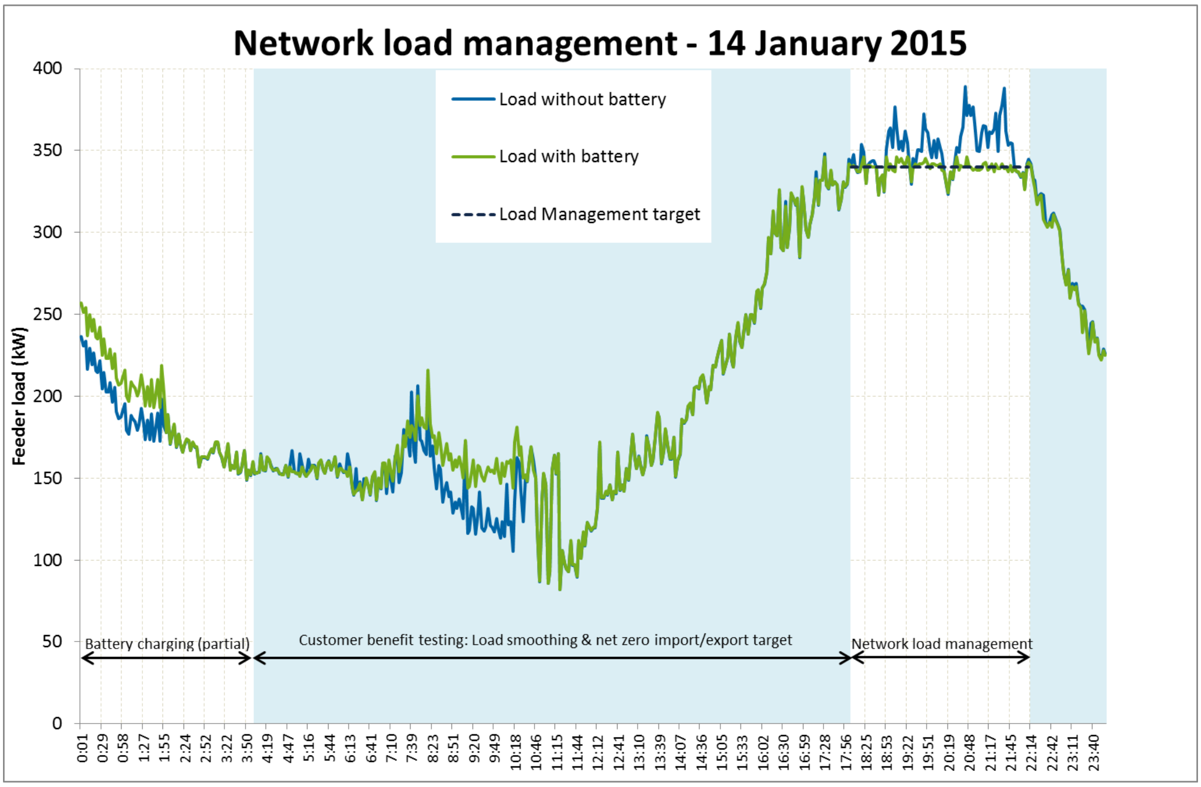


Figure 4 – Peak reduction trial on January 14th 2015

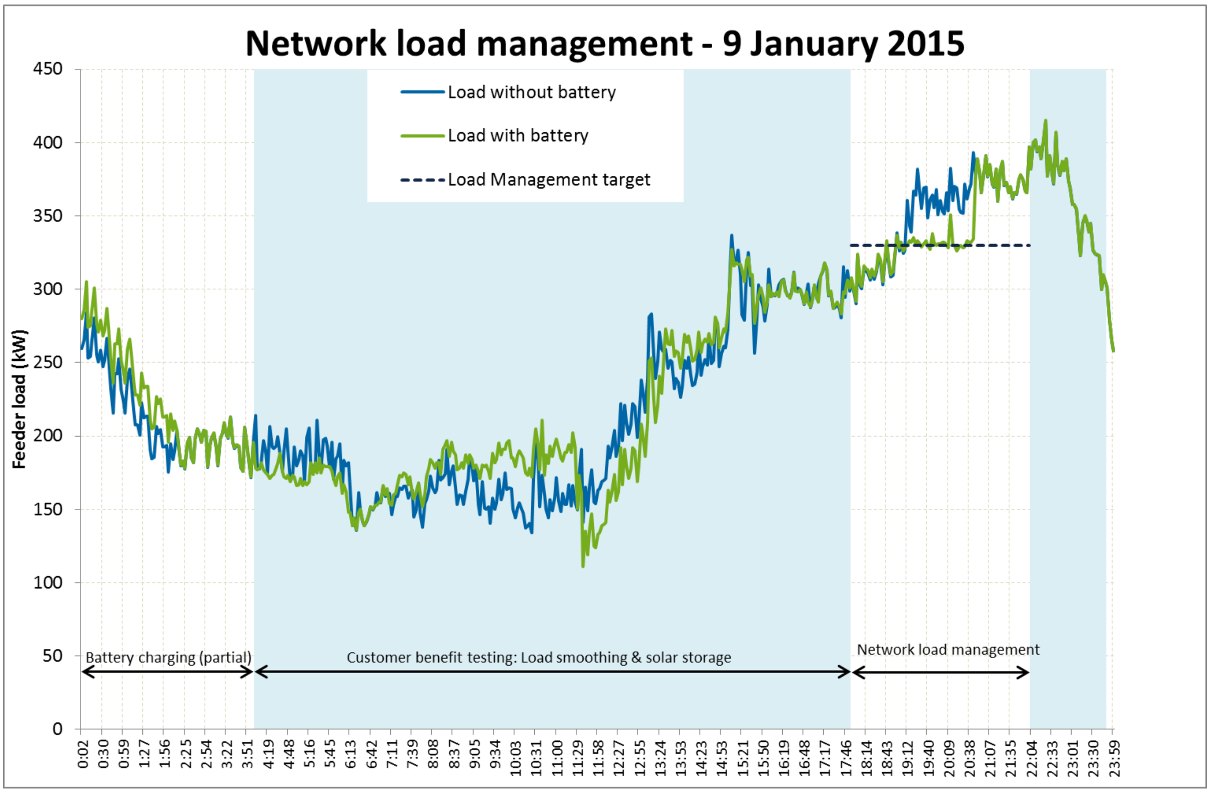


Figure 5 – Peak reduction trial on January 9th 2015

For an example of the constant power output function, on the 8th February this mode was used to discharge power at 30kW from 6:00pm in order to reduce the feeder peak load. The results from this trial day are shown in Figure 6. It can be seen that the battery runs out of energy storage capacity at about 9:00pm resulting in no significant reduction in the peak load on this day.

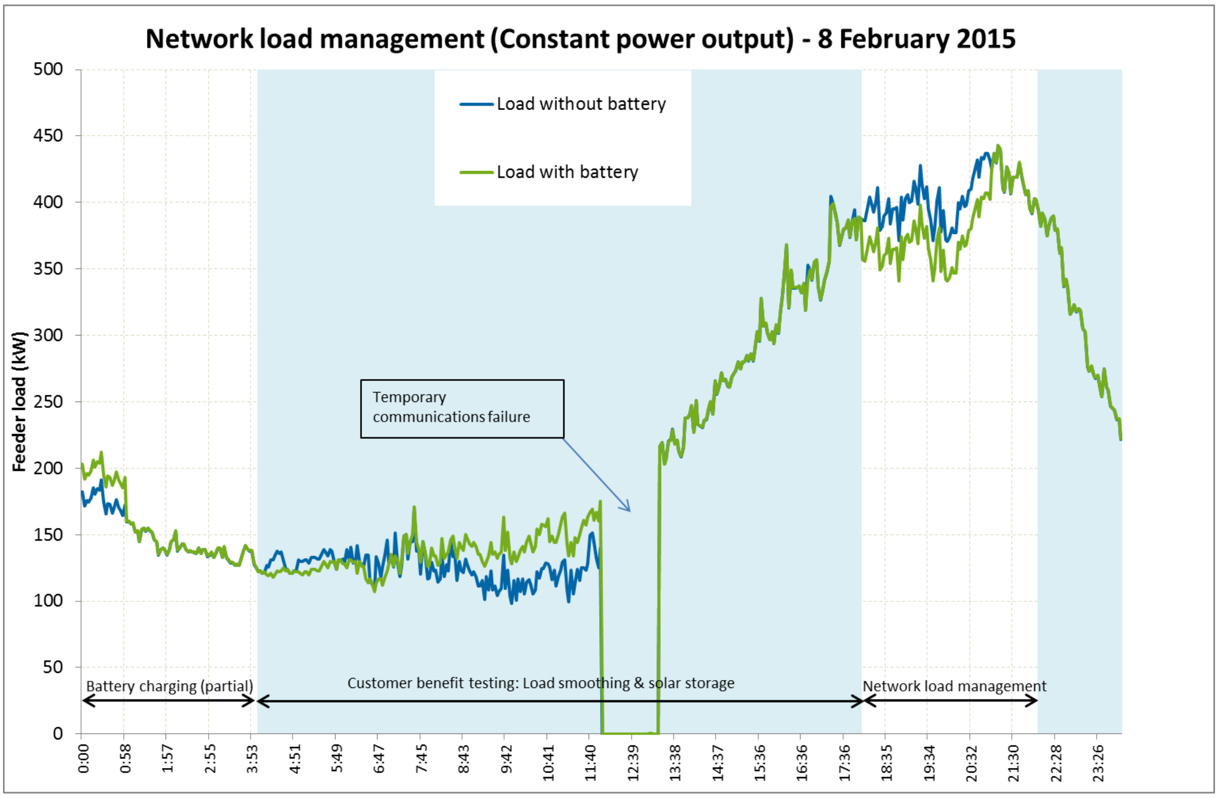


Figure 6 – Peak reduction trial on February 8th 2015

For days where the battery operated as per the planned operation of the battery, there was no occasion when the peak reduction achieved approached the full 60 kW capacity of the battery. Table 4 shows the results from nine trial days where the feeder peak load was above 350kW.

Day	Peak reduction trial description	Peak with battery (kW)	Peak without battery (kW)	Reduction (kW)	Reduction as % of battery power	% feeder load reduction
6/01/2015	Load management (290kW)	349	373	24	40%	6.4%
7/01/2015	Load management (335kW)	340	360	20	33%	5.6%
8/01/2015	Load management (325kW)	335	370	35	58%	9.5%
9/01/2015	Load management (330kW)	415	415	0	0%	0.0%
14/01/2015	Load management (340kW)	346	389	43	72%	11.1%
8/02/2015	Constant power (30kW)	443	443	0	0%	0.0%
15/02/2015	Constant power (30kW)	343	353	10	17%	2.8%
16/02/2015	Constant power (30kW)	352	352	0	0%	0.0%
4/03/2015	Load management (275kW)	360	360	0	0%	0.0%
				Average	24%	4%

Table 4 – Summary of summer peak reduction trial results

As shown in Table 4, the average peak reduction was approximately 24% of the 60kW full power output of the battery system, with four of the nine peak demand days achieving no load reduction as the battery ran out of energy storage capacity before the peak was reached. The trials demonstrate that the load management function worked well on some days with effective utilisation of the available battery storage capacity. However, on days where the battery storage capacity was exhausted prior to the end of the peak period, there was no or limited effectiveness in reducing peak demand.

An assessment of the trial dispatch events indicate several reasons why the reduction in peak demand was much smaller than the maximum power output of the battery.

The principal reason is due to the amount of energy the battery is capable of storing. The battery was capable of discharging the full 60kW for only two hours, and frequently the energy stored in the battery was exhausted before the peak demand had occurred. This ratio was not suitable for the required peak reduction application. For example, on the 9th January (Figure 5) the energy storage capacity would need to be about double in size to effectively reduce the peak to the target 330 kW. This is further impacted by the usable capacity of the battery which typically is about 80% (96kWh) to 90% (108kWh) of the rated storage capacity. For this battery, this allowed about 1 hour 36 minutes to 1 hour 48 minutes of discharge at full power output. Deeper discharging of the battery was possible, but this would have had a negative effect on battery lifetime.

Another reason for the lower peak reduction results was the nature of the trial, and the necessity to predict the daily peak load or time of peak for each trial day. For a real application, a threshold would be set which would be related to a network constraint or load situation and the battery would not be required to operate on days of lower load.

3.3 Discussion

When considering the value to networks of using battery storage systems for peak reduction, the limit of stored energy is a significant consideration as a battery may exhaust stored energy during a peak reduction event if it is not sized appropriately. The two main battery storage system specifications to consider when selecting the size of the battery for this application are the usable energy storage capacity (kWh) and peak power output (kW) which in this case was 120kWh/60kW, giving an energy/ power ratio of 2. This allows two hours of energy export at full power. By sizing a larger battery storage capacity for a given power output, this limitation would be alleviated, but the battery system cost is likely to increase for a given power output as the majority of battery system costs are currently related to the battery costs. As battery prices continue to decrease this may make larger battery systems more affordable such that this concern may be less of an issue.

More advanced battery management functions, such as the load management function used in these trials potentially increase the utilisation of the existing battery capacity meaning a smaller battery storage capacity may be required to limit a network load to a certain threshold. However, these automated functions require reliable remote network measurement devices that can be integrated with the battery management system in order to work effectively. The reliability on the total system performance when these extra devices are included is discussed in section 4.

When considering the potential application of using a battery system as a demand management solution to defer a network investment, a comparable solution might be the use of a relocatable diesel generator. While other options such as customer demand response (load shedding or generation), where available, can often offer a lower cost alternative to relocatable diesel generators, diesel generators offer a useful benchmark for performance and price in that they are both likely to be viable for most network needs. Ausgrid has considerable experience using leased relocatable diesel generators for past demand management projects.

The typical implementation of a temporary generator solution for a network need generally involves siting and connecting the required MW capacity of generators for one or several seasons to address a specific network need. The generators are often only operated on a few peak demand days per season for 4 to 8 hours when the asset load reaches a certain threshold. Because of the low operation hours there is minimal fuel cost or environmental impact. The total project cost from using a leased temporary diesel generator solution to meet a network need is typically about $125 to $200 per kVA per year.

Aside from the current difference in equipment costs, the most significant difference between using a battery system and diesel generator for peak reduction is that the total energy stored is significantly larger for a generator and only limited by the amount of diesel stored on site. For the battery trial conducted on the 9th of January 2015 (Figure 5), if a diesel generator was installed instead of a battery, it is highly unlikely that the energy stored in the generator would have been exhausted. In this situation, the total demand reduction would have been the full power output capacity of the generator as it could have run during the whole peak period at full capacity.

A recent example of an application of an embedded generator for an Ausgrid network need for which battery storage might offer a viable solution in the future was in the Medowie area in 2011/12 and 2012/13. In this instance, leased relocatable diesel generators with a total rated output of 5.0 MVA were installed over two summers to reduce the risk that the load on two 11kV feeders would exceed their license conditions. The total project cost over the two years was $1.7 million which is equivalent to about $170 per kVA of embedded generation capacity per year. The generators were installed with sufficient fuel capacity for the whole summer season such that refuelling would not be required, and the leasing company offered a full maintenance service solution with control of the generators remotely operated by the Ausgrid control room.

In January 2013, the load on the Medowie feeders reached their license condition on five occasions and the diesel generators were operated to reduce demand on the feeders. The generators operated from 2 to 6.5 hours on these days in order to reduce the demand on the feeder by up to 3.4 MW. To achieve an equivalent demand reduction similar to that of the relocatable diesel generators in the example above, an equivalent battery storage system would have needed up to 22 MWh of usable energy storage capacity to operate at 3.4 MW power output for the longest duration of 6.5 hours on the 18th January 2013.

Although battery storage systems are currently more expensive than other similar demand management solutions, this technology does offer other environmental advantages over diesel generators, including noise and exhaust emissions. As battery costs decline, this technology may offer a cost effective alternative to relocatable diesel generators and other forms of demand management such as demand response.

4 Battery Performance and Reliability

In order for battery storage systems to be considered for use in network support situations, utilities need to be confident that the battery system as a whole will perform to an acceptable level of reliability for the purposes it was installed. It was therefore important that we tested the reliability of operation of the whole battery system on summer peak days including the relevant battery functions and systems which would need to work reliably to reduce network peak load.

In addition, it was important to understand the total discharge-charge or round-trip efficiency of the battery system, as previous battery trials under the Smart Grid Smart City project found that the total system round-trip efficiency can be significantly lower than the battery alone or individual components. The total battery storage system discharge-charge efficiency will not only include the DC charge and discharge efficiency of the batteries but also inverter efficiency, as well as energy consumption of other necessary systems such as battery management and control, safety systems (eg. fire protection system) and cooling systems.

The battery system incorporated an air conditioning system to provide cooling for the Lithium ion battery. This has the advantage of keeping the battery cool on hot summer days thereby increasing the stability of the system on hot summer days but with the potential disadvantage of reducing the total round trip efficiency of the battery system when the air conditioner is used during summer peak periods. This is particularly important for customers to better understand if they are considering installing a battery system.

4.1 Reliability of battery system operation

The overall reliability of the whole battery system in operating as planned during the trial was 67%. Figure 7 shows the monthly availability of the battery system for the intended trial operation.

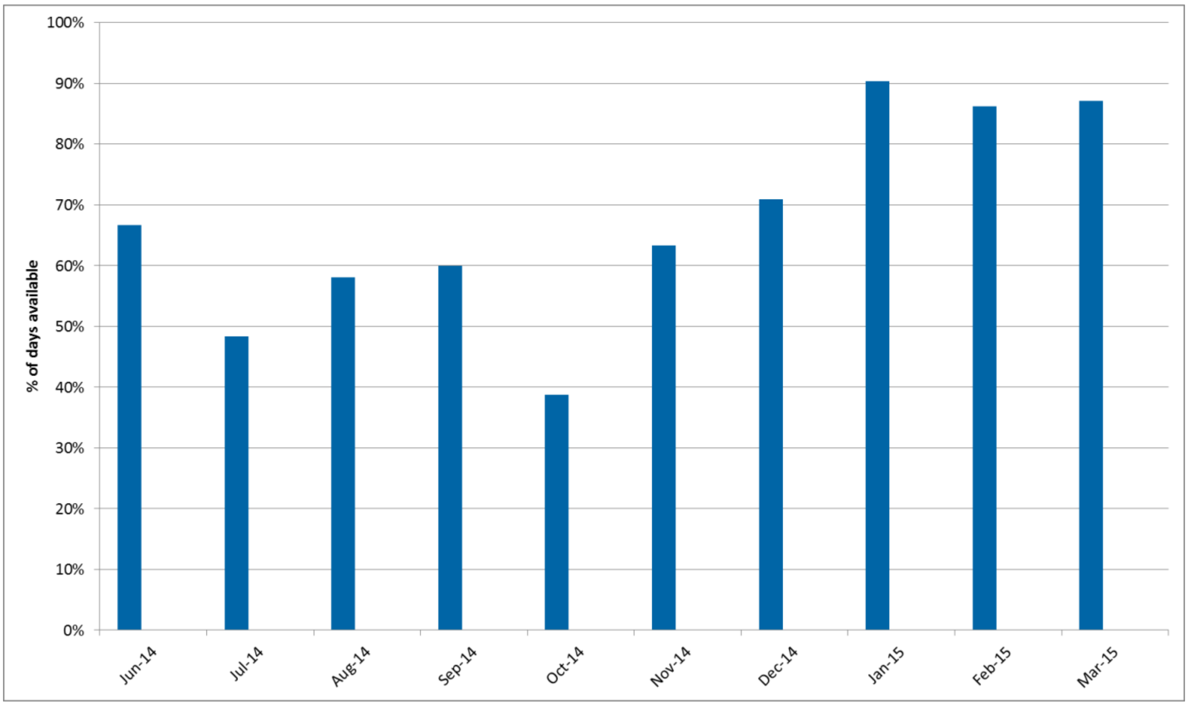


Figure 7 – Battery system availability

The graph shows that the availability for the battery was poor prior to January 2015 with an average availability of 56%. The lowest month was October with an availability of only 39% mainly due to technical issues with the HV Meter located at the zone substation. Most of the reliability issues of the battery system were due to technical and communication issues with this remote meter and integration of this data source with the battery management system. The operation of this functionality was problematic before November, offered intermittent reliability during November and December and reasonably reliable operation during January to March.

A reliable communications link between this meter and the battery system was required for the battery management system to operate the feeder load peak reduction trials effectively using the load management function. There were also technical issues during the trial with other components such as inverters and low voltage meters that needed to be resolved. A possible contributing factor was that support for the battery control system was conducted from overseas which caused delays in making improvements or solving technical issues associated with the battery system operation. Following extensive efforts to resolve key issues, reliability of the battery system improved to about 90% in January, February and March 2015.

While the battery system reliability experienced would not be considered sufficient for such a solution to be viable for network support, we are confident that these issues will be resolved in future as product development by the battery storage system industry irons out issues such as these.

4.2 Battery round-trip efficiency

As outlined in section 2, a separate electricity meter was installed by Ausgrid at the connection point of the battery to the local network in order to measure import and export energy. Data from this meter was used to measure the total round-trip efficiency of the battery storage system. Over the entire 10-month period of the trial (June 2014 to March 2015) the total import of electrical energy into the battery system was 29,355 kWh and total discharge of electrical energy from the battery system was 20,569 kWh. This gives an overall discharge / charge efficiency or round trip efficiency of 70% over the entire trial period regardless of whether the battery system was being used or operational in certain months. This efficiency value might have been affected by the power consumption of the battery system when it was not charging or discharging, which averaged around 360 Watts in winter and 600 Watts in summer.

Daily efficiencies were also measured using the same pre-determined constant power charge / discharge profiles on days in both summer and winter in order to determine the impact of higher summer temperatures on battery efficiency. Aside from any ambient temperature effects on the battery, the efficiency would have been affected by the air conditioning unit used to maintain a safe operating temperature for the Lithium Ion battery. Note that the efficiency may have benefited from the selected location of the battery under a bridge, shaded from direct solar radiation.

The daily efficiencies were calculated on days when there was a single charge and discharge of the battery to varying depths of discharge. The daily efficiency calculations included consideration of the power consumption from the battery system when it was not being operated during the day. Table 5 shows the results from six days comparing the summer and winter daily efficiencies.

Profile Description	Depth of Discharge	Winter		Summer	
		Date	Efficiency	Date	Efficiency
Constant power charge and discharge at 30kW between 15% to 95% state of charge	80%	6/8/2014	78.5%	11/2/2015	73.6%
Constant power charge and discharge at 30kW between 20% to 85% state of charge	65%	9/8/2014	76.7%	14/2/2015	71.4%
Constant power charge and discharge at 30kW between 20% to 80% state of charge	60%	8/8/2014	76.4%	13/2/2015	70.6%

Table 5 – Daily discharge / charge efficiencies

The results from Table 5 show that the daily discharge / charge efficiency was around 5% to 6% higher in winter than summer due primarily to the higher power consumption of the battery system in summer when in stand-by. The influence of the standby power requirements on the battery system efficiency can also be noticed in the difference in the depth of discharge for each test. When the used depth of discharge of the battery is lower the daily efficiency decreases because the standby power consumption is a bigger overall percentage of the usable discharge energy. The standby power consumption of the battery system was approximately 8.6 kWh per day in winter and 14 kWh per day in summer, or around 7% to 12% of the battery energy storage capacity of 120kWh.

4.3 Discussion

For batteries to be considered as a feasible alternative to network investment the reliability and dependability of using a battery storage system needs to be comparable to other alternatives. As mentioned earlier in section 3, Ausgrid has extensive experience of deploying relocatable diesel generators; a relatively low cost, reliable demand management option currently available for addressing a network need. When using relocatable diesel generators for peak reduction applications Ausgrid has not experienced any significant reliability concerns.

The reliability and availability of the battery storage system used in this trial would not be considered sufficient to allow Ausgrid to have a reasonable level of confidence to use this technology in a peak reduction application. Notably, the major issues with reliability during this trial have largely come from issues outside of the battery itself. The difficulties were mainly due to performance issues with communications equipment and the battery management system. Although peripheral to the battery technology itself, the functioning of all aspects of the battery system and service delivery is critical for the technology to be fully functional and able to perform peak reduction tasks. Improved performance late in the trial would indicate that these issues can be resolved and so may not be an issue by the time battery costs are more competitive with alternative solutions.

The reliability of using the battery system for peak reduction would most likely have been higher if the constant power output function had been used as it did not rely upon a remote measurement device as a function input to the battery management system. However, in this case, a larger battery storage capacity would be required to achieve similar demand reductions.

Another important consideration is the long-term performance of the battery system and degradation of the battery capacity for both owners and users of leased equipment. Unfortunately, the trial was not long enough to make any conclusive observations in regards to this aspect.

Finally, when considering the discharge / charge (or round trip) efficiency of a battery storage system, it is important to consider the whole system including power consumption from the auxiliary loads and control equipment. The battery storage system round trip efficiency tested as part of trial was around 70% for the whole trial period. The daily round trip efficiency typically ranged between 70% to 78% depending on the season and depth of discharge. The daily discharge / charge efficiency was about 5% higher in winter than summer due to the higher power consumption of the battery system in summer from the cooling system. The main influencing factor for these lower than expected round trip efficiencies was the high standby power consumption as a proportion of usable energy storage capacity. This efficiency would be improved for a larger battery energy storage capacity, provided that the standby power consumption is largely unchanged.

Note that the round trip efficiency may not be a major consideration for the application of a grid-connected battery where electricity use is not a major cost component of a project. However, consideration of energy efficiency of the whole battery storage system is particularly important for customers considering purchasing a battery system as it will directly affect the overall cost benefit. Customer bill benefits from installing a battery system is discussed further in section 6.

5 Solar Smoothing and Power Quality Impacts

With the growing interest in both distributed generation (solar PV) and distributed storage (batteries), there is also a growing concern over the potential impacts on power quality and grid stability. Of particular interest is the impact on the network from large increases in connected renewable energy sources (solar and wind) which are inherently intermittent in nature. Solar PV generation, for example, varies as the amount of cloud covers the solar panels. The original location of the trial in Newington and final location of the battery (connected to a 64kWp solar system) was chosen to be able to exploit the existing penetration of solar PV systems. The objectives of the testing was to determine if the grid connected battery had a significant effect on the customer and network power quality parameters.

5.1 Ramp rate control function results

The objective of this part of the trial was to test the ramp rate control battery function that could be used for alleviating the variability associated with intermittent solar generation. The high levels of solar penetration in the trial area, at both the low and high voltage level, allowed the opportunity to trial this battery function for potentially alleviating impacts on the network or the customer supply. This variation in generation levels can affect the power quality, particularly with regard to flicker, which is a measure of the rate of change of the voltage level. Flicker levels are said to be unacceptable when the naked eye can observe a light flickering.

The graph below shows the one minute load on the 11kV feeder when the battery was operating in the ramp rate control mode using the LV meter 1, thereby acting to smooth out the solar intermittency caused by the 64kW solar system. It is observable that the load on the feeder without the battery is more variable than the net load of the battery and feeder combined. The battery can be seen to ‘smooth’ out the variation from the intermittent nature of the 64kW solar system.

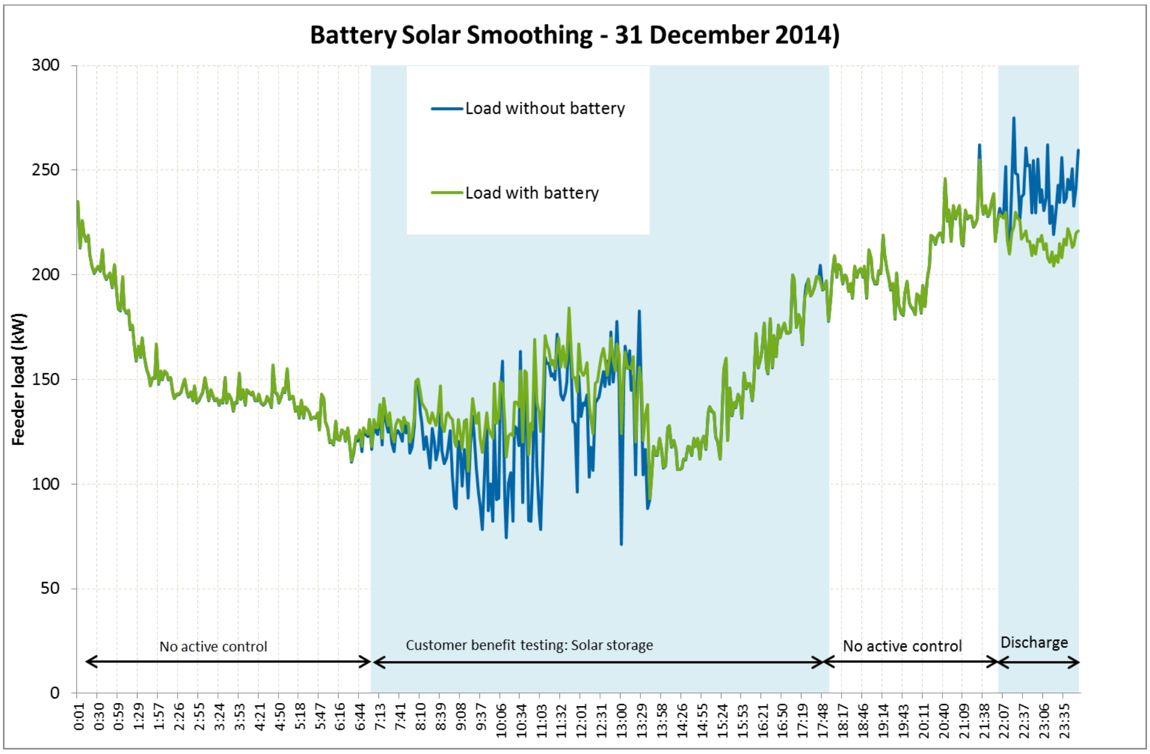


Figure 8 – Ramp rate control results

While the ramp rate control function smoothed the variation in the load on the feeder, there was no observable effect on the flicker values when the power quality data was analysed.

5.2 Power quality impacts

The impact of the battery operation on other power quality parameters was also analysed using data collected from the various power quality measurement devices installed on the 11kV feeder and low voltage network supplying the battery and SOPA customer loads. Various modes of battery operation testing was conducted over the duration of the trial including operation of the battery aimed at alleviating the impacts of high penetration solar and to try to increase the potential impacts by discharging the battery during times of high levels of solar generation.

The power quality parameters analysed included frequency, voltage unbalance, voltage level, total harmonic distortion (THD) and flicker. Generally, analysis was based on power quality data for a continuous one-week period at a specific site to determine if the power quality parameters complied with the limits given by the relevant Australian Standards (AS) and the National Electricity Rules (NER). A summary of the nine weeks where the power quality parameters were studied in more detail is shown in Table 6. This table indicates if the battery was functional during the week, whether the feeder was in the main trial configuration (two distribution centres) and the trials that were conducted during that week.

Trial Period Description	Battery Functional	Feeder switched for trial	Trials		
			Solar smoothing	Peak reduction	Customer benefit
Week 1 – starting 14/7/14	No				
Week 2 - starting 4/8/14	Yes			Yes	
Week 3 - starting 13/10/14	No				
Week 4 - starting 26/10/14	No	Yes			
Week 5 - starting 22/12/14	Yes		Yes		
Week 6 - starting 4/1/15	Yes	Yes	Yes	Yes	
Week 7 - starting 11/1/15	Yes	Yes	Yes	Yes	
Week 8 - starting 13/2/15	Yes	Yes		Yes	Yes
Week 9 - starting 1/3/15	Yes	Yes		Yes	Yes

Table 6 – Summary of power quality study periods

Analysis results indicated that all power quality parameters were within the limits specified by the relevant standards and rules. As an example, the voltage range limits specified in "*AS61000.3.100 Limits – Steady state voltage limits in public electricity systems*" specify a nominal supply low voltage of 230 volts with limits of -6% to +10%, or 216.2 to 253 volts. To be compliant to this standard, the voltages are measured at the customer's point of supply over a week and the 1st and 99th percentile of measured voltages must be within these limits.

The results in Figure 9 show the voltage range results from an analysis of data of the supply voltage to the SOPA customer loads as measured at the Holker Jamieson distribution centre over 9 one-week periods during the trial. Each solid box shows the 25th and 75th percentiles of voltages during each one-week period and the top and bottom lines end at the 1st and 99th percentiles of voltage.

From Figure 9 it can be seen that the voltage levels vary only slightly over the trial periods with a maximum variation of about 5V.

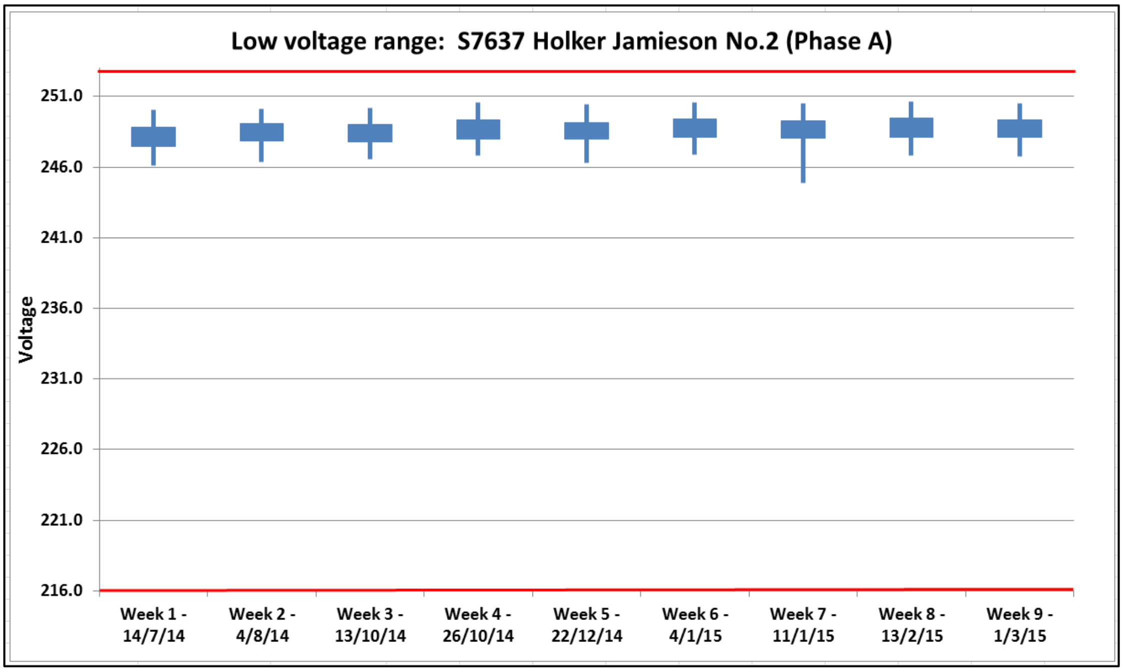


Figure 9 – Voltage range results

Note that due to the location of the battery system at the first distribution centre along the 11kV feeder, it is not unexpected that the voltage range is near the upper boundary. Voltage levels at the zone substation are set so as to ensure that voltage levels for customers at the end of the feeder meet the standard.

5.3 Discussion

For each of the power quality parameters analysed, the existing high solar penetration and effect of the battery operation did not cause there to be any observable power quality issues. Each of the parameters were analysed and found to be compliant with the relevant Australian Standards or National Electricity Rule requirements.

These results are in line with the results from the power quality studies from the original Smart Grid Smart City project in the Newington area, which found that this portion of the Ausgrid urban network was sufficiently resilient with no noticeable power quality impacts from the existing high penetration of solar systems. The Newington and Olympic Park area is a reasonably new suburb built for the Sydney Olympics with an underground network and a high density of customers. This suggests that significant amounts of distributed generation and storage can be installed in urban networks with minimal impact on network power quality.

In terms of other network areas in Australia with high penetrations of solar systems, the Newington suburb could be considered quite unique. Many of the solar installations in recent years have occurred in established suburban housing areas or in rural or semi-rural areas with varying electrical characteristics including overhead lines and different conductor sizes. The effect of a high penetration of solar systems in different networks areas needs to be assessed on a case-by-case, and the results from the Newington suburb are not necessarily transferable to other network areas.

6 Customer Benefits

One of the trial objectives was to consider the potential customer bill benefits from using a battery storage system. There are three primary ways a customer can lower their energy costs using a battery storage system.

1. Time of use tariff arbitrage: When a customer's tariff includes different rates for different times of the day (time-of-use pricing), the customer can charge the battery during off-peak times when the cost is lower and discharge during peak times, when the cost is higher.
2. Solar storage: When a customer's solar power system exports excess energy to the grid at a feed-in-tariff rate lower than the import tariff, the customer can use a battery storage system to store the excess energy for re-use later when customer energy demand exceeds supply from the customer's solar power system.
3. Demand charge minimisation: When a customer's tariff includes a charge for the maximum customer demand, the customer can operate the battery so as to minimise the maximum electricity demand from the network. The demand charge is typically calculated during peak periods only.

6.1 Customer bill benefits

As the size of the battery used in the trial (60kW and 120kWh) is significantly oversized for a residential customer, assessment of customer bill benefits is necessarily applied against a non-residential customer. In this instance, it was Sydney Olympic Park's Building 46 facility now used as an education centre but which also includes irrigation pumps for the local parkland and a 64kWp solar system.

This customer's photovoltaic system is oversized for the typical customer load with a large amount of excess solar energy exported to the grid during the middle of the day, but with customer loads consuming energy from the grid during the late afternoon and evening on a typical working weekday. Assessment of customer bill benefits against this location allows for inclusion of benefits from solar storage, relatively uncommon for most non-residential customers.

To estimate the customer savings from installing a battery system of the size used in the trial, EnergyAustralia's LoadSmart time of use tariff (Table 7) was used. The LoadSmart tariff is a basic tariff offer for non-residential customers who consume between 40,000 and 160,000 kilowatt-hours (kWh) of energy annually and would be representative of a customer of this size.

Tariff Component	Description	Price (incl. GST)
Peak Energy	Between 2pm and 8pm, Monday to Friday (excluding public holidays)	28.60 c/kWh
Shoulder Energy	Between 7am and 2pm, and 8pm and 10pm, Monday to Fridays	20.90 c/kWh
Off-Peak Energy	All other times	12.32 c/kWh
Capacity Demand Charge	The maximum kW demand recorded in the last 12 months, during the peak period (2pm to 8pm, Monday to Friday)	38.137 c/kW/day

Table 7 – LoadSmart tariffs for non-residential customers

For the customer benefit trial the load management function, with LV Meter 1 (Figure 2) as the input to the battery management system, was used to simulate the scenario where the grid battery was connected to the customer loads. A threshold value of zero was set thereby attempting to limit the import and export of energy to the grid.

Note that the differential between the peak and off-peak energy tariffs for the LoadSmart tariff is 16.3 c/kWh, which is significantly lower than the differential of about 39 c/kWh for a residential time of use tariff in the Ausgrid network area. The differential for larger non-residential customers (using more than 160,000 kWh per year) is lower still at about 5-7 c/kWh. These lower time of use differentials offer lower time of use arbitrage and solar storage benefits for customers.

Customer Benefits – Winter Day (24 June 2014)

The trial operation on this day attempted to minimise the import and export from the grid during the shoulder and peak period from 7:00am to 10:00pm. This was tested by using the load management function with a zero load threshold starting from 7:00am, but with a small initial charge (20%) on the battery at 6:00am to serve the early morning energy use occurring before the solar system generated any power.

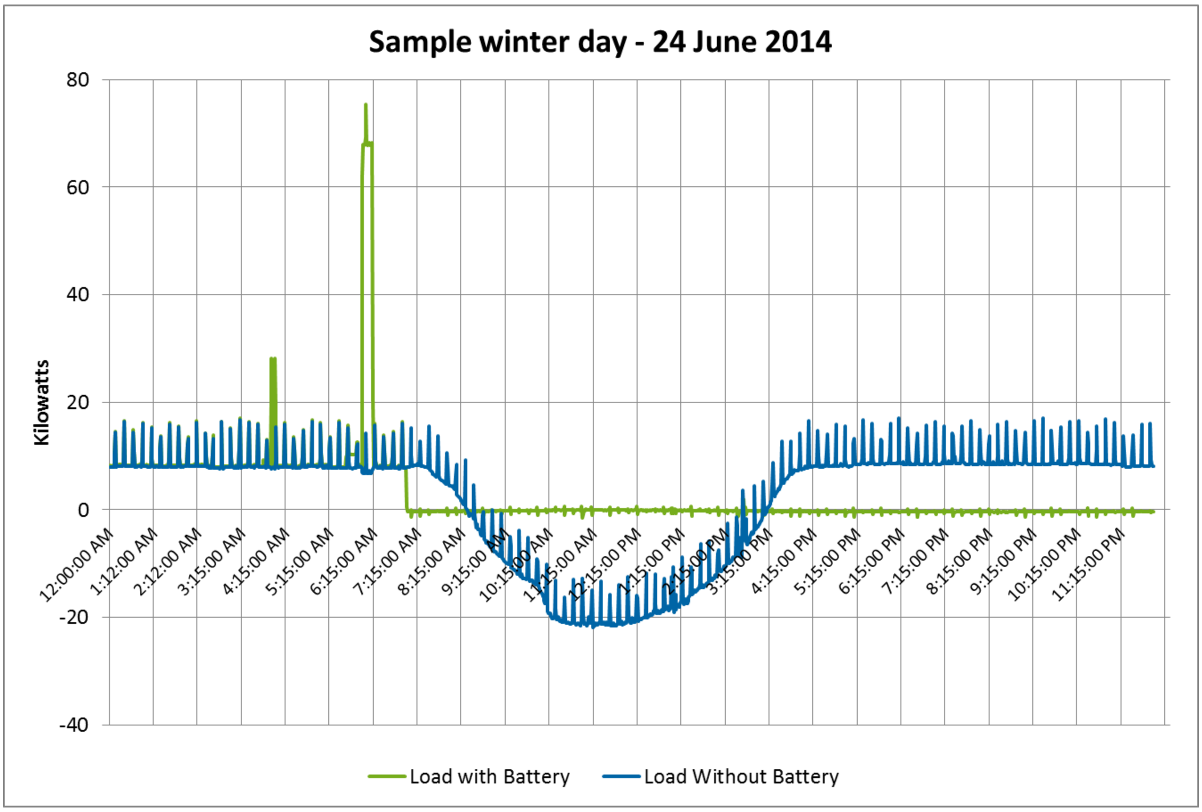


Figure 10 – Customer benefits trial for sample winter day, 24 June 2014

Figure 10 shows the simulated customer load with and without the battery storage system. The graph shows the battery was discharging from 7:00am to 8:15am to power customer loads. From 8:15am the solar system was generating enough energy to serve the customer load and excess solar energy started to charge the battery from this time through to around 3:00pm. From around 3:00pm the stored battery energy supplies the customer load. For this day, the battery is well sized to meet the customers energy needs for the day and is able to supply the demand for the remainder of the day during the remaining peak period (until 8:00pm), evening shoulder period (8:00pm to 10:00pm) and then into the evening off peak. It should be noted that there is still value in using the stored solar energy during the off peak period as off peak import charges of 12.32 c/kWh are greater than the typical export tariff of about 6.0 c/kwh.

On this particular day, without the battery, the customer would have consumed 145 kWh of grid supplied energy and exported 94 kWh to the grid. With the use of the battery, the customer consumed only 76 kWh of grid supplied energy and exported 5 kWh to the grid. The reduction in the peak demand between 2:00pm to 8:00pm, used to calculate the capacity demand charge, was about 11 kW.

Based upon the Loadsmart tariff for grid imports and assuming 6 c/kWh as the solar feed-in tariff, the winter day bill benefits calculated for the energy component of the bill was estimated to be \$12.25 per day with energy bill costs of \$21.40 without the battery and \$9.15 with the battery. The bill benefits for the capacity demand charge are assessed below in combination with the summer day test.

Customer Benefits – Summer Day (22 January 2015)

For the customer benefits trial during summer a similar methodology was used, with a load management battery operation of zero set using the LV meter 1 (Figure 2) from 7:00am. Because the solar system generated much more energy during summer, the battery was operated so as to be fully discharged at 7:00am to be able to store all the excess solar generation. At 7:00am the load management function started, with the aim of maintaining zero import or export to the grid. Figure 11 shows the load (with and without the battery).

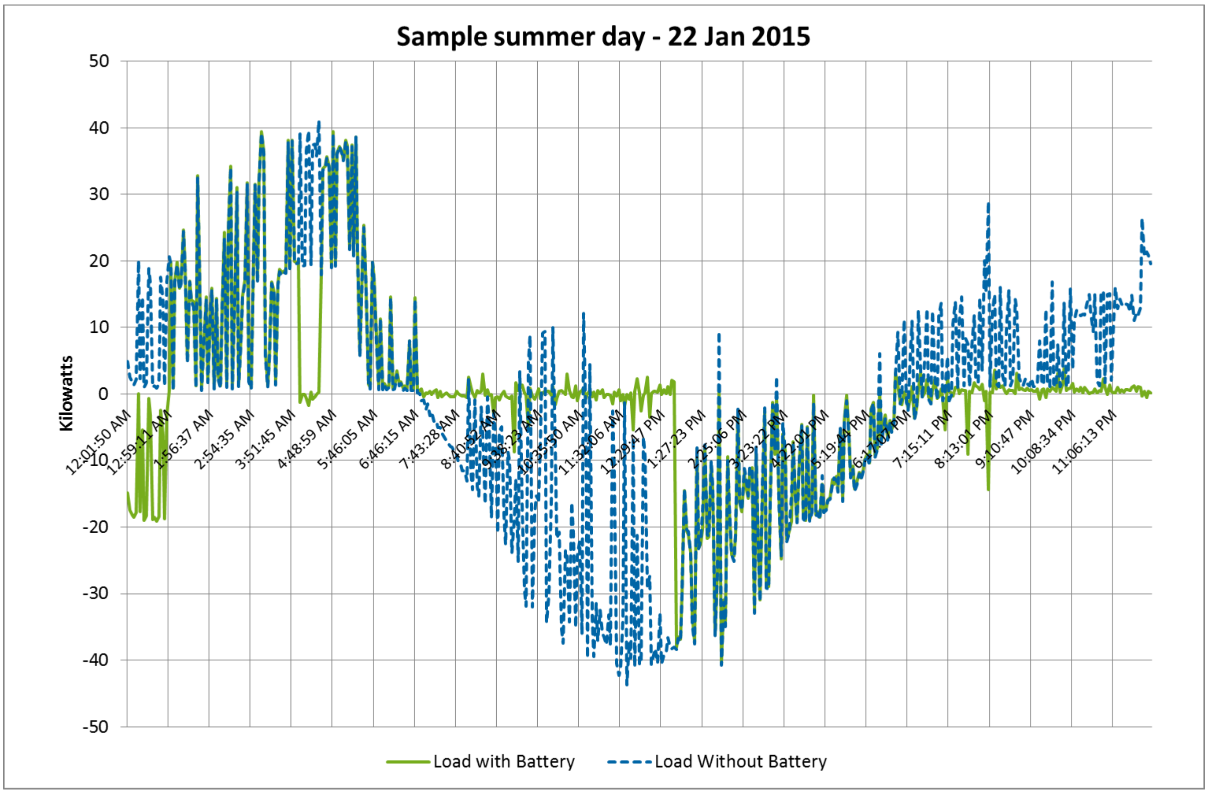


Figure 11 – Customer benefits trial for summer

As shown in Figure 11, from 7:00am the battery is being charged with excess solar energy. During the morning there appears to be some periods of intermittent solar generation which the battery acts to smooth out. At approximately 12:30pm, the battery is full and unable to maintain the zero export to the grid, at which point excess solar energy is exported to the grid and the two profiles match. From 6pm, when the customer demand exceeds the solar generation, the battery begins discharging and maintaining zero import from the grid. For this summer day, the battery is undersized to store all excess solar power generation.

On this particular day, without the battery, the customer would have consumed 166 kWh of grid supplied energy and exported 204 kWh to the grid. With the use of the battery, the customer consumed only 95 kWh of grid supplied energy and exported 101 kWh to the grid. The reduction in the peak demand between 2:00pm to 8:00pm, used to calculate the capacity demand charge, was about 10 kW.

Based upon the Loadsmart tariff for grid imports and assuming 6 c/kWh as the solar feed-in tariff, the summer day bill benefits calculated for the energy component of the bill was estimated to be $5.80 for the day with an energy cost of $11.80 without the battery and $6.00 with the battery.

Based upon energy bill savings of $5.80 per day for an average summer working weekday and $12.25 per day for an average winter working weekday, it is estimated that the annual bill savings from the energy component of the bill would be about $2,000-$2,500 per year.

Bill savings from the capacity demand charge would be contingent upon the battery storage system operating effectively for all working weekdays in the year and if so, could be as much as $1,400 per year if the typical maximum demand of 10 kW is reduced to 0 kW in the 2:00pm to 8:00pm peak period. Based upon the trial reliability performance, there is a material risk that these savings would not eventuate.

During both the winter and summer customer benefit trials, it was found that the battery system operation was more reliable than with the summer peak reduction trials. This was mainly due to the higher reliability of the local measurement of the customer load (with LV meter 1) that operated the battery's load management function.

6.2 Network benefit of customer installed battery systems

During the trials, we attempted to operate the battery storage system according to likely customer benefit drivers based on existing tariff scenarios (section 6.1) with no regard to the potential benefit to reducing the network peak demand. In this way, we might discover some insight into the impact from electricity tariffs alone.

Figure 12 shows the load profile of the 11kV feeder load on the same day (22 January 2015) that Ausgrid conducted the customer benefits trial discussed in section 6.1 (Figure 11). On this day, the customer would have operated the battery to minimise the import and export from the grid according to their connection or metering point. In this instance, the resultant reduction in the network feeder peak was about 5 kW.

In an ideal operating scenario, a full battery would have been discharged during the network peak time reducing the feeder load by about 60 kW. But based upon the trial observations detailed in section 3, the effective reduction on the feeder load might have been in the order of 30-45 kW; though still potentially close to an order of magnitude greater than the reduction achieved when the customer responded on this day to a tariff signal only. This reinforces the need to compare the effectiveness of broad retail tariffs with a strategy where networks contract directly with customers for network control of their battery system on the 5-10 days each year when network demand peaks.

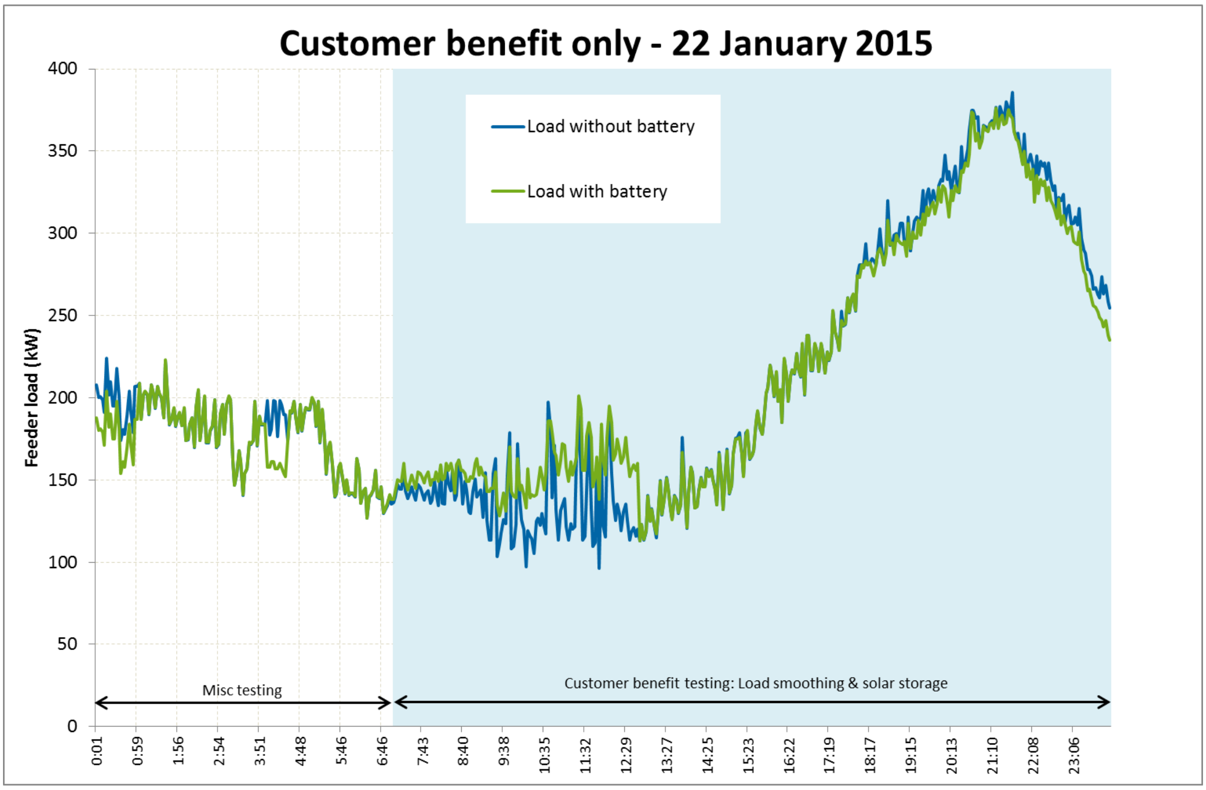


Figure 12 – Customer benefits trial in summer

The trial also included testing to explore the potential for dual customer and network benefit. On a number of days, the battery was operated according to the customer benefits operating regime described in section 6.1 (minimise grid import and export) from 7:00am to 6:00pm, then controlled according to the network management operating criteria similar to that described in section 3 from 6:00pm to 10:00pm. An example is shown in Figure 4 in section 3 for trials operations on the 14th January.

As shown in Figure 4, the battery is charged from the customer's excess solar generation during the mid-morning period with the battery fully charged by about 10:30am. Because the battery remains fully charged up to the network peak demand period from 6:00pm to 10:00pm, the battery is ready to provide network support in the evening. The stored battery energy is then discharged in support of the network to maintain the target maximum feeder demand of 340 kW. The fact that the customer's solar power system is quite large in comparison with their load is a significant factor in this outcome.

6.3 Discussion

Using 2016 electricity tariffs for a non-residential customer consuming between 40,000 and 160,000 kWh per year, it has been shown bill benefits are achievable from battery systems by reducing energy usage during peak periods and reducing the impact of maximum demand charges. When the daily examples for winter and summer bill benefits are annualised the energy bill benefit range is estimated to be from $2,000 to $2,500 for the non-residential customer connected at the grid battery location. If the battery reliability was such that the typical customer maximum demand of 10 kW was reduced to 0 kW in the 2:00pm to 8:00pm peak period for all working weekdays in the year, further bill savings of $1,400 per year would be possible.

For this particular customer, the bill benefit was higher in winter due to a better matching of the battery size to the solar system and the higher energy consumption of the customer in winter.

Assuming that battery system reliability was not sufficient to achieve the capacity charge savings, then over five years the estimated bill benefit would be about $10,000 to $12,500. For this non-residential customer, the installed cost for a 120kWh battery storage system would need to be about $80 to $100 per kWh in order to achieve a five year simple payback period. Where the capacity charge savings are possible, the battery system cost would need to be about $140-$160 per kWh to achieve a five year payback. For larger non-residential customers (usage greater than 160,000 kWh per year), the bill benefit would be smaller due to a lower price differential between off peak and peak energy prices (5 to 7 c/kWh compared to 16 c/kWh).

Note that although the size of battery used in the trial may not be optimal for the customer's load, it provides an example of the potential bill benefits and battery system price range required to achieve a customer payback period on bill benefits alone.

The regular use of the battery in this customer benefit scenario means that consideration should also be given to the battery lifetime and how daily depth of discharge affects battery lifetime. This is in contrast to how a network may implement or use a battery system to address a network peak demand issue as described in section 3, where the battery system may only be required for 5 to 10 days a year.

The installation of battery storage systems by customers presents an opportunity for networks. However, the trial result shows that battery operation by customers to maximise bill benefits do not necessarily lead to network peak demand reduction benefits for a specific asset located in the network. For better utilisation of customer installed battery storage systems for network needs, direct incentives or contract agreements with customers for operation of batteries during network peak times and in specific locations of need is likely to be required.

Contracting with customers to reduce electricity demand at peak times by either operating their embedded generation or load shedding so as to address a network need has been used by Ausgrid as part of a past demand management solutions. It is possible that similar agreements could be made with customers who have a battery storage system. However, an important consideration for customers might be how battery operation on peak demand days may affect the customer's energy bill, in particular the demand charges. In addition, having enough energy storage capacity available at the time when the battery is needed to reduce peak demand is an important consideration. If the customer's battery is empty or nearly empty when called upon for a network peak event dispatch there will be little or no peak demand reduction.

Taking the example presented in section 3.3 where a least cost demand management solution of a relocatable generator was around $170 per kVA of generation capacity per year to address a two-year network need. From this, we can calculate a hypothetical additional network value if a battery system was to operate during peak times at a particular location. For the battery system size in this trial, because of the energy to power ratio limitations a more realistic peak reduction value for the 120kWh battery system would have been around 20kW. A two-year agreement with a customer to deliver 20kW of demand reduction at times of network peak demand might be valued at around

$7,000 over the two year period. However, because network needs occur in specific locations over varied time periods and Ausgrid implements the least cost solution, the ability of a customer to leverage this benefit would depend upon there being a deferrable network need and the battery storage solution offering a competitive alternative to other demand management options.

Information on how Ausgrid assesses non-network options is detailed in Ausgrid's Demand Side Engagement Document, which is published on Ausgrid's website at www.ausgrid.com.au/dm.

7 Conclusions

The main conclusions from the project are summarised according to three themes:

- The use of grid-connected battery storage systems to address a network need,
- The effects of batteries on the grid in terms of power quality,
- The potential benefits of customer installed battery storage systems.

7.1 Grid-connected battery storage systems

The trial results showed that:

1) ***It is possible to use a grid-connected battery storage system to reduce the load on a network asset on peak demand days.*** The trial demonstrated that storage systems have the potential to be considered for demand management solutions when they become more cost effective and offer improved reliability. *An important issue encountered in the trial was that the reliability of the whole battery storage system was compromised primarily due to control systems* such as metering and communication devices. Battery storage technology is developing quickly and it is envisaged that the reliability issues encountered in the trial will be resolved.

2) ***An important observation from the trial was the importance of battery storage capacity for use in demand management.*** While peak demand periods can vary across a range of network needs, *a solution which provides a short term reduction in the peak demand on a network asset should ideally have the potential to provide 4-6 hours of demand reduction*. The battery used in this trial was capable of 2 hours at full power output, or 4 hours at 50% power output. Where a solution is only capable of shorter dispatch periods, networks would typically combine demand reductions from multiple sources to achieve the required reduction. This inevitably leads to a higher cost and so such solutions would be at a cost disadvantage compared with alternative solutions.

   The energy storage capacity of battery systems can be optimised by using automated battery management functions which better utilise the available storage capacity by only discharging at partial power output to maintain network demand to a pre-set threshold. However, as was discovered in the trial, the use of remote measurement devices increases system complexity and a resultant higher risk of battery system failure.

3) ***The battery leasing arrangement was a desirable feature for Ausgrid*** as leased battery systems provided as part of a full service solution is expected to offer a lower cost solution when applied to a typical one to three year deferral of a network investment.

4) ***For battery storage systems to be used to achieve peak reduction, the ability to locate the battery in a specific geographic area that enables deferral of a network need is critical.*** It was predicted that securing a site location for the battery system might be straightforward with few community concerns. However, our experience demonstrated that concerns from the local community can still introduce project delivery delays or the need to locate at less than ideal locations. Notably, visual impact concerns remained an issue to be addressed.

7.2 Power quality impacts

The trial tested the ability of the battery system to minimise the variation in network load caused by the intermittent nature of the solar systems. However, no significant impacts, positive or negative, were observable during the trial that caused power quality parameters to go outside the standard and guideline ranges. This was due primarily to the robust nature of the urban network in the trial location. If battery systems were installed in different parts of the network with different characteristics then the effects may have been more observable.

7.3 Customer installed battery systems

Results from customer benefits component of the trial indicate that:

1) ***Solar smoothing and storage can be effective, with annual savings of about $2,000 to $2,500 from the energy component of the bill*** and the potential for a further $1,400 from the capacity charge component of the bill if system reliability was such that the customer's peak demand was reduced for all working weekdays from 2:00pm to 8:00pm.

   A fully installed battery storage system would need to reduce to about $100 to $150 per kWh of storage capacity in order to achieve a five year simple payback for the non-residential customer used as a case study for the trial. This is considerably lower than the existing battery storage system prices.

   As bill savings are a function of battery system performance and the customer's tariff and load and generation profiles, these results may not be representative of other non-residential customers. But, battery system performance results, in combination with customer energy data and tariff information, could be used to estimate the financial return for other customers.

2) ***Round trip efficiency was measured at 70% to 78% depending on the season and depth of discharge***, with the efficiency about 5% higher in winter than summer due to power consumption from system cooling. While the round trip efficiency of the storage system may not be a major consideration for the application of a grid-connected battery, energy efficiency of the whole system is important for customers considering purchasing a battery.

   Standby power consumption was measured at 8.6 kWh per day in winter and 14 kWh per day in summer, or around 7% and 12% of the energy storage capacity of 120kWh.

3) ***When operated to maximise customer benefit, there was a modest network benefit but one that was much lower than when the battery was operated to maximise network benefit.*** For better utilisation of customer installed battery storage systems for network needs, direct incentives or contract agreements with customers for operation of batteries during network peak times and in specific locations of need is likely to be required. However, this needs to be considered in the context of a least cost solution analysis of non-network options for a specific network need.

8 Next Steps

This trial, in conjunction with the battery storage trials conducted as part of the Smart Grid Smart City project, has provided Ausgrid with useful knowledge and experience in system performance, reliability and estimated benefits from using battery storage.

The results of the Newington grid battery trial are broadly consistent with the Smart Grid Smart City findings in that distributed storage is potentially a valuable opportunity for networks, but that further product development and price reductions would be required before battery storage could compete with existing alternative demand management solutions. ***As battery system solutions improve in both reliability and cost effectiveness, Ausgrid would consider such solutions when assessing demand management alternatives for deferral of network investment.***

While there are no immediate plans for conducting further grid-connected battery storage trials, Ausgrid will be reviewing technology developments regularly to understand battery cost projections and the point in the future when battery system costs may become competitive with more mature demand management solutions. ***We estimate that when total solution costs reach about $500 to $750 per kVA for a 0.5MVA to 1.0MVA battery storage system, Ausgrid would consider a technology trial to re-verify system performance.***

Of greater interest at present are customer attitudes towards investment in their own battery storage systems and the willingness of customers to partner with networks to reduce peak demand. To help us understand customer views, we are planning to conduct customer research of our existing solar and non-solar customers to gauge their attitudes and potential motivations for investing in a battery storage system. These customers will include both residential and non-residential customers.

Depending upon the outcomes from this research and current storage system costs, a trial to measure the customer response to a commercial offer for network support would be explored. Such a trial might focus on a demand response type direct incentive arrangement with the customer. In this way, the customer owns and operates the battery and a direct incentive agreement is made with the customer for allowing Ausgrid to control battery operation on network peak demand days (about 5-10 days a year).

This type of trial would be similar to Ausgrid's *Cool*Saver trial where a demand response interface for air conditioners (AS4755.3.1) is used to remotely activate the customer air conditioner's power saving modes on network peak demand days by agreement with the customer. At the time of writing, the demand response standard for battery storage systems (AS4755.3.5) was still in development. By exploring the costs, performance and issues associated with partnering with customers for use of their battery system, we might verify whether this can offer a cost effective solution to deferral of network investment.

Demand management stakeholders, research organisations or other interested parties are encouraged to comment and provide feedback on this report and our future plans and projects. Please email us at demandmanagement@ausgrid.com.au.

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