Final Report

Grid Energy Storage System

Grid Energy Storage System Trial

Introduction

AusNet Services was the first electricity distribution business in Australia to initiate a trial of a large scale battery energy storage system. The aim of the Grid Energy Storage System (GESS) trial was to build the knowledge, experience and capabilities required to capitalise on the expected benefits provided by grid-connected battery storage systems and prepare for the anticipated cost reductions and technical improvements of battery storage systems over time.

Fig 1: The AusNet Services Grid Energy Storage System, installed in Thomastown ***(Photo credit: ABB)***

Potential value

For Distribution Network Service Providers (DNSPs) such as AusNet Services, one of the main benefits of battery storage is the potential to help the network run more efficiently by reducing peaks in demand.

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. 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.

Battery storage also offers a number of other important benefits including the provision of higher network reliability and managing the impact of new energy technologies such as solar PV uptake.

The range of potential benefits to both the network and customers includes:

- managing peak demand on the network and reducing the risk of supply outages caused by overloaded assets;
- deferring network upgrades, therefore reducing network investment costs;
- offsetting operational costs such as hire of temporary generators during periods of peak demand;
- improving power quality through power factor and voltage level corrections;
- supplying customers in islanded mode during network outages; and
- facilitating customer uptake of new energy technologies such as solar power by managing technical impacts such as voltage rise.

Implementation

In 2012 AusNet Services conducted a feasibility study for a GESS trial in terms of the costs and availability of technology and suppliers. After a formal and competitive tendering and assessment process, a contract was awarded to a consortium led by ABB Australia Pty. Ltd. including Samsung SDI as battery supplier to design and construct the GESS. The system included:

- **1MW/1MWh (nominal) battery and inverter system:** stores energy in the lithium-ion battery bank and interacts with the network to charge or discharge the battery through an inverter system that has control over the 4 quadrants of active and reactive power. An energy management system is programmed to control the behaviour of the overall system.
- **1MW (nominal) diesel generator:** effectively extends the capacity of the battery to provide several hours' worth of power and can run in parallel with the battery system
- **Balance of plant:** 3MVA 22kV/415V transformer kiosk, switchgear, measurement and SCADA RTU equipment.

The GESS facility as shown in Figures ~~1 and Figure~~to ~~2~~3 is housed in seven containers, most of which are standard 20' shipping containers. It consists of 4 containers for the battery bank, 1 container each for the inverter, the generator and the switchgear, plus the 3MVA transformer. The GESS overall (battery combined with genset) has a nominal power output capacity of over 2MW, capable of improving power quality and transition between grid connected and islanded modes. The containerised design facilitates mobility, offering the potential for the facility to be relocated to other areas on the AusNet Services network.

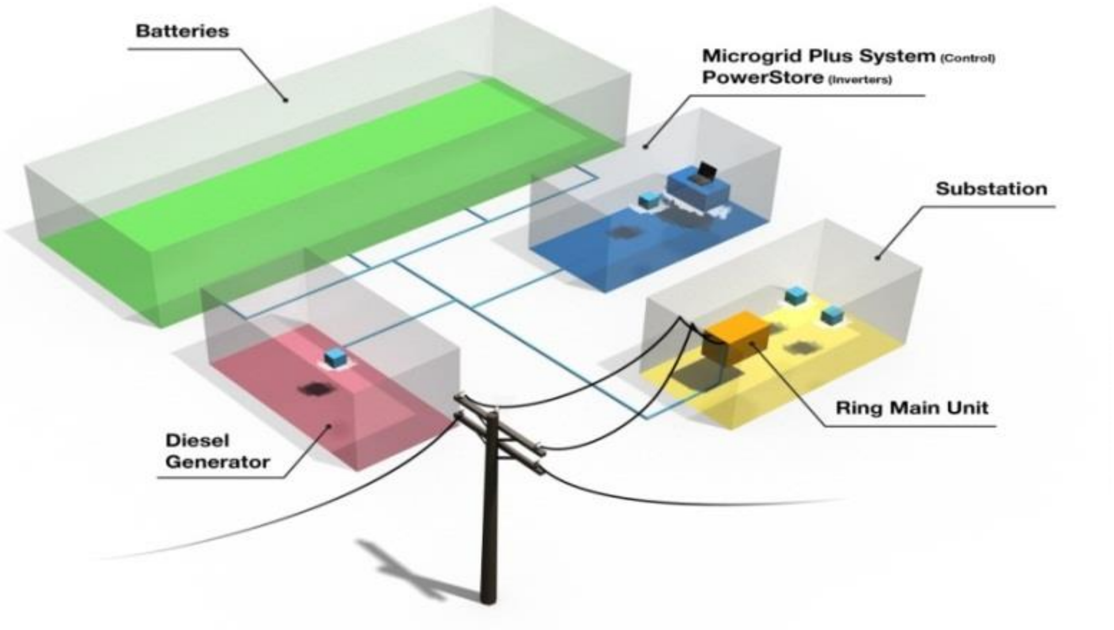


Fig 2: GESS system layout

Fig 3 Samsung battery container (left) and battery racks (right)

Operating Scenarios

Peak lopping

A primary function of the GESS is to reduce peak demand on the local power line (feeder) by directly supplying customer loads at the end of the feeder. This is achieved by employing the 'Peak Lopping' function, which has two variants, local peak lopping and feeder peak lopping.

Local peak lopping allows the network power flows to the customers downstream of the GESS and effectively capped at a pre-defined set point. The local peak lopping function controls the amount of power provided by the GESS to meet the downstream demand that is above the setpoint.

Feeder peak lopping works in a similar manner by limiting the load on the entire feeder. The GESS reads the total feeder load value from the network SCADA system and calculates the power required to meet the total demand whilst limiting the feeder demand, and injects the required power into the local network. This function has the capability to delay network augmentation and allow better utilisation of distribution assets. An example of the peak lopping function in operation is shown below in Figure 4 where the Feeder Peak lopping setpoint was adjusted to 3700kW as shown by the red horizontal line. When peak lopping is initiated at 9:00am (first red vertical dashed line), the GESS outputs an initial 1000kW (blue line) to bring the total feeder demand (green line) down to the 3700kW setpoint (purple line).

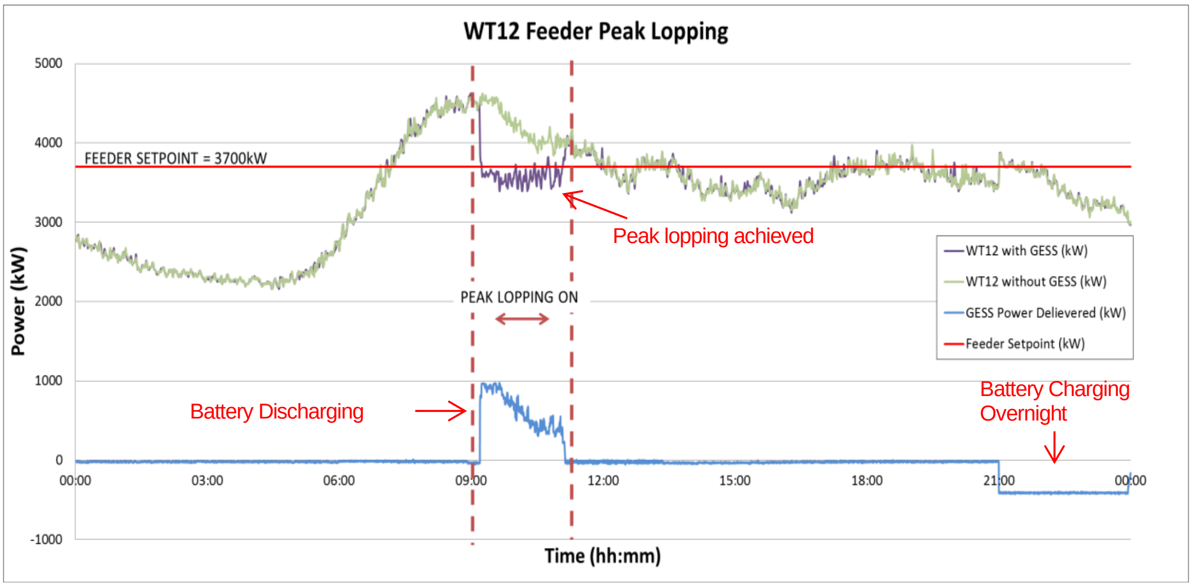


Fig 4: Example of feeder peak lopping on feeder WT12

Island mode

Providing power supply to a section of network in isolation from the main network is called islanded supply. The islanding capabilities of the GESS were investigated by AusNet Services to improve system supply reliability by continuing to supply local customers with power even when there has been a local network fault (upstream of the GESS), outage or more widespread blackout.

Figure 5 shows how the GESS operates in both grid-connected and island modes. In the event of a network outage, the GESS will island the downstream section of network by opening the upstream circuit breaker (shown in green). This creates an islanded ‘micro-grid’, which the GESS can supply until its energy reserves are depleted or the network outage is rectified. When network supply is restored, the GESS can re-connect to the grid and transfer supply back to the network. Moreover, the batteries can begin recharging on a scheduled pre-set programmed time of day to be ready for an outage or other network events.

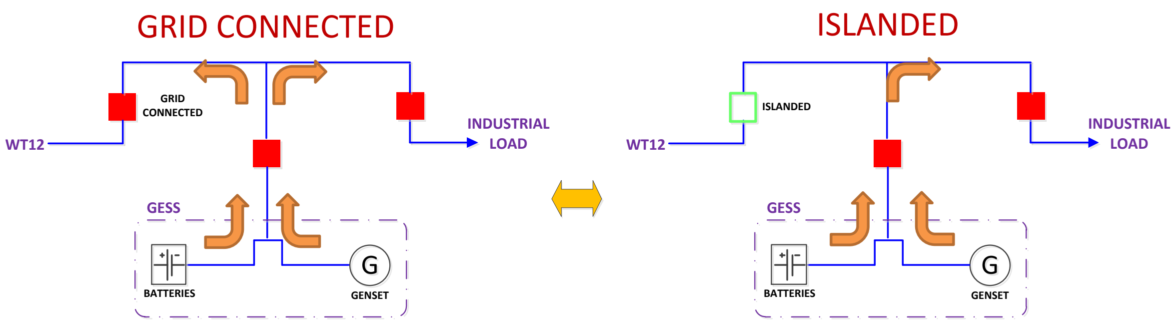


Fig 5: GESS network support modes for grid connected and islanded operation

There are 104 commercial and industrial customers downstream of the GESS that the facility can supply in island mode as shown in Figure 6.

Fig 6: Aerial view of the customers that can be supplied solely by the GESS in 'island mode'

Power Quality

Power quality from the GESS can be maintained by either one of the following two methods:

Voltage Support (Vdroop): Aims to maintain the network voltage to within 3% of a predefined voltage set point (around 22kV in a typical distribution network). This is achieved by comparing the network voltage with the voltage set point. The difference is used to determine the amount of reactive power injected or absorbed from the grid by the inverter to stabilise the network voltage.

Power Factor Correction (PF): Maintains the actual power factor of the system to a predefined set point by utilising the reactive components of the four quadrant inverter.

These functions are provided by the inverter and since neither requires any active power or energy from the battery, the State of Charge (SoC) of the battery is conserved. If reactive power alone is not sufficient to control voltage, active power can also be used but this requires battery energy that could drain the battery relatively quickly. During the summer trials, these two parameters were varied to test the quality of supply with and without peak lopping.

System Compliance

Electricity Distribution Code (EDC) Compliance

The EDC outlines the requirements for a general load customer, an Embedded Generator (EG) customer as well the Distribution Network Service Provider (DNSP) when connected to the grid. The GESS must adhere to all relevant Electricity Distribution Code (EDC) requirements as if it is an external EG connection as well as meet all the DNSP requirements. The GESS however does deviate from some of these requirements as it is an EG designed to actively improve the power quality of the network and therefore some rules that apply to a general EG customer do not apply to the GESS (e.g. power factor limits). When the GESS is islanded, the EDC does not directly apply however AusNet Services have adopted the EDC for islanded mode as well to ensure customers receive the same high quality of electricity supply at all times, even when supplied by the GESS.

The acceptable thresholds, for the above parameters, when the system is grid connected and islanded are shown in the tables 1 and 2 below.

Grid connected

Quality of Supply				
Parameters	Flicker	Harmonics	Voltage Unbalance	Supply voltage
Acceptable Range	PST < 1.0 PLT < 0.8	THD < 3%	< 220 V (±1%)	20.68 kV < v < 23.32 kV

Table 1: EDC requirements when in grid connected mode

Islanded

Quality of Supply					
Parameters	Flicker	Harmonics	Voltage Unbalance	Supply voltage	Supply frequency
Acceptable range	PST < 1.0 PLT < 0.8	THD < 3%	< 220 V (±1%)	22 kV (±5%)	50Hz (±0.2%)

Table 2: AST requirements when in island mode

Under the full range of tests conducted, the GESS proved that it operates within the EDC thresholds while in grid connected and islanded modes.

Environmental Compliance

The GESS must comply with a number of environmental requirements including noise and diesel fume emissions from the diesel generator. Noise levels in particular were a concern due to the close proximity to the nearby residential zone (see Figure 6).

In order to comply with the EPA guidelines for noise levels, the generator was equipped with a noise attenuator for the cooling fan outlet, super critical silencer for the exhaust and a mobile billboard which acted as a noise barrier. Noise measurements conducted by independent consultants concluded that the noise levels of the generator met code requirements.

The rated diesel fume emissions from the generator were compared to the 'The Victorian State Environmental Protection Policy for Air Quality Management'. It was found that the generator used in the GESS complies with this policy without requiring any modifications.

Performance Results

Performance Summary

The aim of the final summer testing (2015/2016) was to assess the performance of the GESS when operating under different network configurations and various control modes. In this period a total of 30 tests were performed. Table 3 below summarises the results.

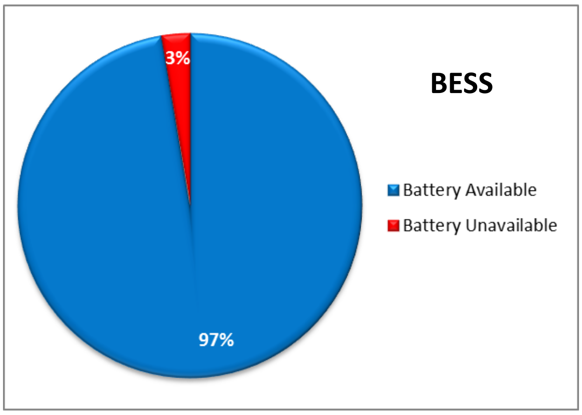
Operational Mode	Test	Tests Performed	Passed (P)	Indeterminate (I)	Fail (F)
Grid Connected	Peak lopping (bulk)	6	4	2	0
	Peak lopping with varying Vdroop or PF correction	12	12	0	0
	Network Switching: Cap-bank switching & WT12 feeder transfer	6	6	0	0
Islanded	Islanding	5	4	1	0
	Blackstart	1	0	1	0
Total		30	26	4	0

Table 3: Testing and Performance Summary

In summary, 87% of the tests passed, meeting all testing requirements satisfactorily (green). The remaining 13% fell short on meeting AST requirements and thus were deemed indeterminate (yellow). None of the tests were considered a fail (red) since the main equipment namely the batteries and generator operated satisfactorily, however in some instances the poor operation of ancillary equipment and control functions directly impacted on the overall system performance. The specifics of each test conducted along with the judgment criteria is detailed in the GESS final report.

Availability of Battery and Diesel Generator

During the final testing period, the availability of the battery system and generator was analysed. Figure 7 below summarises the findings. As shown the BESS was available 97% of the time that tests were conducted in comparison to 70% for the diesel generator. The major reasons for the unavailability of each are shown in Table 4.



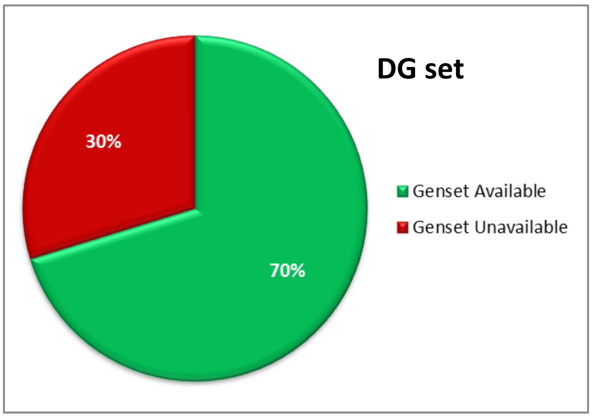


Fig 7: Availability of the BESS and DG set

BESS	Diesel Generator
Battery rack contactors tripping	Oil and coolant leaks
HVAC compressor tripping due to high pressure	Engine oil overheating - Fan protection relay wrong setting and incorrect fan operation
Battery rack fuses blowing	HMI screen replacement (due to sun exposure)

Table 4: Reasons for main component unavailability

Despite the GESS battery being relatively new and experimental, its reliability was higher than a tried and tested diesel generator. This can be most likely attributed to lack of moving parts and solid state structure of battery units.

Performance during a network outage

On 2 February 2016, a network fault resulted in an outage on the WT12 feeder to which the GESS is connected. The fault was located upstream of the GESS and the AusNet Services Customer and Emergency Operations Team (CEOT – control centre) initiated a recovery procedure to start up the GESS in 'island mode'. In this mode, the GESS powered the 104 commercial and industrial customers downstream of the facility. Islanding had previously been tested under trial conditions, but this was the first time it had been initiated in response to a live network outage event. The chart in Figure 8 below captures the event. The purple line indicates the power in kW being delivered to the customers downstream of the GESS. Upon the fault being detected, the power to the customers is lost (first vertical red dashed line). When the GESS switched on in island mode (second vertical red dashed line), it is able to instantly supply the customer load (light blue line) using its batteries while the network fault is being repaired. Once the repair was complete, the GESS was able to smoothly resynchronise back onto the network (green circle).

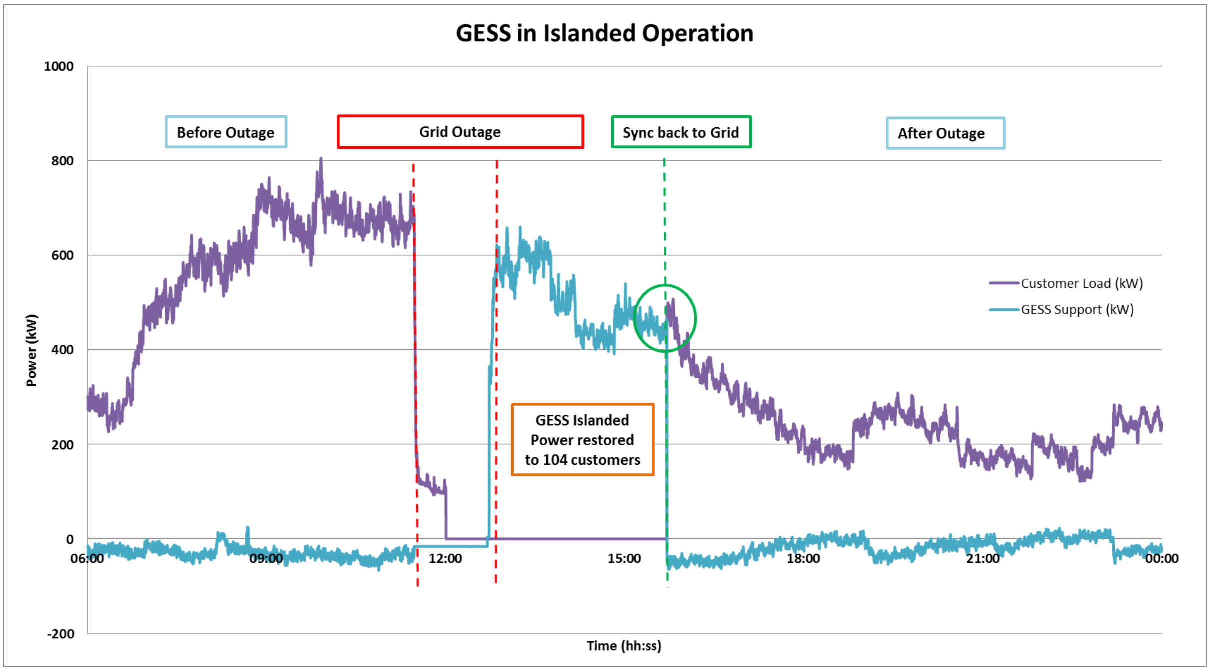


Fig 8: GESS supplying downstream customers during a network outage

Shift Supervisor, Scotty Nimmo from CEOT, who was on duty at the time, said: "Being able to supply the 104 customers downstream from the GESS, in 'Island Mode', reduced the customers' outage by approximately 2 hours and 20 minutes. This was a great result for all the commercial customers affected as this fault was during normal business hours. This was also a great saving in customer minutes off supply and an absolute proof of concept with regard to being able to supply customers in island mode".

Financial Analysis

Storage System Costs

The cost of grid-scale storage has been reducing steadily over the past few years, driven by reductions in battery module costs as well as an increase in knowledge, efficiency and competition within the supply market. Despite this progress, the supply market in Australia can still be considered as emergent, in terms of the small number of opportunities, lack of depth in the number of experienced providers, reliance on customised rather than standardised solutions and a lack of transparency around costs.

During the initial design phase of the trial, both Lithium ion and Lead-acid based battery chemistries were considered. The GESS tender was battery chemistry agnostic to test the market for grid scale storage solutions. The vast majority of the suppliers in the market prposed the use of Lithium ion batteries for the trial despite the higher cost of Lithium-ion when compared to Lead-acid. The main reason for this is thought to be the increased production of Lithium ion batteries due to the profileration of EVs entering the market. Although Lead-acid battery systems are lower cost for applications where the cycling requirement (frequency of charge-discharge cycle) is low, Lithium ion batteries are generally more economic for applications that require regular cycling (such as that required for daily feeder peak-lopping applications).

In general, current grid-scale battery storage system costs can be expected to fall within $1m to $2m per MWh, when considering a 3-hour or 4-hour system. The wide price range reflects the different technologies available in the market, different design approaches and the appetite for some suppliers to provide discounted strategic pricing.

Network Benefits

Grid scale storage offers three main benefit streams to network service providers:

- **Demand management:** Where capacity constraints exist in the network, the greatest value of energy storage is through performing peak demand management to avoid or reduce the risk of incurring asset overloads that can lead to unserved energy (energy that customers would have consumed had it not been for the outage due to overload). An equivalent value stream can be accessed through deferring a capital investment that otherwise addresses this risk of unserved energy. The demand management value is quantified by two different methods. These methods include the Long Run Marginal Cost (LRMC is the long-run cost of adding extra capacity to the network which is an indicator of the average value of demand management when deployed across areas of the network that are experiencing load growth.) of augmentation and the Value of Customer Reliability (VCR is set by AEMO, this metric represents the cost that customers place on failing to receive energy and is used to determine the time at which a network augmentation is economically justified).

GESS Sizing	Representative demand reduction	Annual value at LRMC	Annual value at VCR
1MW/1MWh	0.4 MW	$17,000	$144,000
1MW/3+MWh	1.0 MW	$42,000	$360,000

Table 5: GESS demand management benefits under different valuation methods

- **Backup power provision:** In areas of relatively lower network reliability, provision of power during network outages can have significant economic and social value to local communities. This value is reflected onto AusNet Services via the AER's Service Target Performance Incentive Scheme (STPIS) and the Victorian Guaranteed Service Levels (GSLs). As representative examples, the value of backup power provision is shown below for two remote communities on the AusNet Services network.

Location example	STPIS benefit p.a.	Value of GSL	Peak MVA
Mallacoota	$679k	$508k	1.75
Corryong	$363k	$496k	3.0

Table 6: Value of backup power provision and peak MVA required for Mallacoota and Corryong

- **Power quality improvement:** With the right functionality in the inverter, storage can help improve network power factor, which can also increase the real power that the network is able to deliver. Storage can also provide voltage control by injecting or absorbing real and/or reactive power near load centres. Levels of voltage flicker may also be reduced if the storage control system is set to react quickly to changes in network voltage.

  The GESS is able to provide 1MVAr of reactive power continuously, or 600kVAr at the same time as delivering its maximum real power output of 1MW. Assuming a starting power factor of 0.9, the 600kVAr would allow the network to carry approximately an additional 250 kW, which has a value to the network of between $10.5k p.a. (valued at LRMC) and $90k p.a. (valued at VCR).

GESS output	Increased network capacity	Annual value at LRMC	Annual value at VCR
1MW/0.6MVar	250kW	$10.5k	$90k

Table 7: Value of power quality improvement

In addition to the DNSP value streams, other value streams may be able to be captured by other parties such as energy retailers, registered market participants and aggregators. The potential value streams include the following:

- **Energy market:** The wholesale energy market benefit of storage could be captured by a retailer if the retailer has sufficient control of the storage asset and takes financial responsibility of the energy flows. However, daily price fluctuations are currently only in the order of $50/MWh (5c/kWh) which equates to $18k per annum per MWh of storage that is cycled daily. This value is not sufficient to justify a large-scale storage project in isolation, but may form a material benefit to the overall business case. Market volatility is also increasing which provides an upside for storage to capture the additional value in short-term price spikes.

- **Ancillary services:** The Frequency Control Ancillary Services (FCAS) market could potentially be tapped by battery storage systems. Under current market structures and conditions, large incumbent generators can provide FCAS at very low marginal cost, therefore the size of the market is small and the value stream to new flexible assets such as energy storage is low. This picture is changing rapidly however, with the current trends of fossil-fuel generation being withdrawn, wholesale market prices and volatility increasing and renewed stakeholder focus on potential reforms to the National Electricity Market rules to adapt the power system to modern technologies such as inverter-based renewable energy and storage. Overseas energy markets that have developed specific market mechanisms for fast-acting FCAS have driven significant investment in grid-scale storage assets.

If these non-network value streams are significant, an energy storage project may best be contractually structured so that the multiple parties can access the various value streams and share costs accordingly.

Investment Case

A simplified financial assessment for nominal costs and benefits assuming a 1MW/3MWh battery system is shown in Table 8. It should be kept in mind that storage sizing is highly customised to specific project needs. The table also indicates which of the value streams can be aggregated, or stacked under two scenarios. The analysis is performed over 15 years and includes an assumed 3% p.a. degradation in battery performance over time. The expected economic life of 15 years for a battery storage system is reasonable given the cycle life figures that manufacturers commonly quote. However it is important to note that this has not been proven in practice given that modern lithium ion battery storage systems have not been in existence for that long.

	Item	Annual value $'000	NPV - Scenario 1	NPV - Scenario 2
Benefits	Demand management	$360	$2,956	
	Power factor correction	$90	$739	$739
	Voltage support	$20	$164	$164
	Backup power	$165		$1,354
	Energy trading	$55	$338 (75%)	
	Total Benefits (rounded)		**$4,200**	**$2,300**
Costs	Capital		$4,400	
	Operating	$100	$730	
	Total Costs		**$5,130**	

Table 8: Comparison of costs and benefits under two opportunity scenarios ($ 000's)

In this example, the grid-scale storage system is close to cost effective under Scenario 1 when deployed for peak demand management in a situation where the alternative network solution is expensive. Costs would have to fall by around 20% in order to make this case economic. Where deployed for backup power provision as per Scenario 2, the storage system is not economic at current capital costs but it may not be too long until it is cost effective.

It is also worth noting that the design of the GESS allows it to be more cost effective under both scenarios due to the inclusion of the diesel gen set which is cheaper per MW when only run for a small number of occasions per year.

Mission Zero: our safety vision

Safety was a priority throughout the life cycle of this project. Some of the key undertakings are listed below:

- A detailed "Safety in Design" document was created to address operational safety of the batteries. Design features include an advanced battery management system, fire suppression system and exclusion zone in case of total fire.
- Safe work methods, proper operating instructions, safe utility standard works practices and authorisation procedures were followed to make GESS project completely incident free.
- Three near miss events were reported during the project work which helped improve operational safety processes.
- The HV switchgear was altered to avoid arc venting from the top.
- Significants efforts were made to comply with environmental regulations, especially in regards to noise from the diesel generator.
- Staff from Melbourne Fire Brigade visited the site to enhance their familiarity with this new technology.

Conclusion and next steps

The GESS has been a major innovation exercise for AusNet Services, initiated in 2012 and concluded in 2017. The GESS performance and reliability was tested during the summer of 2015/2016 and the overall performance and compliance of the GESS was positive. The reliability of the GESS is considered adequate although there is room for improvement particularly on the auxiliary equipment that supports both the diesel gen set and batteries.

The trial also identified that the financial performance (at the time of implementation) is not quite economic however if a site is found where several GESS benefits could be stacked and realised or where the traditional solution to a network need is very expensive, this could result in a net positive NPV. Further given the steady decline in battery costs, net positive NPV result could be achieved by leveraging even just one GESS benefit (in particular Demand management and Backup power provision) in the near future.

The GESS trial has resulted in significant gain in knowledge and experience for designing and deploying large scale energy storage and inverter based supply systems. AusNet Services will consider opportunities to relocate the GESS to a more critical network location for the benefit of our customers. AusNet Services is also investigating the potential of enhancing the GESS functionality to allow it to operate as an UPS where it could transition into island mode automatically when it detects the loss of supply on the network.

The benefits leveraged and captured by this innovation trial have been communicated within AusNet Services as well as to the wider electricity industry. The knowledge gained from the GESS trial has instigated the Network Planning Department at AusNet Services to now consider the use of Energy Storage to solve network constraints alongside traditional network solutions.