Current Operational Battery Energy Storage Systems in Australia and Their Intended Project Objectives on Grid Operational Issues: A Literature Review

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Abstract

As energy companies look to diversify their portfolio in renewable energy, the demand for electrification will continue to increase. There will be increasing demands on the electrical grid infrastructure. Distributed energy resources (DER) such as solar photovoltaic (PV) on rooftops and electric vehicles will experience a host of operational issues such as hosting capacities, overloads, reverse flow, phase balance, frequency drift and voltage variation. Battery energy storage systems can help mitigate some of these problems. In this paper, the literature and public available information on operational battery storage systems in Australia are reviewed and discussed. It is found that both small batteries and large batteries both fundamentally address grid operational issues. As Australia moves towards high DER penetration and high renewable energy generation, there will be a need for more battery energy storage systems to offset operational issues. The lack of private funding especially for smaller batteries may possibly cause PV DER to lag the overall demand for electrification.

Keywords
Distributed energy resources, Battery energy storage systems; grid infrastructure, grid operational issues

1. Introduction
Battery energy storage systems (BESS) are currently experiencing a rapid surge in interest in public and private firms looking to diversify their portfolio in renewable energy. As distributed energy resources (DER) such as solar photovoltaics (PV) on rooftops, electric vehicles (EV) and electrification increases, demand on grid infrastructure also increases and the need to mitigate grid operational issues. BESS' can serve as a means to mitigate grid operational issues. These operational issues include DER hosting capacity limits, equipment overloading, reverse flow, phase balancing, frequency drift, voltage variation and system inertia all contributing to overall system stability and resilience. However, there is not much literature on how the grid operational issues are mitigated apart from the objectives that firms declare and aim to achieve in their BESS projects.

1.1 Objectives
In this paper, BESS' that are currently operational in Australia are reviewed for their grid operational issue mitigation objectives and their associated effectiveness.

2. Literature Review of Operational Issues BESS Projects can Address
The objective of mitigating grid operational issues can be summed up as: In Australia, the Australian Energy Market Operator (AEMO) operates the National energy market (NEM), wholesale energy market (WEM) and ensures that Australian business, industry and household consumers have access to safe, reliable electricity exactly when required. Renewable Integration Study (RIS) 2019 recommends maximum Distributed photo voltaic (DPV) penetration and

minimum central electricity generation load shedding as a back stop measure due to the increasing DER penetration, electrification and EV uptake. Under all integrated system plan (ISP) scenarios, recommendations include large increases in grid scale and distributed energy storage as well as other measures (AEMO 2020). The problem is only increasing over time though quarterly installed capacity of PV rooftop has peaked, the number remains high. In Q3 2023, almost 100K households installed PV rooftop equating to 915MW (Australian Energy Council 2023). As renewable DER increases, over the next 10 years, 20% of Australia's coal and other carbon based generation are reaching end of life further highlighting the need for more BESS as an operational issues mitigation measure (AEMO 2023). Below are some of the operational issues that face distributed network service providers (DNSP):

2.1 Low Voltage Distribution Network (LVDN) hosting capacity

The amount of DER such as roof top PV that can be cost effectively and safely connected to the distribution network while remaining in its technical limits is called hosting capacity. The households with PV are generally connected to the LVDN by 1 phase or 3 phase.

2.2 Distribution transformer (DT) overload

Distribution transformers which sit between medium voltage and the LVDN is subject to overloading during peak solar and peak demand as consumption increases over time. Overload can be characterised by excess current draw leading to increased heat and significantly reduced lifespans. As consumption increases over time, peak demand on the DT can start with short instances once or twice a year but gradually increase. Generally, DTs can tolerate overload for short instances without significant reduction in lifespan. When DTs are increasingly operating above 150%, life span is significantly decreased and an upgrade to the DT and all associated equipment is required.

2.3 Reverse flow

Reverse flow in the LVDN is usually characterised by excess DER solar PV generation where the net of all 3 phases of a DT is negative current. Reverse flow can have far reaching consequences such as protection systems malfunction, overloading and waste renewable energy if power goes to ground. This is mainly due to ageing LVDNs not designed for bidirectional flow before DER penetration increased.

2.4 Phase balancing

Generally, DER households with PV have a single-phase connection to the grid. Multiple households with PV may connect to the same phase which may result in imbalance of current. Cloud passages can also affect phase balancing. Out of balance can affect the hosting capacity of a LVDN and grid stability**.**

2.5 Deferred Augmentation

DNSPs upgrade infrastructure based on future consumption and plan for change every 5 years when the network price resets as per Australian Energy Regulator (AER) requirements. With ageing equipment not designed previously for exponential uptake in DER PV, BESS' can help reduce peak loads through peak shaving and defer the requirement to perform an uncosted upgrade of the network. Particularly costly is the conversion of single wire earth return (SWER) connections to three phase as consumption increase. Installing a BESS can effectively defer the upgrade until the next price reset or eliminate the requirement thus saving costs compared to upgrading DTs, insulators, poles, conductors, power equipment and protection.

2.6 Fast Frequency Support (FFS)

Sometimes known as contingency FCAS or very fast response FCAS, this is an AEMO service that BESS firms can sign up to and operate to provide fast acting injection of power to quickly assist short term frequency transient events. This is usually caused by sudden or unplanned loss of generation or power system outage. There are 2 options: very fast raise contingency FCAS or very fast lower contingency FCAS.

2.7 Frequency Control Ancillary Services (FCAS)

The FCAS service is requested by AEMO to keep the national energy market (NEM) frequency within technical specifications of 49.85hz and 50.15hz. If a load on the network suddenly changes and the generation of power does not respond, frequency can change by speeding up in frequency if load goes down. Likewise, if the load goes up, frequency can slow down to compensate. FCAS is a short-term frequency support service.

2.8 System Integration Protection Scheme (SIPS)

A contract is formed between AEMO and a battery firm on behalf of a state to reserve battery capacity for the use of grid stability. For example, Neone's Big Victorian battery tendered and won a contract for 250MWh of its 300MWh of capacity for use if there is a Victorian network outage, the battery reserve can provide enough emergency power to allow the Victoria to New South Wales interconnect (VNI) the time required to optimise electricity flow (AEMO 2020).

2.9 Time shifts peak solar

The famous "Duck Curve" (Synergy 2023), graphically depicts the effect of increasing year on year solar PV DER penetration, peak solar generation during the day and peak demand in the evening as in Figure 1. As more solar energy is exported to the grid, the system load during the day dips to levels where there is potential for grid instability. When the sun sets and generally people return home in the evening, the system load swings with extreme changes to high load. It is worldwide phenomenon now widely referenced. Energy storage systems could be used to increase demand during the day and reduce the severity of the "duck curve" by time shifting the energy.

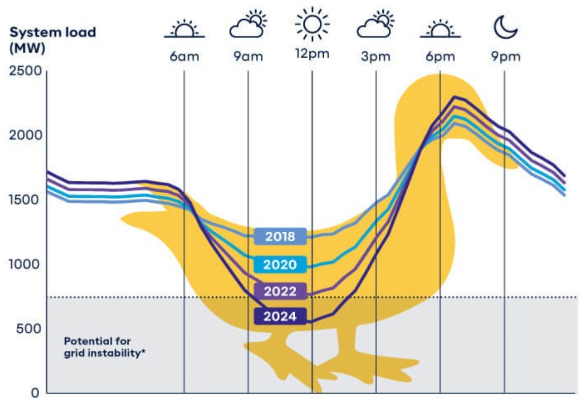

Figure 1. Duck Curve graphical representation of system load due to solar DER penetration (Synergy 2023)

2.10 Microgrid Islanding

Microgrids islanding allows a LVDN circuit to isolate itself from the main network with the use of a BESS to maintain uninterrupted power. This is usually a protective measure in the case of a network outage, the isolated LVDN circuit can remain operational until the network is restored when the microgrid can reconnect.

2.11Energy Arbitrage

This is not necessarily a grid operational issue but a market driven mechanism to match supply of electricity generation to demand. When BESS' perform energy arbitrage, it contributes to the stability of the grid because prices are high when supply is low and demand is high and prices are low or negative when supply is high and demand is low.

2.12 Virtual Inertia

As synchronous generators, such as coal fired power plants with large rotating machinery, reach end of life and removed from service, the inertia of frequency is weakened which can affect the resilience of the grid. BESS' and other non-synchronous generators such as PV or wind follow synchronous generator frequencies. To improve network resilience, BESS' can install hardware with the feature of virtually mimicking a synchronous generator. For example, Telsa megapacks with this feature call it Virtual machine mode (VMM).

2.13 Off grid

Some BESS' are installed on fully off grid circuits to time shift solar PV and reduce the reliance of diesel generators for electricity generation therefore reducing carbon emissions. Diesel generators can remain on the system as a form of backup if there is a BESS outage or insufficient PV generation.

3. Methods

The approach of this paper was to create an extensive list of operational BESS systems that connect to the NEM or WEM and to review the publicly available information on its project objectives relating to the mitigation of grid operational issues. These operational issues can be but not limited to high PV DER penetration. BESS projects reviewed must be operating and not under construction or feasibility study because some projects fail to proceed to completion and therefore cannot realise its project objectives. The data collected (Table 1) can be used to discuss about the distribution of operational issues BESS projects consider other than financial viability which is increasingly a challenge as FCAS revenue diminishes when more BESS' comes online.

4. Data

Table 1. Table of Operational Battery Projects Nov 2023

Project Name	Owner	Operator	Location	Initial Operational Year	Power / Storage	Operational issue mitigation objective described in the sections of this paper
Greenvale BESS	Jemena		Greenvale, VIC	2020	100kW/200kWh	2.1, 2.2, 2.3, 2.4
Ausgrid Community batteries	Ausgrid		Various[1], NSW	2021		2.1, 2.5, 2.7, 2.11
Yack01 Community Battery	Indigo Power		Yackandandah	2021	-/274kWh	2.7, 2.11
Beehive Project	Enova Community Energy		Kuri Kuri, NSW	2021	1.072MW/2.15MWh	2.1, 2.9, 2.11
Power Bank	Synergy		Various[2], WA		116kW/464kWh	2.1, 2.9, 2.11
Electric Avenue Tarneit	Citipower		Tarneit, VIC	2023	120kW/360kWh	2.1, 2.2, 2.5, 2.6, 2.7, 2.10, 2.11
YEF FN1	Yarra Energy Foundation		Fitzroy North, Vic	2021	120kW/309kWh	2.1, 2.7, 2.9
Bungarribee Community battery	Endeavour Energy	Origin Energy	Blacktown, NSW	2023		2.1, 2.5, 2.7, 2.9, 2.11

[1]Dingely Village, McCrea, Forest Hill, Vermont, Mount Waverley, Bentleigh East, Pearcedale, Blairgowrie, Brighton East, Rosebud, As part of the second stage of the project we have already completed the installation of batteries across: Eumemmering, Keysborough, Hampton East, Dingley Village

[2]City of Mandurah, Meadow Springs, City of Mandurah, Falcon, City of Swan, Ellenbrook #1, Ellenbrook #2, City of Wanneroo, Two Rocks, City of Wanneroo, Ashby, City of Canning, Canning Vale, City of Rockingham, Port Kennedy, City of Stirling, Yokine, City of Kwinana, Parmelia, City of Kalgoorlie-Boulder, Kalgoorlie-Boulder, City of Busselton, Vasse, Shire of Augusta-Margaret River, Margaret River – behind the meter community battery (5 year trial)

Black River BESS	Yurika		Bohle Plains, Townsville, QLD	2020	4MW/8MWh	2.5, 2.7, 2.11
Ginninderry Residential Battery Trial	CWP Storage	Evoenergy	Ginninderry, ACT	2022	250kW/275kWh	2.5, 2.6, 2.7, 2.11
Pole top batteries	United Energy	Simply Energy	Various, VIC	2022	30kW/66kWh	2.1, 2.2, 2.5, 2.7, 2.10, 2.11
Alkimos Beach Energy Trial	Synergy		Alkimos Beach Estate, WA	2016	?/1.1MWh	2.1, 2.9, 2.11
Phillip Island Community Energy Storage System	Mondo		Phillip Island, VIC	2023	5MW/10MWh	2.1, 2.5, 2.6, 2.7, 2.10, 2.11
Ballarat Battery	Ausnet	Energy Australia	Ballarat	2018	30MW/30MWh	2.6, 2.7, 2.11
Gannawarra Energy Storage System	Edify Energy / Wirsol	Energy Australia	Wandella	2019	25MW/50MWh	2.7, 2.11
Bouldercombe battery	Powerlink		Bouldercombe	2023	50MW/100MWh	2.6, 2.7, 2.11
Bulgana Green Power Hub	Neoen		Stawell	2021	20MW/34MWh	2.6, 2.7, 2.10, 2.11
Lake Bonney	Infigen		Lake Bonney	2019	25MW/52MWh	2.1, 2.6, 2.7
ESCRI-SA	ElectraNet	AGL	DALRYMPLE NORTH	2018	30MW/8MWh	2.6, 2.7, 2.8, 2.11
Wallgrove Grid Battery Project	Transgrid	Iberdrola Australia	Wallgrove	2022	50MW/75MWh	2.6, 2.7, 2.12
Victorian Big Battery	Neoen	Neoen	Moorabool Terminal Station, Geelong	2021	300MW/450MWh	2.6, 2.7, 2.8, 2.10, 2.11
Hornsdale Power Reserve	Neoen	Neoen	Jamestown, SA	2017	100MW/129MWh	2.6, 2.7, 2.12
Degrussa Solar and storage project	Neoen	Neoen	Meekathara, WA	2016	6MW/1.4MWh	2.9, 2.13
Hazelwood Battery Energy Storage System (HBESS)	ENGIE / Eku energy	Fluence	Hazelwood, Vic	2022	150MW/150MWh	2.6, 2.7, 2.11

Capital Battery	Neoen	AGL	Queanbeyan , Canberra	2022	100MW/200MWh	2.6, 2.7, 2.11
Riverina ESS 1	Edify Energy		Darlington Point, NSW	2023	60MW/50MWh	2.6, 2.7, 2.12
Riverina ESS 2	Edify Energy		Darlington Point, NSW	2023	65MW/130MWh	2.6, 2.7, 2.12
Darlington Point Energy Storage System	Edify Energy		Darlington Point, NSW	2023	25MW/50MWh	2.6, 2.7, 2.12
Torrens Island BESS	AGL		Torrens Island, SA	2023	250MW/250MWh	2.6, 2.7, 2.9, 2.12
Tailem Bend 2 Hybrid Renewable Power Station	Vena Energy		Tailem Bend, South Australia	2023	41MW/41.5MWh	2.6, 2.7, 2.11
Wandoan BESS	Vena Energy	AGL	Wandoan South, QLD	2021	100MW/150MWh	2.1, 2.6, 2.7, 2.11
Queanbeyan BESS	GPG		Queanbeyan, ACT	2022	10MW/20MWh	2.6, 2.7, 2.11
Kwinana BESS	Synergy		Kwinana, WA	2023	100MW/200MWh	2.9, 2.11
Latitude Solar Battery	Byron Bay Solar Farm Holdings		Boggabilla, NSW	2017	5MW/10MWh	2.6, 2.7, 2.11
Mt Newman BESS	Alinta		Newman, WA	2018	30MW/11.4MWh	2.9, 2.10, 2.12

5. Results

The Table 2 shows the grid operational issues project objectives distribution

Table 2. Summary of grid operational issues project objectives distribution

	Low Voltage Distribution Network (LVDN) hosting capacity	Distribution transformer (DT) overload	Reverse flow	Phase Balancing	Deferred Augmentation	Fast Frequency support (FFS)	Frequency Control Ancillary Services (FCAS)	System Integration Protection Scheme (SIPS)	Time shift peak solar	Microgrid Islanding	Energy Arbitrage	Virtual Inertia	Off grid

	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.12	2.13
Total number 35	12	3	1	1	7	21	28	2	9	6	24	7	1
	34%	9%	3%	3%	20%	60%	80%	6%	26%	17%	69%	20%	3%

5.1 Smaller batteries <2MWh

From 2, in general smaller batteries tend to explicitly state an objective that increase LVDN hosting capacity. If a BESS is installed on the LVDN of a household who was previously constrained for example, max 5kW instantaneous export, the constraint could be lifted with increased hosting capacity. Smaller BESS tend to also be DNSP led trials as discussed below.

5.2 Larger batteries >2MWh

Larger batteries are significant investments from private firms and tend to target revenue over grid operational issue mitigation. As such FFS, FCAS, SIPS and energy arbitrage are often clearly stated in their public documents. It is observed that larger batteries at the edge of grid like Edify Energy's Darlington operations and Neone's Horsdale Power Reserve have implemented or are in the process of testing virtual inertia support. Unlike WEM, NEM does not have a market for strengthening the grid via virtual inertia, but should it become a future market, early implementation should reap good return on investment. For example, ESCRI-SA was an early power BESS that predominantly operated on the FFS and FCAS market. In the first-year operations, revenue was $2-3M. In the second year of operation, its revenue was $16M and ElectraNet notes it was an exceptional 1st half results but returned to norm in the 2nd half followed by projection of reducing FCAS revenue in the long run (ElectraNet 2021).

5.3 DNSP neighbourhood batteries

DNSP led BESS trials tend to favour deferred augmentation operational issue mitigation because they can defer augmentation of a network to after the price regulatory reset. This allows DNSPs to price in costly augmentation which costs significantly more than installing and operating a BESS. Another reason most smaller projects tend to be DNSP led is because they are partially funded by government grants and offer real savings.

5.4 Special contracts

SIPS competitive tender for special cases such as reserve power for allowing sufficient time to optimise VNI connection negate a BESS' ability to act as a peak solar time shift and power battery. It is noted that the 2 BESS projects with SIPS contracts were selected for their lowest cost and tend to be the batteries with the greatest economies of scale such as the big Victorian battery.

5.5 WEM

The WEM in Western Australia operates under different dispatch and spot price market mechanisms hence none of the BESS' explicitly mentions frequency support. The WEM, at 1.1million customers, is completely islanded from the NEM, which has over 9 million customers and does not have flexibility for interconnect support so BESS' tend to be less reactive to market forces and thus often state their objectives of peak solar time shifting. It is also noted there are no community led BESS trials as DNSP deferred augmentation in the WEM is generally required for economic viability (AEMO 2023).

5.6 Time shifting peak solar is key for community impact

Several projects such as the Bungarribee Community battery and Power Bank have direct community impact where they allow households to subscribe to energy storage in lieu of households purchasing their own domestic BESS. The majority of other BESS trials and operations do not have any direct impact and operate in the background for revenue generation. Enabling hosting capacity and encouraging solar PV DER penetration is the simplest way for Australia to increase renewable generation. Community BESS systems that directly impact a household's electricity bill, shorten PV pay back period and allow direct access to reduce thermal generator reliance can accelerate this further (Graham and Mediwaththe 2022).

6. Conclusion

As small batteries tend to justify their viability with DNSP deferred augmentation and large batteries aim for maximising revenue from FCAS markets, they are both fundamentally addressing grid operational issues. As Australia moves towards high DER penetration and high renewable energy generation, growth in BESS' supply is required to continue to offset operational issues. The lack of private non DNSP firms funding smaller batteries is clear that revenues are not tied to the operational issues of time shifting peak solar and increasing host capacity. If BESS growth was to slow due to lack of investment, it is possible to see PV DER also lag (Gilmore, Nolan and Simshauser 2022).

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