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Utility Scale Storage Performance and Opportunities in the FCAS Regulation Market

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Abstract

Australia's National Electricity Market (NEM) is undergoing rapid transition in its generation mix. Importantly, large-scale synchronised generation is increasingly being replaced with variable renewable resources, such as wind and photovoltaics (PV). These technologies have rather different operational characteristics to conventional thermal and hydro plants introducing new frequency management challenges and opportunities.

Wind and PV plants are inverter connected to the grid, and hence don't inherently offer the same ancillary services as generators with synchronous machine grid interface. In particular, they do not provide inertia, which plays a key role in maintaining frequency stability by inherently and automatically resisting rapid frequency deviations. Inertia effectively buys time for slower acting frequency control services to act. With increasing wind and PV penetration, the NEM's Frequency Control Ancillary Services (FCAS) markets are becoming more important for ensuring system stability. An increased demand for FCAS Regulation services, procured to constantly correct minor frequency deviations of the system, is already emerging in parts of the NEM with significant changes in the generation mix, while there are growing discussions regarding the need for incentives to encourage faster responses to frequency deviations.

Utility-scale battery energy storage, also inverter-connected, is emerging as an effective technology for providing FCAS Regulation services. The Hornsdale Power Reserve Plant (HPR) was the first utility-scale storage plant commissioned in Australia, it has demonstrated success in responding quickly and accurately to regulation targets and reducing FCAS costs.

This paper explores the advantageous characteristics of utility-scale storage in providing frequency regulation, by comparing the performance of HPR to the traditional generators that currently participate in the NEM's FCAS Regulation markets. It assesses the extent to which the NEM's FCAS Regulation market rewards performance and incentivises future deployment of technologies with similar capabilities. An alternative FCAS market design is briefly explored to illustrate the potential for NEM arrangements and revenue calculations to be improved and better reflect the very fast and accurate frequency response capabilities of emerging technologies, such as utility-scale storage.

1. Introduction

Australia's electricity industry is transitioning away from traditional, large-scale, centrally dispatched and synchronous generation towards more variable, nonsynchronous and renewable resources. This is creating challenges for frequency management in the Australian National Electricity Market (NEM). First, wind and solar are highly variable and hence increase supply variations between five-minute wholesale market dispatch. Secondly, they are displacing conventional thermal plant in the

generation mix, plant that has traditionally provided both inherent inertia to resist rapid frequency changes, as well as frequency control services.

Of course, power systems have always had to manage frequency control challenges including ongoing demand variations, as well as major contingency events, such as the loss of large generating units. Management of these challenges are often separated into load following or regulation serves to deal with ongoing relatively small deviations in supply and demand, and contingency services of different response speeds. The NEM has created a range of Frequency Control Ancillary Services (FCAS) markets in which generation (and demand) participants can compete to provide such services. These FCAS arrangements were introduced in 2003 and, certainly initially, appeared to be working reasonably efficiently at providing secure and reliable frequency control services while renewable penetrations grew (Riesz, et al., 2015). More recently, however, utility wind and photovoltaics (PV) deployment has accelerated and renewed attention on frequency control challenges. Fortunately, utility-scale storage is an emerging technology that is quickly proving an effective source of some types of frequency control services. This paper focuses on the potential role of utility-scale storage as a source of FCAS Regulation services, including its characteristics and performance relative to other generators, as well as the extent to which current NEM arrangements incentivise some of the enhanced frequency control services it can provide. Potential opportunities and arrangements, which could improve FCAS Regulation Market incentives are also briefly explored, which would allow utility-scale storage to potentially reap higher revenues.

This paper's scope only examines battery energy storage systems at a utility-scale within the FCAS Regulation market, for simplicity it will be referred to as BESS. The structure of this paper is as follows. Section 2 presents the current context for FCAS market arrangements in the NEM. Section 3 outlines the method undertaken and presents results of assessing the capabilities and performance of BESS in the FCAS market. These results are discussed and final conclusions made in Section 4.

2. Background and Context

The Australian Energy Market Operator (AEMO) oversees the operation of the NEM and uses a range of ancillary services to manage grid security and reliability, notably frequency and voltage control. Importantly, the NEM's frequency must remain close to fifty cycles per second (AEMO, 2015). To maintain a stable frequency, demand and supply must be closely matched at all times. The NEM's FCAS Regulation markets are used to correct ongoing, relatively minor, frequency deviations from variations in supply and demand between wholesale market dispatches. Generators and loads submit bids to participate in the FCAS markets every five minutes, via AEMO's Market Management Systems (MMS) (AEMO, 2015). Many generators may submit joint offers for both the spot wholesale as well as a range of FCAS markets. AEMO co-optimises wholesale and FCAS markets to determine dispatch and payments to participants every five minutes. AEMO continuously monitors frequency, and activates frequency regulation services from those participants enabled to provide them, through Automated Generation Control (AGC) (AEMO, 2015). Signals (or setpoints) are sent by AEMO every four seconds when minor frequency deviations need to be corrected.

2.1. NEM's Changing Generation Mix

Synchronous generation, such as thermal and hydro generators have large rotating masses, electromagnetically coupled to the power system frequency (IFC AND ESMAP, 2017), providing inertia to dampen frequency deviations and slow the rate of change of frequency (RoCoF) (AEMO, 2017). Synchronous generators, which have typically met the majority of demand in power systems, have therefore traditionally been relied upon to inherently support power system security and reliability through their inertia provision. Nonsynchronous generators, such as wind and PV, are connected to the grid via inverters and therefore cannot provide traditional inertia. With increasing penetrations of nonsynchronous generators, and the decline of synchronous generation, there is now a greater need for fast frequency response to deviations. Over slightly longer time frames, in

the order of seconds to minutes, fast ramping generation is also required to assist with the variability of renewables as well as demand. This has typically been largely provided by thermal coal plants which are not particularly flexible, but can provide some level of output response over such time. The displacement of such plant by wind and solar therefore also has impacts on the provision of such frequency response. Over minutes, other flexible generation such as hydroelectric plant, and gas and liquid fuel peakers can also participate. Now, however, BESS is emerging as an ideal solution for frequency management over a range of time frames since it can charge and discharge extremely rapidly, yet continue to contribute for extended periods. The National Renewable Energy Laboratory (NREL) has demonstrated flexibility with its one megawatt energy storage system, responding to signals in less than 30-40 milliseconds (NREL, 2018).

2.1.1. Hornsdale Power Reserve

Hornsdale Power Reserve (HPR) in South Australia (SA) is the first BESS of its scale in Australia, and was the largest lithium-ion battery globally when installed (Hornsdale Power Reserve, 2018). It is rated at 100MW discharge, 80MW charge and registered to provide up to 30MW of its capacity in FCAS Regulation services (AEMO, 2018). It is also the first nonsynchronous generator to provide regulation services in the NEM (AEMO, 2018). HPR has been celebrated for successfully reducing FCAS prices and the ability of gas generators to exploit their market power, within four months of commencing operation, regulation FCAS prices dropped by 90% (Vorrath & Parkinson, 2018). Despite its relatively small size – representing 2% of SA capacity – HPR has captured over 55% of FCAS revenues in SA (Vorrath & Parkinson, 2018), demonstrating that only a small amount of storage capacity is required to have an impact on the market.

In April 2018, AEMO released an assessment of HPR's performance, specifically within the FCAS Regulation market (AEMO, 2018). It concluded that HPR could almost perfectly meet its AGC setpoints, and that a large conventional steam turbine was unable to match HPR's accuracy (AEMO, 2018). Steam turbines displayed a considerable delay before their output responded to a change in the AGC setpoints (AEMO, 2018). Whilst HPR proved to be more accurate in meeting setpoints, there are currently no arrangements within the FCAS market rewarding this superior performance. Instead, both HPR and a conventional steam turbine receive the same price per MW (AEMO, 2018), limiting the incentive to deploy more highly flexible capacity, such as BESS in the NEM. AEMO has raised this as an issue, and the potential for arrangements used in other electricity markets to be replicated in the NEM to improve incentives (AEMO, 2018). It is important to note, participants only respond once they receive the AGC signal, every four seconds. However, frequency deviations occur on a much shorter timescale, limiting the effectiveness and response efficiency of the FCAS Regulation market.

2.1.2. PJM Interconnection Case Study

The United States' PJM Interconnection Market (PJM) is an example of a frequency regulation market that rewards speed and accuracy in following AGC instructions, by producing separate regulation products depending on a participant's speed of response. RegA is the AGC signal sent to traditional regulating participants, such as large steam turbines, whilst RegD is sent to dynamic or fast responding regulating participants, such as BESS (Ogburn & Bresler, 2012). RegD AGC signals respond to frequency deviations in real time, whereas RegA signals permit a slower response. PJM uses several performance metrics to calculate regulation payments, rewarding high quality performance (AEMO, 2018). These are described in more detail later in this paper.

3. Research Design

The aim of this paper is to contribute to the understanding of BESS' capabilities, specifically within the FCAS Regulation market, highlight current barriers and present potential opportunities to improve the efficiency of incentives. Key research areas and questions have been developed to address this overall aim:

1. Investigate HPR's ramping abilities relative to other NEM generators.
2. Analyse NEM generators providing FCAS Regulation services, determine the extent to which HPR has impacted their regulation dispatch and regional aggregate dispatch.
3. Investigate the effect of implementing incentives similar to the PJM Regulation Model on NEM Regulation FCAS market outcomes.

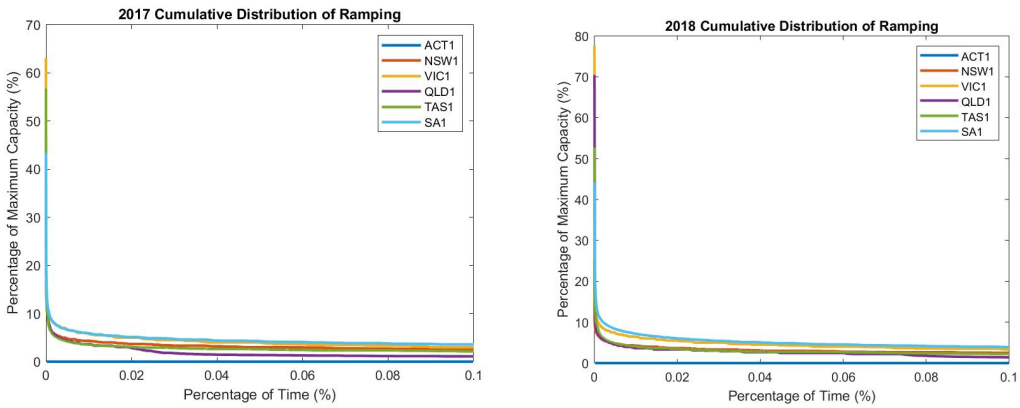
Generators of all technology types registered in the NEM are included to show how performance differs across technologies. Data from the month of March 2018 is modelled as it was the most recent data available at the time of the study. Where 2017 data is available, March 2017 data has also been modelled to compare differences before and after HPR was commissioned.

3.1. Generator Ramping

3.1.1. Method Overview

For this paper, ramping will refer to any controlled change in generation between two consecutive intervals, it is given in MW or as a percentage of the generator's maximum rated capacity. The AEMO Ancillary Services Market Causer Pays Data was the key data input used to investigate generator ramping behaviour in March 2017 and 2018. The relatively short period of analysis for each year was necessitated by the very large data sets involved, and the only limited period of operation of HPR at the time of the study. To calculate the ramp, the output at each four second interval was subtracted from the previous interval. The ramp or change in generation was then normalised by dividing it by each generators' maximum rated capacity so it could be compared across generators. To eliminate large ramps, which occur during generator start up, intervals where the generator was operating at 5% capacity or less were removed.

3.1.2. Generator Ramping Results

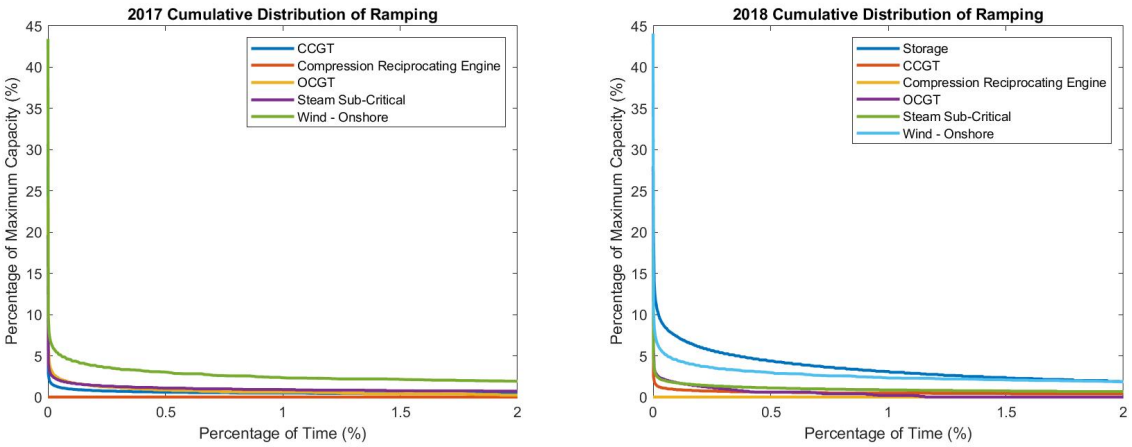


(a) (b)

Figure 1: Cumulative distribution of all generators ramping by state for (a) March in 2017 & (b) 2018

The largest change in generation calculated was on 14th March 2018 by Yallourn 'W' Power Station – Unit 4 (YWPS4), a brown coal fired plant in Victoria. YWPS4 decreased its generation by 77.58% of its rated capacity within four seconds. The next largest change was the Kidston Solar Project (KSP1), a PV generator in Queensland at 70.44% of its rated capacity. However, ramps of this size very rarely occurred. For each region, ramps that exceeded 5% of generator capacity occurred less than 5% of the time, shown in Figure 1. YWPS4's drop in generation on 14 March was caused by a trip, removing 380MW of generation from the system (AER, 2018). It is important to note that changes of this scale are not considered ramps, as the definition of a ramp is a controlled change in generation, these changes or trips are not scheduled. YWPS4 and KSP1's next largest change was

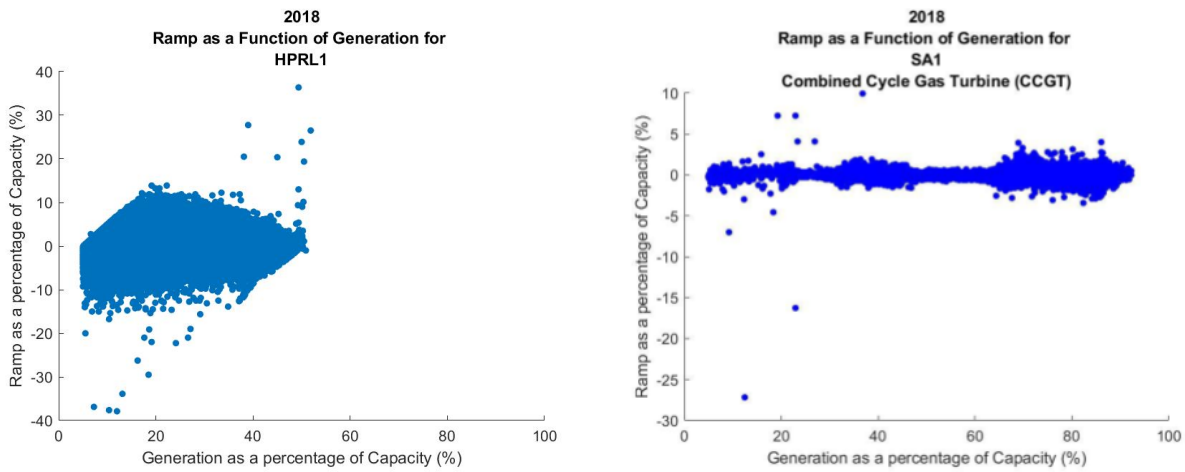
only 6% and 20% of their rated capacity respectively. Whilst the largest changes in generation calculated are significant, it is important to note they occur rarely, and often are unscheduled, hence not a ramp. The average ramp is significantly lower. Most states had an average ramp under one per cent of generator capacity.



(a) (b)

Figure 2: Cumulative Distribution of SA Generator Ramping (a) March 2017 & (b) 2018

Excluding variable generation (wind, since it is involuntary) in SA, HPR had the largest ramp as a percentage of capacity in both directions. It exceeded the maximum ramp of fossil fuel powered generators by 12% and 10% in ramps up and down respectively. Figure 2 shows ramping for the largest two per cent of ramp events, underscoring the infrequent nature of large ramps. In general, the majority of all generator ramps (99%) were under 5% of capacity in magnitude. Importantly, BESS recorded the largest ramps as a percentage of capacity, relative to the other scheduled technologies. This confirms HPR's technical advantage for FCAS regulation, since fossil fuelled generators ramping abilities is limited by inertia and thermal efficiency.



(a) (b)

Figure 3: (a) HPR and (b) CCGT Ramping as a Percentage of Generation Target March 2018

Ramps have also been compared to the target that the generator was ramping to at the end of the four second period (Figure 3), to better understand the circumstances when ramping occurred. Figure 3 plots ramp against target, both as a percentage of capacity. For instance, if the ramp between time 1 and 2 was -40% and the generation was 30%, the generator ramped down from 70% to 30% of capacity. Most of HPR's ramps calculated were between -20% and 20% of capacity. In

contrast, SA closed cycle gas turbines (CCGT) has a much narrower range, with most ramps between -5% and 5% of capacity. Fossil fuelled generators seldom ramped at magnitudes of 30% to 40%, which is not considered a ramp but rather outliers e.g. these can often be attributed to a plant trip. Figure 3 also shows that HPR did not reach 60% of capacity during March 2018, likely an outcome of the contractual arrangements with the South Australian Government.

3.2. HPR Impacts on FCAS Regulation Markets

3.2.1. Method Overview

To compare how the NEM's FCAS Regulation Markets may have been impacted by HPR, the DISPATCHLOAD and DISPATCHREGIONSUM databases from the NEM MMSDM (Market Management System Data Model) were analysed. This data includes the actual regulation availability (available capacity each generator was paid to provide for regulation) and regulation dispatch target of each generator on a five-minute resolution as well as the aggregate regulation dispatched per region (AEMO, 2017, p. 153). The actual availability and target of a generator was normalised to the generator's maximum capacity. For the analysis, to avoid statistical skewing, for intervals where a region's regulation dispatch was zero, the region's data was omitted, and for intervals where a generator's availability or target was zero, that generator's data were removed.

3.2.2. FCAS Regulation Analysis Results

The distribution of each NEM region's contribution to FCAS Regulation in March 2017 and 2018 are summarised with boxplot distributions, in Figure 4 (Lower) and Figure 5 (Raise).

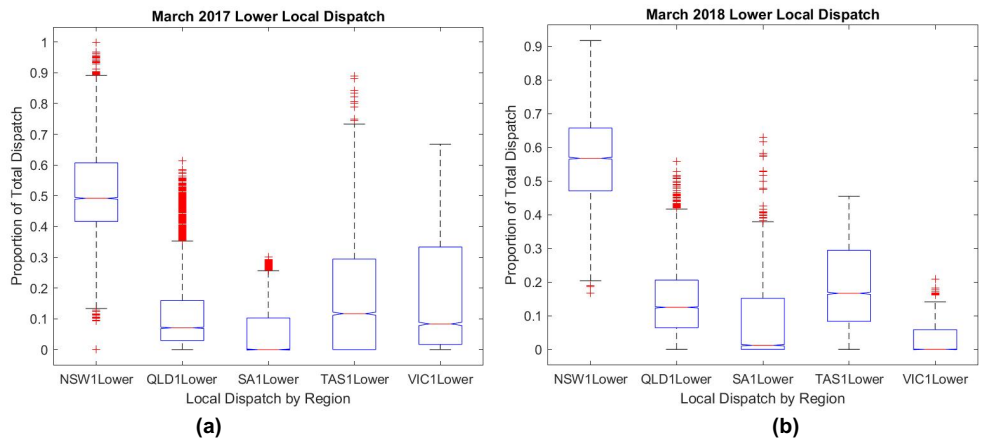
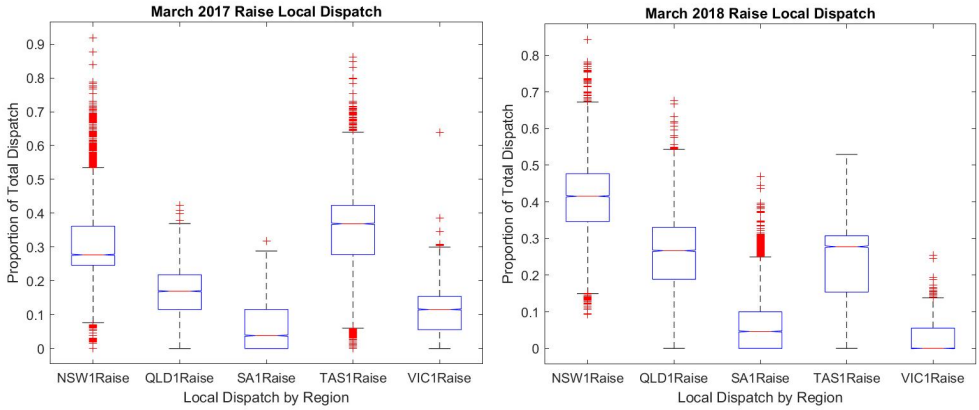


Figure 4: Lower Local Dispatch per region in (a) March 2017 & (b) 2018

NSW dominated the provision of FCAS Lower and Raise Regulation services in 2018 with a median of 58% and 42% in regulation contribution respectively, which is unsurprising since it has the largest number of registered generators providing FCAS Regulation. SA's relative Regulation dispatch increased from 2017 to 2018, likely to be due to the operation of HPR. Interestingly, Victoria was the only region where the proportion of regulation dispatch decreased from 2017 to 2018 for both raise and lower services. While Victoria is a relatively small source of FCAS Regulation, this could potentially be due to HPR allowing SA to be less reliant on imports from other NEM states. However, interconnector flows would need to be assessed to make this conclusion with confidence. The decommissioning of the Hazelwood Power Station also very likely contributed to a decrease in VIC's dispatch.

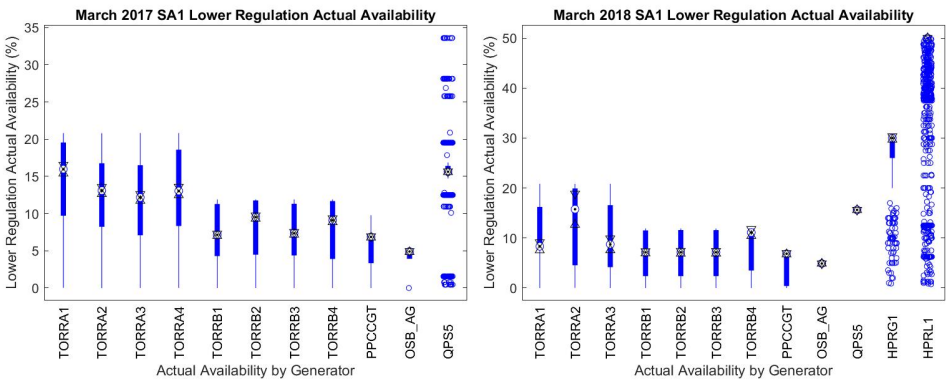
The impact of HPR on SA FCAS Regulation is shown in boxplots of South Australian generators' actual availability in Figure 6.



(a) (b)

Figure 5: Raise Local Dispatch per region in (a) March 2017 & (b) 2018

Figure 6 shows that HPR clearly dominates Lower Regulation market (similar results were found for the Raise Regulation Market), with the largest availability as a percentage of its capacity in 2018 for both raise and lower services. Note that HPR is categorised as both a generator and load in the AEMO data. In terms of targets, HPR was allocated the largest target relative to its capacity, with a median or 30% for HPRL1 (load), as shown in Figure 7.



(a) (b)

Figure 6: Actual Availability for Lower Regulation in (a) March 2017 & (b) 2018

In contrast, the largest target of other generators did not exceed 16%, which was considered an outlier. However, data shows the commissioning of HPR has had a minimal impact on other South Australian generators' availability and targets. Whilst there were units whose median actual availability or targets fell, most stayed constant and changes were relatively small.

To better assess the impact of HPR on other generators in the FCAS Regulation market, SCADA Regulation dispatch data for each generator would be required, unfortunately, AEMO only publishes this data as a regional aggregate. It is possible that HPR may have reduced the regulation dispatch of SA generators, however this conclusion cannot be made from this research alone, only the impact on availability and targets can be assessed. Interestingly, the number of generators assigned Regulation targets by AEMO is less than the number of generators available for the service. This reflects the competitive aspects of FCAS in the NEM, where participants effectively compete to provide ancillary services.

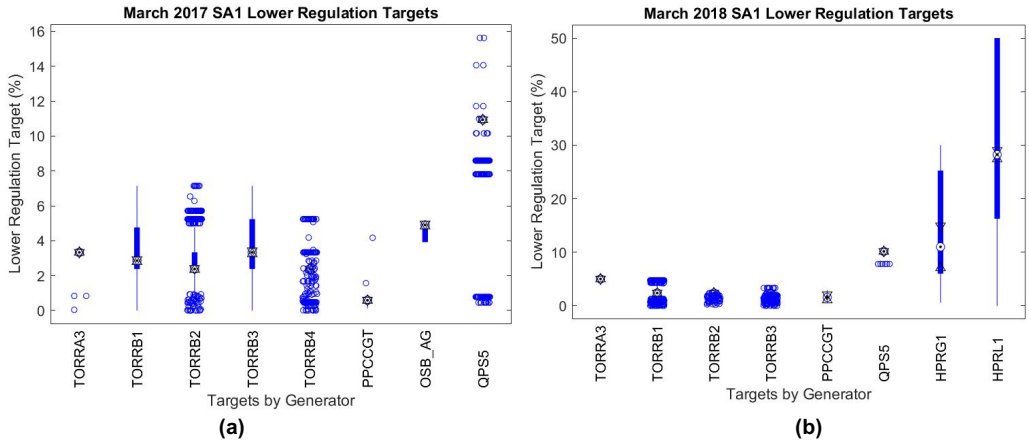


Figure 7: Lower Regulation Targets in (a) March 2017 & (b) 2018 for SA.

3.3. Exploring PJM Regulation Incentives for faster frequency response in the NEM

As a very preliminary assessment of how the PJM regulation market arrangement for rewarding better performing frequency control providers might be applied in the NEM, this investigation analysed how the value of offers changed for each participant during one five-minute interval on March 18th 2018. This date was chosen as the data was accessible at the time. Only one five-minute interval for each regulation service was analysed due to time constraints, hence the findings below should be seen as exploratory only.

In the PJM Regulation market, several scores are calculated to adjust the value of generator offers according to performance. The Performance Score (PS) is a historic, hourly score, based on ten second data reflecting a participant's ability to meet the AGC signal (PJM, 2018). It ranges from 0 – 1 and takes into account a participant's speed of response and how precisely it can match the AGC signal. Participants are incentivised to respond quickly and accurately to signals, as their PS directly alters the dollar and energy value they submit in their bids. Participants will notify PJM of the amount of regulation they are capable to provide on a given 5-minute interval, which is adjusted on the basis of their historical PS, as shown in Equation 1.

$$Performance\ Adjusted\ MW_i = Capability_i\ (MW) \times Performance\ Score_i$$

Equation 1

Equation 2 shows how a low PS increases the dollar value of a participant's offer, making it less attractive, deteriorating their position in the dispatch hierarchy, and by extension reducing revenue.

$$Total\ Adjusted\ Offer_i\ (\$) = \frac{Total\ Offer_i\ (\$)}{Performance\ Score_i}$$

Equation 2

A second performance metric is the Benefits Factor (BF), which assists in improving the probability of fast responding participants being dispatched. Once the PS is calculated, all generators' Total Adjusted Offers are ordered in ascending order and the Cumulative Performance Adjusted MW for each generator is calculated. This is used to find the BF, as shown in Equation 3, which will range from 0 to 2.9. It only applies to RegD generators, all RegA generators always have a BF of 1 (PJM, 2018). The Effective MW is the final performance adjusted MW, used to calculate revenue and varies with BF as shown in Equation 4 for RegD resources. It is calculated one-hour ahead of a generator's bid and then recalculated every 5 minutes to consider any rebids (PJM, 2018). Since RegA participants have a fixed BF of 1, the chances of RegD participants being dispatched ahead of RegA participants is increased, up to a point of diminishing returns, where BF = 1 (PJM, 2018). Overall,

PJM's BF adjusts the cost of RegD resources to better reflect their value in maintaining system stability and improve their position in the dispatch hierarchy.

$$Benefits\ Factor_i = \frac{Cumulative\ Performance\ Adjusted\ MW_i \times (0.0001 - 2.9)}{Percentage\ RegD \times Regulation\ Required} + 2.9$$

Equation 3

$$Effective\ MW_i = Benefits\ Factor_i \times Performance\ Adjusted\ MW_i$$

Equation 4

For this study, the generator actual availability data was analysed from the DISPATCHLOAD database as well as the BIDDAYOFFER database, which details the rebids generators submitted for regulation services (AEMO, 2010). Since Performance Scores are not known for NEM generators, Average Performance Scores (PS) for the same technologies from PJM's 2015 *Performance Score Report* (PJM, 2015) were used as per Table 1. For this model, two scenarios were analysed: Scenario 1 (S1) where only BESS was considered to be a RegD (fast) resource; and Scenario 2 (S2) where all resources were considered to be RegD resources.

Table 1: Performance Scores used as inputs for each scenario

Resource Technology	Scenario 1		Scenario 2	
	Regulation Type	Performance Score	Regulation Type	Performance Score
Battery	RegD	0.940	RegD	0.940
Hydro	RegA	0.757	RegD	0.796
OCGT	RegA	0.900	RegD	0.844
OCGT & CCGT	RegA	0.900	RegD	0.844
CCGT	RegA	0.900	RegD	0.844
PV	RegA	0.900	RegD	0.844
Steam Sub-Critical	RegA	0.757	RegD	0.796
Steam Super-Critical	RegA	0.757	RegD	0.796
Wind	RegA	0.900	RegD	0.844

The data was analysed to find the performance adjusted MW offer for each generator. For Raise Regulation the 8:55PM 5-minute period was used and 5:45PM was used for Lower Regulation, as these intervals had the largest MW available on March 18th. BIDDAYOFFER contains each participant's ten price band offers for the day in $/MWh, including both daily and rebid offers, provided to AEMO (AEMO, 2010). It was assumed the most recent rebid offer would most likely reflect the cost of providing the service, if there were multiple rebid offers, the rebid with the higher version number was chosen. In total, 27 participants submitted a Regulation Raise offer and 29 submitted a Regulation Lower offer during these periods, listed in Table 2. It was assumed only generators that submitted offers for these services were dispatched. Since the MW rebid or dispatch data is not available, the availability of the generator for the time interval was used.

Table 2: Generators who submitted a regulation bid and their relevant actual availability

Generator DUID	Region	Fuel	Technology	Lower Actual Availability (MW)	Raise Actual Availability (MW)
LOYYB2	VIC1	Brown Coal	Steam Sub-Critical	50	-
UPPTUMUT	NSW1	Water	Hydro - Gravity	20	12
MURRAY	VIC1	Water	Hydro - Gravity	10	10
ER02	NSW1	Black Coal	Steam Sub-Critical	15	-
ER03	NSW1	Black Coal	Steam Sub-Critical	15	-
ER04	NSW1	Black Coal	Steam Sub-Critical	15	-
MP1	NSW1	Black Coal	Steam Sub-Critical	60	No bid
MP2	NSW1	Black Coal	Steam Sub-Critical	59	No bid

PPCCGT	SA1	Natural Gas	Combined Cycle Gas Turbine (CCGT)	2	35
CALL_B_1	QLD1	Black Coal	Steam Sub-Critical	-	-
CALL_B_2	QLD1	Black Coal	Steam Sub-Critical	15	-
GSTONE2	QLD1	Black Coal	Steam Sub-Critical	18	-
GSTONE3	QLD1	Black Coal	Steam Sub-Critical	-	-
GSTONE4	QLD1	Black Coal	Steam Sub-Critical	-	18
GSTONE5	QLD1	Black Coal	Steam Sub-Critical	14	8
GSTONE6	QLD1	Black Coal	Steam Sub-Critical	-	-
MPP_1	QLD1	Black Coal	Steam Super Critical	15	-
MPP_2	QLD1	Black Coal	Steam Super Critical	15	-
TUNGATIN	TAS1	Water	Hydro - Gravity	-	-
REECE1	TAS1	Water	Hydro - Gravity	8	70
REECE2	TAS1	Water	Hydro - Gravity	-	82
POAT110	TAS1	Water	Hydro - Gravity	-	-
POAT220	TAS1	Water	Hydro - Gravity	-	-
JBUTTERS	TAS1	Water	Hydro - Gravity	100	128
GORDON	TAS1	Water	Hydro - Gravity	305	-
DEVILS_G	TAS1	Water	Hydro - Gravity	51	2
CETHANA	TAS1	Water	Hydro - Gravity	74	16
HPRG1	SA1	Storage	Battery and Storage	30	30
HPRL1	SA1	Storage	Battery and Storage	40	-
TOTAL				**932**	**411**

All offers submitted were adjusted to consider the Performance Score (PS) of each technology for the two scenarios, using Equation 1 and Equation 2. To find the total adjusted offer the units of the rebid offer were converted from $/MWh to $, using the actual availability of the generator. If the actual availability of the lower or raise service was zero MW, it was assumed the generator was unable to be dispatched and was removed. The remaining generators were sorted in ascending order based on the value of their Performance Adjusted Offer. The BF of each generator was calculated using Equation 3 for each of the ten price bands. The Percentage RegD was kept constant at 40% which is consistent with PJM's calculations (PJM, n.d.). In the PJM Interconnection Market, the Regulation Required is set at 700MW. We used the total actual availability for the interval in the NEM to represent Regulation Required, which is given in Table 2. The final Effective MW was calculated using Equation 4. For RegA resources the Effective MW is the same as the Performance Adjusted MW, since the BF equals one.

3.3.1. PJM Regulation Exploration Findings

The BF is designed to increase the chance of RegD generators being dispatched. In theory if the BF is less than one the generator will be dispatched last or not at all, this highlighted in red in Table 3. Importantly in every scenario the BF for battery and storage was above one. Interestingly in Scenario 2, Hydro had a higher PS but its BF was now below one, likely due to a lower cumulative adjusted MW.

Table 3: Average BF for each generation technology

Technology	Lower S1	Lower S2	Raise S1	Raise S2
Hydro - Gravity	1.00	0.71	1.00	0.86
Steam Sub-Critical	1.00	1.21	1.00	1.08
Steam Super Critical	1.00	1.71	-	-
Battery and Storage	1.43	1.37	1.53	1.46

For Scenario 1, the Effective MW of hydro, steam sub-critical and steam super critical was the same as their Performance Adjusted MW since they are RegA resources and have a BF of 1.

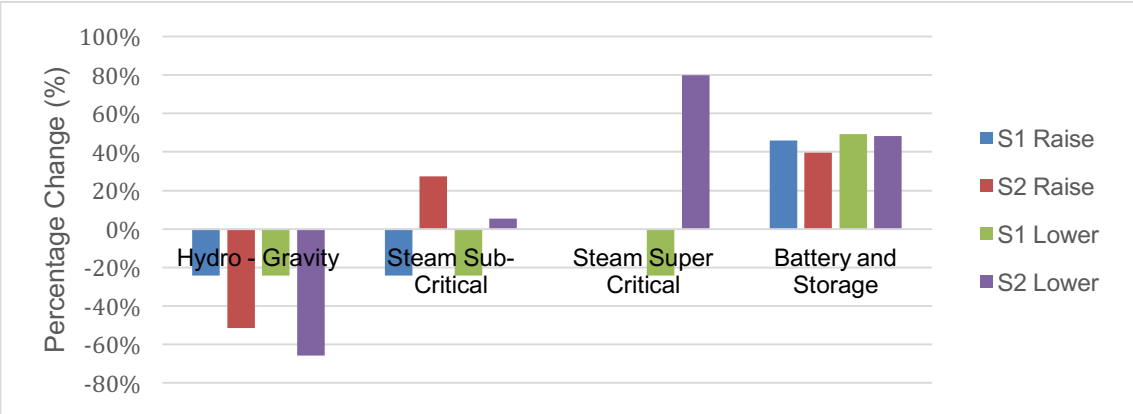


Figure 8: Average percentage change in actual availability and effective MW

The average percentage change of the Effective MW from the initial availability of each generating technology is given in Figure 8. Importantly, for every scenario, BESS' Effective MW improved by around 40% to 50%. No other generating technology saw an improvement as consistent as this. However, in Scenario 2, when steam super critical was considered a RegD resource, its improvement was approximately 80%.

In this preliminary investigation, applying the PJM Regulation Model in the NEM had the effect of increasing HPR's revenue relative to slower responding generators (such as fossil fuel powered generators) by improving its chance of being dispatched. Whilst BESS did have a BF of less than one at times, this occurred very rarely in comparison to other generators, such as hydro. Comparison of the Effective MW is to the initial Actual Availability MW, confirm that the performance metrics improve BESS' order in being dispatched. It is important to note that the BF also caused an increase to the Effective MW for steam sub-critical and steam super-critical generators in Scenario 2. Whilst steam super critical saw the largest percentage improvement, it was not consistent with BESS' average percentage change, which was greater than 40% in all scenarios, as shown in Figure 8.

Only one day of bid offers were considered in this study and only one five-minute interval analysed for each service. While this study allowed visibility of how the PJM mechanism might work in the NEM, to gain an understanding of the extent to which the performance metrics improve BESS' attractiveness as a regulating resource, analysis of a much larger period of data would be required. Several simplifications and assumptions were also made which limit the reliability pf the findings. Since regulation dispatch SCADA data was unavailable, the actual availability of the generators was used, whereas in reality the amount dispatched may differ. The RegD percentage input in the Benefits Factor formula was kept constant at 40%, consistent with the PJM market. However, this could differ in the NEM and in future work, it would be useful to explore how results vary with different RegD percentage input values.

4. Discussion and Conclusion

Overall, the study showed that BESS looks to be effective in providing FCAS Regulation services due to their relative enhanced ability to ramp, respond quickly to AGC signals and match targets accurately. Investigation into the ramping capabilities of generators highlighted the important role the FCAS Market plays in stabilising the grid. The investigation found that significant changes in generation are not considered scheduled ramps but trips, demonstrating how generator tripping creates problems for system stability, and a need for fast responding systems such as BESS. The distribution of generator ramps analysed showed that conventional generators are rarely required to ramp more than five per cent of their capacity over a period of four seconds. BESS, such as HPR are capable of much faster ramps in comparison to fossil fuel powered generators. If FCAS

Regulation dispatch data were available, it would allow for a greater insight into the capabilities of generators to respond quickly to AGC regulation signals specifically.

Analysis of regulation Actual Availability and Target data for South Australia showed that HPR is a significant source for Regulation services, as expected. However, it is difficult to assess the impact of HPR on another generator's dispatch without having access to regulation dispatch data. Whilst there were some changes apparent in the availability and targets of other SA generators from 2017 to 2018, these were minimal. There has also seen an increase in the proportion of total NEM Regulation SA provides since HPR has been commissioned. SA appears to be less reliant on imports from other states for Regulation services, since Victoria's Regulation dispatch has dropped. It might be concluded that since HPR has begun operating SA is better able to manage system stability autonomously, a conclusion that could be further supported by analysing changes in interconnector flows. It is important to note that the drop in Victoria's regulation dispatch cannot be attributed to the commissioning of HPR alone, the decommissioning of the Hazelwood Power Plant would also be a significant contributor, amongst other factors. Analysing frequency deviations in other NEM regions would also provide an indication of the value of fast response BESS to regulate frequency in those regions. The major limitation hindering this investigation was the lack of access to FCAS Regulation generator dispatch data. This limits the extent to which the HPR's contribution to the FCAS Regulation market can be assessed.

Currently generators in the NEM FCAS Regulation markets are not incentivised nor rewarded to respond quickly and accurately to AGC signals. Preliminary modelling of the PJM Regulation Model in the NEM has indicated how application of the PJM performance metrics could improve the chances of a fast responding generator being dispatched. However, care should be taken when interpreting the results since there were several assumptions and simplifications made in this. Arbitrary inputs, such as the Percentage RegD requirement and Regulation Requirement input in the BF formula were kept constant, matching PJM values. For future work, it is recommended that the BF be calculated with these inputs changing to better assess their impact. A significant constraint of the PJM model exploration was that only one day of data was used for the bid offers and only one specific interval modelled to calculate the BF. Developing a program which could calculate the BF and optimise the adjusted offer for every five-minute interval per day would allow for a more holistic understanding of the PJM model. Further, only March data was analysed and it is recommended this be expanded to at least a year to better assess the distribution of ramps and the impact of seasonal factors. Modelling using a larger set of data would need to be completed to make any preliminary conclusions more reliable.

Should a system like the PJM Regulation Model be implemented in the NEM it would require modification and formal consultation with industry. This would also raise the question of what determines the ideal mix of regulating generators. In the PJM model, a fast and accurate rate of response is valued through the Performance Score. However, there may be other characteristics that are important in providing regulation, such as the ability of a generator to maintain output. BESS' ability to maintain output is limited by its state of charge at the time of dispatch. Careful consideration should be taken when deciding which generating characteristics should be valued ahead of others.

Finally, the scope of this paper was limited to the FCAS Regulation Market. HPR is also registered to participate in the FCAS Contingency market. It would be interesting to compare how revenue differs between all eight FCAS markets, and where BESS adds the most value. Given BESS' fast response capabilities, this feature would be especially useful in responding to contingency events.

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