Five Minute Settlement Working Group:
Working Paper No. 1:
Materiality of the Problem and Responsiveness of Generation and Load

12 October 2016

1. Introduction

The AEMC is currently assessing the Five Minute Settlement rule change request submitted by Sun Metals Corporation. The proposal seeks to align the dispatch and settlement intervals in the wholesale electricity market in order to improve market efficiency.

The AEMC has already undertaken one round of consultation on the proposal, resulting in formal submissions from 29 stakeholders. The AEMC team has also spoken to a wide range of stakeholders on a bilateral basis.

On 22 August, the AEMC extended the period of time to consider the proposal by revising the publication date of its draft decision to 30 March 2017. The time extension allows the AEMC to undertake further consultation on the complex issues raised. A stakeholder Working Group is an important component of this consultation.

This paper has been prepared to stimulate discussion in the first meeting of the Working Group. This meeting will cover the materiality of the problem and how participants may respond to a 5-minute price signal.

Issues relating to the design of any potential solution, implementation and transitional arrangements will be discussed in the second Working Group meeting. The AEMC is seeking to separate its consideration of the potential benefits from its evaluation of the likely costs.

The objectives of this meeting are to:

- communicate to stakeholders the AEMC's current thinking about the rule change proposal;
- present analysis undertaken in response to stakeholders' submissions; and
- stimulate further discussion and engagement.

This paper has been prepared as an AEMC staff paper and does not have the same status as a formal AEMC publication. It may not reflect the views of the AEMC's Commissioners.

Throughout this process, we encourage stakeholders to provide feedback, including complementary or competing analysis that can help us in making our decision.

We acknowledge that there are linkages between this rule change proposal and other AEMC projects, such as the Non-scheduled generation and load in central dispatch rule change, Demand Response Mechanism and Ancillary Services Unbundling rule change, and the System Security Market Frameworks Review. We are interested to understand from stakeholders what they consider these linkages to be.

The remainder of this working paper is structured as follows:

- **Section 2** describes our approach to assessing this rule change proposal, including the critical questions that we will seek to address; and
- **Section 3** sets out the analysis that we have undertaken to date to answer the questions identified in section 2.

2. Approach to assessing rule change request

This section sets out the AEMC's approach to assessing this rule change request and provides context for the analysis and questions presented to the Working Group through this paper.

As a starting point, the AEMC is guided by the National Electricity Objective, or NEO. The NEO is:

> *"to promote efficient investment in, and efficient operation and use of, electricity services for the long term interests of consumers of electricity with respect to:*
>
> *(a) price, quality, safety, reliability and security of supply of electricity; and*
>
> *(a) the reliability, safety and security of the national electricity system."*

The AEMC may only change the National Electricity Rules (NER) if it is satisfied that the change will, or is likely to, contribute to the achievement of the NEO. As such, the AEMC will, through this process, form a view on whether changing the NEM settlement arrangements would be in the long term interests of electricity consumers.

The rationale for the proposal is to increase the efficiency of spot market prices and the signal that they provide as to the value of generating and consuming electricity at different points in time. Among other things, the AEMC is seeking to test the rationale behind the rule change request, that the current arrangements:

- accentuate strategic late rebidding, where generators have been observed to withdraw generation capacity in order to influence price outcomes; and
- impede market entry for fast response generation and demand side response.

The AEMC is considering whether or not the proposed changes are likely to be efficiency enhancing, and so contribute to the NEO.

It is conceivable that the proposed changes will affect investment in and operation of electricity assets and services. The AEMC's consideration therefore includes both the potential benefits to consumers of more efficient decisions in operating the existing power systems, as well as the potential for more efficient investment decisions.

Based on information we have received from stakeholders and our own analysis to date, we have formed a preliminary view that:

1) economic theory supports aligned intervals for dispatch and settlement;

2) applying such a change to an existing market would have far-reaching consequences, so there may be significant costs associated with making the rule; and

3) the key question for this rule change process is therefore one of materiality: how significant are the differences between 5 and 30-minute prices and how might behaviour change if they were to be aligned?

The remainder of this section provides more detail on each of these points.

2.1. Economic argument

The current market arrangements for dispatch and settlement are:

- every 5-minutes the dispatch process determines the optimal combination of scheduled generation to meet demand, subject to network and other constraints; and
- financial transfers between the participants who buy from and sell into the pool occur based on 30-minute market outcomes (i.e. the 30-minute average of price, multiplied by the sum of energy supplied or consumed over six dispatch intervals).

These arrangements have been in place since the start of the NEM in December 1998.[1] They reflect a trade-off between optimising balancing costs while also settling the market with the technology available at the time. In particular, the 30-minute settlement interval reflects limitation in the metering and data handling technology at the time.

Relative to a longer interval, the 5-minute dispatch interval more closely matches the dynamic nature of the power system. It reduces the potential for supply and demand to deviate from their expected levels within the dispatch interval, resulting in lower ancillary service payments to keep the system in balance.

The design of the dispatch process recognises that demand and supply outcomes change from one 5-minute interval to the next. Though, in effect, 30-minute settlement obscures price and quantity variations w*ithin* the trading interval from the settlement process, and therefore the prices that are signalled to the market. This potentially gives rise to inefficiency.

Examples of the potential inefficiencies include the following:

- **Productive efficiency:** 30-minute settlement may distort participant bidding leading to inefficient dispatch. For example, generators may 'pile-in' at the same time as large users are curtailing consumption following a price spike early in a

[1] NECA, *National Electricity Code*, version 1, 19 November 1998.

trading period; batteries may have less of an incentive to discharge during the dispatch interval in which a price spike occurs (instead deferring output until later in the half hour). The resultant dispatch solution may be inefficient, meaning that the same level of production could have been achieved at lower cost.

- **Allocative efficiency**: Averaging the 5-minute price signal turns marginal prices into a 30-minute average price, potentially leading to inefficient consumption decisions at the margin (i.e. electricity may not be allocated to the highest value applications). For example, consumers may be 'caught out' by a spike late in the half hour. Or in the case of an early spike, price-responsive loads may decide not to curtail as the spike is smeared across all consumption in the half hour. Since the 30-minute price does not signal the value of electricity within the dispatch interval, the signal to reduce consumption in response to 5-minute price spikes, or consume more when prices are low, is muted and these responses may not occur.
- **Dynamic efficiency**: Over time, the distorted price signal implicit in differentiated dispatch and settlement prices may lead to inefficient investment in new generation, demand side technologies, and electricity consuming infrastructure. The distorted price signal does not convey accurate information about the value of variations in supply and demand across the trading interval. It may therefore act as a disincentive to invest in flexible technologies that may be of benefit to consumers. Examples of these technologies include batteries, demand response capabilities, alternative fast-start generators and upgrades to increase the start-up and ramping capabilities of gas and coal power stations. Further, price-responsive loads, and generators too, face the risk of being 'caught out' by late price spikes. This risk may also act as a disincentive for investments in flexible technologies, resulting in these being undersupplied in the market.

There is therefore a *prima facie* argument that there would be benefits from aligning the dispatch and settlement interval by moving to 5-minute settlement.

The AEMC also notes that the economic merit of aligning dispatch and settlement has been acknowledged by a range of international energy market authorities. In the few overseas markets where dispatch and settlement are not aligned (i.e. some US markets, New Zealand and Alberta), regulators and market bodies are either in the process of aligning or recognise the merit in doing so.

The United States Federal Energy Regulatory Authority (FERC) recently ruled that all system operators under its jurisdiction must settle energy in their real-time markets at the same interval that those markets are dispatched (i.e. 5-minute settlement).[2] The New Zealand Electricity Authority recently noted that aligned dispatch and settlement

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2 FERC, *Settlement Intervals and Shortage Pricing in Markets Operated by Regional Transmission Organizations and Independent System Operators*, Docket No. RM15-24-000, 16 June 2016, http://www.ferc.gov/whats-new/comm-meet/2016/061616/E-2.pdf.

interval would be the ideal market design.[3] Aligning dispatch and settlement intervals has also been discussed by the Alberta Electric System Operator.[4]

A table summarising some relevant characteristics from overseas markets, including those mentioned above, is provided in an appendix.

2.2. Costs of making the change

Notwithstanding the argument set out above, the AEMC recognises that the current arrangements have been operating for 18 years and the 5-minute settlement proposal would have far-reaching consequences.

Given the market design of the NEM, the rules that govern the calculation of settlement prices affect literally *every* transaction that occurs. Since the inception of the market, participants have developed their systems and entered into arrangements on the basis of 30-minute settlement.

It follows that a transition from 30-minute settlement could be a costly exercise. We note that while the New Zealand Electricity Authority considers aligned dispatch and settlement to be the ideal arrangement, it sees this as a potentially costly reform and is not pursuing it at the current time.[5]

Examples of some of the costs that stakeholders have identified during this rule change project include:

- adapting existing settlement procedures from a 30-minute to a 5-minute basis;
- upgrading metering equipment to record, store and transfer 5-minute data;
- reviewing and altering parameters for fast-start plant; and
- modifying or replacing contractual arrangements that are based on 30-minute settlement.

Should these costs exceed the potential benefits, then it would be *inefficient* to move to 5-minute settlement. The AEMC considers it of high importance for it to have an in-depth understanding of the costs of making the change, especially those arising from modifying contractual arrangements.

In its consideration of potential costs, the AEMC will distinguish between transitional costs and on-going costs. Transitional costs, while potentially large, are solely related to switching from the existing arrangements to the new ones. On-going costs on the other hand are additional costs that persist beyond the initial implementation.

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3 New Zealand Electricity Authority, *Assessment of real-time pricing options*, Information paper, 12 April 2016, p16, https://www.ea.govt.nz/dmsdocument/20599

4 The Brattle Group, *International Review of Demand Response Mechanisms*, prepared for the AEMC, October 2015, p36.

5 New Zealand Electricity Authority, *Real-time pricing options*, decision paper, August 2016, p5, https://www.ea.govt.nz/dmsdocument/21127

This distinction is significant. The AEMC considers that there are always transitional costs associated with reform. These immediate, transitional costs are invariably easier to measure and quantify than the benefits that follow reform. However, whatever the quantum, the benefits of a move to 5-minute settlement will be enduring, permanent, and will accrue not only in the short term, but also the long term.

These matters of cost and transitional issues will be the topic of a subsequent Working Group meeting and are therefore not discussed further in this paper. Outside of the first Working Group meeting, we encourage stakeholders to provide information that can inform the AEMC's analysis in advance of the next Working Group meeting in late November.

2.3. Assessing materiality

This paper has so far observed that there is economic merit in aligning the dispatch and settlement interval at 5-minutes, and that a transition from 30-minute to 5-minute settlement may have wide-ranging consequences.

With this in mind, we consider there to be three key questions that must be addressed in assessing the rule change proposal:

1) How different are 5-minute and 30-minute market outcomes?
2) How would 5-minute settlement alter incentives for generators and consumers and to what extent will this alter behaviour?
3) What are the costs of the transition?

The first two questions are intended to inform our assessment of the potential benefits arising from the rule change, whereas the third is an assessment of costs.

The remainder of this working paper focuses on the first two questions. It sets out the analysis that we have undertaken to date on these two issues and highlights points where we are seeking further information from stakeholders.

3. Preliminary analysis

This section sets out the preliminary analysis that the AEMC has undertaken to answer questions (1) and (2) identified in the previous chapter.

3.1. How different are 5-minute and 30-minute price outcomes?

The economic argument for 5-minute settlement is predicated on the assumption that market outcomes vary over the course of the trading interval. There must be some differential between 5 and 30-minute outcomes for there to be benefits from changing to 5-minute settlement.

In this section we seek to quantify and so better understand the difference (or 'variation') between historical 5-minute and 30-minute price outcomes. This contributes to understanding the effect 30 minute pricing may have had on incentives for market participants (which is discussed in section 3.2).

At the outset, we emphasise that any analysis comparing 5-minute and 30-minute prices will show that there is a difference between the two data series. This is in no way surprising, and is simply a corollary to the trading price being the average of six dispatch prices.

It is nevertheless relevant to analyse the magnitude and frequency of the variation because it provides an indication of the difference in *incentives* created by 5-minute and 30-minute prices. The incentives are associated with the payments between loads and generators through the pool, whereby generators are paid for delivering energy and retailers and loads pay for energy consumed.

Our analysis demonstrates how payments through the pool would have changed if historical dispatch prices had been used rather than historical trading prices. It does not assess *what would have happened* under 5-minute settlement. All historical market outcomes occurred under 30-minute settlement, and so participants' behaviour (e.g. their bids, their investment decisions) were driven by the incentives that this price signal provides. It is not possible to reconstruct how participants *would have responded* to 5-minute settlement from historical pricing data.

3.1.1. Measuring the difference in price outcomes

As a starting point, we note the following two characteristics of the NEM pricing data:

1) When 5-minute and 30-minute prices are averaged over the same period of time (so long as that period is longer than half an hour), the resulting average price will be the same.

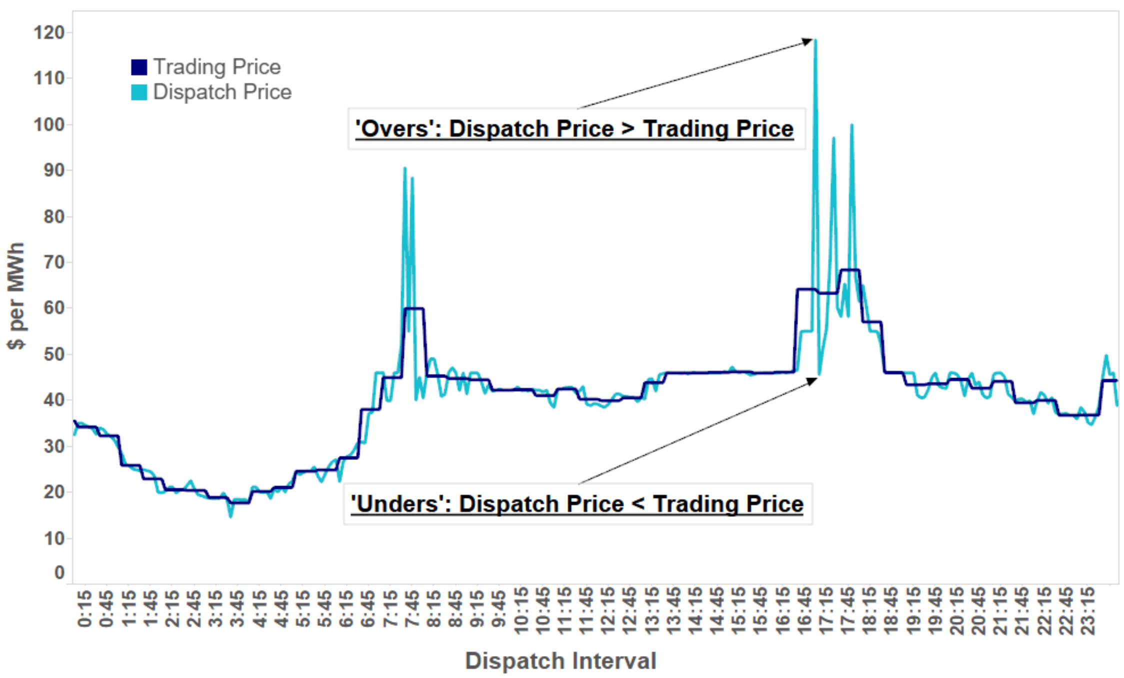
2) The total value of payments through the pool (i.e. energy volumes multiplied by price) is typically very similar between 5-minute and 30-minute settlement. For

example, an analysis of historical outcomes from 2000 to 2016 across all regions of the NEM shows that, on an annual basis, the difference between 5-minute and 30-minute settlement is typically less than 0.1% of total payments through the pool.

Against this backdrop, we have focussed our analysis on the variation between dispatch prices and trading prices which occurs *within* each trading interval. In each 5-minutes, there may have been different incentives, and participants may have responded differently had they been settled on a 5-minute rather than a 30-minute basis. Price differences within trading intervals therefore have the potential to influence the marginal generation and consumption decisions of market participants.

Figure 1 sets out a comparison of dispatch prices (light blue) and trading prices (dark blue) on 18 May 2015 in South Australia. This day has no particular significance. It merely serves as an example of a day where the power system was operating under normal conditions, and where we can observe some difference between dispatch and trading prices.

Figure 1: Comparison of 5-minute and 30-minute prices (SA, 18 May 2015)



To aid in our discussion, it is helpful to define the following three terms:

- **'Overs'** - the value of the dispatch price minus the trading price, when the dispatch price exceeds the trading price.
- **'Unders'** - the value of the trading price minus the dispatch price, when the trading price exceeds the dispatch price.
- **'Variation'** - the sum of overs and unders, which is equivalent to the absolute value sum of the difference between the dispatch price and the trading price.

By definition, for any trading interval (or set of trading intervals) the sum of overs will be equal to the sum of unders because they are both defined with reference to the trading price.

3.1.2. Historical variation by region

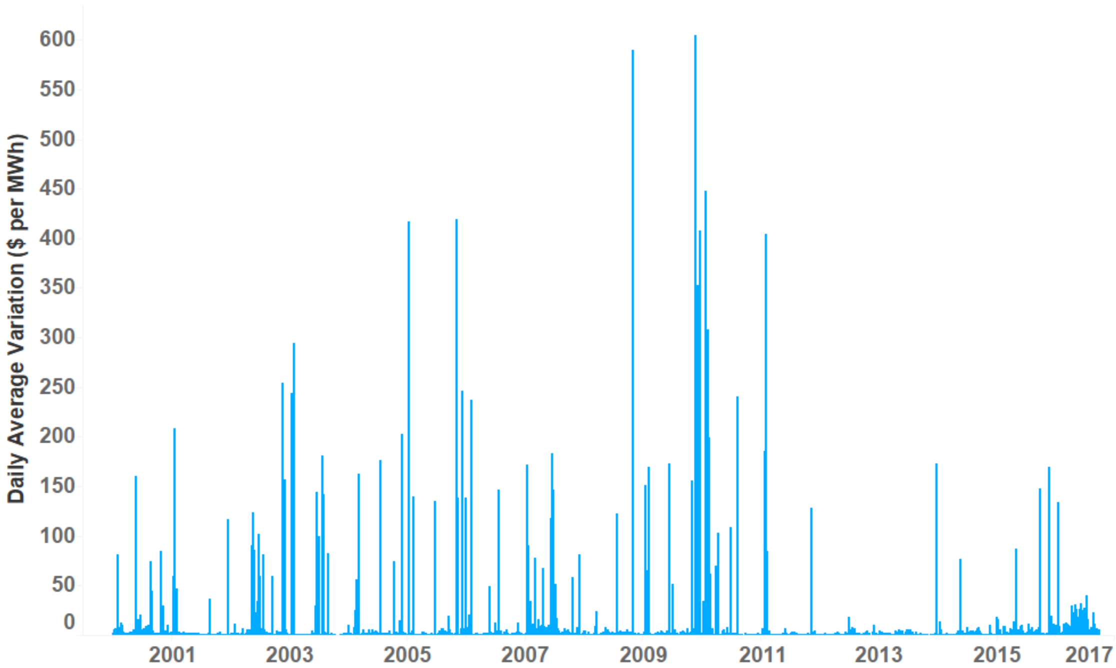
Next, we have considered the historical variation (i.e. the sum of unders and overs) over time and for different NEM regions. In doing this, we introduce the metric of 'daily average variation'. This is the sum of all variation occurring in each dispatch interval of each day, divided by 288 (i.e. the number of dispatch intervals in one day).

Historical variation in New South Wales

First, we consider the historical variation for New South Wales, a NEM region which has historically experienced relatively low levels of price volatility in recent years.

Figure 2 shows the daily average variation from 2000 to 2016. For the past few years, average variation has been relatively low, but there have been periods in which daily average variation exceeded $200 per MWh on multiple occasions.

Figure 2: Daily average variation (NSW, 2000 to 2016 YTD)

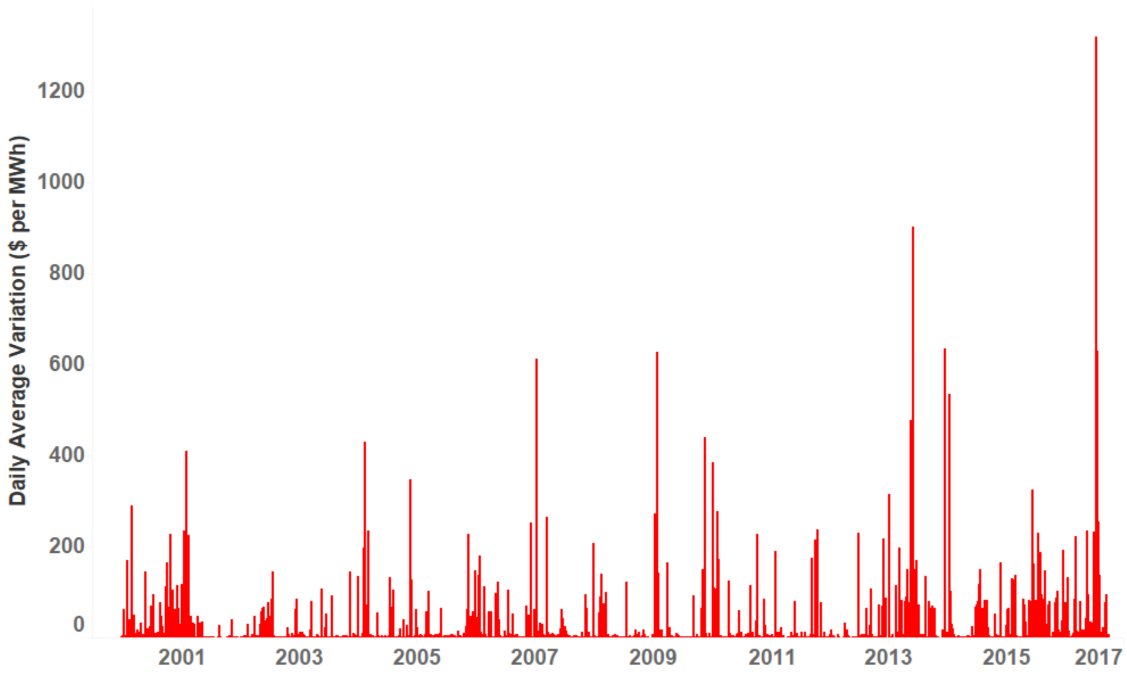


Historical variation in South Australia

Figure 3 considers historical levels of variation for South Australia, a NEM region where prices have historically been higher and more volatile in comparison to other regions.

The highest point on Figure 3 (to the far right) is 7 July 2016, a day that has attracted considerable industry attention.[6] Although this level of variation is uncommon, there are several examples of other days where average variation has been in excess of $300 per MWh, and many days where average variation exceeds $100 per MWh.

Figure 3: Daily average variation (SA, 2000 to 2016 YTD)



As an extension of this analysis of daily average variation, Figure 4 shows average *annual* variation across all regions from 2000 to 2016 YTD. The results, often around $5 per MWh, but as high as $35 per MWh in South Australia in 2016, provide an indication of how the variation in each trading interval, and in each day, flows through to the annual average. This is the annual average of the absolute difference between dispatch prices and corresponding trading prices.

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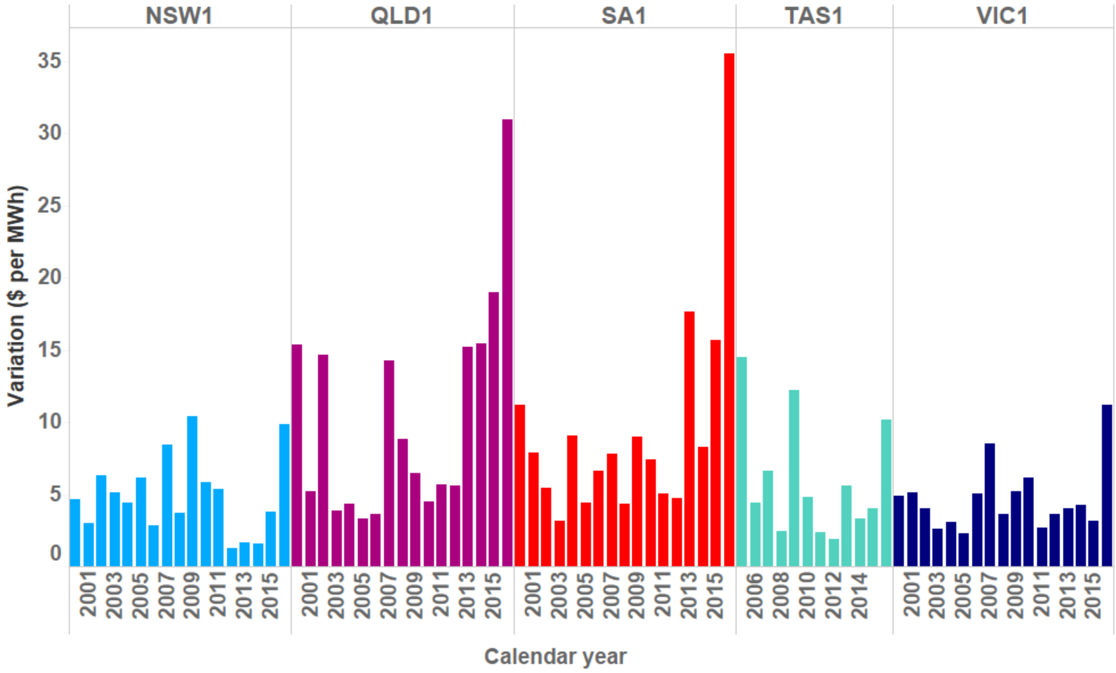
6 E.g. AER, E*lectricity spot prices above $5000/MWh: South Australia, 7 July 2016*, 13 September 2016; Melbourne Energy Institute, *Winds of change: An analysis of recent changes in the South Australian electricity market*, August 2016.

Figure 4: Average historical variation by region (2009 to 2016 YTD)



Overall, this analysis of the historical differences between 5-minute and 30-minute prices shows very large differences on some days. This suggests that there are significant distortions of the 5-minute price and quite different price signals are sent to the market via the 30-minute price on these occasions. More generally, the extent of the variation between 5-minute and 30-minute prices over longer time periods has been observed as being different between NEM regions, and has changed over time.

3.2. How would 5-minute settlement alter incentives?

To understand the potential benefits of more granular price signals we need to consider both the incentives that those price signals provide versus the status quo, and participants' ability to respond to those incentives.

With this in mind, the remainder of this paper presents the following analyses:

- **Relationship between variation and incentives**. An examination of the relationship between variation and incentives to participants to answer the question: what do our variation results tell us about the incentives created by 30-minute versus 5-minute prices?
- **Effect of 30-minute settlement on incentives within the trading interval**. One of the concerns about the mismatch between settlement and dispatch is that incentives are skewed over the course of the dispatch interval. We have examined this claim by building on our above analysis of variation.

3.2.1. Relationship between variation in prices and incentives

In section 3.1, we defined a measure of variation between 5-minute and 30-minute prices, which is a proxy for the 'distortion' introduced by 30-minute settlement. We then calculated the average variation over time.

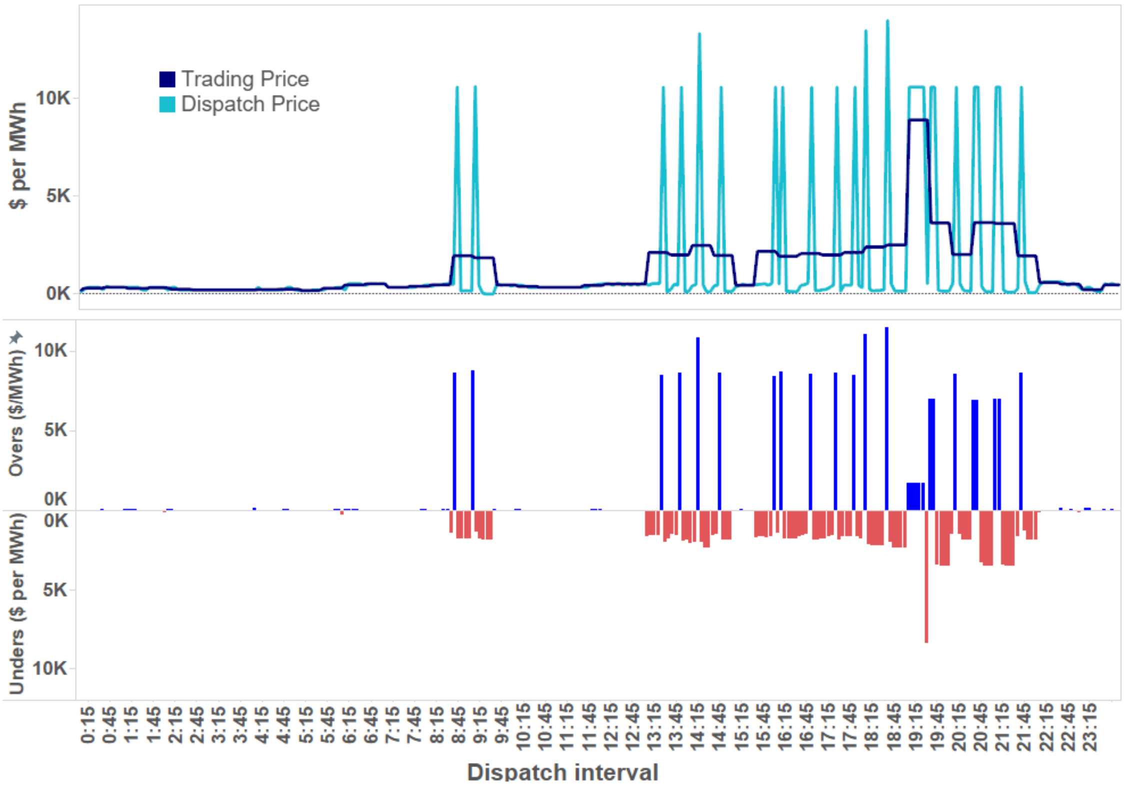
The relevance of variation is that it provides an indication of the difference in the *incentives* offered by 5-minute and 30-minute prices. The incentives are associated with the payments between loads and generators through the pool. The basis for these payments is the spot price – either directly or through its role in determining settlement against hedging contracts.

Using 30-minute prices for settlement rather than 5-minute dispatch prices alters payments and so incentives faced by market participants. In this section, we seek to understand the difference between the 5-minute and 30-minute incentives, and attempt to assess whether it is material.

Example: Assessing materiality of difference in incentives

For the purposes of illustration, we consider an example from a single day, 7 July 2016 in South Australia. This is a recent day when there was large variation between 5-minute and 30-minute prices. The figure below compares dispatch and trading prices in the top panel, while the bottom panel shows overs (in blue) and unders (in red) in each 5-minute period.

Figure 5: Example of variation between 5 & 30 minute prices (SA, 7 July 2016)



Multiplying unders and overs by total regional demand for each dispatch interval gives us an indication of the differing incentives provided by the 30-minute prices, versus those *implied* by the underlying 5-minute prices. In the case of 7 July 2016 in South Australia, we calculate the following:

- **Total value of unders:** 30-minute prices result in $30.0 million worth of payments from loads to generators that are **higher** than the corresponding payments implied by 5-minute prices.

- **Total value of overs:** 30-minute prices result in $30.1 million worth of payments from loads to generators that are **lower** than those implied by 5-minute prices.

- **Variation:** the sum of unders and over for the day is therefore $60.1 million.

- **Total payments through the pool:** over the course of the day, total payments from loads in South Australia to generators were $56.5 million.

What does this mean? If we assume that the 5-minute price outcomes are efficient, then trading prices *undervalue* energy during the price spikes (i.e. when 5-minute prices exceed the 30-minute average price). Holding all other factors constant, this analysis suggests an undervaluation of $30.1 million for this day. One way of thinking of this is that 30-minute prices provided incentives totalling $30.1 million *below* the efficient level to:

- generators for supplying these spikes; and,
- loads for responding to these spikes.

Similarly, trading prices *overvalue* energy in the remainder of the trading period where a price spike occurred. Again holding all other factors constant, this analysis suggests an overvaluation of $30.0 million, which would also have affected the incentives for generators and loads.

These outcomes appear substantial when compared with the total payments made through the pool on the day in question (i.e. $56.5 million). This result would seem to suggest that on this particular day the difference between 5-minute prices and 30-minute prices was material.

Difference between incentives provided by 5-minute and 30-minute prices over time

The extent to which variation between 5-minute and 30-minute prices alters incentives depends on the magnitude of the variation and how often large variations are observed. As a point of reference, the above example of 7 July 2016 in South Australia showed that variation for the day was $60.1 million. This was by all accounts an extraordinary day in the NEM.

We have extended the above analysis to consider the total value of unders and overs on a daily basis from 2000 to 2016 YTD. The following tables summarise the results of this analysis for South Australia and Queensland. The values in the tables are a count of the number of days in each year when the daily variation exceeded the thresholds shown in the column at the left. Each row is non-exclusive, meaning that in Queensland in 2000, the 12 days with variation above $10 million include the 5 days above $20 million and the 2 days above $40 million.

Table 1: Count of high variation days (SA, 2000-2016 YTD)

Year	>$5m	>$10m	>$20m	>$40m
2000	7	1	0	0
2001	8	5	1	0
2002	2	0	0	0
2003	1	0	0	0
2004	8	4	1	0
2005	2	1	0	0
2006	6	1	0	0
2007	4	3	1	0
2008	5	0	0	0
2009	9	6	2	1
2010	8	4	1	0
2011	4	1	0	0
2012	2	1	0	0
2013	14	6	3	1
2014	7	3	1	0
2015	13	3	0	0
2016	13	8	4	1

Table 2: Count of high variation days (Qld, 2000-2016 YTD)

Year	>$10m	>$20m	>$40m	>$80m
2000	12	5	2	0
2001	7	1	0	0
2002	21	10	2	1
2003	6	2	0	0
2004	7	3	0	0
2005	6	3	1	0
2006	5	2	1	0
2007	24	10	3	1
2008	11	6	2	1
2009	10	7	3	0
2010	5	3	2	1
2011	8	4	2	1
2012	5	1	0	0
2013	30	9	4	1
2014	25	14	8	4
2015	28	11	6	2
2016	23	10	6	4

While the outcome for 7 July 2016 in South Australia is uncommon, there are nevertheless other days in the analysis where the total value of unders and overs has been in excess of $40 million.

For Queensland, there were a number of days in recent years where the total value of unders and overs exceeded $80 million. It is not uncommon for the total value of unders and overs to exceed $20 million in a day, though the total value of spot transactions in Queensland is around 3.5 times larger than South Australia. In both regions, the instance of high variation days has generally increased over the period of the analysis.[7]

For emphasis, if we assume that 5-minute price outcomes are efficient, then these values represent the extent to which trading prices *undervalue* or *overvalue* energy during the times when the 5-minute price exceeds the trading price. These values are indicative of the distortion to efficient prices introduced by 30-minute settlement.

While the largest variations between 5-minute and 30-minute prices typically only occur in a handful of days in a year, they would appear to be significant. We observe that:

a) high prices create the potential for the largest differences between 5-minute and 30-minutes prices, leading to the largest variations occurring on days when prices are high; and

b) generators, especially marginal peaking generators, receive a disproportionate amount of their annual spot revenue from the relatively small numbers of days in a year when there are high prices.

It follows that on the days when there is the most spot market revenue at stake, there is the potential for participants' incentives to be most distorted. It is therefore conceivable that 30-minute settlement could lead to different operational and investment decisions compared to a scenario in which participants had been settled on a 5-minute basis.

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7 We note that changes over time to the NEM price cap will have influenced this result to some extent, by increasing the potential for dispatch prices to vary from average values. Similarly, our analysis is based on dollars of the day, and so makes no adjustment for inflation.

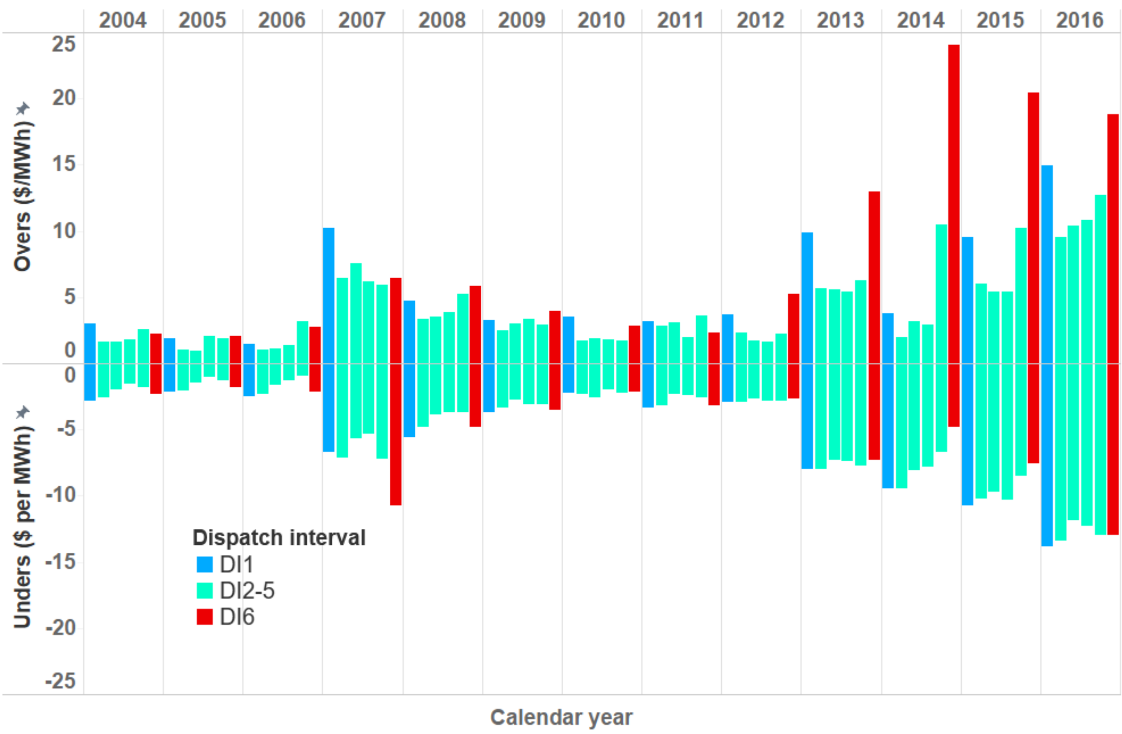
3.2.2. Distortion of incentives over the course of the trading interval

One of the concerns about the mismatch between settlement and dispatch is that the settlement arrangements create differing incentives over the course of a trading interval. A key question is whether this distortion of incentives has affected market outcomes and, if so, whether the effect is material.

To investigate this question, we have examined average unders and overs for each of the six dispatch intervals (i.e. DI 1 to DI 6) in Queensland from 2004 to 2016 YTD.[8] In Figure 6 these are expressed as annual averages for each dispatch interval.

For the purposes of illustration, the under and overs in the first dispatch interval of the half hour have been coloured blue and the last interval is coloured red. The same charts of the other NEM regions are provided in an appendix to this paper.

Figure 6: Average historical variation by dispatch interval (Qld, 2004 to 2016 YTD)



Between 2013 and 2015 overs were considerably greater in DI 6, and to a lesser extent in DI 1. This might mean that either:

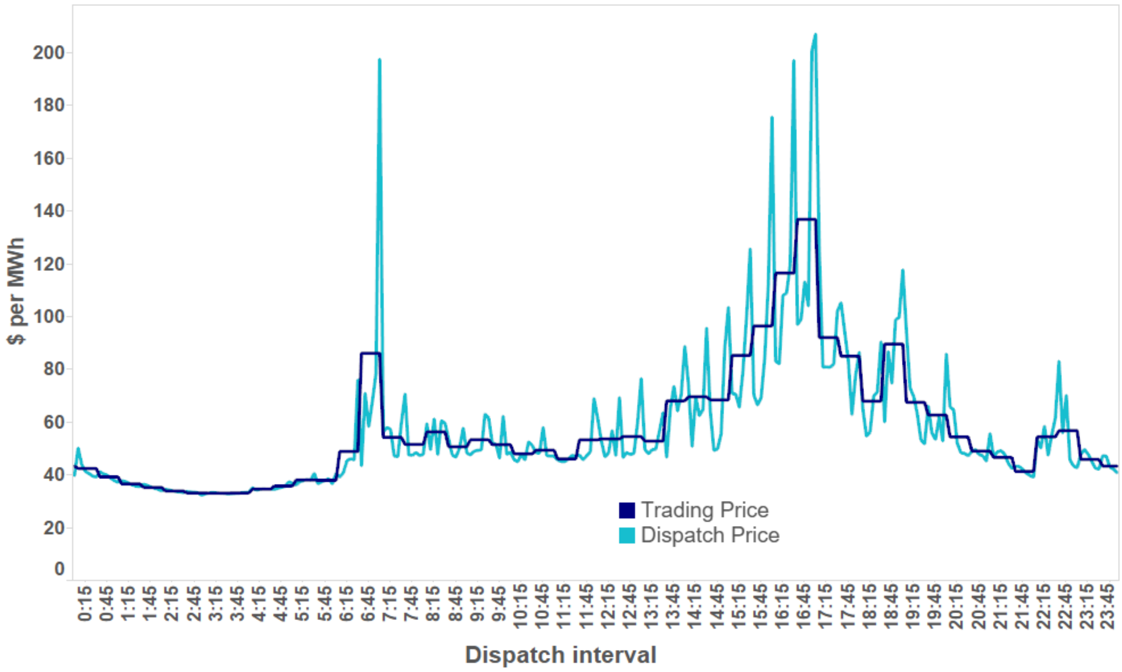
- there was some structural reason why dispatch prices tended to be higher in DI 1 and DI 6 (e.g. the daily peak may have consistently occurred between 4:55 and 5pm); or

8 In this figure, we have shown unders and overs rather than variation, to show how these values vary over the course of the dispatch interval.

- the arrangements for 30-minute settlement create incentives that lead to dispatch prices being higher in DI 1 or DI 6.

To determine which of the two is the case, Figure 7 sets out a comparison of average 5-minute and 30-minute prices in Queensland for the years 2013 to 2015 by time of day.

Figure 7: Average 5-minute and 30-minute prices (Qld, 2013-2015)

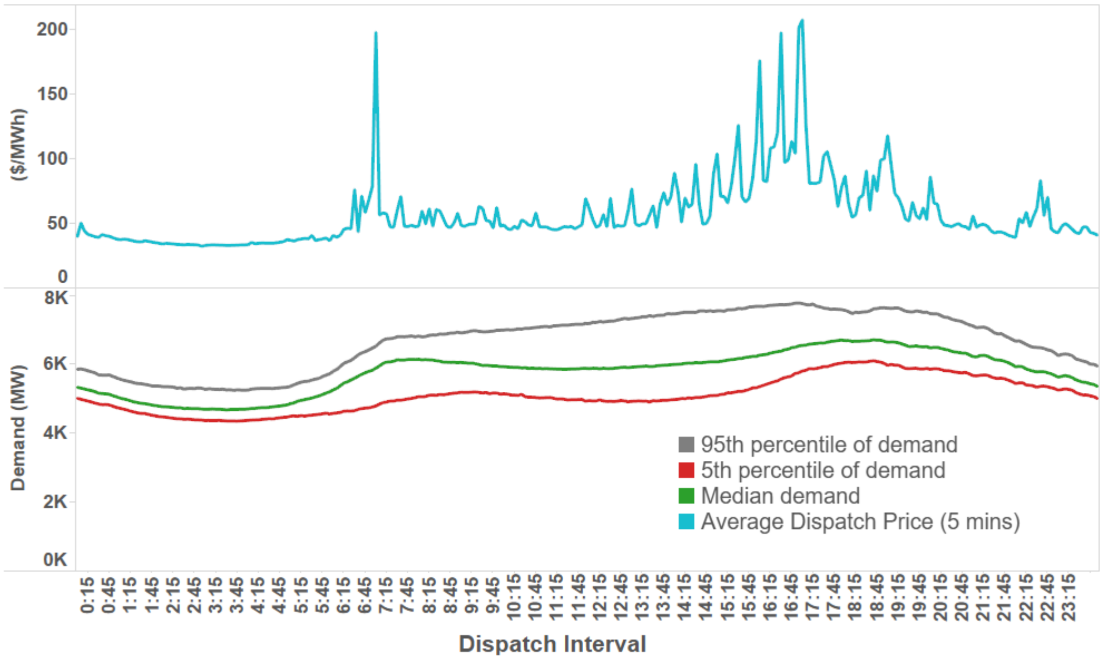


The chart above shows average trading price (in dark blue) and average dispatch price (in light blue) by time of day from 2013 to 2015 in Queensland. The difference between the trading and dispatch prices is unambiguous, and is consistent with the variation results for Queensland in Figure 6.

The sharp, volatile nature of the dispatch prices is surprising, particularly when we recognise that this chart is not for a single day, but for 3 years' worth of observations (i.e. each point on the light blue line is the average of 1095 data points). It is therefore unlikely that the volatility in dispatch prices is a result of 'random noise' – something structural in either supply or demand is influencing the outcome.

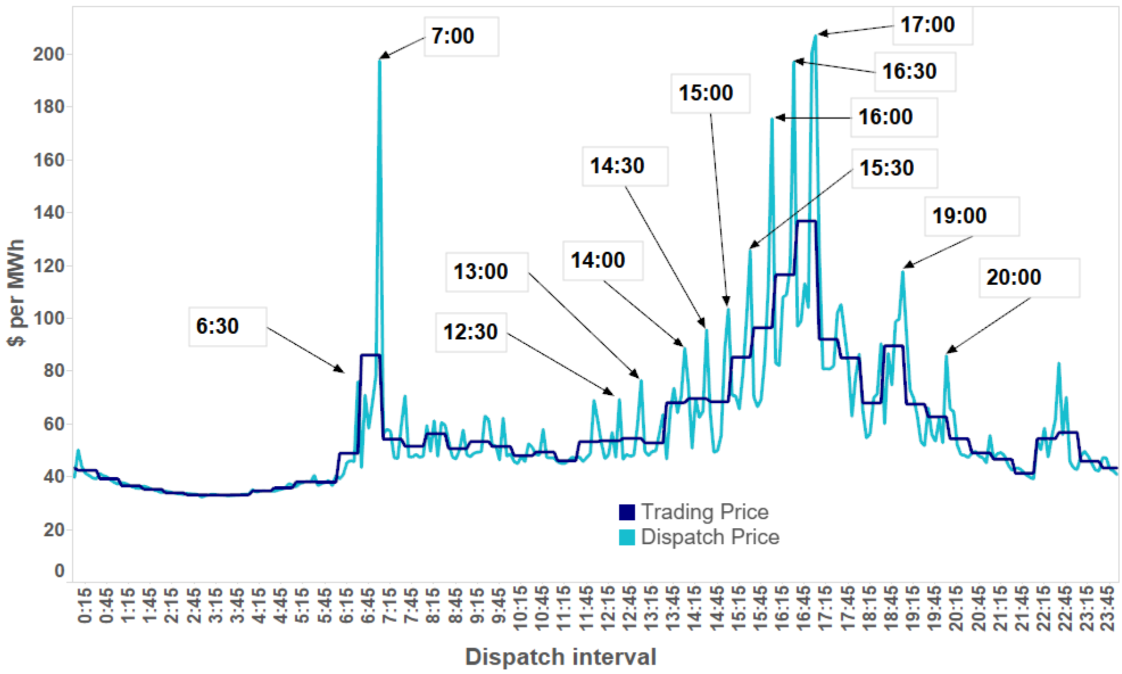
Figure 8 compares 5-minute prices with demand (in the form of the median, 5th and 95th percentiles of demand) over the same period. There does not appear to be any structural variation in demand to account for the variability in average dispatch prices. However, we would be interested to hear from Working Group members if they have a different interpretation.

Figure 8: Average 5-minute price versus demand (Qld, 2013-2015)



We therefore turn to whether the volatility is related to the period in the dispatch interval. Figure 9 overlays a set of labels onto Figure 7 indicating the price spikes that occur in DI 6. The vast majority of spikes in the average spot price occur in DI 6.

Figure 9: Dispatch price spikes typically occur in DI 6



This result appears to support the concerns of Sun Metals, and others in the market, that the skewing of incentives caused by 30-minute settlement has a material effect on price outcomes.

3.3. How might participants respond to 5-minute prices?

A key area of interest for the AEMC is the ability of supply and demand side participants to change their behaviour in response to moving to 5-minute settlement. This has also been a key issue raised by stakeholders in submissions on the consultation paper. If participants cannot change their behaviour as a result of the new granular price, this would diminish the economic argument for making such a change.

The changes in behaviour can relate to:

- **Short run decisions:** An existing participant responds to the new pricing interval by altering their decisions about how much energy they produce and/or consume at particular times. These decisions do not involve changes to infrastructure, just changes in the way existing infrastructure is operated.
- **Long run decisions:** New and existing participants respond to the new pricing interval by altering their decisions about the type of plant and equipment in which they invest, or whether they invest at all. This includes upgrades and modifications to existing plant and equipment, new investments and retirements. We will demonstrate that this could involve investments in technologies that are currently available as "off the shelf" solutions.

3.3.1. Potential short run responses to 5-minute settlement

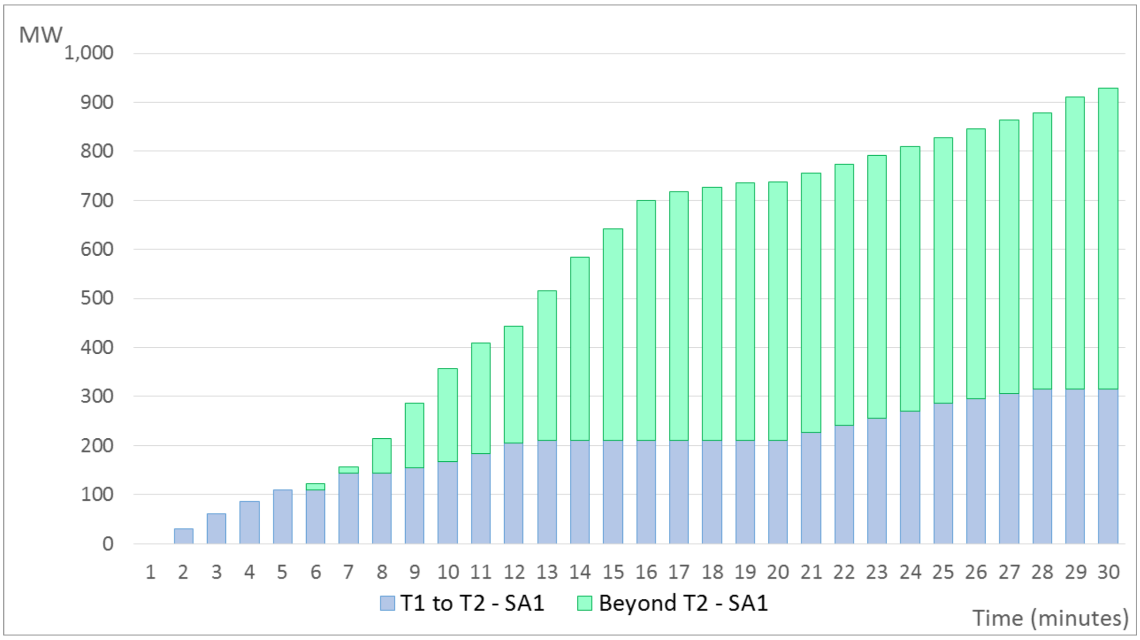
In the short run, existing generators, loads and storage operators could potentially change the way in which they operate to maximise their revenue under 5-minute settlement. A summary of the potential responses from these categories of participants are provided below.

Responding from rest

Most of the short run response would be expected to come from existing generators. The responsiveness of generators can be observed through market data describing the ability of generators to respond from rest (i.e. fast-start inflexibility profiles) and when they are already running (i.e. ramp rates, minimum and maximum loading).

To observe the potential response from rest we extracted the fast-start profile for all scheduled, fast-start generators for one day (15 May 2016). In the following chart, we assume that all fast-start generators are offline and receive a start-up instruction at the same time. They synchronise, ramp up to minimum load (blue) and then continue to ramp at their ramp rate (green) until they are constrained by their capacity rating. The result for South Australia is shown in Figure 10 below. It shows that 109MW of capacity is available within a 5-minute period, increasing to 929MW over the half hour.

Figure 10: Theoretical response from fast-start plant in SA



We have undertaken the same analysis for each NEM region and the corresponding charts are presented in an appendix to this paper. The caveats on this analysis are that fast-start profiles are only for one day and ramp rates have been assumed at nameplate ratings. It does not include network or economic constraints, nor factor in the time for AEMO to send dispatch instructions. It may also underestimate the potential response of fast-start plant as non-scheduled generators, many of which are reciprocating engines, are not included in the analysis.[9]

Notwithstanding these caveats, this analysis provides an indicative result that there is very little fast-start capacity in the NEM that can respond from rest within a 5-minute period. In South Australia and Queensland there is a small amount of scheduled capacity that can provide energy within 5-minutes. In other regions this response from rest is in the order of 6 to 10 minutes.

Ramping online plant

The other response than can be provided is from generators that are already online, which can include fast-start generators if they are already running. For this analysis, we calculated the historical ramping of scheduled generators by comparing, for every dispatch interval in 2015 and 2016 YTD, the difference in dispatch targets from the previous 5-minute interval. The results show that generators demonstrate a range of

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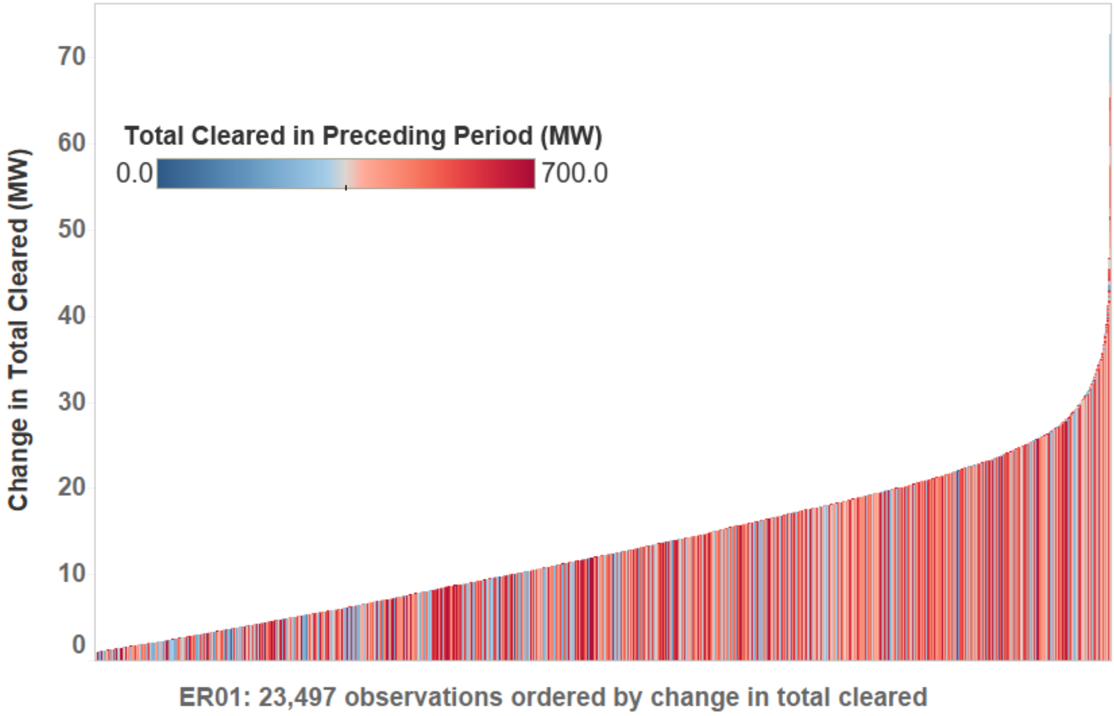
[9] AEMO registration data indicates that there is 740MW of non-scheduled, reciprocating engine capacity in the NEM.

ramping capabilities, often dependant on the operating level at the start of the dispatch interval in question.

The following charts show the change in output in every dispatch interval when power output increased by more than 1MW. The bars are sorted in ascending order and colour-coded based on the initial output at the start of the dispatch interval (blue indicates an initial condition close to zero, while red indicates close to full capacity). The charts show that baseload plant (e.g. Eraring) has historically not ramped very much over individual dispatch intervals.

Figure 11: Historical 5-minute ramping of Eraring unit 1 (2015)



Hydro and gas-fired generators have demonstrated a wider range of ramping capability, presumably reflecting market conditions. The following charts for Lower Tumut (hydro) and Oakey unit 2 (open-cycle gas) are provided as examples.

Figure 12: Historical 5-minute ramping of Lower Tumut (2015)

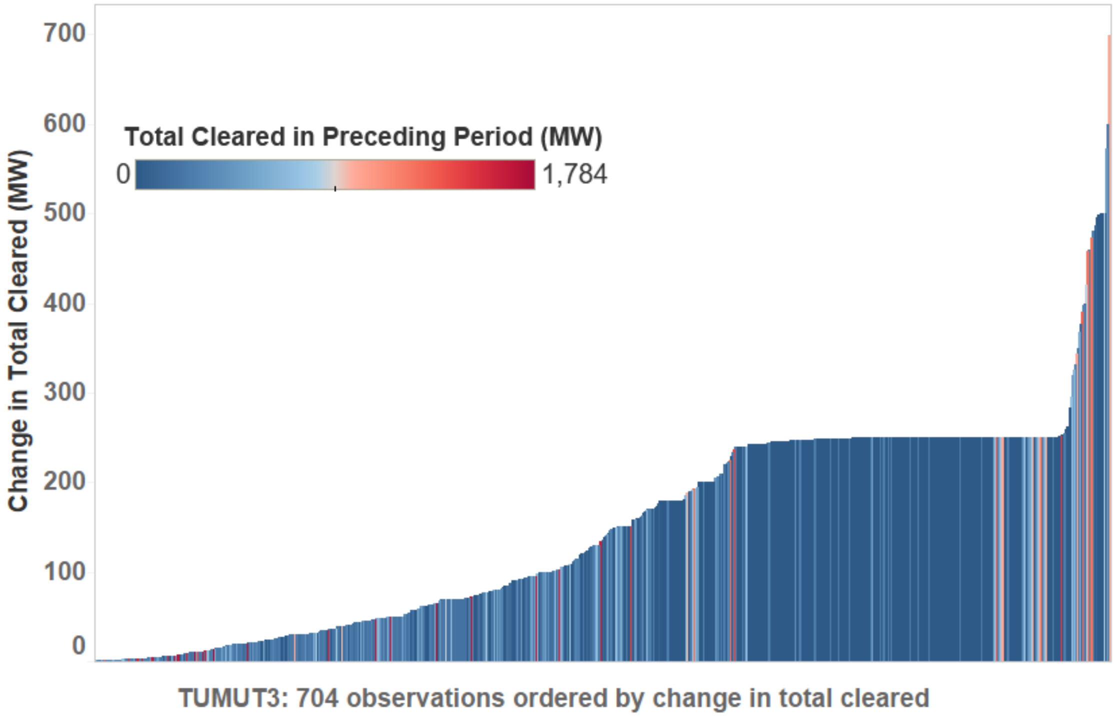
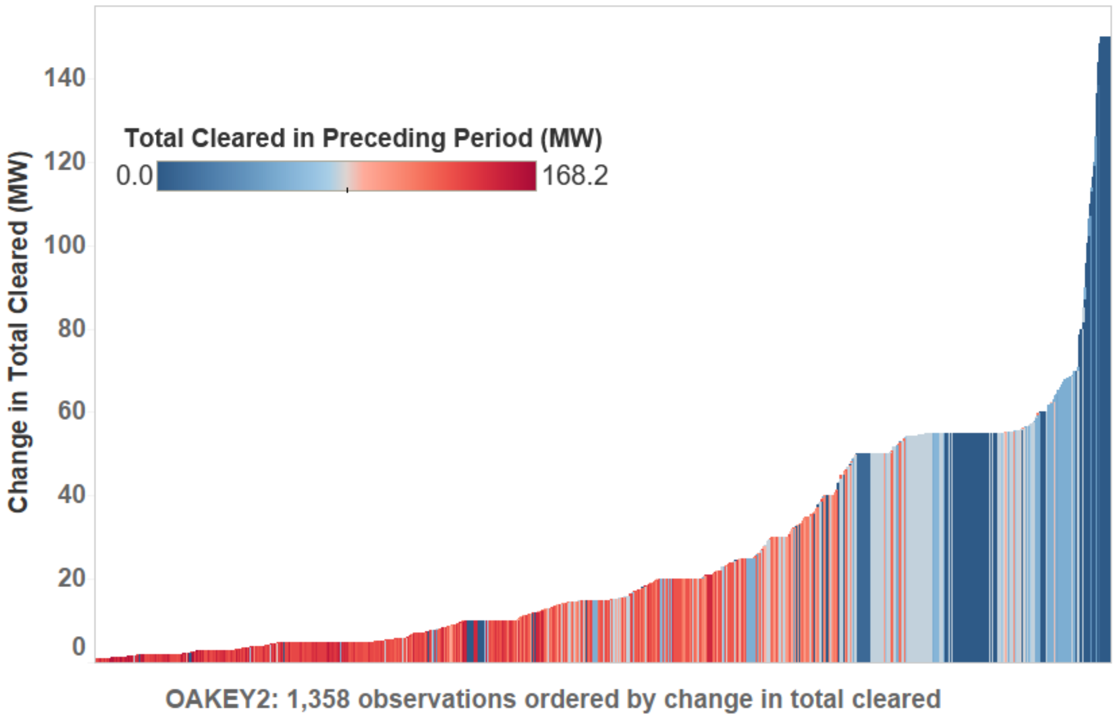
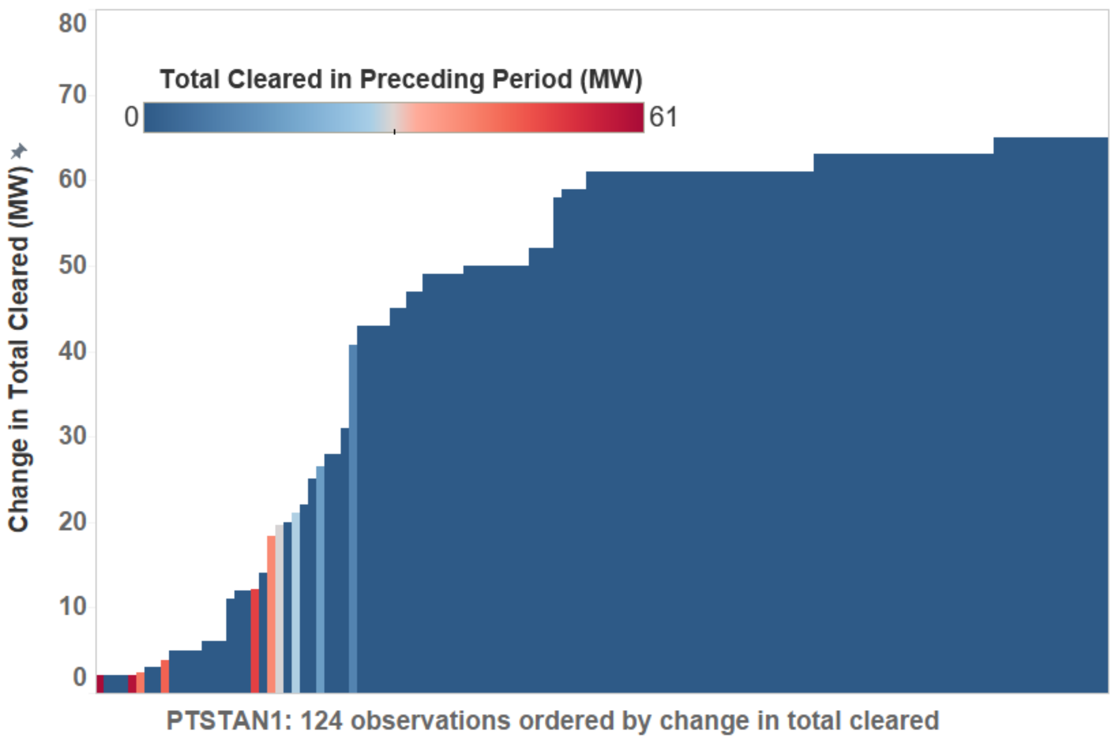


Figure 13: Historical 5-minute ramping of Oakey unit 2 (2015)



Diesel generators appear to spend most of their operating time ramping between zero and full output. The following chart is for the diesel generator Port Stanvac using 2016 data.

Figure 14: Historical 5-minute ramping of Port Stanvac (2016 YTD)



This analysis shows that responses in the hundreds of MW in 5-minute periods can be provided by existing generators in the NEM, though there may be additional costs associated with faster ramping. It is also worth noting that generators are paid on the basis of energy provided to the market, rather than the output level that they achieve by the end of a dispatch interval.

In a market with 5-minute settlement, fast-start plant may spend more time online in anticipation of price spikes. The AEMC is interested in understanding the potential costs and benefits associated with operating in this way.

To provide a snapshot of the ramping capacity provided by generators that are online, we calculated aggregated, regional ramping capability in 2016, averaged for each 5-minute period of the day. This analysis uses the same data as above (i.e. changes in the dispatch targets of scheduled generators from one dispatch interval to the next).

In each dispatch interval, each unit's ramping potential was calculated as:

- the minimum of: its maximum ramp rate and its available, unused generation; or
- zero if a unit is not generating.

The maximum ramp rate was calculated as the 5-minute ramp that the unit achieved or exceeded for over 2 hours' worth of dispatch intervals in 2015 and 2016 YTD (i.e. the 24th highest observed change in total cleared output). The ramping potential for all generators in a region was summed together for each dispatch interval (i.e. all 7:00, all 7:05, etc.), then divided by 257 (i.e. the number of days in the year to date at the time of the analysis, and therefore the number of instances of each dispatch interval).

The results for New South Wales and South Australia are presented below in stacked format. The same charts for the other jurisdictions are provided in an appendix. The ramping capacity is colour-coded by the fuel source of the generators providing the ability to ramp. The charts show that between 1 January and mid-September 2016 there was, on average, hundreds of MW of ramping capability in each dispatch interval in each region of the NEM. In New South Wales there was around 600MW of capacity that could have been provided within 5-minutes, compared to 200MW in South Australia, 500MW in Queensland, 350MW in Tasmania and 300MW in Victoria.

Figure 15: Ramping capacity, coloured by Fuel Type (NSW, 2016 YTD)

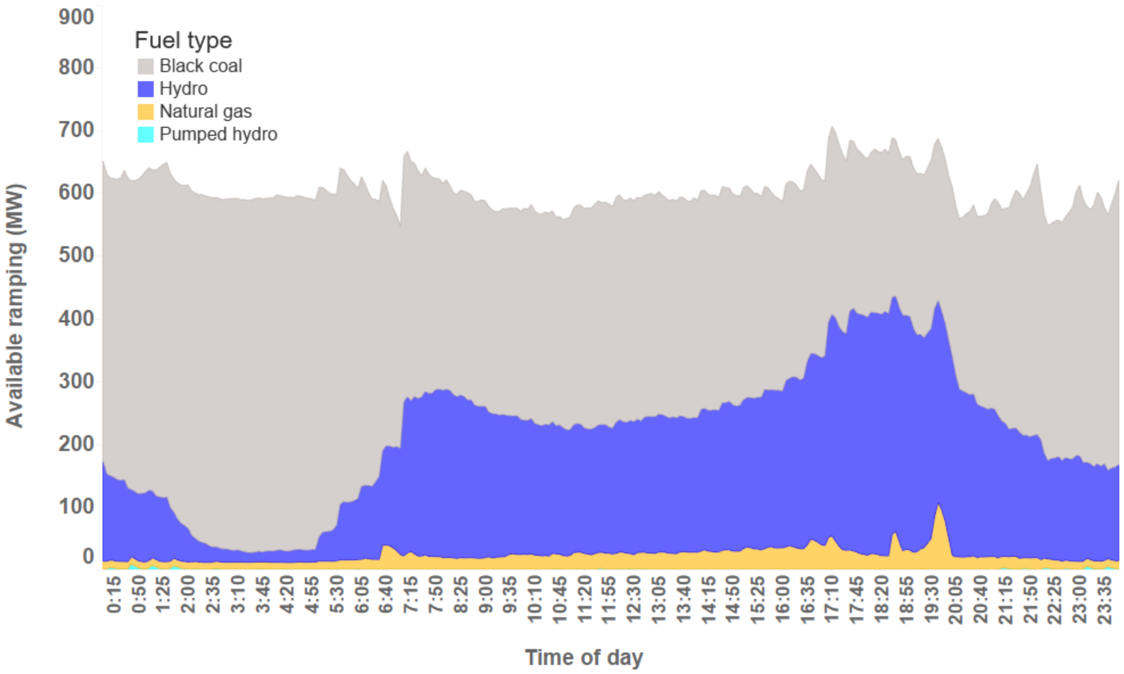
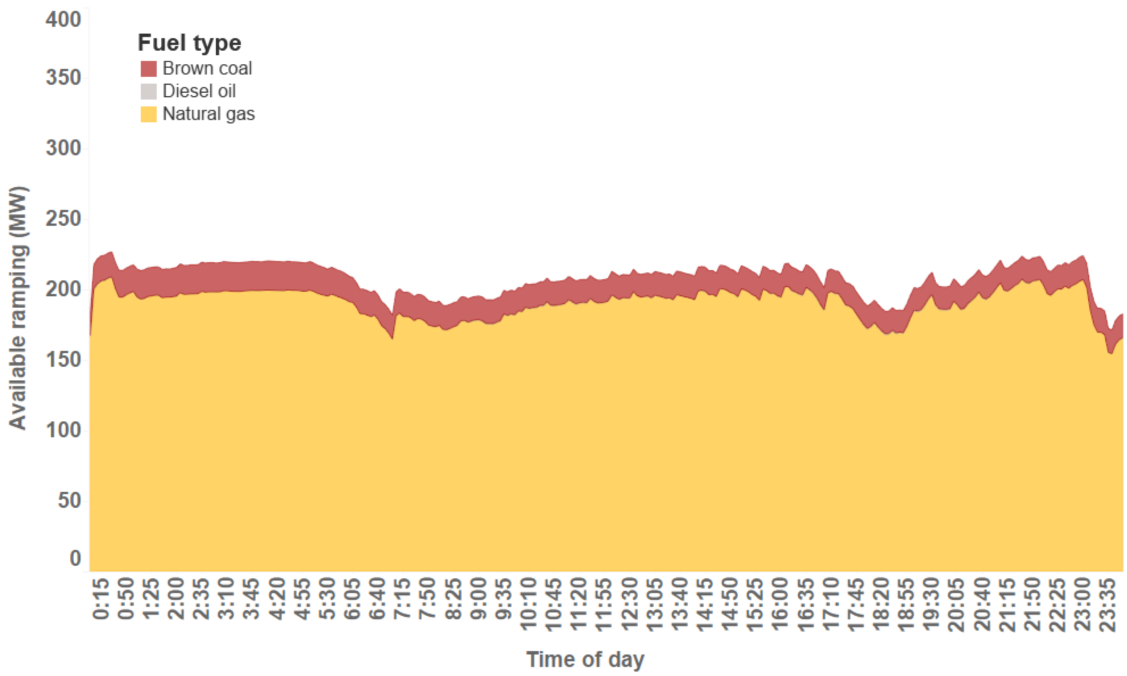


Figure 16: Ramping capacity, coloured by Fuel Type (SA, 2016 YTD)



Demand response

Another source of fast response in the short run could come through demand response from electricity consumers. A recent survey of demand response in the NEM found that there is upwards of 2,500MW of demand response active in the market. This is based on estimates of 2,000MW from large industrial facilities such as aluminium smelters, 235MW aggregated by retailers, and 300MW aggregated by specialist demand responses service providers.[10] Participation in the wholesale market can be in the form of spot price exposure, spot pass-through arrangements, or a benefit-sharing arrangement between loads and retailers.

A crude estimate of responsiveness was that, across a demand response portfolio, 10% of the demand response could be provided within 5 minutes, 70% in half an hour and the remainder within an hour.[11] A box below provides a case study on the rule proponent, Sun Metals, who can provide a demand response in the order of 100MW over several minutes.

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10 Oakley Greenwood, *Current Status of DR in the NEM: Interviews with Electricity Retailers and DR Specialist Service Providers*, prepared for the AEMC, 30 June 2016.

11 *Ibid.*

Sun Metals case study

Sun Metals operates a zinc refinery located in Townsville, North Queensland. Its main input is zinc concentrate (ore), from both local Australian and international suppliers.

With the recent increase in electricity prices in Queensland, electricity makes 50 per cent of the operational cost of producing zinc. The most energy-intensive part of the refining process is *electrolysis* - it accounts for the majority of Sun Metals' electricity consumption.

Sun Metals is a market customer in the NEM and manages its price risk via hedging contracts and demand management. It has undertaken demand management since 2004 when it became a market particpants in the NEM.

Electrolysis involves passing an electrical current through from anodes to cathode plates. Zinc deposits itself on the cathode plate from the zinc sulphate solution. When enough zinc has collected on the cathode plate, the plate is taken out of the solution and the solid zinc is removed.

Sun Metals' demand management system curtails production automatically when a threshold trading price is reached. The decision to restore load is made once staff are satisfied that high prices have subsided. The electrolysis process can remain at the holding current for up to 8-12 hours, though this comes at the cost of lost production.

Energy storage

The final source of fast response in the short run is energy storage in the form of batteries. With the exception of pumped-storage hydro, the AEMC understands that most energy storage in Australia is for standby power applications, such as data centres, utilities, hospitals and other critical loads. Much of this storage capacity is probably not participating in the wholesale electricity market. There are a number of pilot projects being undertaken with agencies such as the Australian Renewable Energy Agency,[12] and jurisdictional incentive schemes.[13]

The residential market for energy storage is estimated to include around 3,000 installations, but could be as many as 2.0-2.3 per cent of solar households (implying

12 Examples include the Lakeland project involving a 10.8MW solar farm and 1.4MW/5.3MWh lithium ion battery system, as well as pilot projects run by Ergon Energy, Ausnet Services and United Energy/AGL.

13 The ACT Government is subsidising battery storage in around 5,000 homes by 2020, including ~800 in 2016. The Northern Territory Government offers grants of up to $2,000 towards the installation of energy storage under its Northern Territory Home Improvement Scheme.

upwards of 30,000 installations) according to some surveys.[14] Estimated new installations are in the order of 300-400 per month.[15] In any case, the proportion of installed systems that participate in the wholesale market would be quite small. Aside from demand management applications (as above), distributed storage can participate in the wholesale market through platforms such as Reposit that provide a service similar to fast-start generators to retailers and network businesses (i.e. a price risk management service). Across the NEM, the amount of storage capacity under control via such software is likely less than 10MW at present.

3.3.2. Potential long run responses to 5-minute settlement

In economics, the 'long run' refers to the period of time in which all factors of production and costs are variable. There is the potential for new participants to enter the market with new equipment and new services, and for existing participants to make changes to their plant. The new equipment and changes could include "off the shelf" solutions that are currently available.

The following fast response options could be available:

- upgrades to improve the synchronisation and ramping time of existing generators;
- new investments in faster starting gas or diesel generation;
- greater volumes of, and faster response from, demand response providers;
- energy storage (i.e. utility scale and behind-the-meter applications).

Upgrades to existing generators

The AEMC understands that fast-start generators can undertake measures to reduce the synchronisation time and/or increase ramping capability. For example, gas peaking plant can be configured to bypass some stages of the start-up process before energy is provided to the grid. This can allow units to run at "full speed, no load" and synchronise very quickly (perhaps 1-2 minutes) when required. The AEMC is interested in the potential for such upgrades to occur in the NEM and what the likely costs and operational gains would be.

New thermal generation

New gas and diesel generators are capable of providing a very fast response, both in terms of time to synchronise and time to ramp up. The GE LM6000 turbine can ramp from rest to full load (50MW) in 8 minutes, which includes 2.8 minutes to

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14 Energy Consumers Australia, *Energy Consumer Sentiment Survey*, July 2016; and Newgate Research, *New and Emerging Energy Technologies and Services*, consumer research report for the AEMC, June 2016.

15 Industry estimate.

synchronise.[16] Wartsila engines (10MW units) can respond form rest to full load in 2 minutes (ramping at ~98kW/s in the process).[17] A similar operational capability is demonstrated by diesel generators already installed in the NEM, such as Port Stanvac, Lonsdale and Angaston.[18] When 5-minute settlement was implemented in the Southeast Power Pool in the US, there was a three-fold increase in the capacity factor of internal combustion engines.[19]

Demand response

In terms of demand response, we observed above that the majority of response capacity currently requires more than 5 minutes to be activated. A key question is whether these responses could be faster if there was a financial incentive to provide this flexibility. Interesting examples of fast demand response internationally are the frequency control markets in New Zealand and Alberta. In May 2016, up to 260MW of load was offered in New Zealand's North Island market, and 326MW in Alberta, to provide a response in less than 1 second.[20]

Figure 17 below is an example of a ~140MW demand response provided by EnerNOC customers on New Zealand's North Island on 16 February 2016. EnerNOC's demand response portfolio for the New Zealand frequency control market includes over 130 loads from 12 different industry sectors. The largest contributions come from heavy industry, pulp and paper, and hot water heaters.

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16 Data provided by GE in August 2016.

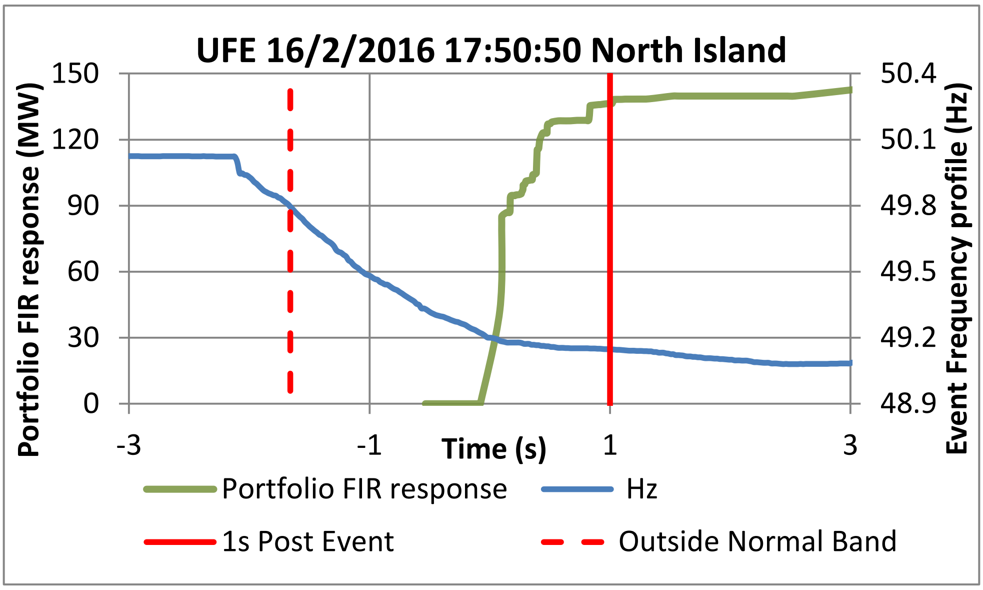
17 Data provided by Wartsila in September 2016. This ramp rate is for Wartsila multi-fuel engines. For further information see: Wartsila, *Value of Smart Power Generation for Utilities in Australia*, white paper prepared by Wartsila and ROAM Consulting, 2014.

18 All three of these power stations feature Cummins diesel engines.

19 FERC, *Settlement Intervals and Shortage Pricing in Markets Operated by Regional Transmission Organizations and Independent System Operators*, Docket No. RM15-24-000, 17 September 2015, p13, http://www.ferc.gov/whats-new/comm-meet/2015/091715/E-1.pdf

20 Data provided by EnerNOC. Based on the EM6 Aggregated Reserves Report (NZ) and public data retrieved via Morningstar (Alberta).

Figure 17: Demand response in New Zealand frequency control market



The AEMC is interested in the views of the Working Group on whether there would be more and/or faster demand response if settlement was on a 5-minute basis. The AEMC recently made a draft rule in relation to the unbundling of ancillary services that will allow new, potentially smaller operators to provide frequency control ancillary services (FCAS). To the extent to which this rule change encourages loads to participate in the FCAS markets, these loads could potentially also provide a demand response in the NEM spot market as well.

Energy storage

As noted above, non-hydro energy storage currently plays a relatively small part in the wholesale electricity market. In the coming years, a potentially significant increase in energy storage has been forecast, including separate predictions of 33GWh by 2030,[21] 6.6GWh by 2035,[22] one million households with storage by 2020,[23] and an installation rate of 244MW per year by 2020.[24]

The economic feasibility of investments in storage is likely to depend on accessing multiple value streams, including:

- avoiding network demand charges;
- network support services,

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21 Bloomberg New Energy Finance.

22 AEMO, *National Electricity Forecasting Report 2016*.

23 Morgan Stanley research.

24 Greentech Media, *Can Battery Storage Recharge Australian Utilities?*, 18 July 2016, http://www.greentechmedia.com/articles/read/can-battery-storage-recharge-australian-utilities

- energy ancillary services; and
- participating in the wholesale energy market (i.e. time-shift arbitrage and/or price risk management).

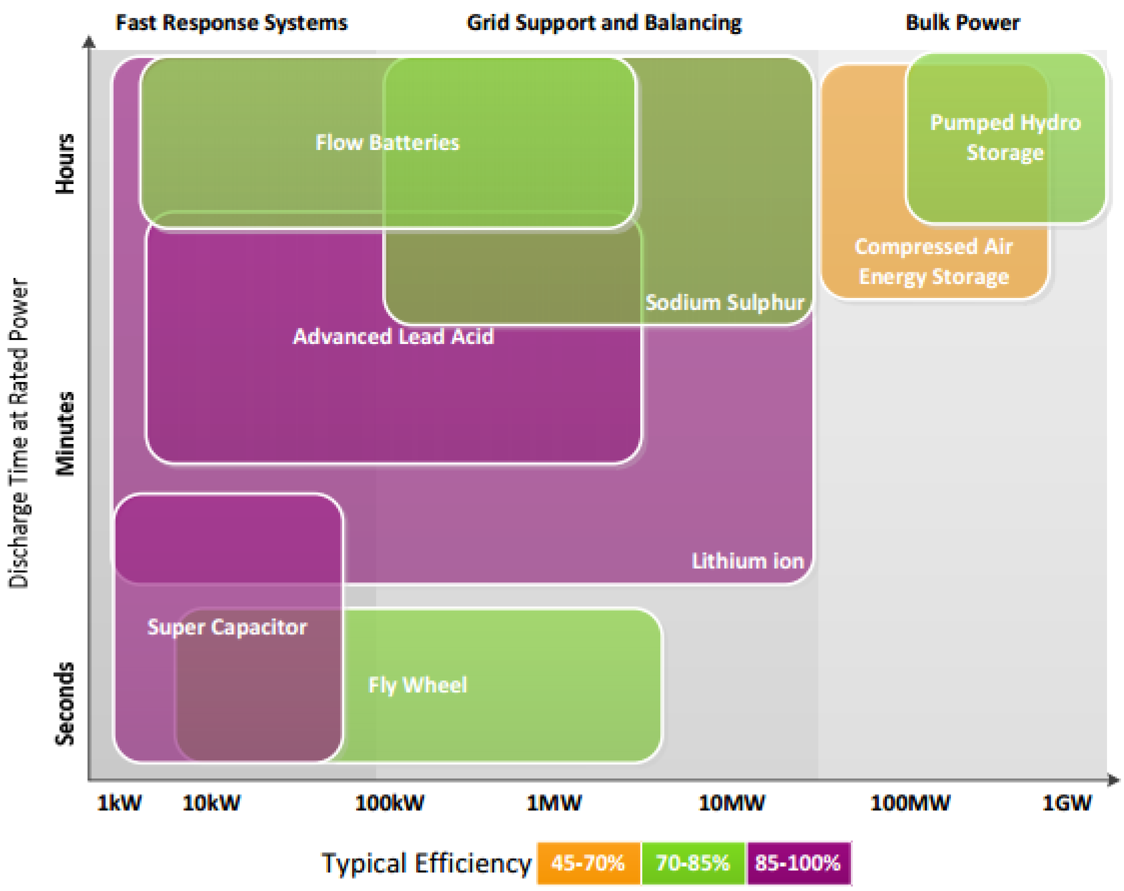
While access to every value stream is not required, the greater the value that can be captured, the more likely it will be for a storage project to be feasible. Further, if storage is deployed to avoid demand charges or for network support applications, it would be a logical step for this storage capacity to also be used in ancillary service and energy markets, if circumstances allow.

A change to 5-minute settlement could have a direct impact on the incentives of storage operators to participate in the wholesale energy market, and may indirectly impact on the incentives to provide energy ancillary services. 5-minute settlement may make it easier for participants to identify the value in providing either an energy or ancillary service, thereby assisting with decision making around which service to offer.

Energy storage comes in a wide range of different forms, with varying capabilities in terms of the amount of energy that can be stored and the length of time for which discharge can be maintained. Figure 18 below compares these characteristics for a range of battery technologies.[25] These characteristics, along with technology response times (discussed below), determine the suitability of the different types of energy storage for particular applications.

25 AECOM, *Energy Storage Study: Funding and Knowledge Sharing Priorities*, prepared for ARENA, 13 July 2015, p27.

Figure 18: Discharge time and power capacity of common storage technologies



Internationally, there are examples of a range of battery technologies being used for frequency control applications in power grids where responses <1 second are required.[26] These technologies include lithium ion, flow batteries and advanced lead-acid. Flywheels and super capacitors are other fast response options. All of these technologies have been used in applications where responses <1 second are required. They may therefore also be suitable for operating in a 5-minute energy market.

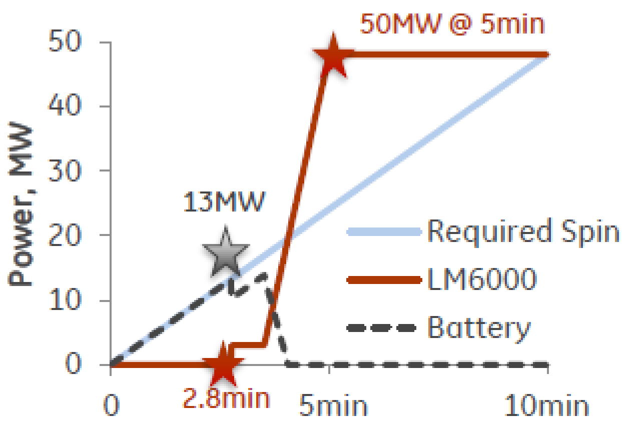
The AEMC has identified a range of potential applications for energy storage to provide a fast response (i.e. within 5-minutes) in the wholesale energy market, including:

- Collocating batteries with existing power stations, such as gas turbines. This arrangement involves discharging the battery system to provide energy in the time that a gas turbine requires to synchronise and/or ramp up. GE offers such a product which integrates a LM6000 turbine (mentioned above) with a 15MW battery. The combined gas turbine/battery provides a near instantaneous response using the battery, shifting to output from the turbine as it ramps up (see Figure 19

26 GE Energy Consulting, *Technology Capabilities for Fast Frequency Response*, report prepared for AEMO, 31 July 2016.

below). GE anticipates that as a result of optimising the operation of the turbine, the LM6000 will be able to ramp from rest to full load within 5 minutes within the next 12 months.

Figure 19: Operational capability of GE Battery-Gas Turbine hybrid (Source: GE)



- Collocating batteries with wind or solar farms. This arrangement would allow the variable output of a wind or solar farm to be balanced out by the battery (i.e. by either producing or consuming energy). This would allow these generators to be more responsive to conditions in the market, and potentially capture more value through contracts or on a merchant basis. There may also be power quality and system stability benefits that could be achieved through this configuration. To provide an example, there is a project under construction in Hawaii that will combine a 13MW/52MWh battery with a 13MW solar farm, allowing solar generation to be shifted to other times of the day or night.[27]

- Standalone utility-scale batteries. MW-scale batteries can be operated in isolation to capture the different value streams listed above, including contracting with an existing generator. Many of the existing projects are located in the US to take advantage of energy storage mandates in California and Oregon, and capacity markets in other states. Such projects demonstrate the technical feasibility of utility-scale storage, but the AEMC acknowledges that the financial incentives are different in the NEM. The US Department of Energy's Global Energy Storage Database indicates that globally there are 284 operational projects involving storage output capacities above 1MW. The total output capacity of these storage projects is 3.1GW.[28]

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27 Utility Dive, *Inside the first fully dispatchable utility solar-storage project in Hawaii*, 29 October 2015, http://www.utilitydive.com/news/inside-the-first-fully-dispatchable-utility-solar-storage-project-in-hawaii/408208/

28 US Department of Energy, *Global Energy Storage Database*, accessed on 14 September 2016. This total applies to electro-chemical and electro-mechanical storage applications only.

- Aggregating distributed storage units. Behind-the-meter storage installation can be used in the same way as demand response to reduce energy consumption from the grid. In the commercial and industrial space, distributed storage can be used to provide a very fast response via the same mechanisms as existing demand response activities (i.e. spot price exposure, spot pass-through arrangements, or benefit-sharing arrangements). In the residential space there are options such as "virtual power plants" (VPPs), such as the one recently announced by AGL and ARENA in South Australia,[29] and businesses that aggregate and control distributed storage to provide services to retailers and network businesses (e.g. Reposit). If there are 1 million households with solar and storage by 2020, as one analyst from Morgan Stanley suggests, VPPs and other businesses models that involve the aggregation and control of distributed resources could facilitate significant amounts of fast response in the wholesale market.

The examples above demonstrate the technical potential of energy storage technologies, as well as the potential for upgrades to existing generators, investments in new gas and diesel plant, and demand response technologies. The AEMC's research suggests that, over time, technology is providing the ability for faster response technologies.

The AEMC is interested in stakeholders' views on the financial viability of these investments, and whether the incentives for undertaking such projects would change if the NEM moved to 5-minute settlement.

[29] ARENA, *Battery storage set to strengthen South Australian grid*, media release, 5 August 2016.

4. Appendix

4.1. Dispatch and settlement in overseas markets

Country/market	Type	Dispatch and settlement intervals (real-time)	Gate closure (real-time)[30]
Australia	Mandatory energy-only	5:30	No
New Zealand	Mandatory energy-only	5:30[31]	Yes. 2 hours
Singapore	Mandatory energy-only	30:30[32]	Yes. 65 minutes
Alberta (Canada)	Mandatory energy-only	1:60[33]	Yes. 2 hours
ERCOT (US; non-FERC)	Voluntary energy-only Day-ahead and real-time	5:15[34]	Yes. 1 hour
PJM (US; FERC)	Energy and capacity market Voluntary day-ahead and real-time markets	5:60[35]	Yes 6pm day before
NYISO, CAISO and SPP (US; FERC)	Energy and capacity market Day-ahead and real-time	5:5[35]	
MISO and ISO-NE (US; FERC)	Energy and capacity market Day-ahead and real-time	5:60[35]	

30 Competition Economists Group, *International review of rebidding activity and regulation*, December 2014.

31 The system operator can issue dispatch instructions whenever they are needed, which could be more or less frequent than once every 5-minutes. New Zealand Electricity Authority, *Real-time pricing options*, decision paper, August 2016.

32 Singapore Energy Market Authority, *Introduction to the National Electricity Market of Singapore*, October 2010, https://www.ema.gov.sg/cmsmedia/Handbook/NEMS_111010.pdf

33 Alberta Electric System Operator, *Guide to understanding Alberta's electricity market*, accessed 29 March 2016, https://www.aeso.ca/aeso/training/guide-to-understanding-albertas-electricity-market/

34 Competition Economists Group, *op. cit.*

35 FERC, *op. cit.*

4.2. Variation by dispatch interval

Figure 20: Average historical variation in New South Wales by dispatch interval (2004 to 2016 YTD)

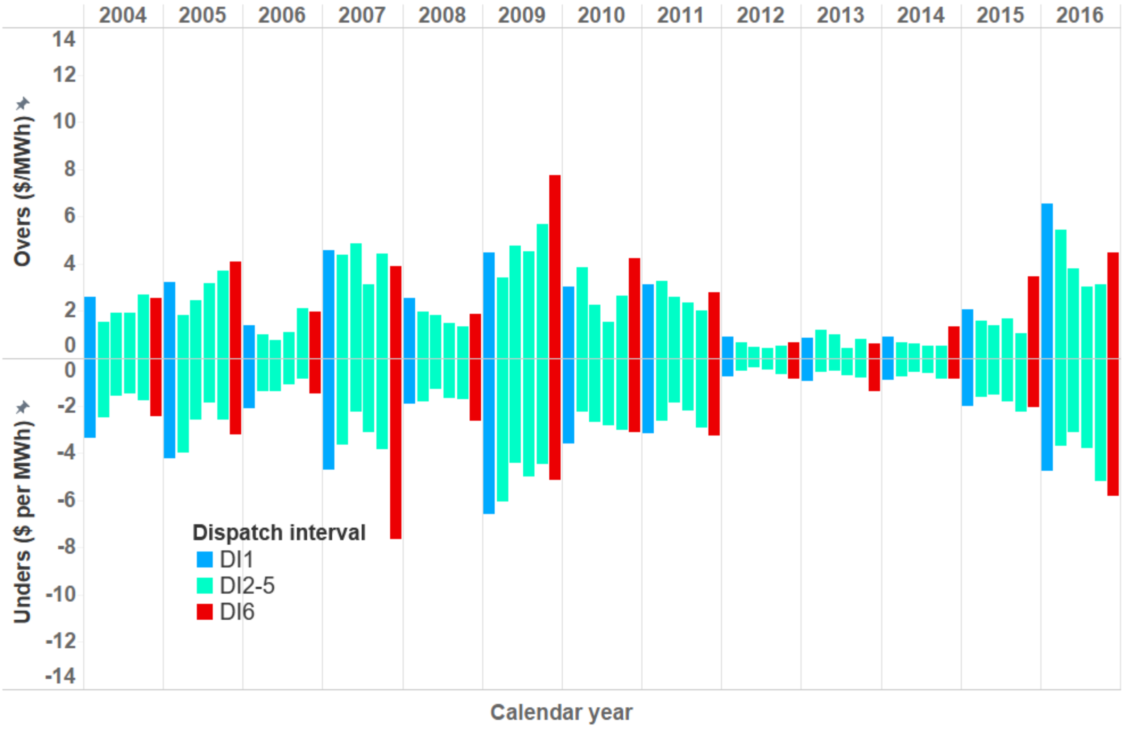


Figure 21: Average historical variation in Tasmania by dispatch interval (2004 to 2016 YTD)

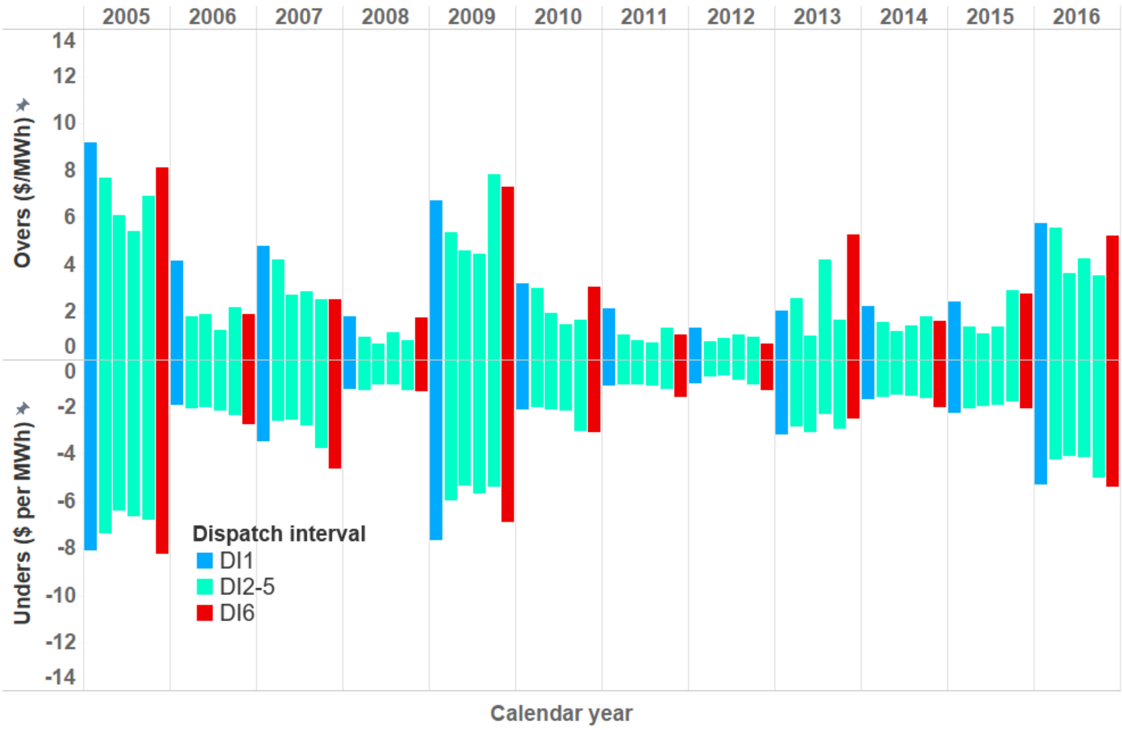


Figure 22: Average historical variation in Victoria by dispatch interval (2004 to 2016 YTD

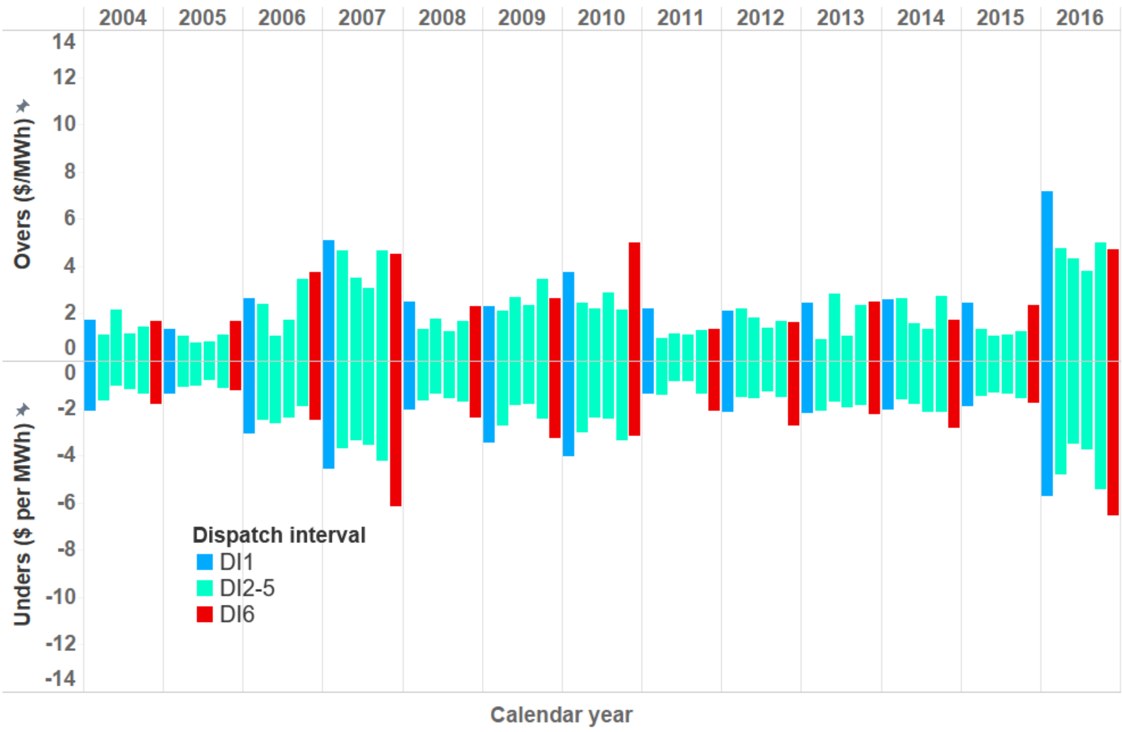
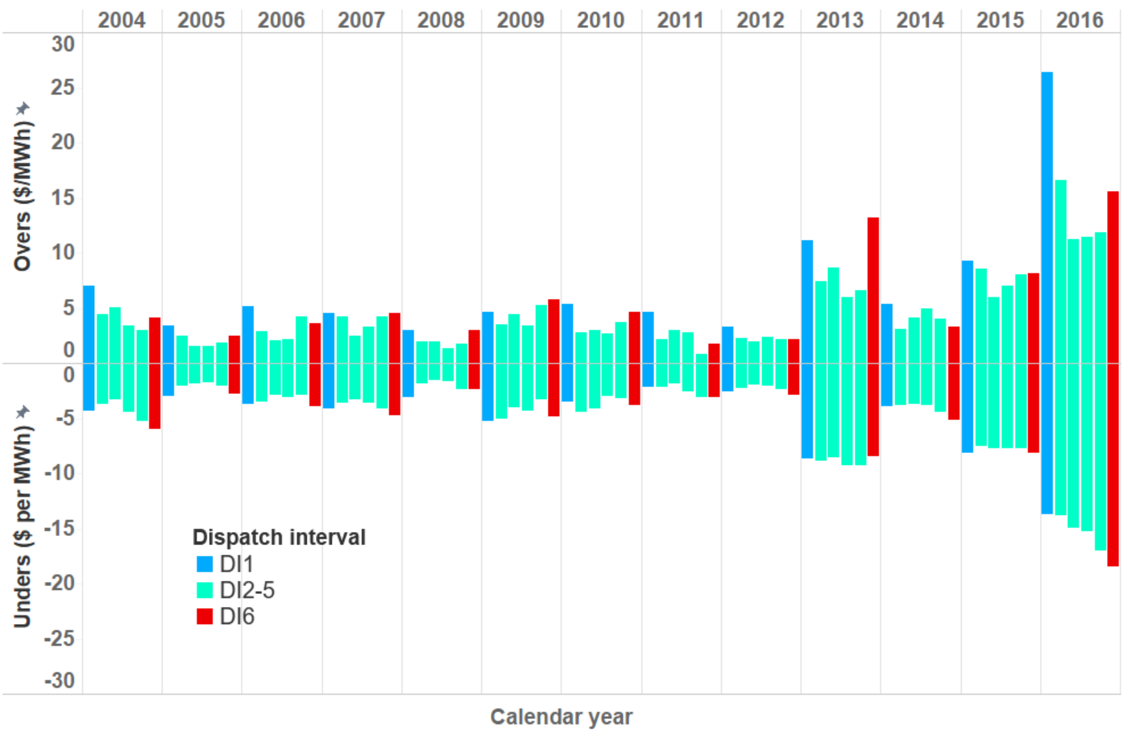


Figure 23: Average historical variation in South Australia by dispatch interval (2004 to 2016 YTD



4.3. Fast-start analysis

Figure 24: Theoretical response from fast-start plant in NSW

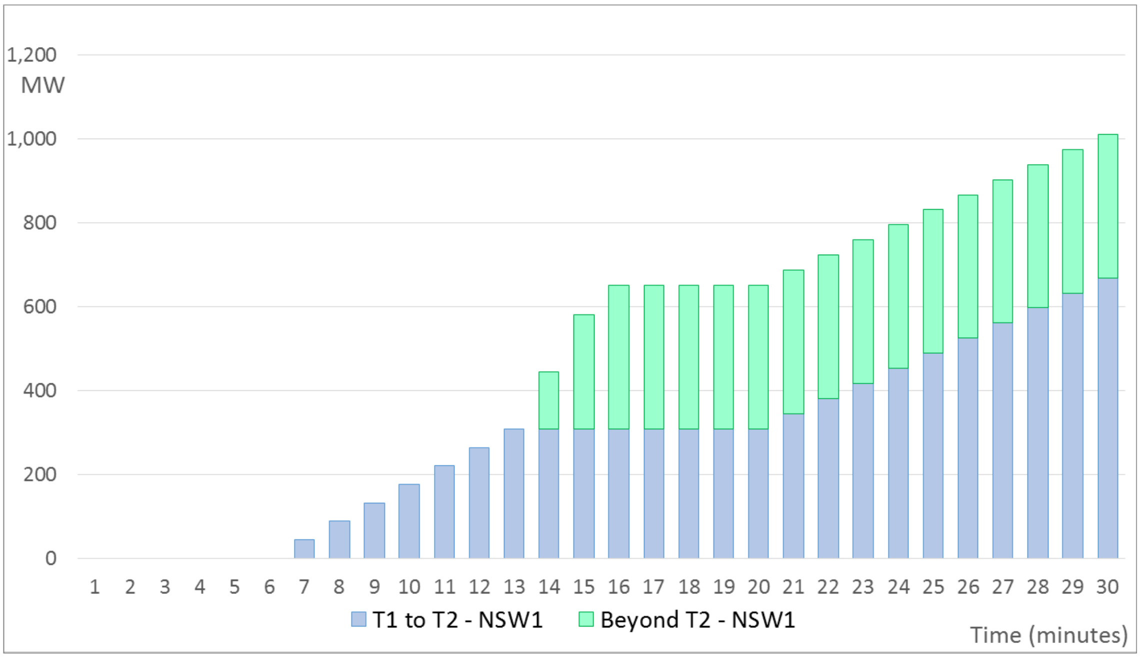


Figure 25: Theoretical response from fast-start plant in Qld

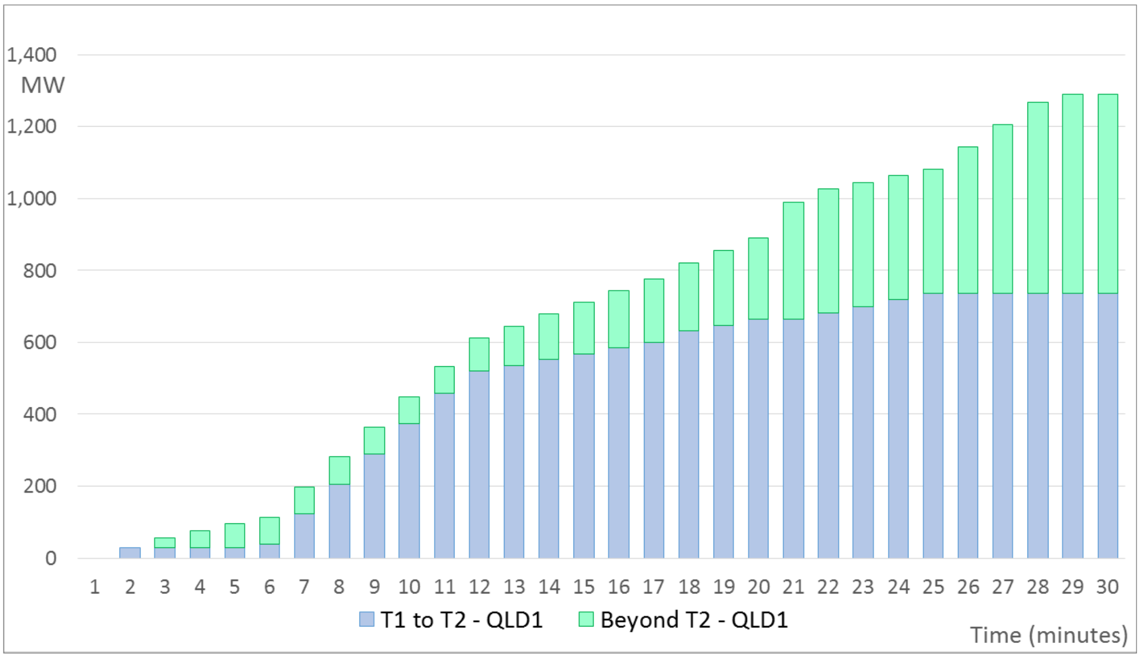


Figure 26: Theoretical response from fast-start plant in Tas

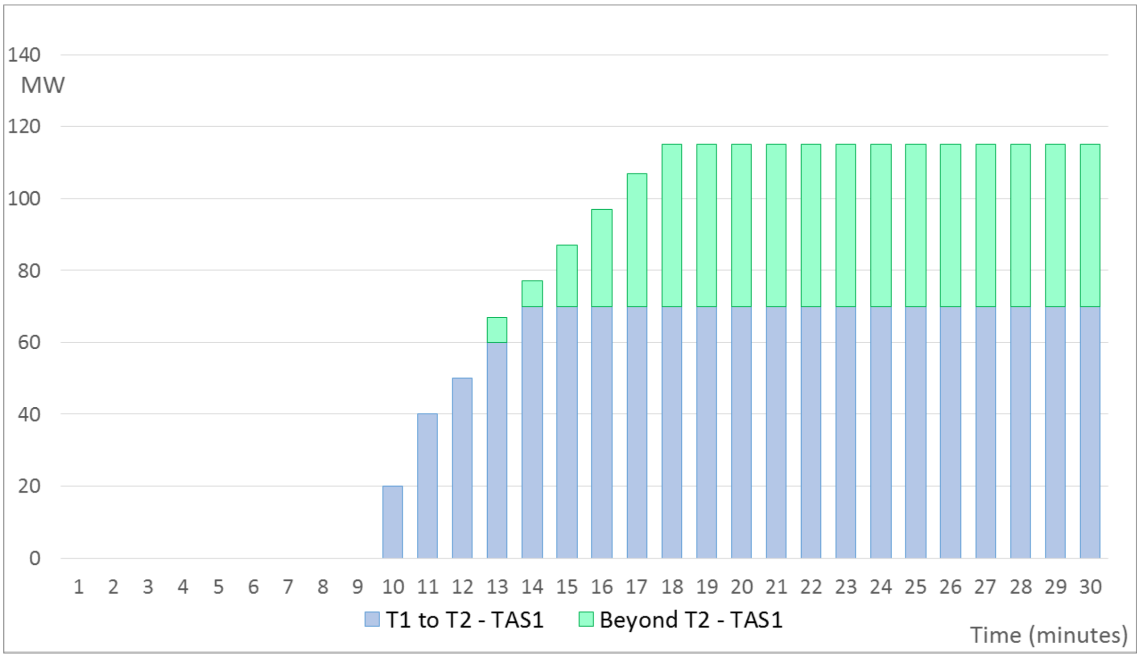
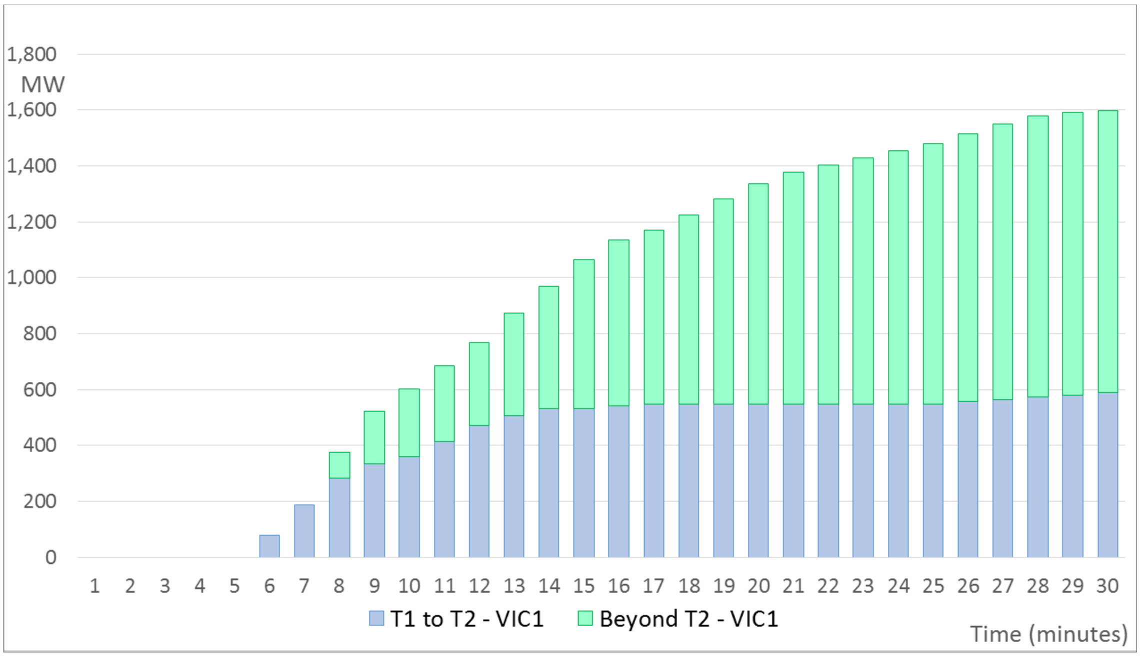


Figure 27: Theoretical response from fast-start plant in Vic



4.4. Ramping by fuel type

Figure 28: Ramping capacity, coloured by Fuel Type (Qld, 2016 YTD)

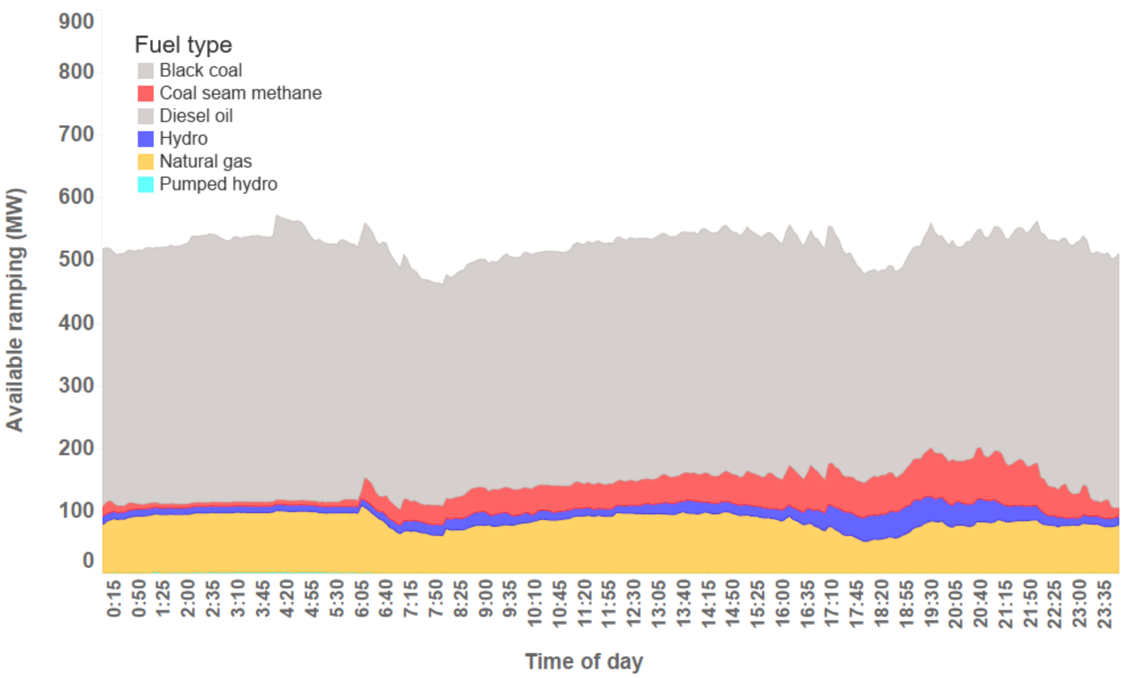


Figure 29: Ramping capacity, coloured by Fuel Type (Tas, 2016 YTD)

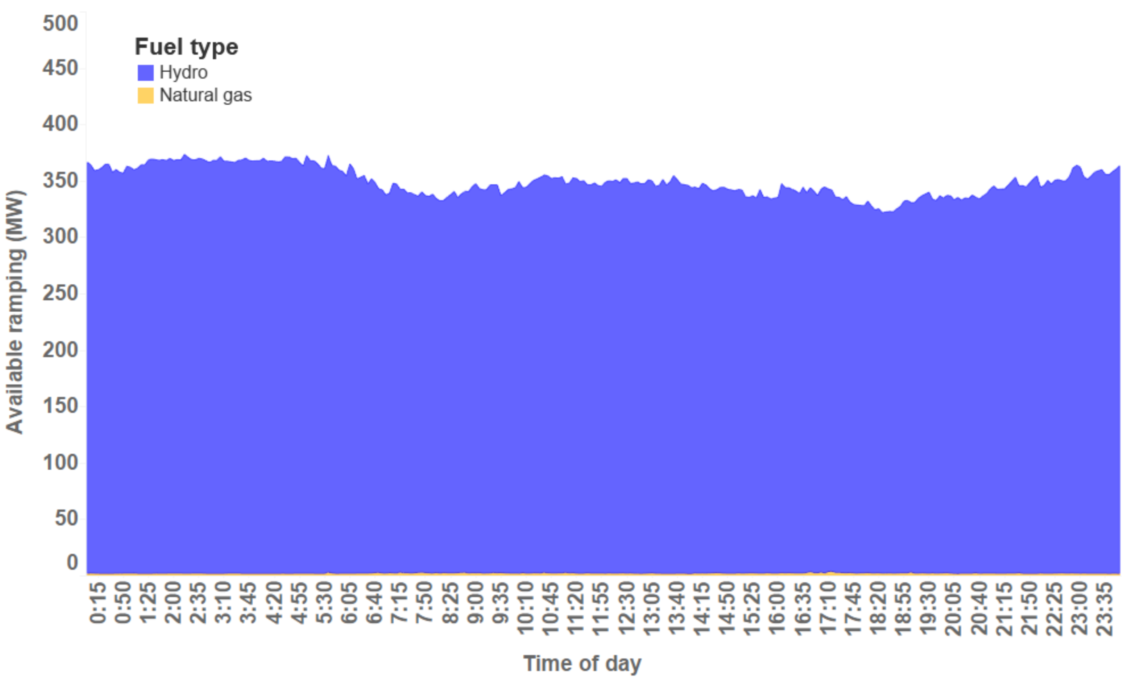


Figure 30: Ramping capacity, coloured by Fuel Type (Vic, 2016 YTD)