Hornsdale Power Reserve

Year 2 Technical and Market Impact Case Study

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Executive summary

THE HORNSDALE POWER RESERVE (HPR) HAS PROVIDED SIGNIFICANT VALUE TO THE NATIONAL ELECTRICITY MARKET (NEM), REDUCING THE COST OF FREQUENCY CONTROL ANCILLARY SERVICES (FCAS) BY APPROXIMATELY $116M IN 2019 ALONE.

Key findings in review of HPR's market impact during the 2019 calendar year are:

- HPR captured approximately 15% of the Contingency FCAS market volume and 12% of the Regulation FCAS market volume across the mainland NEM regions.
- HPR is modelled to have reduced the total Contingency FCAS cost by approximately $80M, and the total Regulation FCAS cost by approximately $36M, for a total NEM cost reduction of approximately $116M.
- Approximately $102M of these cost reductions (88%) were during periods when South Australia was interconnected with other NEM regions
- HPR's market value was also particularly evident during a 5-hour South Australia separation event on 16 November 2019, in which it is modelled to have provided a market benefit of approximately $14M.
- Upon the introduction of HPR into the FCAS markets, average yearly regulation FCAS costs from South Australian generators fell from a high of $470/MWh to less than $40/MWh, where they remain today, resulting in considerable savings in South Australian energy costs.

HPR has responded to three South Australian separation events since entering service. On each occasion it has supported system security for the South Australian network by responding with its Fast Frequency Response capability to reduce the severity of the disturbance and support a return to normal frequency conditions.

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Case study overview

Background

Hornsdale Power Reserve (HPR), owned and operated by Neoen, and supplied by Tesla, is the world's largest lithium-ion battery energy storage system, with a discharge capacity of 100MW and energy storage capacity of 129MWh. Located near Jamestown, South Australia, it shares the same 275kV network connection point as the 30MW Hornsdale windfarm.

The project reserves 70MW of its discharge capacity for designated system security services contracted with the South Australian (SA) Government. The remaining 30MW power capacity and 119MWh energy storage is available to Neoen for market participation.

This case study on HPR's second operational year follows on from an earlier Year 1 Technical and Market Impact Case Study, which examined the array of technical services and market benefits provided by the project. This study focuses in greater depth on quantifying the market benefit of HPR's presence in the Frequency Control Ancillary Services (FCAS) markets over its second operational year.

Case study scope

This case study presents the results of a bid analysis of each FCAS market on the National Electricity Market (NEM) throughout 2019. Pricing for each service across all 2019 dispatch intervals is compared with modelling of what the pricing would have been if HPR had not been present.

FCAS pricing across NEM mainland regions is generally equal, as when interconnection constraints do not apply these services can be sourced across mainland regions. On 16 November 2019 South Australia experienced a separation event from the remainder of the NEM, with its own FCAS supply sourced locally from a limited number of providers. A specific case study on the market impact of HPR during this separation event is provided.

HPR's response to three South Australian separation events since entering service is also assessed to demonstrate its system security support for the South Australian network during these major contingency events.

HPR FCAS services and registrations

HPR is registered in each FCAS market with the capacities shown in the following table. These registered capacities, in conjunction with an agreed operating protocol for the battery charge and discharge capacity reserved by the South Australian government sets limits on the volume that can be bid into and dispatched in each FCAS market.

FCAS market	Registered capacity (MW)	Comments
Raise Regulation FCAS	100MW	• HPR's full discharge capacity registered • Normally only 30MW is bid into the market. The 70MW discharge capacity reserved by the SA Government is not normally bid into this market
Lower Regulation FCAS	80MW	• HPR's full charge capacity registered • Normally only 40MW is bid into the market. The 40MW charge capacity reserved by the SA Government is not normally bid into this market.
Raise 6 second Contingency FCAS (R6)	63MW	• Registration limit is set by AEMO in consideration of permissible droop response settings • HPR's full 100MW discharge capacity is however enabled to respond to contingency events as required across each of the 6 second, 60 second and 5 minute timescales
Raise 60 second Contingency FCAS (R60)	19MW	
Raise 5 minute Contingency FCAS (R5)	41MW	
Lower 6 second Contingency FCAS (L6)	63MW	• Registration limit is set by AEMO in consideration of permissible droop response settings • HPR's full 80MW charge capacity is however enabled to respond to contingency events as required across each of the 6 second, 60 second and 5 minute times-cales
Lower 60 second Contingency FCAS (L60)	19MW	
Lower 5 minute Contingency FCAS (L5)	41MW	

Regulation FCAS market 2019 impact

HPR has a provided a significant portion of the total procured Regulation FCAS services on the NEM in 2019. It has put considerable downward pressure on prices, especially in the Raise Regulation FCAS market.

In 2019 HPR was a significant participant in the Regulation FCAS markets, contributing:

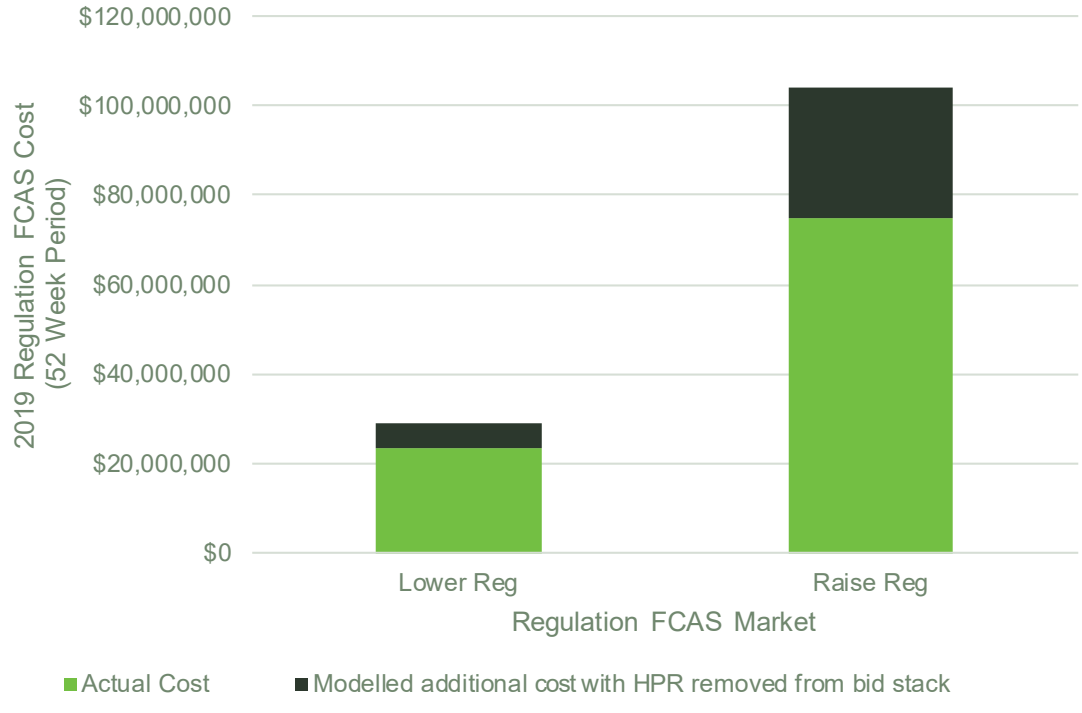
- 10% of the enabled NEM-wide Raise Regulation reserves (34% of SA local dispatch)
- 14% of the enabled NEM-wide Lower Regulation reserves (45% of SA local dispatch)

The impact of HPR on the NEM FCAS market was analysed by removing HPR from the FCAS bid stack and then reserving generators from the bid stack until the gap caused by HPR's removal was filled.

For periods in which SA was connected to other mainland NEM regions, removing HPR from the bid stack resulted in:

- A 39% increase in NEM-wide[1] payments for the Raise regulation market in 2019, corresponding to a $29,384,230 increase
- A 25% increase in NEM-wide[1] payments for the Lower Regulation market in 2019, corresponding to a $5,759,254 increase

It should be considered that it is likely the absence of HPR would result in existing generators adjusting their bids. The NEM Dispatch Engine would also have made some adjustments to co-optimise dispatch across all markets, decreasing some generator availabilities in the energy market to increase the available FCAS. These factors are expected to result in some reductions in additional modelled costs.



- In the Raise Regulation market, the highest price in 2019 was $1372. With HPR removed from the bid stack this maximum was exceeded in 49 5-minute dispatch periods, which equated to $9,350,596 (32% of the cost increase)

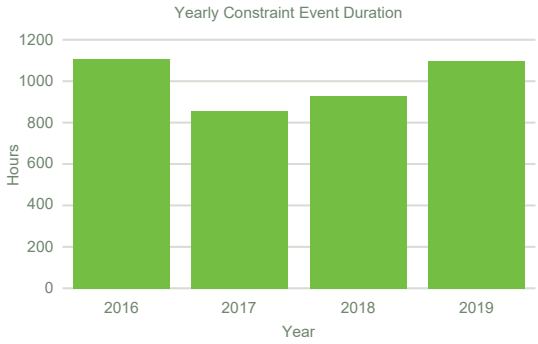
[1]These figures exclude consideration of Tasmania generators, which are separately dispatched. They also exclude dispatch intervals in which AEMO price interventions applied, and the 16 November separation event. The market impact of the separation 16 November event is presented separately herein.

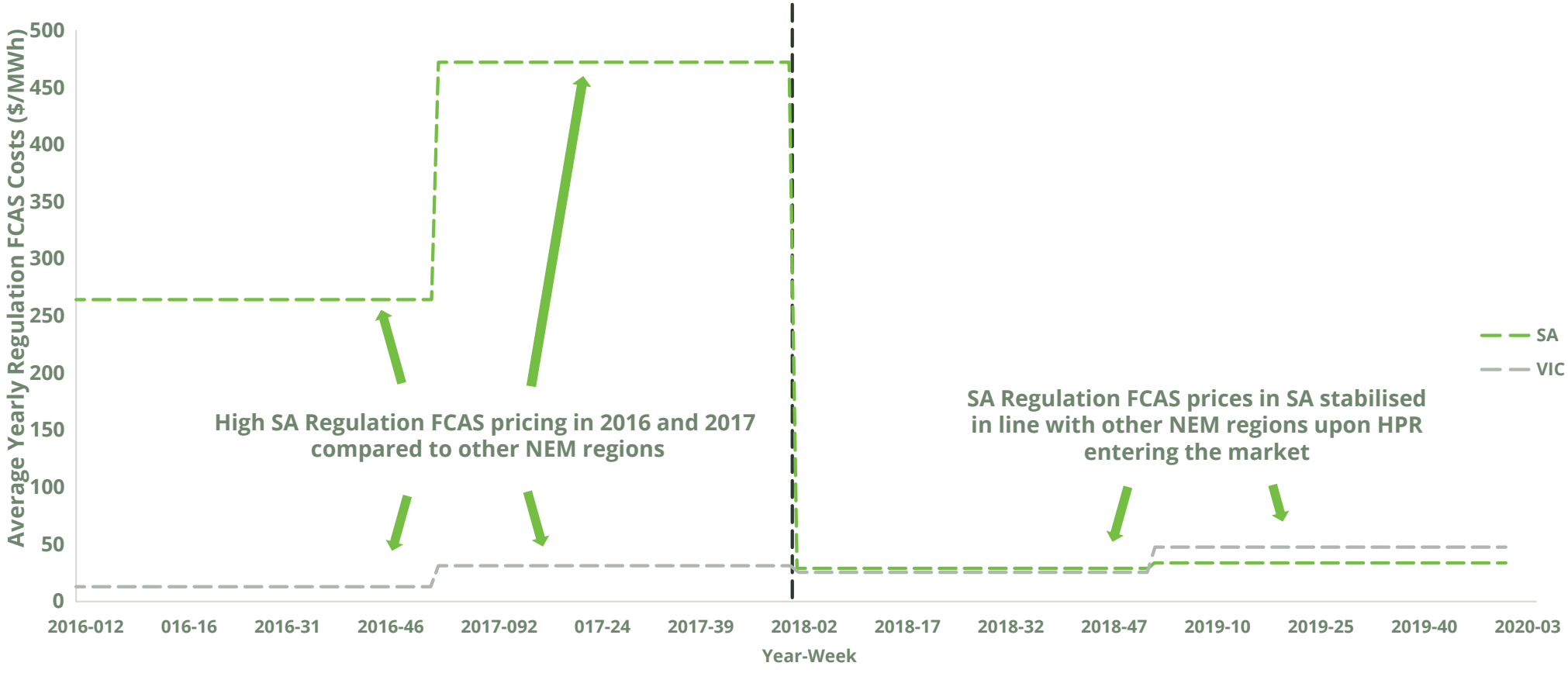
HPR continues to suppress South Australian Regulation FCAS costs

Upon the introduction of HPR into the FCAS markets, average yearly Regulation FCAS costs from South Australian generators fell from $470/MWh to less than $40/MWh (a 91% reduction), where they remain today, bringing Regulation FCAS costs for South Australia in line with other mainland NEM regions. This has resulted in considerable savings in South Australian energy costs.

High South Australian Regulation FCAS costs in 2016 and 2017 were caused by a lack of competition when the service was provided by SA generators alone, during constraint events for maintenance on the Heywood interconnector.

Despite a similar total duration of such maintenance events in 2018 and 2019, the presence of HPR caused Regulation FCAS costs to drop. This is considered to be an ongoing saving.





Raise Contingency FCAS market 2019 impact

HPR's most significant market impact has been in the Raise 6 second Contingency FCAS market, where 2019 prices were reduced to approximately one-third of what they would have been without HPR.

In 2019 HPR was a significant participant in the Raise Contingency FCAS markets, contributing:

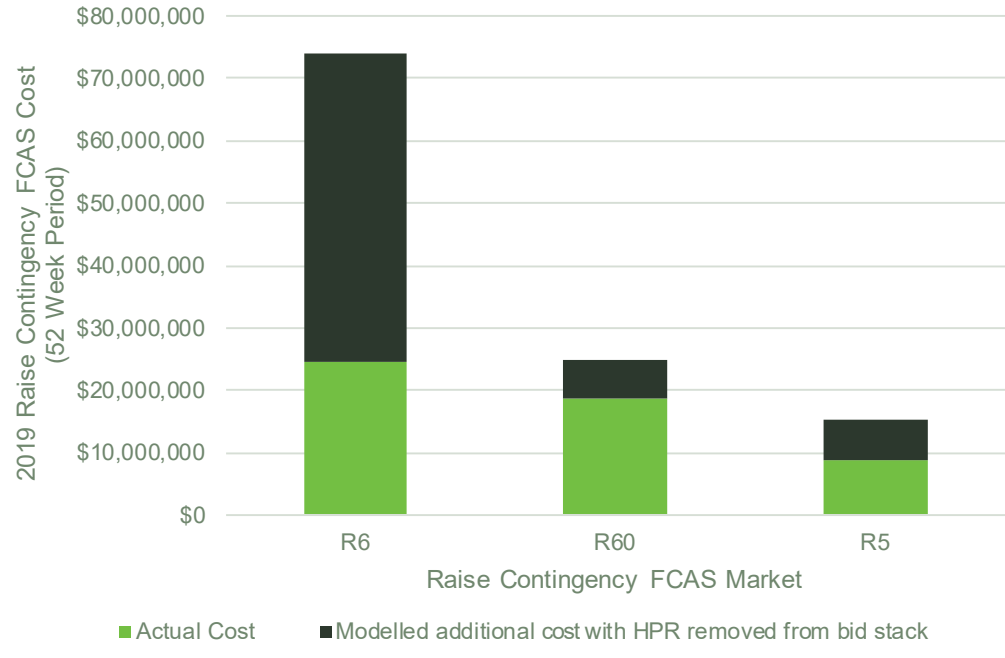
- 19% of the enabled NEM-wide R6 Contingency reserves (53% of SA local dispatch)
- 6% of the enabled NEM-wide R60 Contingency reserves (23% of SA local dispatch)
- 11% of the enabled NEM-wide R5 Contingency reserves (57% of SA local dispatch)

The impact of HPR on the NEM FCAS market was analysed by removing HPR from the FCAS bid stack and then reserving generators from the bid stack until the gap caused by HPR's removal was filled.

For periods in which SA was connected to other mainland NEM regions, removing HPR from the bid stack resulted in:

- A 202% increase in NEM-wide[1] payments for the R6 market in 2019, corresponding to a $49,455,587 increase
- A 33% increase in NEM-wide[1] payments for the R60 market in 2019, corresponding to a $6,180,524 increase
- A 75% increase in NEM-wide[1] payments for the R5 market in 2019, corresponding to a $6,601,995 increase

It should be considered that it is likely the absence of HPR would result in existing generators adjusting their bids. The NEM Dispatch Engine would also have made some adjustments to co-optimise dispatch across all markets, decreasing some generator availabilities in the energy market to increase the available FCAS. These factors are expected to result in some reductions in additional modelled costs.



- The R6 market saw the greatest growth in NEM-wide cost of all the Raise markets (202%). This was primarily due to R6 being a higher valued market as well as HPR having a higher registered capacity in this market of 63MW (232% greater than R60 and 54% greater than R5).

[1]These figures exclude consideration of Tasmania generators, which are separately dispatched. They also exclude dispatch intervals in which AEMO price interventions applied, and the 16 November separation event. The market impact of the separation 16 November event is presented separately herein.

Lower Contingency FCAS market 2019 impact

HPR has provided a high portion of the total procured Lower Contingency FCAS services on the NEM in 2019. It has put considerable downward pressure on prices, especially in the Lower 6 second FCAS market.

In 2019 HPR was a significant participant in the Lower Contingency FCAS markets, contributing:

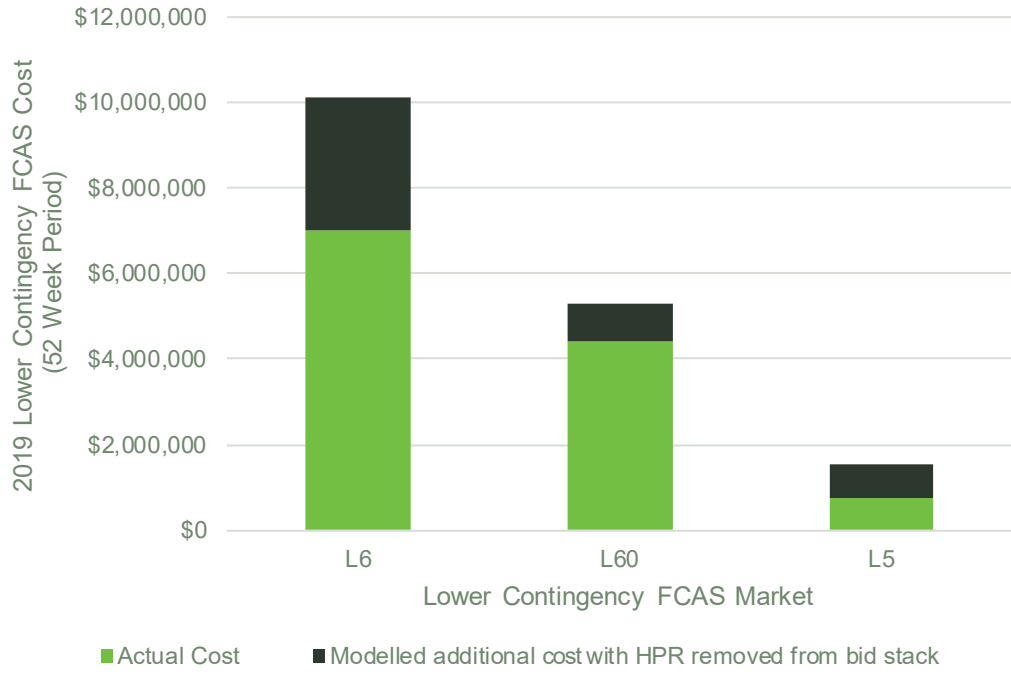
- 35% of the enabled NEM-wide L6 Contingency reserves (60% of SA local dispatch)
- 14% of the enabled NEM-wide L60 Contingency reserves (51% of SA local dispatch)
- 24% of the enabled NEM-wide L5 Contingency reserves (91% of SA local dispatch)

The impact of HPR on the NEM FCAS market was analysed by removing HPR from the FCAS bid stack and then reserving generators from the bid stack until the gap caused by HPR's removal was filled.

For periods in which SA was connected to other mainland NEM regions, removing HPR from the bid stack resulted in:

- A 44% increase in NEM-wide[1] payments for the L6 market in 2019, corresponding to a $3,112,772 increase
- A 20% increase in NEM-wide[1] payments for the L60 market in 2019, corresponding to a $900,140 increase
- A 101% increase in NEM-wide[1] payments for the L5 market in 2019, corresponding to a $778,457 increase

It should be considered that it is likely the absence of HPR would result in existing generators adjusting their bids. The NEM Dispatch Engine would also have made some adjustments to co-optimise dispatch across all markets, decreasing some generator availabilities in the energy market to increase the available FCAS. These factors are expected to result in some reductions in additional modelled costs.



- In the L5 market, the highest price in 2019 was $1115. With HPR removed from the bid stack this maximum was exceeded in 12 5-minute dispatch periods, which equated to $218,778 (28% of the cost increase)

[1]These figures exclude consideration of Tasmania generators, which are separately dispatched. They also exclude dispatch intervals in which AEMO price interventions applied, and the 16 November separation event. The market impact of the separation 16 November event is presented separately herein.

16 November separation event case study

On 16 November 2019, South Australia disconnected from the other mainland NEM regions due to equipment failure on the Heywood interconnector. This caused an initial frequency disturbance in the islanded power system and considerable volatility in South Australian market prices throughout the 5-hour separation event.

	Technical summary
1	Prior to separation event the flow on the Heywood interconnector was 308MW from South Australia to Victoria
2	At 18:06:47, maloperation of a communication multiplexer caused the protection systems on both Heywood interconnector 500kV transmission lines to trip, islanding South Australia
3	Oversupply of generation in the South Australian islanded system caused a high frequency event
4	HPR responded as required in accordance with its droop curve, with a swing of approximately 64MW, transitioning from 8MW discharge to up to 56MW charge
5	The collective high frequency response of HPR and other SA generators maintained the frequency within the permitted range for a separation event with a peak of 50.85Hz, and a return to the normal operating fre - quency range of 50 ± 0.15Hz at 18:22, approximately 16 minutes after the initial separation
6	The frequency was maintained generally within the normal operating range until resynchronisation with Victoria was effected nearly 5 hours after the initial separation at 22:57

	Market summary
1	• Network and FCAS constraints to manage the South Australia island were invoked at 18:09 for South Australia's FCAS and generation to be sourced locally with no interconnector flow
2	• Energy prices in South Australia initially fell, while energy prices in other mainland regions initially rose due to the changes in generation across regions.
3	• South Australian energy and FCAS prices during the remainder of the separation event were highly variable, due to a combination of co-optimisation between the energy and FCAS markets and rebidding by Market Participants.
4	• Very high prices occurred at times in the R6, L6 and L60 Contingency FCAS markets, with prices up to $12,376, $14,700 and $4,699 respectively • HPR did not set price in any dispatch interval in R6 or L60 markets, did not set price at market cap in the L6 market, and put downward pressure on total prices • Regulation FCAS prices were limited to a peak of $350 in the Raise market and $414 in the Lower market
5	• Insufficient total volume of Lower Contingency FCAS was available for the islanded South Australian system, and at 18:54 AEMO directed a reduction in load at Olympic Dam from 180MW to 130MW to address the shortfall. HPR was contributing to the supply of the Lower Contingency FCAS markets providing a minimum 40MW, 19MW and 40MW respectively into the L6, L60 and L5 markets.

The 16 November separation caused a high frequency event in the islanded South Australian region. HPR responded to charge as required, and along with other generators maintained the frequency within the permissible range.

The separation event caused considerable market volatility and periods of very high FCAS prices in the South Australian market when all services needed to be procured within the region. HPR's presence significantly reduced the duration of price spikes during the event, putting significant downward pressure on pricing.

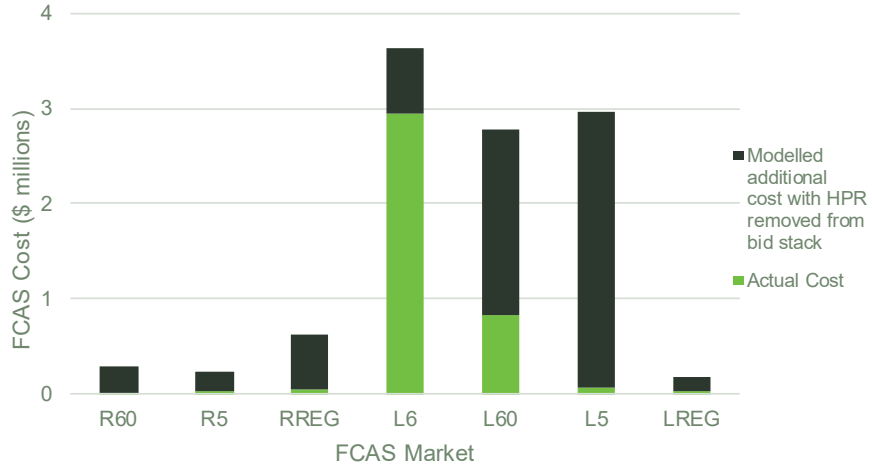
16 November event – HPR market impact

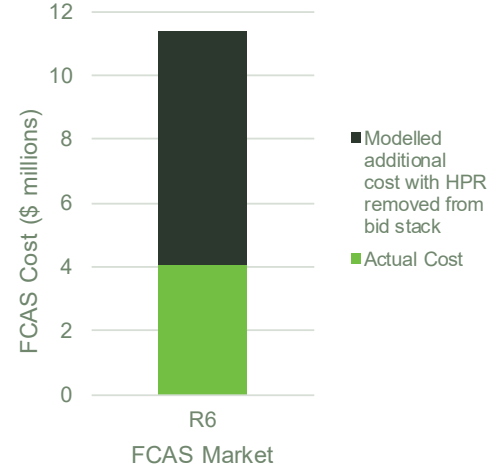
HPR's participation in the South Australian FCAS markets during the 16 November 2019 islanding event resulted in significant cost savings of approximately $14 million.

The modelled scenario of HPR removed from the bid stack led to cost increases in every market, resulting in a:

- 178% increase in cost for the R6 market
- 11694% increase in cost for the R60 market
- 829% increase in cost for the R5 market
- 1324% increase in cost for the RREG market
- 23% increase in cost for the L6 market
- 232% increase in cost for the L60 market
- 4738% increase in cost for the L5 market
- 485% increase in cost for the LREG market

The R6 market had the highest cost increase in the scenario of HPR removed from the bid stack. Due to a lack of availability in this service from other generators, the price would have been pushed to the market cap ($14,700) for the entire event.





	R6	R60	R5	RREG	L6	L60	L5	LREG	TOTAL
Actual Cost (HPR Present)	$4,103,240	$2,524	$25,693	$43,852	$2,950,069	$837,194	$61,373	$29,545	$8,053,489
Modelled Cost HPR removed from bid stack)	$11,418,127	$297,632	$238,674	$624,422	$3,625,910	$2,776,240	$2,969,081	$172,705	$22,122,791
Cost Differential	$7,314,887	$295,108	$212,980	$580,569	$675,840	$1,939,046	$2,907,708	$143,159	$14,069,301
Savings (%)	64%	99%	89%	93%	19%	70%	98%	83%	75%

Appendix A – Market impact modelling methodology

Aurecon's market modelling of the impact of HPR on energy and FCAS markets has applied the following methodology:

1. Dispatch intervals in which HPR is reserved in the target FCAS market are identified and the reserve amount recorded
2. The market price is identified for the target market for that dispatch interval
3. The generator setting the current price in the target market is identified
4. The price-setting generator(s) are reserved up to their maximum availability in the price-setting availability band, provided they have availability according to their FCAS trapezium
5. If the gap caused by the removal of HPR has not been filled, the next lowest price in the bid stack is identified where the associated generator(s) have availability according to their FCAS trapezium.
6. The price is adjusted to the new set price, and generators are reserved at that price up to their maximum availability in the price-setting availability band.
7. Check conducted on whether the HPR gap has filled. If not, repeat steps 5 and 6 until the HPR gap has been filled.
8. If the new set price in the Contingency FCAS markets is above the volume weighted average energy price, the new Contingency FCAS price is capped at the volume weighted energy price, except in dispatch intervals in which the original FCAS price was already above the volume weighted average energy price. This correction is applied to minimise the effect of reduced trapezium adjusted Contingency FCAS availability from generators due to their dispatch in the energy market, and adjustments that would likely be made in the NEM dispatch engine to increase the availability of lower cost Contingency FCAS.
9. Recalculate total cost to the NEM for the target market in the 5 minute dispatch period by multiplying the new price by the total dispatched in the NEM. This step was not applied to the SA separation event analysis of 18 November 2018 since FCAS prices were generally significantly higher than energy prices throughout the event.

The above steps exclude:

- Tasmanian generators and their associated local dispatch from all calculations
- AEMO price intervention events, and events where the price in SA is different from the rest of the NEM, although the same methodology with the exception of step 8 is applied separately to the 16 November separation event with SA generators only.

Appendix B – HPR response to separation events

HPR has responded to three South Australian separation events since entering service. On each occasion it has supported system security for the South Australian network by responding with its Fast Frequency Response capability to reduce the severity of the disturbance and support a return to normal frequency conditions.

HPR provides a Fast Frequency Response (FFR) service to the power system, which involves the fast dispatch of active power in response to a frequency disturbance outside the normal frequency operating range of 50 ± 0.15 Hz. HPR currently provides its FFR capability through participation in the existing Contingency FCAS markets, albeit with a much faster response than required by these markets.

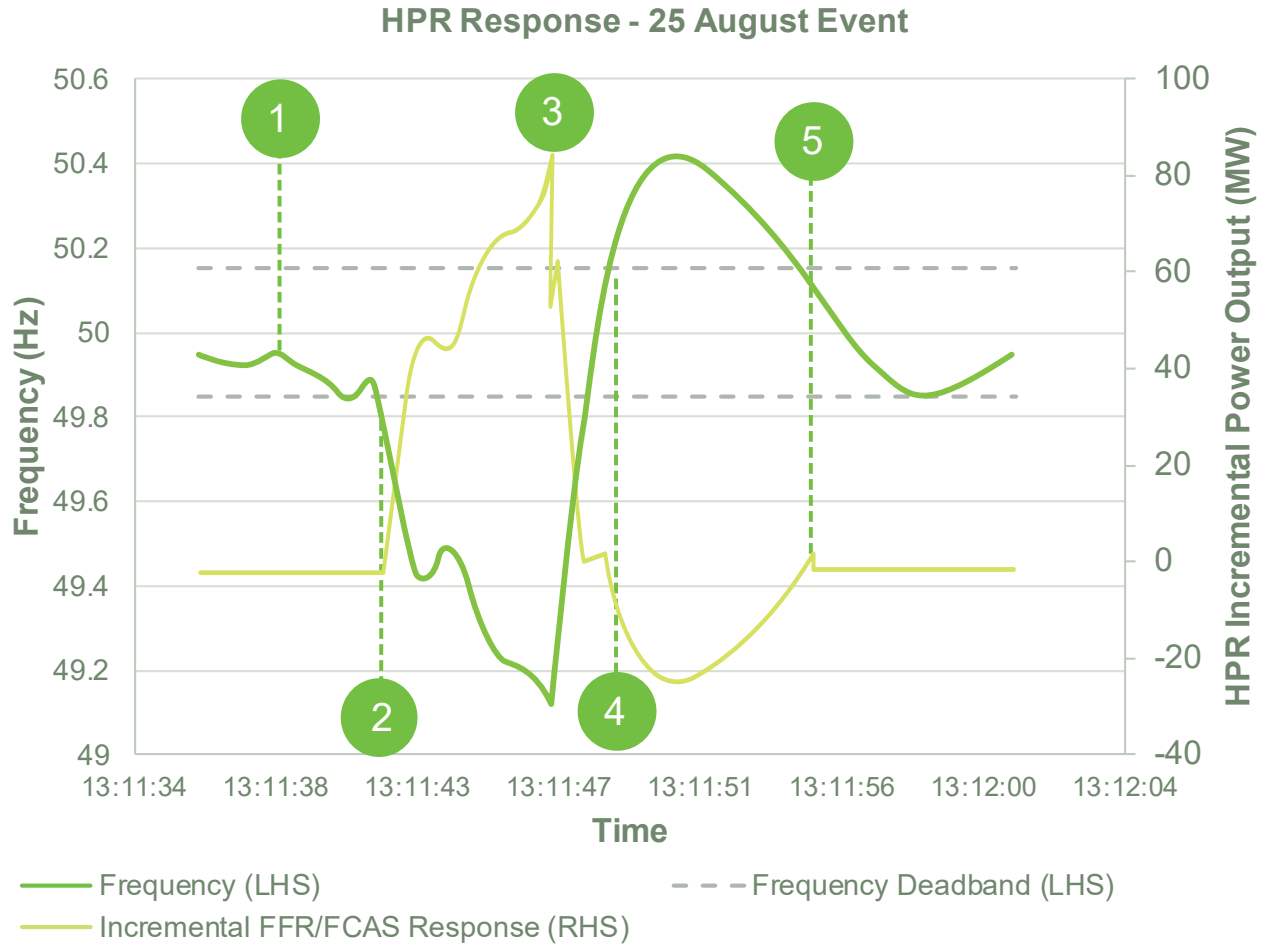
This service is particularly valuable upon contingency events in which South Australia is unexpectedly separated from the other mainland NEM regions due to a disconnection of the Heywood interconnector. Three such events have occurred since HPR entered service; on 25 August 2018, 16 November 2019 and 31 January 2020.

On each occasion, HPR responded by closely tracking the changing frequency and accurately changing its power dispatch as required. HPR's response during the initial, crucial period of each of the three events is shown on the following pages.

Appendix B.1 – HPR response to 25 August 2018 separation event

On 25 August 2018 the NEM experienced a major system security event, involving the loss of both QLD-NSW and VIC-SA interconnectors. The sequence of events and HPR's response to the initial separation is shown as follows.

	Market summary
1	• QLD – NSW interconnector (QNI) trips, islanding QLD region. • Initiates high frequency event in QLD, and low frequency event for other regions. • Preliminary investigation indicates cause was flashover consistent with a lightning strike at the QNI fault location.
2	• Frequency on non-QLD mainland NEM regions falls below 49.85 Hz (lower bound of the normal frequency operating range, and deadband for HPR's FFR activation). • HPR automatically shifts into FFR mode, closely tracking its frequency droop curve to dispatch active power as required. (Note: HPR was charging at approx. 37 MW at the time of the event). Its droop response is an incremental response based on the last AGC command prior to activating FFR.
3	• Frequency falls to a minimum of 49.12 Hz, and HPR's incremental response rises to 84.3 MW • Frequency drop, combined with changes in the power flow on the Heywood interconnector leads to the activation of the Heywood Emergency Control Scheme and separation of SA from VIC • Frequency in SA begins to rise quickly and HPR reduces power output according to droop curve, until frequency returns to 49.85 Hzw • No UFLS was required in SA • Frequency in NSW and VIC continued to fall activating UFLS
4	• Frequency rises to 50.15 Hz (upper bound of the normal frequency operating range, and deadband for HPR's FFR activation). • HPR re-activates FFR and charges active power, closely tracking droop curve • No shedding of generation was required during high frequency event
5	• Frequency returns to normal operating range of 50 ∔ 0.15 Hz and HPR ceases FFR as required

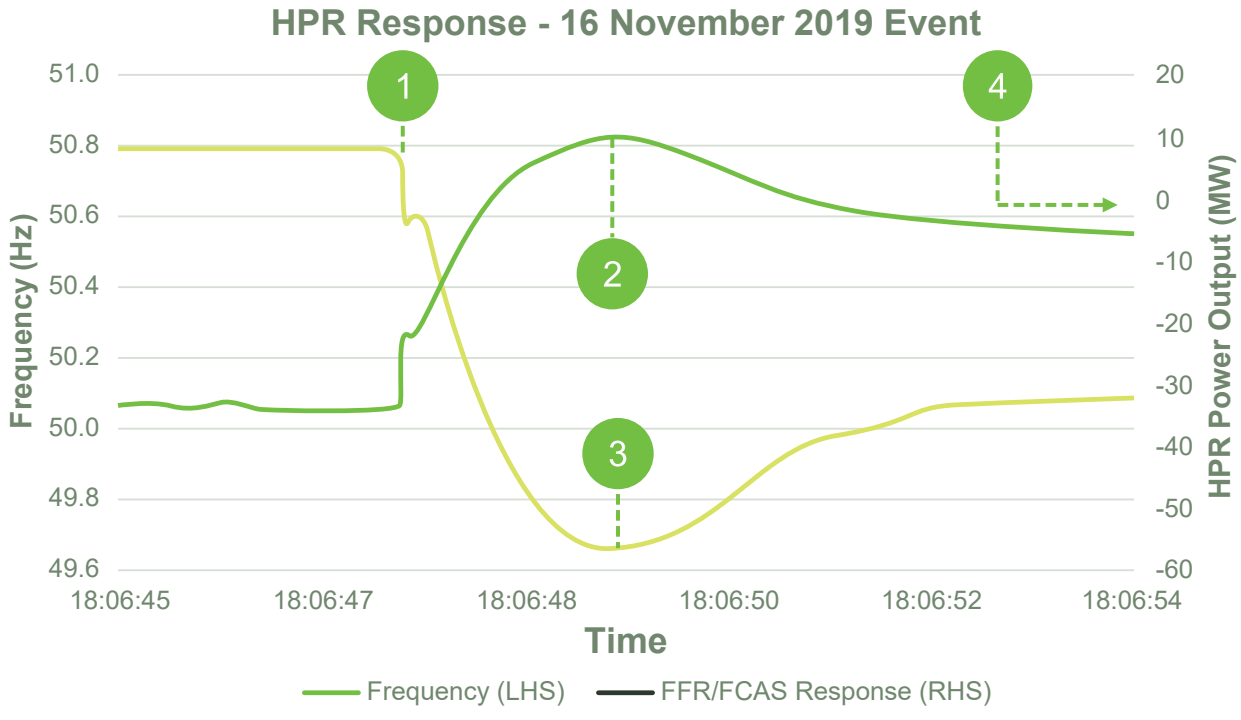


Sources:
1. AEMO Final Report – Queensland and South Australia system separation on 25 August 2018
2. Aurecon analysis of HPR logged data

Appendix B.2 – HPR response to 16 November 2019 separation event

On 16 November 2019 South Australia separated from other mainland NEM regions due to equipment maloperation on the Heywood interconnector, resulting in intial high frequency conditions and a 5-hour separation event. The sequence of events and HPR's response to the initial separation is shown as follows.

	Event/HPR Response Description
1	• Prior to separation event, the flow on the Heywood interconnector was 308MW from South Australia to Victoria. • At 18:06:47, maloperation of a communication multiplexer caused the protection systems on both Heywood inter connector 500kV transmission lines to trip, islanding South Australia
2	• Oversupply of generation in the South Australian islanded system caused a high frequency event. The collective high frequency response of HPR and other SA generators maintained the frequency within the permitted range for a separation event with a peak of 50.85Hz.
3	• HPR responded as required in accordance with its droop curve, with a swing of approximately 64MW, transitioning from 8MW discharge to up to 56MW charge
4	• Frequency returned to the normal operating range of 50 ± 0.15Hz at 18:22, approximately 16 minutes after the initial separation
5	• The frequency was maintained generally within the normal operating range until resynchronisation with Victoria was effected nearly 5 hours after the initial separation at 22:57

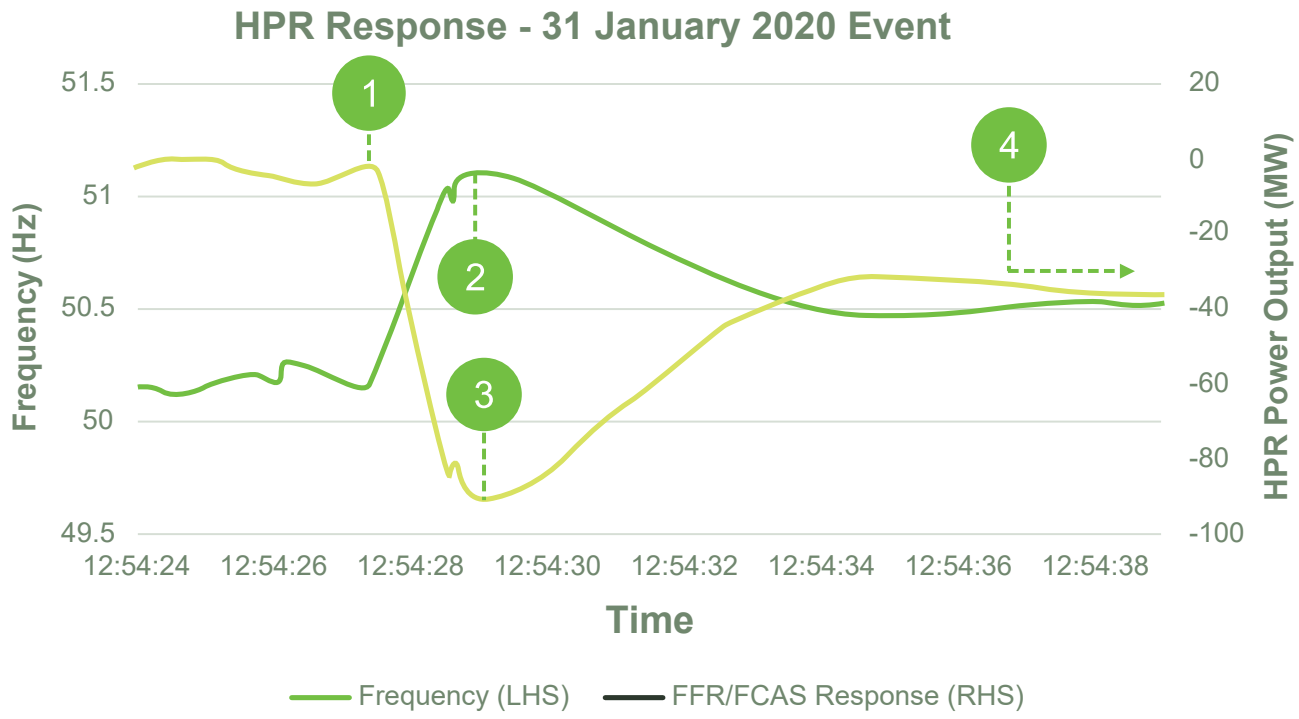


Sources:
1. AEMO Preliminary Report Non-Credible Separation Event South Australia – Victoria on 16 November 2019
2. Aurecon analysis of HPR logged data

Appendix B.3 – HPR response to 31 January 2020 separation event

On 31 January 2020 South Australia separated from other mainland NEM regions due to loss of transmission towers on its 500 kV transmission connection with Victoria, resulting in initial high frequency conditions and a 17-day separation event. The sequence of events and HPR's response to the initial separation is shown as follows.

	Event/HPR Response Description
1	• Prior to separation event, the flow on the Heywood interconnector was 522MW from South Australia to Victoria. • At 12:54:27 the loss of transmission towers on one of the main 500kV lines connecting South Australia with Victoria during extreme storm conditions caused a separation event
2	• Oversupply of generation in the South Australian islanded system caused a high frequency event. Despite the high frequency response of HPR and other SA generators, the frequency rose to 51.2Hz.
3	• HPR responded as required in accordance with its droop curve, with a swing of approximately 91MW, transitioning from standby to up to 91MW charge
4	• The frequency initially stabilised at approximately 50.5 Hz before being brought back to within the normal frequency operating range approximately 36 minutes after the separation occurred • Following stabilisation, AEMO directed HPR out of Energy and Regulation FCAS markets to maximise the availability of fast acting Contingency response within the state.
5	• Following transmission system repairs South Australia was resynchronised to the NEM on 17 February



Source:
Aurecon analysis of HPR logged data