Hornsdale Power Reserve

Year 1 Technical and Market Impact Case Study

aurecon

Bringing ideas to life

Executive summary

The Hornsdale Power Reserve (HPR) has delivered on high expectations of its performance and market impact

Key findings in review of HPR's performance in relation to market and network impact are:

- It is an integral element in protecting the Heywood interconnector from tripping, thereby reducing the risk of separation of South Australia from the National Electricity Market (NEM) and a System Black Event.
- HPR provides a premium Contingency Frequency Control Ancillary Service (FCAS) through its Fast Frequency Response. Modelling of some cases demonstrates its potential to provide significant frequency support to avoid or reduce South Australian load shedding with the speed and accuracy of its response.
- HPR also provides a high quality Regulation FCAS service compared to other traditional generation sources, which would further improve frequency control on the NEM if incentivised to deploy more widely.
- The introduction of the HPR has contributed to removing the need for a 35 MW local FCAS minimum constraint – estimated to have added nearly AUD 40 million in Regulation FCAS costs in both 2016 and 2017.
- There are a range of regulatory changes that could be developed to further enable batteries to be recognised for the services they provide and strengthen the commercial case for new projects.

The energy market transition to increasing penetrations of renewable energy presents growing opportunities for batteries to provide a wide range of services to support a secure network and reliable generation

Contents

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 100 MW and energy storage capacity of 129 MWh. Located near Jamestown, South Australia, it shares the same 275 kV network connection point as the 300 MW Hornsdale windfarm.

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

Case study scope

This case study presents a review of the services provided by HPR in terms of its impact on system security and energy markets. Its provision of key system security services under contract with the SA Government, namely its capability to provide Fast Frequency Response (FFR) to contingency events, and participation in the System Integrity Protection Scheme (SIPS) for preventative protection of the Heywood interconnector. HPR's contribution to system security is reviewed through an appraisal of its technical response capability and control integration, a case study of its response to a large system security event that occurred on 25 August 2018, and modelling of HPR's impact on system security in a credible, but hypothetical contingency event on the network.

HPR has also had a significant market impact, with particular focus on South Australia's Regulation FCAS market. The case study outlines the project's quality of Regulation FCAS service provided and impact on market pricing since inception.

The project is registered and participates in the National Electricity Market (NEM) as a scheduled and ancillary services generator and load. The existing rules and specifications for NEM market participants were not developed in consideration of the capability and services available from battery energy storage systems. Key areas in which regulations may be further developed in this emerging market context are proposed.

Finally, an overview of emerging market challenges and opportunities is presented in terms of how the capabilities of battery energy storage systems may be further deployed in the transition to increasing renewable energy penetration.

Case study overview

System security

The key system security services provided by HPR are participation in the System Integrity Protection Scheme (SIPS), and Fast Frequency Response (FFR) to contingency events. HPR has responded to contingency events as required since inception.

System Integrity Protection Scheme (SIPS)

SIPS is a scheme developed by AEMO and ElectraNet, designed to prevent a loss of the Heywood Interconnector in the event of a loss of multiple generators in South Australia. Such an event can result in a sudden spike in interconnector flow, causing it to trip on protection and induce an abrupt drop in frequency in the separated South Australian network. This has potential to cause a System Black event in South Australia, which is what occurred in the September 2016 event.

The SIPS incorporates three progressive stages, the first of which is a fast response trigger to inject energy from battery energy storage systems, and HPR is a key participant in this stage of the SIPS.

Upon receipt of a signal from ElectraNet, HPR will discharge up to 100 MW output in less than 150 ms. This will potentially prevent activation of the next stage of the scheme, which involves load shedding in South Australia.

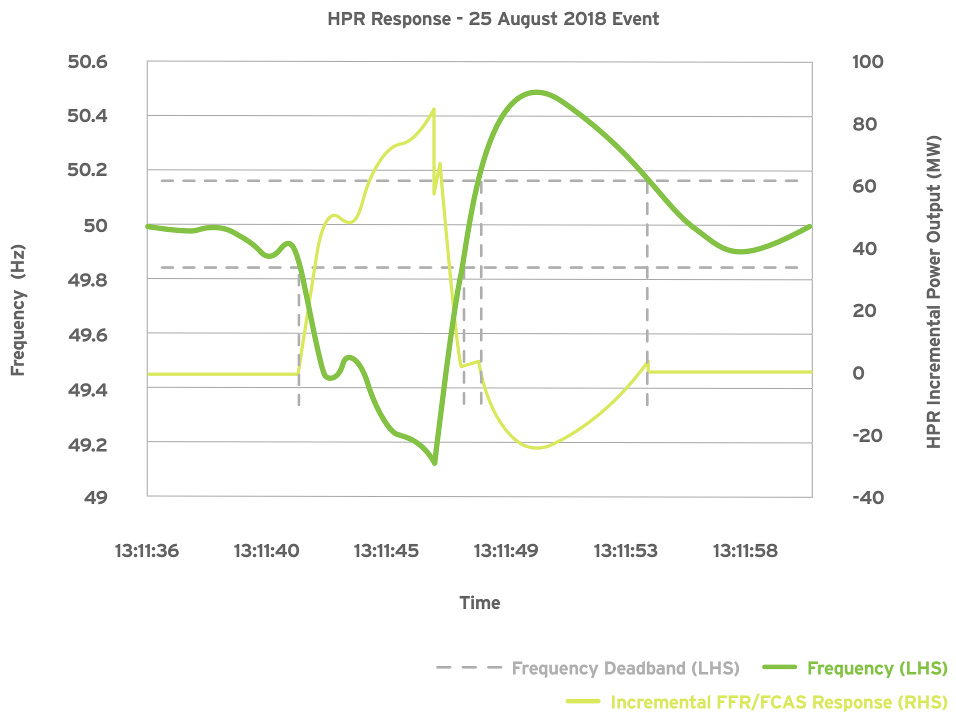
Key outcome

HPR is an integral element of the SIPS, which protects the Heywood interconnector from tripping due to extreme import flows, thereby reducing the risk of separation of SA from the NEM and a system black event. It will also potentially prevent 200 MW of load shedding in SA during such a contingency event.

Fast Frequency Response

Fast Frequency Response (FFR) is the fast dispatch of active power in response to a frequency disturbance outside the normal frequency operating range. The active power dispatch is in accordance with a frequency droop curve, generally proportional to the magnitude of the frequency deviation.

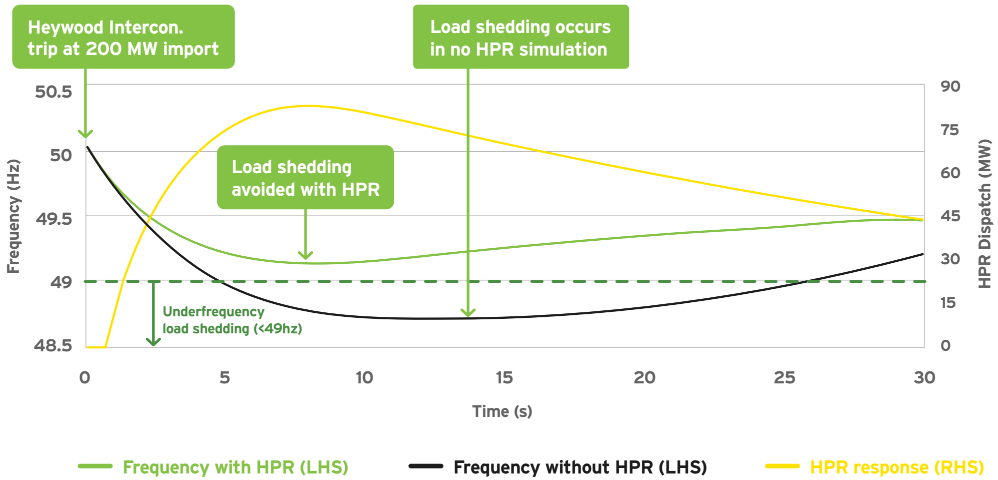
The following chart shows HPR's fast frequency response to a major system security event on 25 August 2018. Its response is as required and closely tracks the changing frequency. It provided significant frequency support to all connected NEM regions during the initial low frequency event, and the SA region during its islanded, high frequency event.



Case study overview

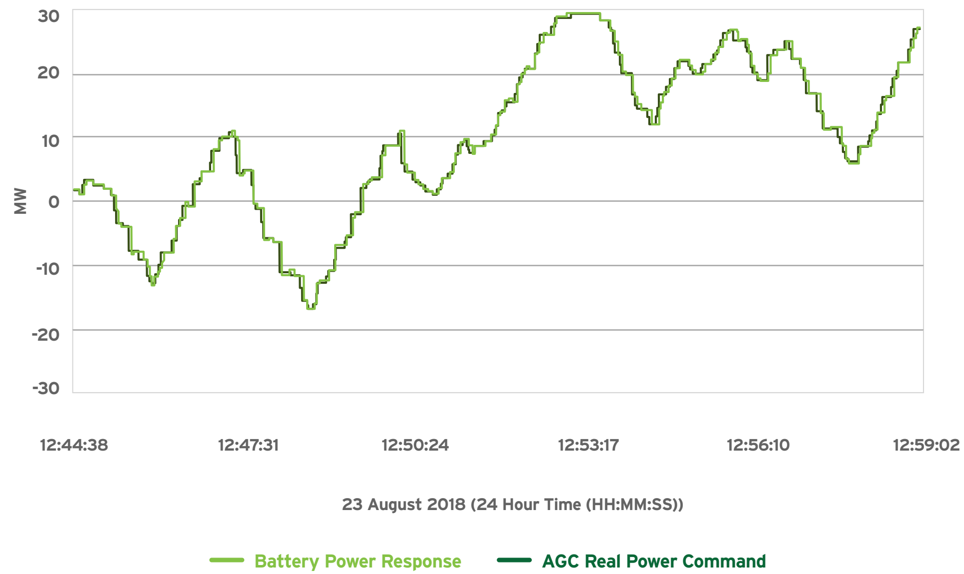
HPR currently provides FFR while participating in all six of the existing Contingency FCAS markets. It provides a premium service in this market through its fast response time of approximately 100 ms, compared to the minimum required 6 second response under existing Contingency FCAS markets. This premium service supports a reduced Rate of Change of Frequency (RoCoF) and total deviation in frequency during contingency events.

In a hypothetical contingency event case modelled for this study, HPR's FFR is shown to assist in maintaining the South Australian network frequency at above 49 Hz, which is the point at which under-frequency load shedding is activated. Without HPR's contribution in the scenario considered, the frequency is modelled to fall to approximately 48.7 Hz, in which case load shedding would be required to arrest the falling frequency.



Regulation FCAS

Operational data shows that HPR provides very rapid and precise response to regulation FCAS signals. This is in contrast to large conventional steam turbines, which can lag the Automatic Governor Control (AGC) signal by up to several minutes. A sample data set of HPR's response to AGC setpoints is shown as follows.



Key outcome

HPR's Fast Frequency Response provides a premium Contingency FCAS service on the NEM with the speed and accuracy of its response. Modelling demonstrates its potential to provide significant support to arrest falling frequency due to contingency events which, in some cases will avoid or reduce the activation of load shedding.

Key outcome

HPR provides a high quality Regulation FCAS service. Increased deployment of such high quality Regulation FCAS would assist in maintaining network frequency within the 50 ± 0.15 Hz normal operating range.

Case study overview

Market impact

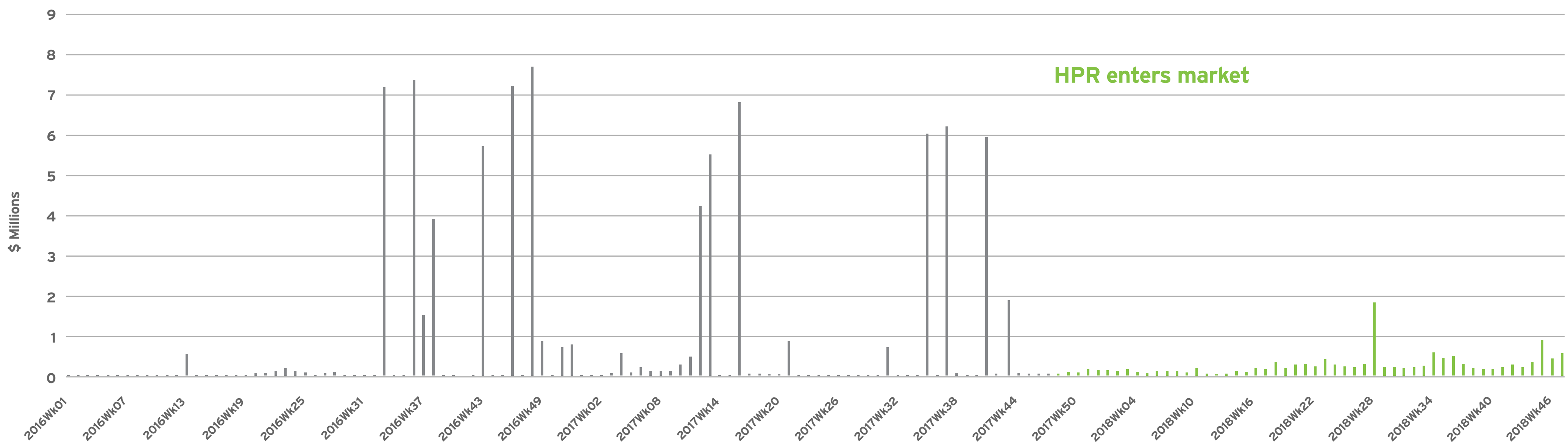
HPR's most significant market impact has been in the Regulation FCAS market. For system security purposes, AEMO has historically required the local procurement of 35 MW of regulation FCAS in South Australia at times when the separation of the region at the Heywood Interconnector is a credible contingency. During these times, South Australian FCAS prices have been very high due to the limited number of suppliers of these services in the region. Aurecon estimates that the additional regulation FCAS cost due to the 35 MW FCAS constraint over each of 2016 and 2017 approached AUD 40 million. HPR commenced operation towards the end of 2017 and during Q1 2018, it captured nearly 10% of the raise FCAS market in the NEM, displacing higher priced (predominantly coal) supply.

During Q4 2017, the constraint bound for 20 hours resulting in approximately AUD 8 million of additional FCAS costs whereas during Q1 2018 it bound for 13 hours without significant cost impact due in part to HPR's contribution to the South Australian FCAS market.

Key outcome

The introduction of HPR has significantly increased competition in the Regulation FCAS market. This has effectively reduced the pricing impact of the South Australian 35 MW FCAS constraint, which is estimated to have added nearly AUD 40 million in regulation FCAS costs in both 2016 and 2017.

South Australian Total Regulation FCAS Payments



Source: AEMO Market Data, 2018

Case study overview

Regulatory Changes

There are a range of regulatory changes that could be developed to further enable batteries to be recognised for the services they provide, strengthen the commercial case for new projects, and enable their deployment to support the energy transition. These include:

- Energy storage registration category to enable registration as a single facility, including for projects that have storage co-located with other renewable assets — to enable streamlined registration and operation of combined assets
- Frequency control framework to value Fast Frequency Response capability and incentive based mechanisms for primary regulation frequency response

Emerging Challenges and Opportunities

Opportunities are emerging for batteries to provide a wide range of services to support a secure network and reliable generation. Emerging opportunities include:

- Increasing share in existing ancillary services markets, and future market mechanisms anticipated to emerge to appropriately value battery services, such as FFR
- Enabling Volume Firming Agreements to complement Power Purchase Agreements
- Non-network solutions to transmission and distribution network constraints — particularly with increasing solar PV and electric vehicle deployment
- Enabling firm / dispatchable generation from variable renewables to manage reliability obligations and characteristic changes to net operational demand

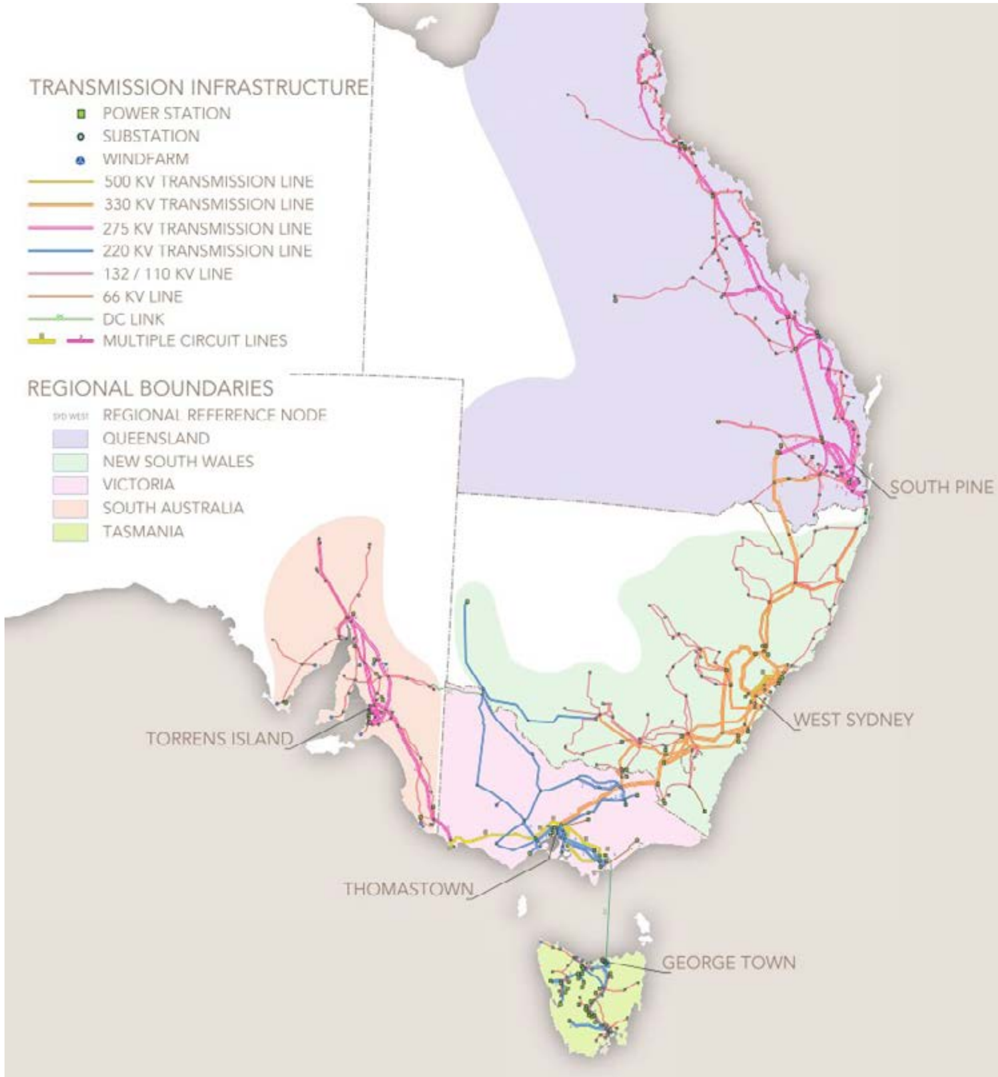
South Australia's network is dependent on limited interconnection to Victoria for system reliability and security

The South Australian region is at the western end of the NEM. It is connected to the Victorian region via two interconnectors: the Heywood interconnector (AC interconnection), and the lower capacity Murraylink (HVDC interconnection).

Interconnection with Victoria allows reduced generation dispatch costs and asset utilisation, particularly from import of lower cost power during peak periods, and exporting of surplus wind generation. In 2016, the Heywood interconnector was upgraded and has a current operational capacity of 600 MW import to SA, and 500 MW export to Victoria. This has enabled increased flows between the regions. Closure of local generation in SA in conjunction with increased interconnection capacity has increased SA's reliance on interconnection for reliability of supply.

The Heywood AC interconnector provides synchronism of SA with the other mainland NEM regions. This supports improved stability from contingency events within SA, but also results in system security challenges that need to be mitigated in the event that the interconnector is lost.

Other network challenges include the high concentration of load in the Adelaide region, and relatively low load in other regional centres, supplied via long transmission lines with limited redundancy in some areas.



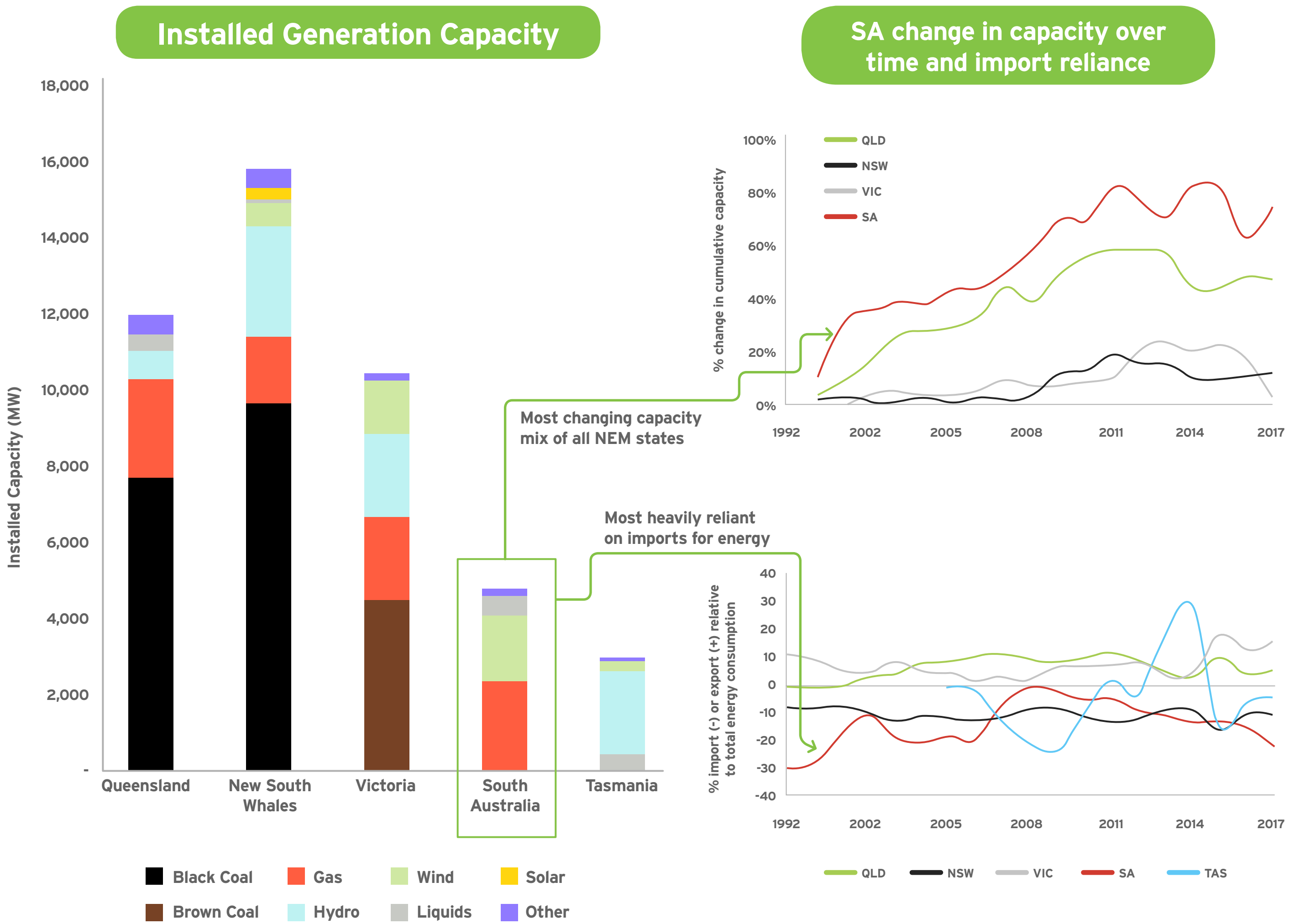
Source: AER's State of the Energy Market, 2009

SA's energy market has been under transition with increasing reliance on variable renewable energy and imports to meet demand

The SA region has one of the world's highest penetrations of renewable energy (RE) generation, with 48.9% in 2016/17 (39.2% large scale wind and 9.2% rooftop solar PV). This is an increase from less than 1% in the early 2000s, and RE deployment is accelerating, with a projected 73% renewable energy generation in 2020/21.

The SA region has a highly variable load profile, with a range of approx. 800 – 3000 MW (average 1500 MW). The total installed generation capacity is approx. 5566 MW, comprised of 2668 MW Gas, 289 MW diesel and small non-scheduled generators, 1698 MW Wind, 781 MW Rooftop Solar, and 130 MW of Batteries.

This transition has enabled increased trade between regions, with high export flows when wind generation is high, and high import flows when wind generation is low. The changing generation mix has also increased reliance on interconnection for import and reliability when RE generation is low, noting that the existing fully dispatchable generation is currently less than the maximum load.



Source: Australian Energy Regulator (AER)

The closures of synchronous thermal generation has increased demand for system security services

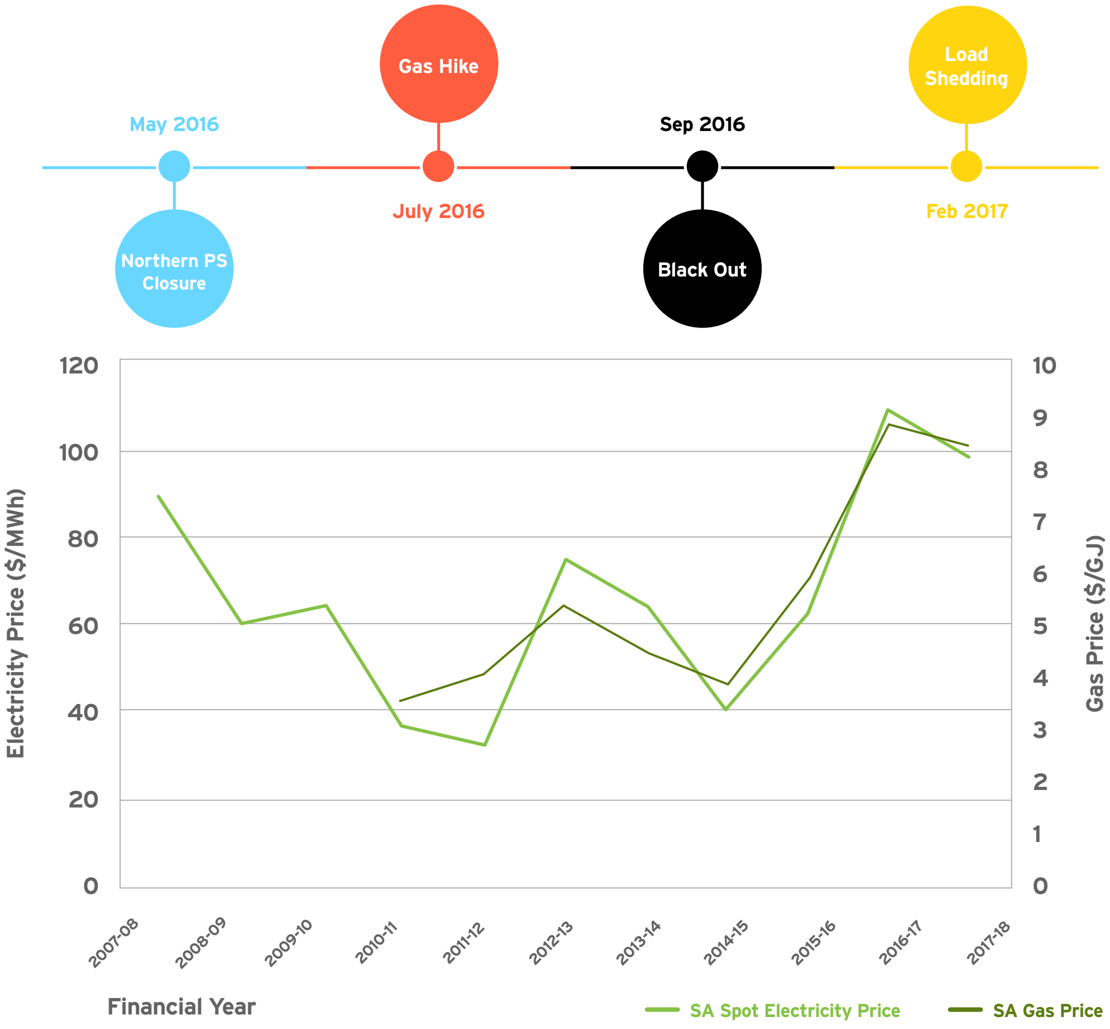
The transition to reducing synchronous generation, and increasing asynchronous wind and solar PV generation has led to system security and market challenges on the SA network. These changes in the generation mix have resulted in declining inertia and system strength on the SA network. To mitigate these issues AEMO has implemented minimum requirements for on-line synchronous generation, which at times leads to constraints being applied to the level of wind generation. This results in a level of curtailment of wind generation, and increased energy spot prices at these times.

The increasing reliance on the Heywood interconnector, while enabling more optimal market energy flows, has also increased reliance on the interconnector for the SA system security. This has introduced challenges, such as the risk of high Rate of Change of Frequency (RoCoF) and System Black upon separation of the SA network from the NEM, as experienced in the September 2016 event.

Several market challenges have also arisen through this transition period. Exiting market participants have reduced competition in the energy and ancillary services markets, which has been seen most acutely through spikes in Regulation FCAS pricing at times when this service has been required by AEMO to be provided locally within the SA region.

Rising wholesales gas prices have also contributed to increasing electricity prices due to the increasing cost of gas generation, and regular price setting by gas generators.

It is in this context that a 100 MW battery project was conceived and developed by the SA Government, and operational objectives defined.



Source: South Australian Historical Market Information Report, AEMO, 2017

HPR project structure and objectives

The HPR project had varying objectives between the SA Government and Neoen

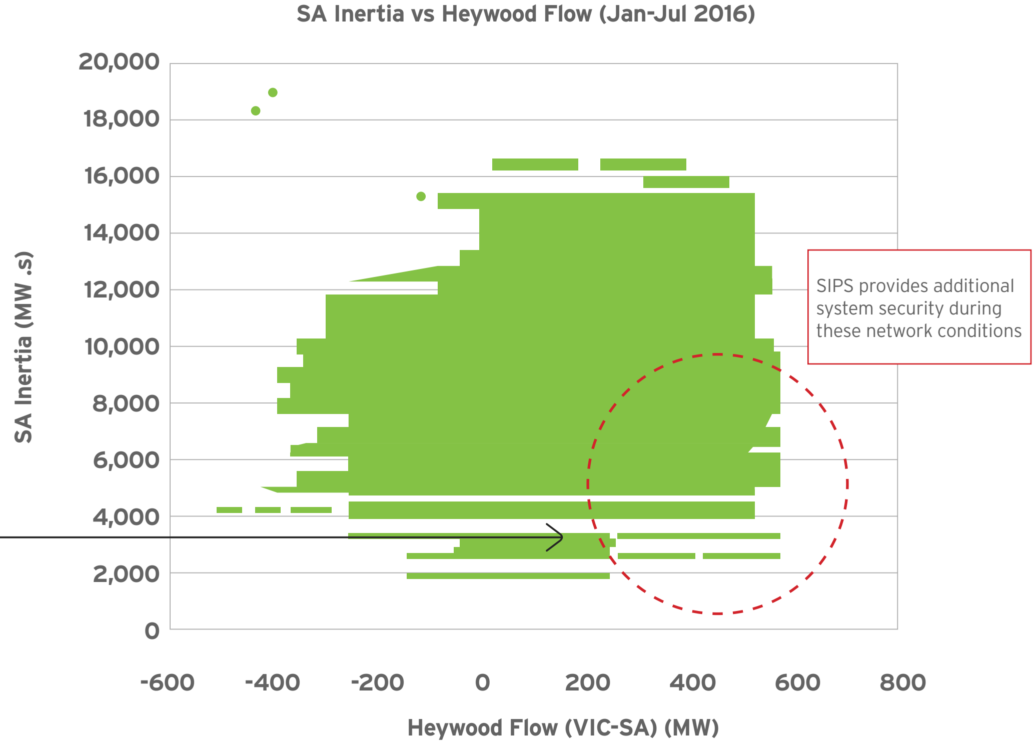
HPR 100MW, 129MWh	Battery Capacity	Project Objectives	Services Provided
SA Government Reserved Capacity	70MW, 10MWh	• Improved System Security for SA network • Downward pressure on ancillary services prices • Improved reliability of supply	• Participation in System Integrity Protection Scheme (SIPS) • Fast Frequency Response • Contingency FCAS • Regulation FCAS • Back-up reliability measure
Neoen Market Capacity	30MW, Balance of energy	• Commercial market participation • Optimised bidding across energy and all eight FCAS markets	• Energy Arbitrage • Regulation FCAS • Contingency FCAS

SA introduced a System Integrity Protection Scheme (SIPS) to mitigate the conditions resulting in System Black events

The SA network can be at risk of a high Rate of Change of Frequency (RoCoF), and statewide black out if three conditions combine:

1. Low inertia, when the share of asynchronous generation + interconnector import flow is relatively high compared to synchronous generation.
2. High import flow across the Heywood interconnector.
3. The 'non-credible' loss of multiple generating units in SA.

If these three conditions combine, there is a risk of extreme flows across the Heywood interconnector, causing it to trip under its protection scheme. An interconnector trip in this scenario will cause a sudden islanding of the SA network and drop in frequency at a very high RoCoF, inducing a high risk of a statewide System Black event.



Source: AEMO (August 2016), The Future Power System Security Program: Frequency Control

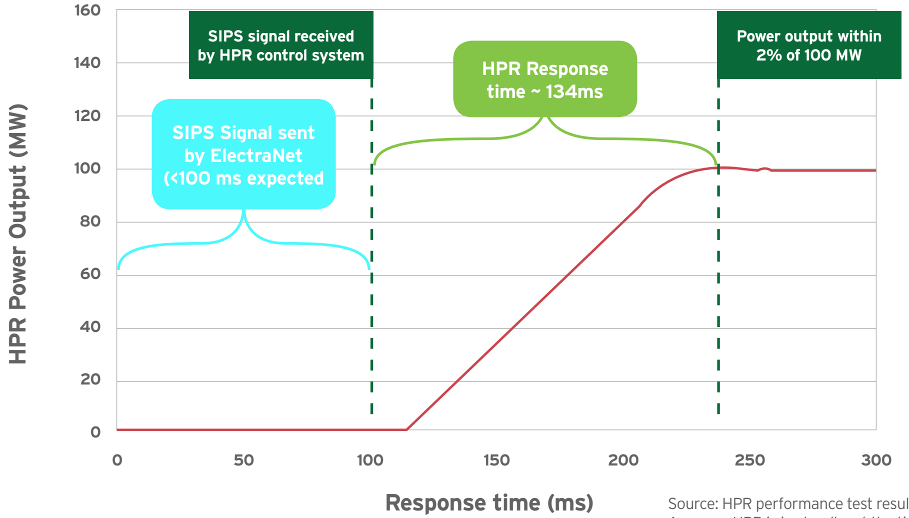
A SIPS was recommended following the 28 September 2016 event, when these conditions combined

The conditions described above are what occurred in the 28 September 2016 System Black event. Multiple generating units in SA tripped due to a series of network faults caused by extreme storm conditions. This resulted in a spike of the interconnector flow and its protection activating to cause it to trip. The frequency of the islanded SA network then dropped at an extremely high RoCoF of > 6 Hz/s. This was too fast for under-frequency load shedding (UFLS) to operate and stabilise the decline. Once the frequency reached 47 Hz the remaining on-line generators also tripped and a state-wide black out ensued.

The SIPS was structured such that the HPR plays a key role in maintaining SA system security and reliability

The SIPS is designed to rapidly identify conditions that could otherwise result in a loss of synchronism between SA and Victoria. It is designed to correct these conditions by rapidly injecting power from batteries, and shedding load (if required) to assist in rebalancing supply and demand in South Australia and prevent a loss of the Heywood Interconnector. The SIPS incorporates three discrete progressive stages, intended to operate in an escalating manner, such that the outcome from the preceding stage may defer or prevent the onset of the next stage. The three stages are:

- Stage 1: Fast response trigger to inject energy from battery energy storage systems
- Stage 2: Load shedding trigger to shed approximately 200 MW of SA load.
- Stage 3: Out-of-step trip scheme (islanding SA)



Source: HPR performance test results
Assumes HPR is in standby at the time for a 100 MW discharge response

HPR participation

HPR is a key participant in Stage 1 of the SIPS. Within approximately 250 ms of a signal being sent by ElectraNet, HPR will discharge to 100 MW output. The actual incremental discharge will depend on its operating state at the time. Its minimum incremental discharge under a SIPS command will be the SA Government's reserved 70 MW capacity, however the incremental response could be up to 140 MW if HPR is charging its full market capacity at the time.

During a SIPS event, HPR will provide a near instantaneous 70 – 140 MW support for the interconnector. This will potentially prevent Stage 2 of the SIPS scheme being required and therefore, 200 MW of load shedding in SA (depending on the interconnector flow at the time and magnitude of the contingency event).

Key outcome

HPR is an integral element of the SIPS, which protects the Heywood interconnector from tripping due to extreme import flows, thereby reducing the risk of separation of SA from the NEM and a System Black event. It will also potentially prevent 200 MW of load shedding in SA during such a contingency event.

HPR provides Fast Frequency Response more rapidly that existing market requirements, which were structured on the response capability of thermal generators

Fast Frequency Response is the fast dispatch of active power in response to a frequency disturbance outside the normal frequency operating range of 50 ± 0.15 Hz. The active power dispatch is in accordance with a frequency droop curve, generally proportional to the magnitude of the frequency deviation.

The NEM Frequency Control Ancillary Services (FCAS) markets have been structured based on the response capability of traditional thermal generators and, as such, the most comparable recognised service under the existing framework is the '6 second' Contingency FCAS service. This requires a generator to dispatch according to its droop curve within 6 seconds of the frequency disturbance.

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 FFR capability is of particular value in arresting a high RoCoF during the initial frequency disturbance.

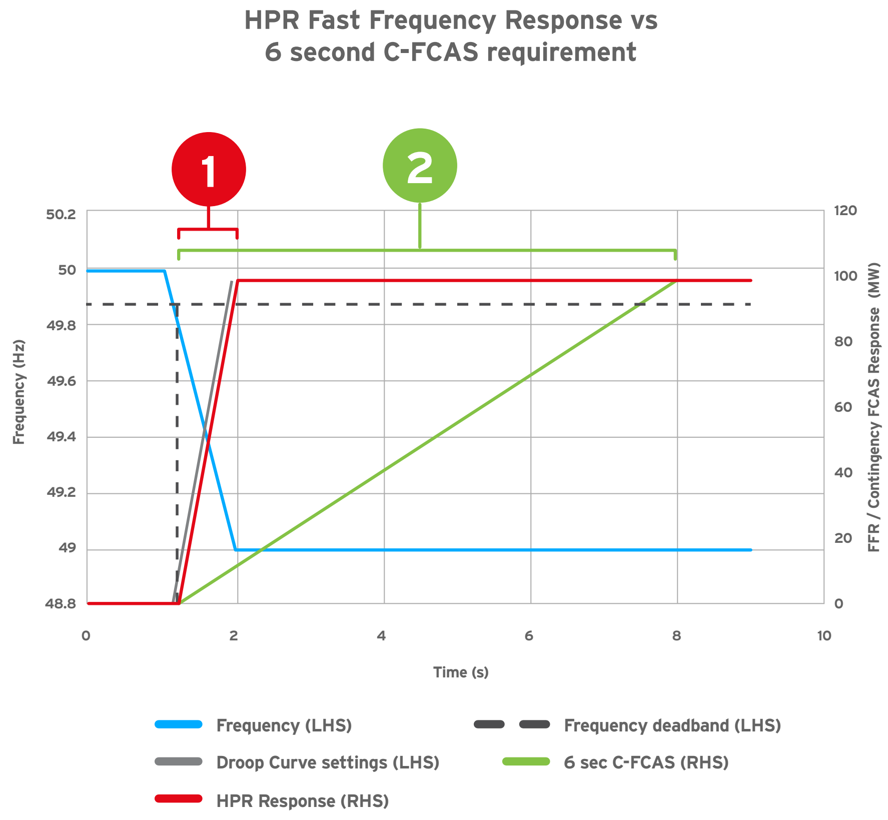
The chart to the right compares the FFR response characteristic of HPR to the minimum requirement for the 6 second Contingency FCAS service, based on a drop in frequency at a RoCoF of 1 Hz per second, down to 49 Hz:

1. HPR closely tracks the droop curve power dispatch requirement, with minimal delay (response based on lab test results of inverter response characteristic)
2. This contrasts with the relatively slow minimum required response characteristic for the existing 'Fast Raise', or 6 second Contingency FCAS service

Note: HPR has droop curve settings of: deadband of 50 ± 0.15 Hz and 1.72% droop. This correlates to a 100 MW discharge at 49 Hz, in advance of the activation of any Under-Frequency Load Shedding (UFLS). These are the droop settings agreed with AEMO. Droop settings for a BESS are however highly configurable to the desired characteristic, and AEMO is undertaking a MASS review looking at improvements in compliance and verification of service provision, and better recognition of the relative performance characteristics of different technologies providing ancillary services.

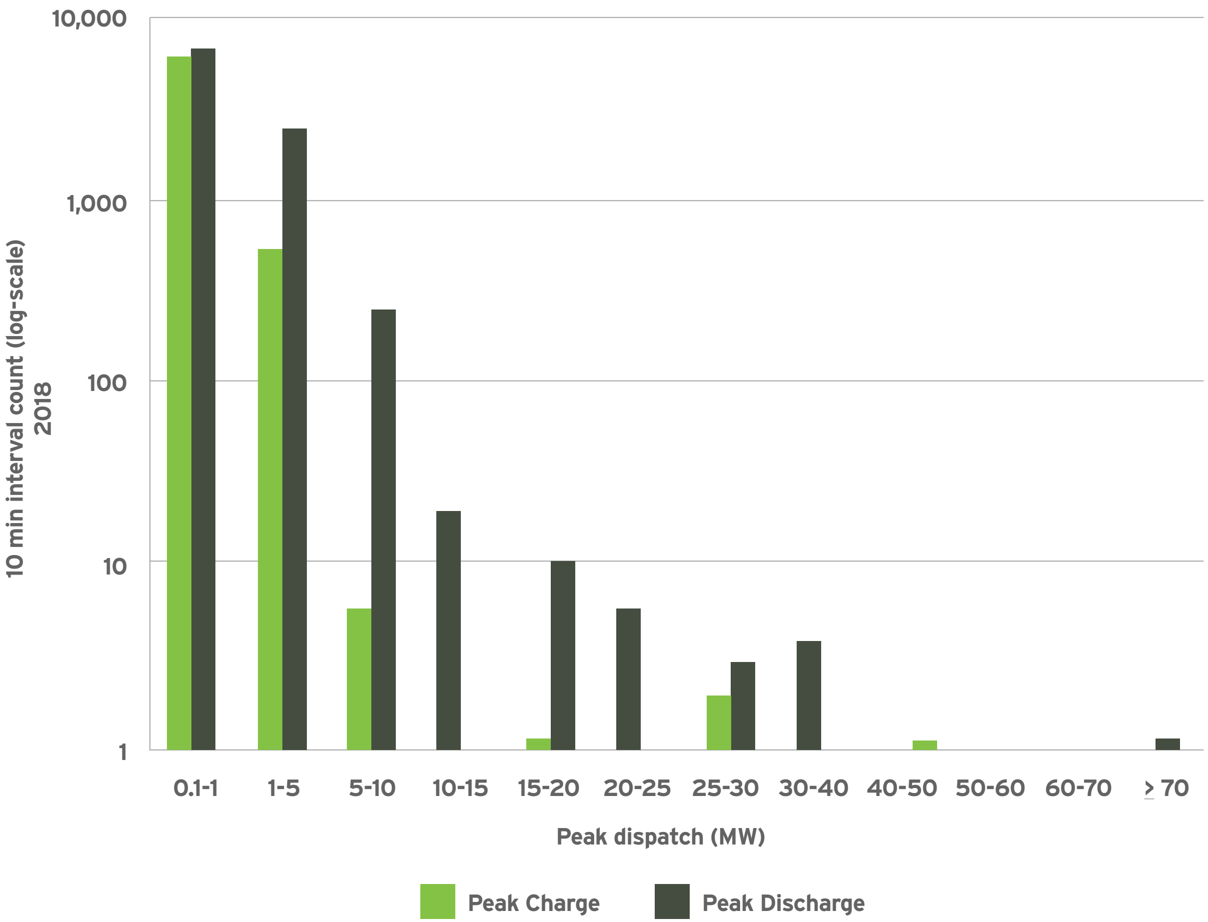
Key outcome

Through its FFR capability HPR provides a premium Contingency FCAS service. This results in reduced RoCoF and total frequency deviations during contingency events.



Source: Aurecon analysis of Tesla lab test results (HPR Response)

HPR Contingency FCAS Operation



Source: Aurecon graph of analysed HPR data provided by Tesla

HPR is regularly dispatching Contingency FCAS services for minor frequency disturbances, and responding occasionally, as required, to large contingency events

Loosening of frequency control on the NEM is increasing the occurrence of the frequency falling outside the normal operating band of 50 ± 0.15 Hz, and the demand for primary frequency control through the Contingency FCAS markets.

HPR provides Contingency FCAS services in all six markets (fast, slow and delayed services for both raise and lower contingency FCAS). It is regularly responding to small frequency disturbances at a low MW range, and occasionally for more significant events.

The demand for Contingency FCAS at the low MW range is related to the effectiveness of Regulation FCAS in maintaining the frequency within the normal range. One factor impacting this is the penetration of variable renewables which, under variable conditions (such as cloud cover over solar PV plants), can lead to reduced frequency stability within the normal range.

HPR's speed and accuracy in Regulation FCAS assists in tightening the overall frequency control on the NEM during normal conditions. When the frequency does fall outside the normal operating range, HPR's fast frequency response, deployed through the Contingency FCAS markets, is well suited to supporting restoration of frequency. It rapidly and accurately follows the frequency and provides its required active power response for both small deviations caused by minor contingency events or in support of the Regulation FCAS service and large deviations caused by more significant contingency events.

The high occurrence of small Contingency FCAS responses indicates the need for greater deployment of fast and accurate Regulation FCAS (as provided by HPR), and potentially increasing demand in the procurement of Regulation FCAS services.

HPR's Fast Frequency Response modelling shows improved system security

Aurecon has undertaken limited modelling of the potential impact of HPR's FFR capability. The scenario modelled and presented reflects a hypothetical but possible contingency event on the network. For comparison, simulations have considered cases of HPR in and out of service, using the following tools and assumptions:

- An Aurecon in-house tool has been used to simulate the dynamic characteristics of the network frequency, and the response of HPR and other providers of Contingency FCAS in the modelled scenario.
- HPR response is based on lab tested characteristics and the implemented frequency droop curve. HPR modelled response is up to 100 MW, a response time of 100 ms (lab response time to 2% accuracy), deadband 50 ± 0.15 Hz and 1.72% droop.
- Typical turbine and generator characteristics are used for the assessment of on-line synchronous generators. Dynamic behaviour of turbines is assumed based on their type. Frequency regulation deadband of 50 ± 0.15 Hz is assumed for the thermal generators.
- Inverter based generation (solar and wind) is assumed to not contribute to frequency regulation.
- Modelled contingency event is loss of the Heywood interconnector under the network conditions summarised in the following table.

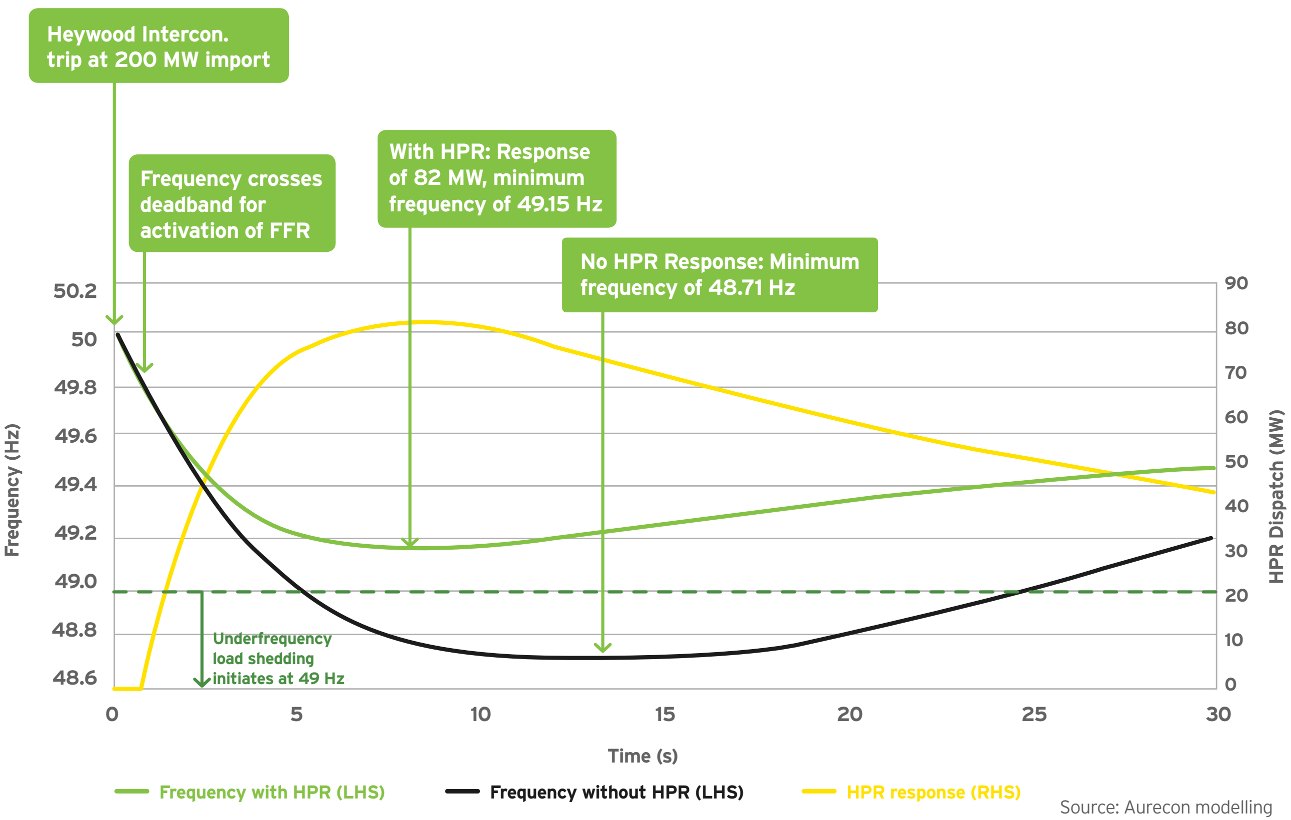
The network load and generation scenario is summarised as follows:

Parameter	Value
SA Network Load	800 MW
Heywood Interconnector Import Flow	200 MW
SA asynchronous generation	200 MW
SA synchronous generation: • Pelican Point CCGT • Torrens Island B CCGT	Total: 400 MW • Generates 220 MW for a 480 MW capacity (one GT on, HRC on) • Generates 180 MW for a 800 MW capacity (two steam turbines on)
Modelled Contigency Event	Trip of Heywood interconnector

HPR's FFR can prevent SA load shedding

Notes on modelling results

- The case of 'With HPR' shows it responding to the frequency disturbance and discharging up to 82 MW. In this case, the frequency nadir reaches a minimum of 49.15 Hz, with under-frequency load shedding (UFLS) avoided.
- In the case of 'No HPR', the frequency is modelled to fall to 48.71 Hz. UFLS would however operate at 49 Hz, which would act to arrest the declining frequency. The impact of UFLS is not included in the modelled results.
- It should be noted that the minimum frequency experienced during particular contingency events is a function of numerous variables, and HPR's FFR contribution would not prevent load shedding in all scenarios.
- HPR's droop curve is set to 100 MW at 49 Hz, which ensures its 100 MW capacity acts in advance of load shedding. Higher droop settings, for example to provide 100 MW at 49.5 Hz would further minimise the decline in frequency, and also enable > 100 MW to be deployed in advance of UFLS if HPR was charging at the time of an event. Tightening of the frequency deadband (currently set at ± 0.15 Hz) could also enable HPR to provide a faster responding Primary Frequency Control Service.
- Implementing RoCoF into the control functionality to more closely simulate an inertial response is another area for further development in BESS frequency response.



Source: Aurecon modelling

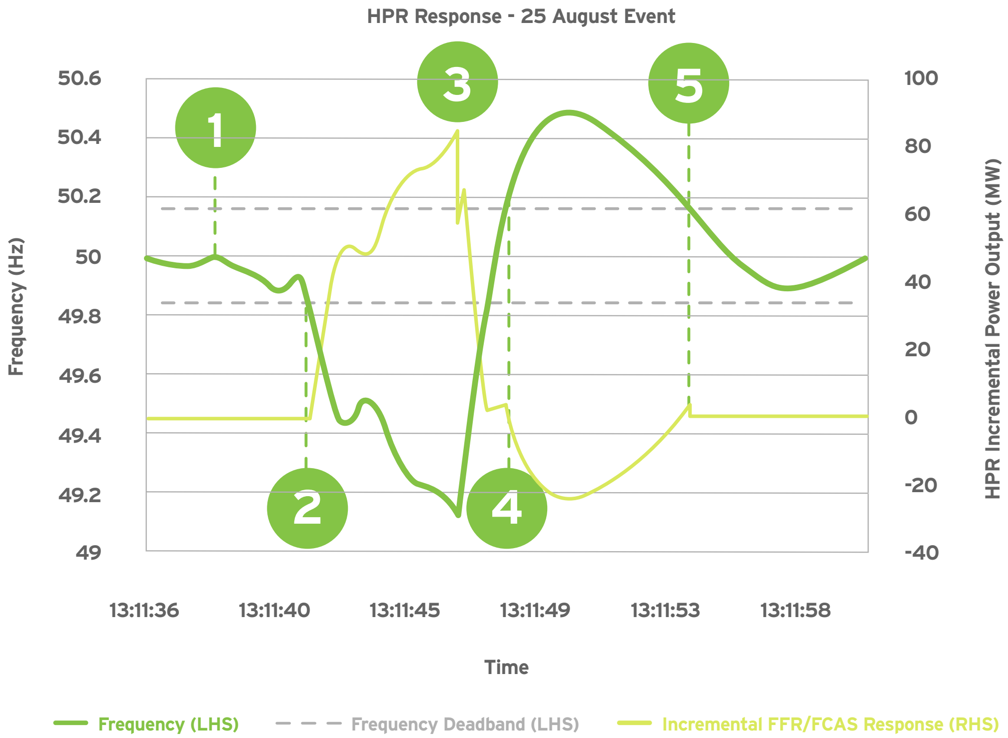
Key outcome

HPR's Fast Frequency Response has the potential to avoid or reduce load shedding due to contingency events on the network. This is of particular benefit to South Australia in the event of loss of the Heywood interconnector and synchronism with other mainland NEM regions.

25 August 2018 case study

On 25 August 2018 the NEM experienced a major system security event. The table and chart show the sequence of events and HPR's response.

	Event / HPR response description
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 Hz • 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

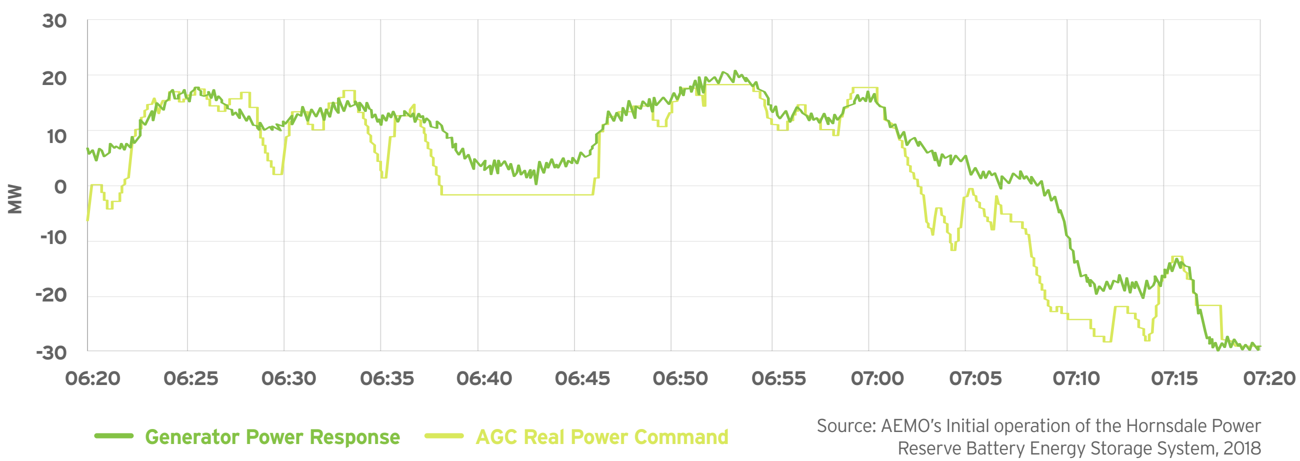


Source: Aurecon analysis of HPR high resolution logged data

Key Outcome

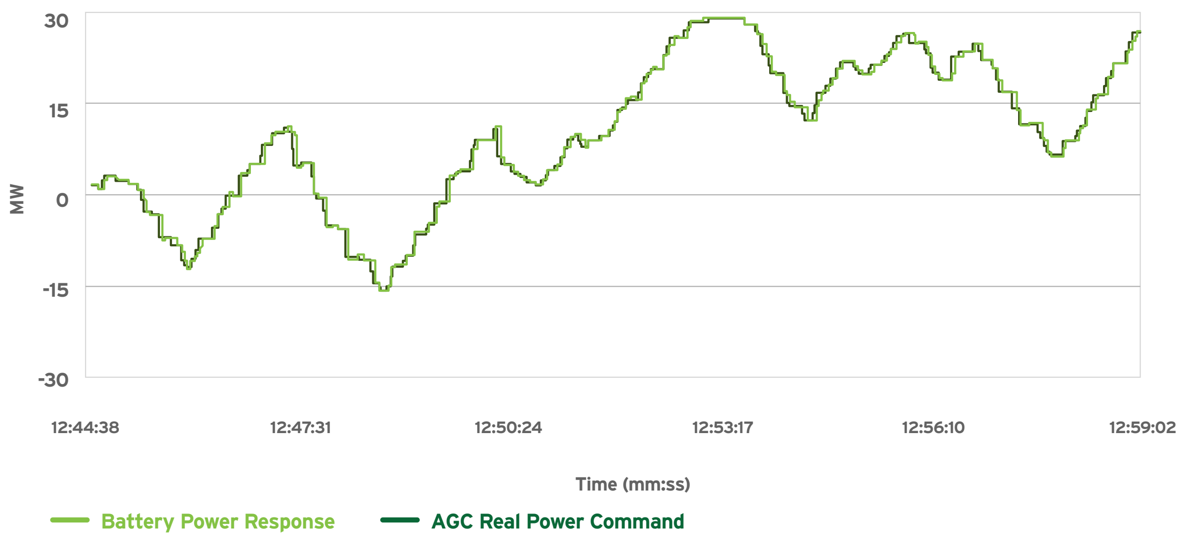
HPR operated as required throughout the contingency event, accurately dispatching according to its droop curve. It provided significant frequency support to all connected NEM regions during the initial low frequency event, and the SA region during its islanded, high frequency event.

Accuracy and speed of regulation FCAS response - large conventional steam turbine



Source: AEMO's Initial operation of the Hornsdale Power Reserve Battery Energy Storage System, 2018

Accuracy and speed of regulation FCAS response - HPR



Source: Aurecon analysis of HPR logged data

HPR provides regulation FCAS at a high speed and accuracy

Operational data shows that HPR provides very rapid and precise response to AEMO AGC regulation FCAS signals. This is in contrast to the response of large conventional steam turbines that typically provide the majority of this service on the NEM, which can lag the AGC setpoint by up to several minutes.

Increased deployment of such high quality Regulation FCAS as provided by HPR would assist in maintaining frequency within the 50 ± 0.15 Hz normal operating range. However the increased quality of the service provided by the HPR is neither incentivised nor rewarded under the existing FCAS framework.

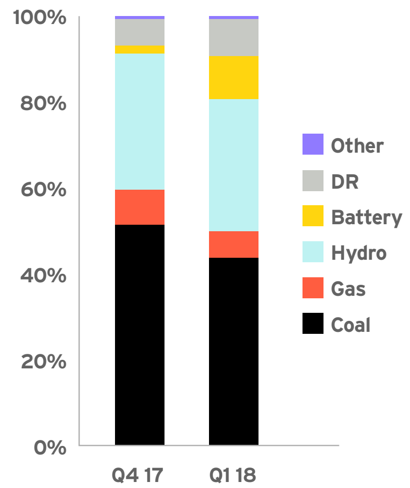
Primary frequency control is another service and market mechanism that could be considered to appropriately value the speed and accuracy of battery response capabilities to maintain frequency within the normal operating range. This would involve batteries such as HPR operating with a tightened frequency droop deadband, and deploying their FFR capability to support frequency control within the 50 ± 0.15 Hz normal operating range. This could potentially be an alternative or complementary service to Regulation FCAS via AEMO AGC control.

Market impact

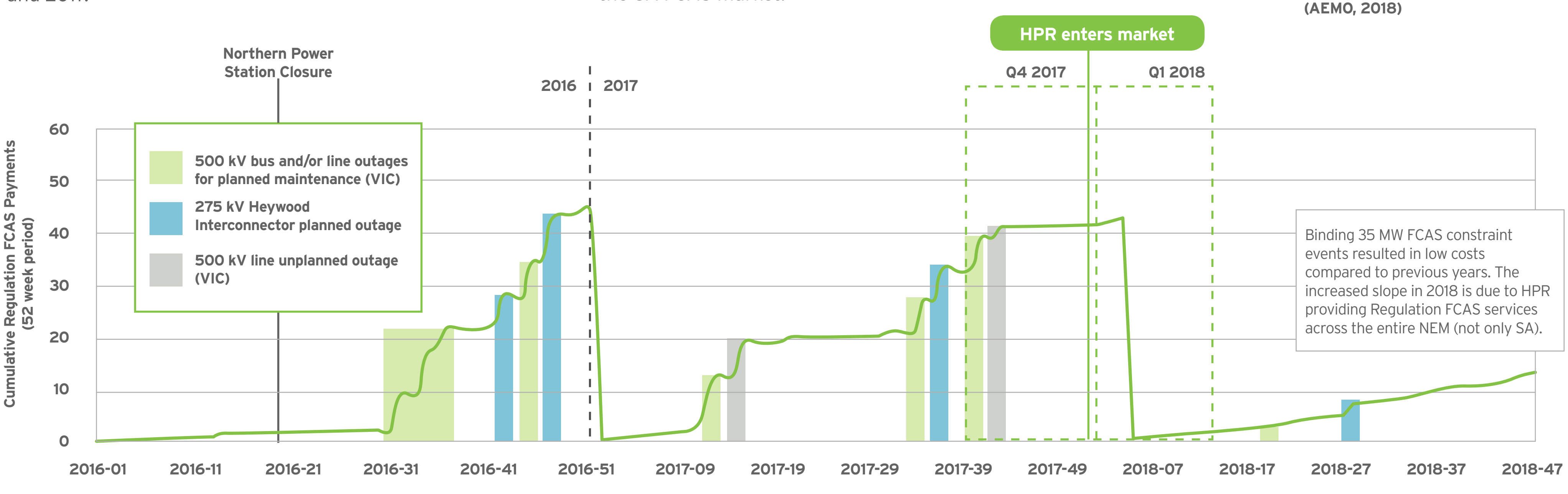
HPR has had a significant impact on the South Australian Regulation FCAS market

For system security purposes, AEMO has historically required the local procurement of 35 MW of regulation FCAS in SA at times when the separation of the region at the Heywood Interconnector is a credible contingency to ensure the system can operate in a stable and secure manner. During these times, SA FCAS prices have been very high due to the limited number of suppliers of these services in the region. Aurecon estimates that the 35 MW FCAS constraint added nearly AUD 40 million in regulation FCAS costs in both 2016 and 2017.

HPR commenced operation towards the end of 2017 and during Q1 2018 it captured nearly 10% of the raise FCAS market in the NEM, displacing higher priced (predominantly coal) supply. The introduction of HPR has also effectively reduced the pricing impact of the SA 35 MW FCAS constraint. During Q4 2017, the constraint bound for 20 hours resulting in approximately AUD 8 million of additional FCAS costs, whereas during Q1 2018 it bound for 13 hours without significant cost impact due in part to HPR's contribution to the SA FCAS market.



FCAS services by technology (AEMO, 2018)



Source: AEMO 'AS Payment Recovery summary' data

Key outcome

The introduction of HPR has significantly increased competition in the Regulation FCAS market. This has effectively reduced the pricing impact of the SA 35 MW FCAS constraint, which is estimated to have added nearly AUD 40 million in regulation FCAS costs in both 2016 and 2017.

Improved performance and enhanced capabilities of HPR enable the grid to be managed differently, resulting in significant savings for generators and customers

Prior to HPR, events leading to a local requirement for FCAS in SA would cost up to AUD 6.5 million a day:

- Historically, a binding 35 MW SA FCAS constraint has resulted in regulation FCAS prices exceeding AUD 9,000/MWh due to limited supply/competition for this service, for example 14 September 2017.
- However, the additional supply from HPR on 14 January 2018 effectively capped average prices at AUD 248/MWh - which AEMO estimates to have saved AUD 3.5 million during the five hour period in which the constraint bound

In early October 2018, AEMO advised that it will no longer require 35 MW of local frequency and ancillary services to be provided in SA when there is a credible risk of separation from the NEM. Going forward, AEMO is satisfied that this requirement is no longer necessary following the installation of HPR along with their new system strength rules which define minimum synchronous generation requirements. These changes ensure there is sufficient regulation FCAS available post-islanding of South Australia such that the system can operate safely and securely by itself.

Key outcome

HPR has effectively reduced the pricing impact of the South Australian 35 MW FCAS constraint. The availability of HPR's FCAS services has also contributed to the lifting of this constraint, minimising the risk of future price spikes for these services.

Supply curves for raise regulation FCAS in SA during binding of 35 MW local regulation constraint

Source: AEMO Insights, Q1 2018

Other market and reliability benefits

Energy peak price competition

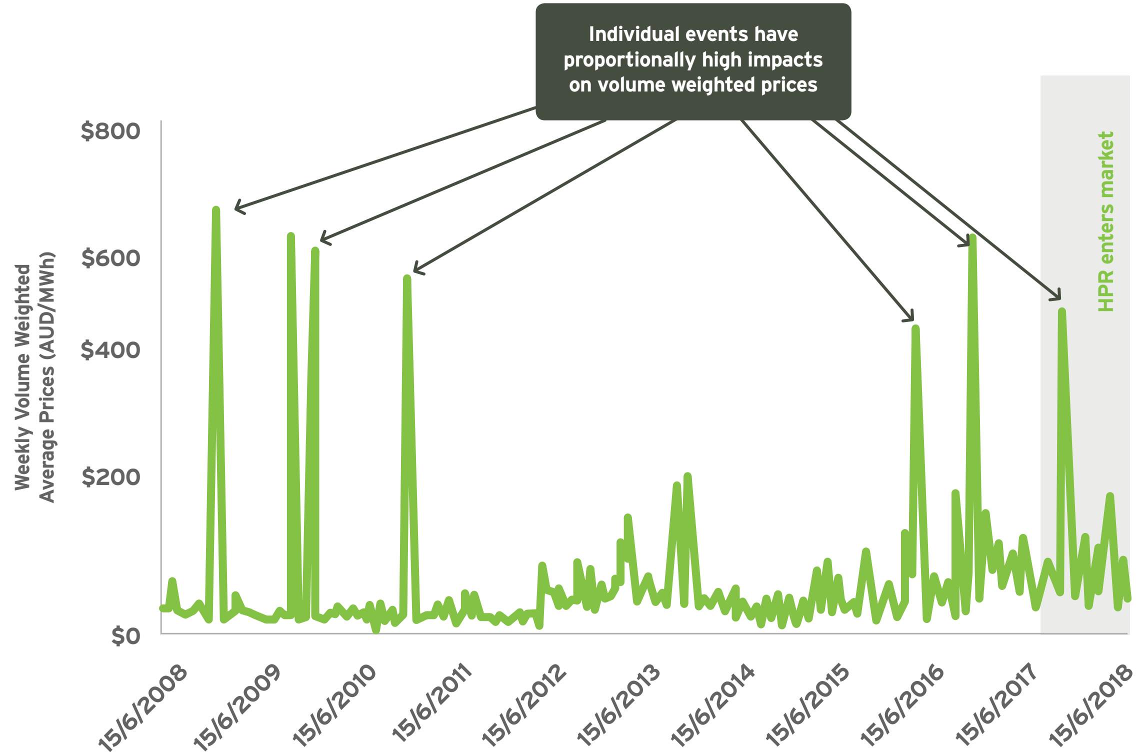
HPR's 30 MW market capacity utilises a bidding algorithm to support optimal commercial bidding and dispatch across the energy and FCAS markets.

While it more frequently provides Regulation FCAS services, it is available and incentivised to bid into the wholesale energy market during high price events. The longer energy storage duration of HPR's market capacity provides flexibility to capture high market price events, and reduces the likelihood of missing peak pricing events in the absence of future price foresight. This is an advantage over short duration batteries that may be discharged in advance of the highest value periods.

Individual pricing events can have a proportionally high impact on wholesale energy prices. Wholesale prices may reach the price cap, which is in excess of AUD 14,000/MWh or the value of loss load. During these events, the spot price is highly sensitive to the level of supply available, and market competition. HPR's provision of an additional 30 MW of supply, bid into the market during such periods provides some additional competition, and a degree of downward pressure on energy prices.

HPR's full capacity can also be deployed as a backup reliability measure under direction of AEMO if required.

Additional dispatchable and flexible generation would provide further reliability of supply and competition during peak demand and energy price periods.



South Australian price volatility in weekly volume weighted average prices

Source: AER's Weekly volume weighted average spot prices, 2018

Regulatory changes

The existing regulatory framework was not designed for energy storage systems.
New frameworks are emerging and need to be developed to streamline their deployment and benefits.

Following the registration and connection of HPR, AEMO has reported an unprecedented growth in registration and connection applications relating to energy storage systems (ESS), and notes that existing systems and processes were not designed for ESS, or the types of new grid-scale business models that are being proposed now, or may be proposed in the future.

Energy storage will be deployed for a range of wholesale energy and ancillary services, hybrid generation and storage projects, and customer integrated solutions. AEMO have been undertaking review and stakeholder consultation on potential changes to the regulatory framework for ESS.

An ESS ($\geq$ 5 MW) is currently required to register as both a scheduled load and market customer. A new registration category could enable a standalone ESS or hybrid ESS + generator to have a single registration, single performance standard applicable to the 'hybrid system', provide a single set of market bids and receive a single dispatch instruction for each service.

While stakeholder engagement is ongoing, AEMO is exploring how a new Bi-directional Resource Provider category can facilitate the integration of batteries. To ensure operational and commercial viability, design details will need to consider classification, dispatch price bands, and any additional compliance requirements.

As mentioned, batteries can react to frequency changes more rapidly than the current Fast Contingency FCAS requirements. Rapid, sustained and accurate delivery of power can be particularly valuable, such as following a large disturbance or when the power system is operating with low inertia that can occur during a separation event.

Fast Frequency Response (FFR) markets have been established in some overseas markets and are typically only fulfilled by batteries. These services will need to be more incentivised in future with increasing penetrations of asynchronous generation.

In view of the increasing challenges to maintaining frequency, and recognising that not all frequency service provision is equal, AEMC's Frequency Control Frameworks Review made several recommendations to ensure effective frequency control could be maintained in the NEM in future.

AEMC found that participants should be incentivised to provide primary frequency control in the normal operating frequency band, and supports AEMO trialing the technical changes to enable this.

In the longer term, AEMC notes that the procurement of frequency services should be incentive-based and also recommends exploring mechanisms for the procurement of a primary regulating response. This could include dynamic payment mechanisms that would recognise and appropriately value fast frequency response from ESS, such as deviation price mechanisms.

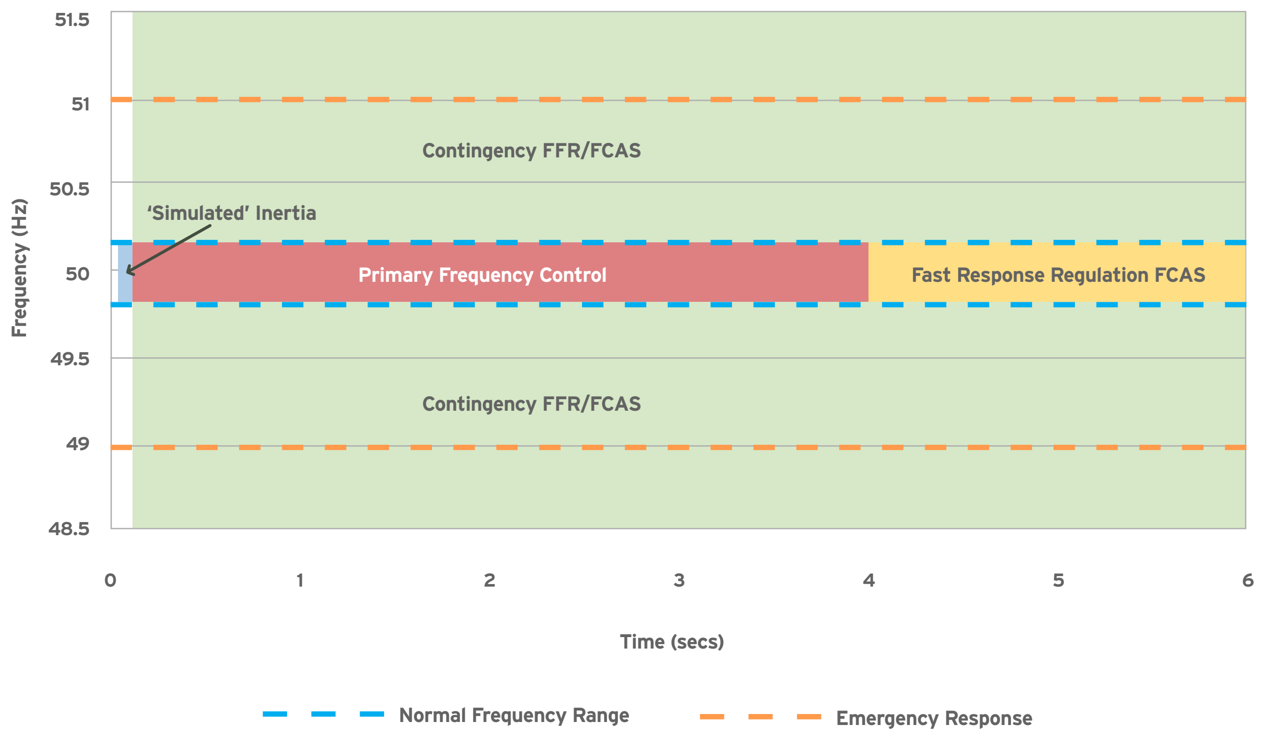
Batteries can provide a range of frequency control services, however not all are currently recognised in the market

The following chart shows the range of frequency control services that can potentially be provided by batteries. HPR currently provides Contingency FFR / FCAS, and Fast Response Regulation FCAS. These are the services it can provide to meet project objectives within the context of the existing FCAS markets, albeit without reward for the speed and accuracy of the services provided.

As previously discussed, HPR's frequency droop curve deadband could potentially be tightened to provide a Primary Frequency Control service. This could be an alternative and / or complementary service to Regulation FCAS, which is controlled through AEMO's centralised AGC dispatch.

With future increases in asynchronous generation and declining real inertia, there is potential for batteries to also provide a 'Simulated' Inertia service. Closely related to FFR, this involves operation without a deadband and potentially with even faster response times. Incorporating RoCoF into the control functionality to more closely simulate an inertial response is another area for further development.

Range of Potential Frequency Control Services



AEMO, Fast Frequency Response in the NEM, 2017

Emerging challenges and opportunities

Battery providers will be able to supply Volume Firming Agreements to complement Power Purchase Agreements

Volume Firming Agreements (VFA) are risk hedging mechanisms to complement a Power Purchase Agreement (PPA). The early adopters and namers of this product are Microsoft and REsurety in partnership with Nephila Climate and Allianz in the United States.

Batteries enable firming of intermittent renewables, which refers to the improved ability to control dispatchability. Such capability reduces the risks of weather inclemency, operational issues, low output during high price periods and the general mismatch of the power output with the load being offset. The demand for VFAs is anticipated to increase, particularly with the higher penetrations of solar PV because output will be at times of lower wholesale market prices. VFAs may support deployment of batteries of 2+ hours storage duration.

Hybrid Battery plus Renewable Generator configurations will be supported by the proposed Bi-directional Resource Provider Registered Participant Category.

Batteries are anticipated to have increasing opportunities to provide non-network solutions, particularly with the adoption of solar and electric vehicles

The rapid uptake of solar and electric vehicles is also anticipated to lead to increased constraints within transmission and distribution networks. Batteries and other energy storage technologies are capable of providing a non-network solution to defer and avoid capital expenditure in network assets, potentially in a short timeframe compared to high voltage network assets.

The mechanism for this is the existing Regulatory Investment Tests (RIT) for distribution and transmission. As part of AEMC's COGATI review and the wider Energy Security Board mandate, options are currently being explored on how to enhance the status quo RIT-T process to ensure that strategic transmission level investments can be accelerated in a way that aligns with AEMO's Integrated System Plan, while maintaining customer protections.

In a related issue, customers and generators are becoming increasingly exposed to the full costs of connecting to the transmission network through negotiated connections. Batteries can provide behind the meter solutions that could reduce the size of connection assets.

Batteries with fast fault current injection and high overload capacities can also contribute to system strength.

Battery economics are anticipated to improve with changes to net operational demand, 5 minute settlement periods and valuing dispatchable technologies

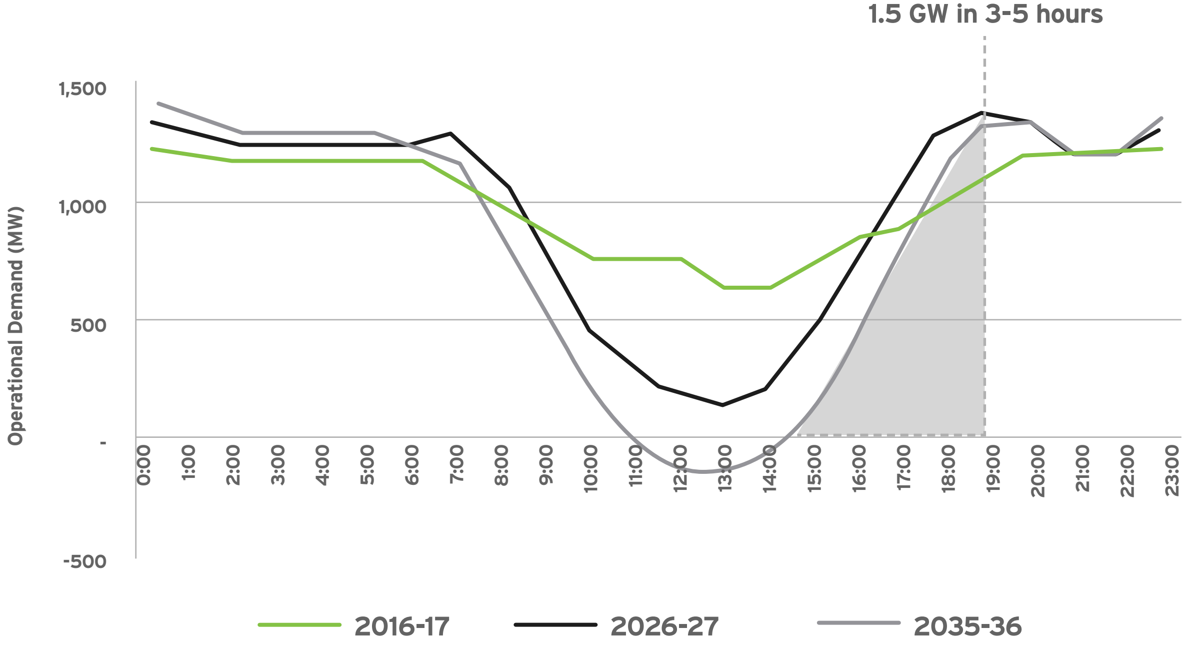
Increasing deployment of solar PV will significantly impact load across the network (i.e. net operational demand) by hollowing out the day, and resulting in a steep ramp up to peak demand in the afternoon.

Battery storage can mitigate the impact of the characteristic 'duck curve' by charging during the day and dispatching to meet the rising afternoon peak. Spot prices during this ramping period are anticipated to increase as the rapid ramp rate increases and places stress upon the response capabilities of other dispatchable generation. Utility scale batteries are expected to be well placed to deploy their flexible capability to capitalise on such opportunities.

Batteries will also benefit from the introduction of five minute settlements from 2021 due to their rapid response times. They will have an advantage over other slower dispatchable sources such as peaking plants, with remuneration no longer based on the average price over a 30 minute trading interval.

Traditional thermal generators are being retired with the increasing penetrations of renewables. This is the result of the National Electricity Market being an energy-only market, and the comparatively low running costs of wind and solar. Policy developments are trending towards valuing dispatchable capacity for example Generator Reliability Obligations and the Reliability Guarantee, which should also benefit battery storage providers.

Minimum daytime operational demand, forecast



Source: AER, 2017

Increasing solar creates a significant need for a 'ramp' period in the afternoon where hundreds of MWs need to come online. Local firming/dispatchable capacity to meet this ramp will be required. Batteries are well placed to contribute to such required flexible generation.

HPR lessons learnt for battery storage capabilities in the National Electricity Market

Assessed against both SA Government and Neoen project objectives, HPR has delivered on the high expectations of its performance and market impact. It is providing key system security services for the South Australian network, has made a significant impact on ancillary services prices, and the Facility's market capacity is being bid and dispatched commercially across all available markets.

The National Electricity Market's generation mix is in transition to increasing penetrations of renewable energy. Opportunities are presenting and growing for batteries to provide a wide range of services to support a secure network and reliable generation.

There are a range of regulatory changes that could be developed to further enable batteries to be recognised for the services they provide, strengthen the commercial case for new projects, and enable their deployment to support the energy transition.