AEMC – Frequency Control Directions Paper

Tesla Response

LAST EDITED
February 2021

Sebastien Henry
Australian Energy Market Commission
Sydney NSW 1235

4 February 2021

RE: AEMC – Frequency Control Directions Paper

Dear Sebastien

Tesla Motors Australia, Pty Ltd (Tesla) welcomes the opportunity to provide a response to the AEMC's Frequency Control directions paper consolidating the two rule change proposals relating to effective power system frequency control for the National Electricity Market (NEM) – specifically on Fast Frequency Response (ERC0296) and Primary Frequency Response (ERC0263).

Tesla's mission is to accelerate the transition to sustainable energy. Within this objective, Tesla is committed to working with market bodies to improve power system security and reliability outcomes in the National Energy Market (NEM) in a manner that is efficient for consumers, timely for ongoing secure system operations, and sustainable over the long-term.

We recognise the real and immediate need for action to improve the current system frequency control frameworks in the NEM and agree with the AEMC and AEMO position that system frequency has been deteriorating over recent years. At the same time, battery storage has proven particularly valuable in managing frequency stability and restoration - providing premium contingency and regulation frequency services since the introduction of Hornsdale Power Reserve in 2017, and as recently demonstrated in South Australia's islanded power system - where grid-scale batteries were controlled by AEMO to support grid stability following extensive storms, bushfires and unexpected outages. Tesla recommends immediate steps to reward this premium regulation response, ahead of the ongoing frequency reforms. As a next step, FFR should be progressed as a matter of urgency, with line of sight to late 2021/22 implementation. Going forward, storage at all scales – transmission, distribution and behind the meter – and in all forms – stand-alone, co-located, and aggregated – will be an increasingly critical component of Australia's energy mix, providing all essential services. As such, it is critical that any frequency reforms do not directly, or inadvertently disincentivise the uptake of future storage projects, or proceed along exceedingly drawn-out implementation timeframes.

Tesla looks forward to working with the AEMC in addressing the priority objective to improve the efficiency and effectiveness of power system security and reliability in the NEM, and believes for both FFR and PFR there are practical pathways towards a long-term approach that still ensures both the National Electricity and System Services Objectives remain central to the reform agenda. Ultimately, investment and innovation in the energy sector will flourish when market design principles focus on achieving outcomes, rather than imposing specific short-term requirements, or procuring services on a reactive and ad-hoc basis.

Our feedback on each element of the directions paper is included in the following submission, along with background content on the capability of Tesla battery systems to provide frequency and inertial services through grid-forming inverters. For more information contact Dev Tayal (atayal@tesla.com).

Kind Regards

Emma Fagan - Head of Energy Policy and Regulation

About Tesla

Tesla Motors Australia, Pty Ltd (Tesla) is a global leader in manufacturing electric vehicle and clean energy products. Tesla produces a unique set of energy solutions such as Powerwall and Megapack, enabling homeowners, businesses, and utilities to manage renewable energy generation, storage, and consumption. Our mission is to accelerate the world's transition to sustainable energy and globally Tesla has deployed more than 6.2GWh of residential and utility scale energy storage systems across 40 countries. In 2020 alone, Tesla deployed more than 3GWh of energy storage systems around the world.

In Australia, Tesla is leading both utility scale and virtual power plant (VPP) developments and playing a key role in the transition to higher penetrations of renewable energy. We have deployed more than 200MW of utility scale assets to date since 2017, with an additional 350MW of Tesla Megapacks to be deployed in 2021 – including the 300MW/450MWh Victorian Big Battery which will be the largest battery storage system in the Southern Hemisphere and will be critical to supporting Victoria's energy reliability while helping to achieve Victoria's 50% Renewable Energy Target (RET).

Tesla is also a leader in delivering high quality VPPs. The South Australia VPP (delivered by Tesla and Energy Locals) currently has 13MW registered to provide all six contingency frequency services – and has been providing high quality frequency response services for almost two years.

Tesla currently employs more than 120 people in Australia to undertake the full range of the development and deployment of utility scale energy storage and VPP work. Our permanent employees provide end-to-end development of all Tesla's local energy projects including Business Development, Engineering, Project Management, Project Deployment, Software Development, Market Integration, Service & Operations.

General Comments & Recommendations

Fast implementation is critical - immediate opportunities exist to reward premium regulation services already being provided and FFR should be pursued as a no-regrets priority

- Ahead of the ongoing FFR and PFR mechanism designs, Tesla recommends recognition of the value already being provided from battery storage assets through its accurate and rapid regulation FCAS response. AEMC and AEMO can assess immediate updates to FCAS settings to positively value this service and move towards performance based mechanisms and incentives, such as deviation pricing as considered by the Frequency Control Frameworks Review.
- The ESB's latest paper shows an indicative operational timeframe for FFR being post 2024. FFR was first proposed in the AEMC's Frequency Control Frameworks Review report of July 2017. Taking over 7 years to progress a reform that has consistently received clear industry support is clearly not keeping pace with the energy transition underway and is decoupled from the identified need. We note AEMO's direction to ElectraNet to procure FFR in South Australia as another clear indication that FFR is required well ahead of 2024.

Tesla supports the AEMC's System Services Objective, and highlights the role storage and inverter-based technologies will play in service provision alongside synchronous plant

- As demonstrated in day to day operations as well as during non-credible power system events, storage technologies are well aligned with the objective of efficient provision of services to meet "multiple system needs, including security, reliability, and resilience". Storage assets have the ability to optimise across multiple services and multiple markets – to provide what is needed when it is needed the most – driving increased flexibility, improved competition and enhanced stability to the local grid and the NEM more broadly. Multiple services can also be provided by a single asset simultaneously – ensuring the cost of service provision maximises efficiency, and can be co-optimised across energy and system services.
- As the AEMC recognise, many of these services can be, to varying degrees, partial substitutes of each other, so that the provision of one service may reduce the need for another service. For example, both AEMO studies and international experience suggests a strong interplay between FFR and inertia, with GB's National Grid recently announcing the introduction of a new rapid response frequency product to support system operations with less inertia.

The reform of frequency markets and mechanisms must be cognisant of impacts on investment signals for low-carbon technologies – storage in particular requires removal of existing barriers and recognition of its capabilities to unlock the required levels of deployment in the NEM

- The NEM currently provides mixed signals for investors looking to develop storage projects, highlighting a significant gap in meeting AEMO's forecast levels of storage deployment by 2030 (i.e. up to 19GW by 2040 as projected in the 2020 ISP 'step change' scenario). These projects are crucial to contribute to both reliability and system security outcomes in the short term, and to drive affordability and efficiency outcomes for consumers over the longer term.
- AEMC must consider both the individual and collective impact of the rule change proposals against a broader assessment of what potential market design features will be necessary to stimulate the requisite levels of private investment in a low-carbon future, where even minor technical changes can have significant commercial impacts on the value stack of storage assets.

A first principles approach to service provision is critical – i.e. defining outcomes that uphold technology neutrality, rather than restrictions based on synchronous classifications

- As the NEM transitions towards a high renewables and low-carbon future, synchronous services are increasingly being substituted by proven (and asynchronous) technologies that can contribute to fault current and actively support voltage waveforms. E.g. electrical inertia measured in MWs can be derived both from synchronous machines (kinetic energy) or asynchronous (chemical potential).
- Structuring markets to value service provision (rather than mandates based on asset type, or size or classification etc.) becomes increasingly relevant for evolving market designs that will need to integrate a suite of technologies providing comparable services across the grid. As a principle, all technologies should be able to access all revenue streams for which they can provide services – it is the MWs of inertia that is important – not how it is derived.

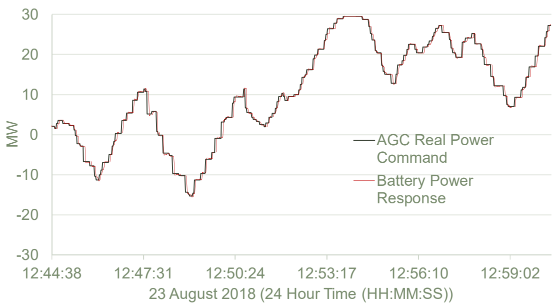
Any changes to frequency market frameworks must also consider the potential role and benefits of DER, demand response, and VPPs in supporting the objectives

- Tesla notes that the future NEM, under any credible future scenario, will see a significant contribution from distributed energy resources (DER), and aggregated fleets operating as VPPs that should be enabled to participate in all energy and system service markets given their ability to provide many of these services much more efficiently and at a localised level. Many of these capabilities are already being demonstrated as part of AEMO's Virtual Power Plant trials.

Immediate Opportunity to recognise premium Regulation FCAS performance

HPR Regulation FCAS Performance

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 set-points is shown as follows:



- As part of assessing mechanisms to improve frequency performance in the NEM through FFR and PFR mechanisms, the AEMC has an immediate opportunity to recognise and reward the premium services already being provided in regulation FCAS markets.
- Battery storage assets across the NEM, such as Hornsdale Power Reserve, have consistently demonstrated their ability to provide both rapid and precise regulation FCAS, particularly when compared to the service typically provided by a conventional synchronous generation unit (see figure left). Whilst this response has been demonstrated since HPR's commissioning in late 2017, regulation FCAS arrangements in the NEM still do not currently recognise differences in the 'quality' of service delivery.
- As a starting point, AEMC should build from the recommendations made as part of the previous Frequency Control Frameworks Review, which concludes:

  "the best approach to the procurement of frequency services in the longer-term will need to be performance-based, dynamic and transparent"

- For example, the viability of a 'deviation pricing mechanism' could be explored to efficiently value the provision of regulation frequency services under normal operation, progressively ramping up the $/MWh price offered as the level of deviation increases.
- These changes could be made before the longer-term PFR reforms are finalised, and inform market design considerations ahead of the 2023 sunset date.
- Ultimately this performance-based pricing mechanism could then be extended to all services – frequency, inertia, FFR etc. This will mean that generators able and willing to provide a frequency response at a lower cost will set their dead bands / control settings at a narrower range and will therefore be the first to respond to any deviations in frequency.
- It is also understood AEMO is continuing to review existing contribution (causer pays) factor procedures and cost recovery processes to ensure that fast responding battery storage technologies are not unfairly penalised due to interim registration requirements (e.g. multiple DUIDs) and the technology's dual dispatch classifications as a scheduled generator and market customer. An immediate clarification to remove these perverse outcomes should ensure the battery system as a whole is viewed as not contributing to a deviation in frequency if either its load or generation side has been enabled and is providing regulation services accurately.
- In addition, any barriers or disincentives to the FCAS registration for battery storage should be addressed in the upcoming MASS review.

Fast Frequency Response – Tesla Feedback

AEMC market options for provision of FFR

1. New market ancillary services to procure FFR FCAS
2. Procure FFR through existing service classifications

- Tesla is strongly supportive of the introduction of an FFR market, as soon as 2021/22, and suggests AEMC accelerate implementation as a 'no-regrets' reform (high benefit, negligible cost) ahead of other more complex market reforms. We note AEMO has also already expressed support for FFR mechanisms in both its Renewable Integration Study and SA Technical report findings.
- Tesla agrees that the existing arrangements for contingency FCAS provide an appropriate model from which to base FFR market arrangements. However, additional consideration needs to be given to improving transparency and visibility, specifically on how AEMO determines enablement levels for FCAS provision. We recommend participants are provided clear guidance on how droop limitations and MW response are set and calculated and this is outlined and addressed through the upcoming MASS review. This has been an ongoing area of opaqueness for battery storage participants in particular – where the full capacity of storage is effectively de-rated based on AEMO's MASS verification across and between 6, 60 sec and 5 min contingency FCAS registration. This undervalues the speed and accuracy of response from battery storage and creates capacity trade-offs between products.
- In regards to potential FFR procurement arrangements, we recommend a co-optimised solution, with a key priority being speed of implementation. As the AEMC recognise, the ISP step change scenario demonstrates the significant and increasing benefit offered by FFR over the next five years. With AEMO now updating its ISP scenarios to reflect even greater ambition across the NEM (e.g. NSW's Electricity Roadmap which accelerates integration of VRE ahead of even the step change scenario), it can be expected that FFR will provide these benefits in greater quantity, and sooner than previously expected (see ElectraNet procurement of FFR).
- Whilst Tesla remains open to both design options, Option 1 would be preferable, with a layered approach to ensure consistency across system services - e.g.: first response primary frequency services (narrow deadband, continuous operations); adding a new FFR product (with <1 or <2 second response, rewarding speed and accuracy); followed by existing contingency response (i.e. current 6 second, with slightly wider deadband).
- If Option 1 is progressed, we agree with the AEMC's approach to co-optimise inertia, FFR and R6 services. Tesla also supports additional consideration on the introduction of performance factors to differentiate the quality and speed of service from different technologies and reward more 'premium' provision accordingly. This will be particularly critical if Option 2 is progressed, but could also act as a complementary function across the potential 10 FCAS services under Option 1.
- Whilst we agree conceptually that there is an opportunity to commence work on valuing inertial response services ahead of potential market mechanisms being introduced via the P2025 work program, we stress that this valuation must be based on technology neutral service provision and not limited to synchronous plant. Virtual inertia demonstrates the ability of equivalent service provision through non-traditional assets. These developments should be encouraged – and ideally be rewarded through pay for performance mechanisms that recognise premium service provision (accuracy, speed etc.) not restricted by definitional based approaches.
- We support AEMO's ongoing work as outlined as part of its Frequency Control Work Plan and await further information on how dynamic constraints for C-FCAS volumes will be implemented in late 2021- noting the implicit links created between FFR and inertia
- For simplicity and to uphold technology neutrality principles, Tesla recommends FFR costs are allocated on the basis of existing FCAS contingency cost allocation principles. Whilst some synchronous plant may argue for only VRE to bear the costs, this logic is inconsistent with the existing arrangements where all generators/loads share the C-FCAS raise/lower costs, even if, for example, certain large ageing thermal plants may be more likely to trip than newer inverter-connected plant.

Primary Frequency Response – Tesla Feedback

AEMC pathway options for enduring PFR

1. Maintain existing Mandatory PFR (with improved pricing)
2. Widen MPFR band & develop new FCAS arrangements for PFR
3. Remove MPFR & replace with market-based PFR procurement

- Tesla supports continued development of the PFR mechanism to ensure it provides a robust frequency outcome whilst also avoids damaging the investment signal for new entrants. We agree with the AEMC's views on seeking operational and allocative efficiencies in the long-term interests of consumers. And support the stated system services objective: "to promote efficient longer-term investment in generation facilities, load, storage, networks (i.e. the power system) and other system service capability".
  - Whichever approach is progressed, it needs to uphold fairness and equitability between all technology types providing this service. As noted in the paper, all options for PFR need to support resource efficiency, improved price formation and facilitate the access of additional value streams for resources (e.g. in C-FCAS and R-FCAS markets), and uphold comparable treatment between new and existing resources.
  - In a broader market design sense, Tesla remains concerned with the lack of clear reform pathway that would introduce appropriate incentives for fast-response and flexible generation – particularly in the near-term when capacity is needed to replace retiring thermal fleet. However, accelerated implementation of FFR and essential system service frameworks, together with the ESB's parallel P2025 market design initiatives including the resource adequacy considerations would all be a significant improvement on the status quo.
- From an engineering perspective, and recognising the critical role AEMO plays in maintaining a secure power system, we agree pathway options 1 (and to a lesser extent option 2) prioritise system security to ensure safe and secure operation of the power system. This is a valid approach. However, if progressed, we recommend these options are still structured in a way that allows for future flexibility – where mandatory arrangements and PFR settings may be fine-tuned over time, or new market arrangements can be introduced based on the demonstrated change in technical capability of the generation fleet and innovations over time (e.g. droop or control setting response of battery inverters relative to other technologies, locational factors, headroom analysis, different dynamics in a predominately inverter-based resource system etc).
  - For procurement, Tesla supports improved pricing and further consideration of interactions with broader incentive-based ancillary service arrangements to ensure there is clarity and transparency on the service provision and costs of PFR.
  - We note AEMO commentary in the SA technical report already suggesting potential to layer some form of compensation: "introducing arrangements to reward higher performers would be suitable, while maintaining a minimum requirement for all capable market participants"
  - The cleanest approach would be to progress an enduring PFR pathway that complements the development of frequency control ancillary and essential system services and does not impinge on existing co-optimised energy and FCAS dispatch and market processes. This could see higher volumes of regulation FCAS enabled, but not utilised (as is the case in USA)
  - AEMC should also codify requirements that ensure battery storage only provides PFR when dispatched for energy >0MW (and not when charging) – to avoid discrimination
  - Further clarity on how a double-sided causer pays mechanism applies to stand-alone battery storage assets would be instructive, given these assets already accurately meet their dispatch targets and therefore face different incentives to other generators who are seeking to minimise negative contribution factors.

T E S L A

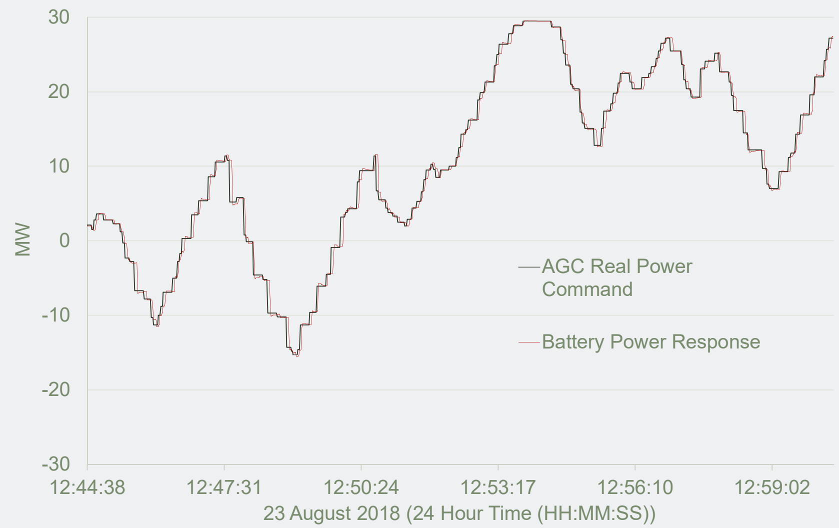
Background: Battery storage frequency & inertial capabilities

Summary of Battery Storage Frequency Services

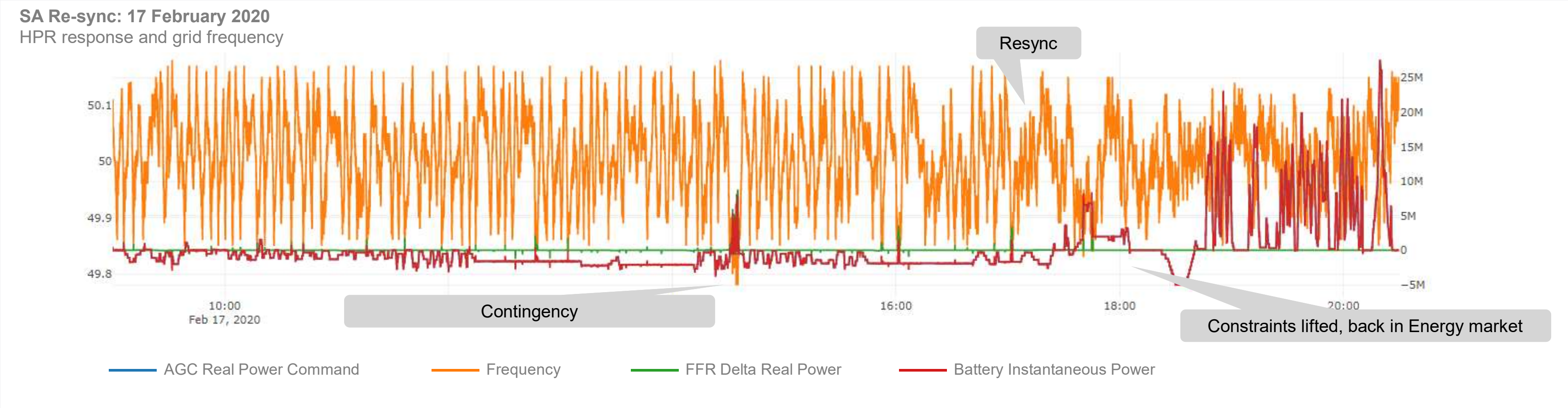
- A key benefit of battery storage is its ability to stack multiple services and provide multiple sources of value across different time-scales. Frequency control services provide a critical area where battery technologies can enhance and drive additional efficiencies in service provision to the benefit of all participants and consumers.
- To date, Tesla has deployed over 4GWh of battery storage providing a range of system services, with around 300MW of batteries on microgrid or off-grid backup sites fully utilising grid-forming and system synchronisation capabilities in particular.
- Multiple reports have also conducted detailed analysis on the performance and capability of battery storage systems operating in Australia since the introduction of Hornsdale Power Reserve in late 2017 – highlighting:
  - "Operation of the HPR to date suggests that it can provide a range of valuable power system services, including rapid, accurate frequency response and control." (AEMO report on initial operation of the Hornsdale Power Reserve)
  - "The large-scale battery storage in SA was valuable in this event, assisting in containing the initial decline in system frequency, and then rapidly changing output from generation back to load, to limit the over-frequency condition in SA following separation from VIC (AEMO Final Report – Queensland and South Australia system separation on 25 August 2018)
  - "The plan [for managing SA islanding] involved Lake Bonney, Dalrymple, and Hornsdale batteries being constrained to zero MW output but remaining at a state of charge sufficient to allow provision of raise and lower contingency frequency control ancillary services (FCAS)" (AEMO Preliminary Report – Victoria and South Australia Separation Event, 31 January 2020)
  - "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." (Aurecon – HPR Year 2 Technical Market Case Study)
- An approach that recognises the benefits of new technologies such as battery storage is also in line with the broader work program being progressed by the ESB's Essential System Services workstream as part of its post-2025 market reform agenda. As outlined by the ESB, a long-term, fit-for-purpose market framework to support reliability and system security will necessarily rely on the capabilities of fast-response and flexible resources, including demand side response, battery storage and distributed energy resource participation.
- Ensuring appropriate frameworks are set up now offers a much less volatile price discovery mechanism that will provide a more efficient pathway to supplement the planned exit of large volumes of incumbent synchronous generators that presently provide much of these system security services. A clear price signal for services from battery storage is required today if it is expected that these technologies will form the bulk provision of this service in the years to come, and also ensure a back-stop insurance against the early closure of thermal plant.
- The following slides provide further background on Tesla battery system's ability to provide (1) **frequency stability;** (2) **FFR;** (3) **Primary Frequency Response;** and (4) **Virtual Inertia.** Additional system services also include: Voltage stability; System strength; and Special Protection Systems for fast active power injection for network support

FREQUENCY STABILITY

- Grid-scale battery storage has consistently demonstrated its ability to provide both rapid and precise regulation FCAS, particularly when compared to the service typically provided by conventional synchronous generation units.
- Whilst this premium response has been demonstrated by Hornsdale Power Reserve (HPR) over 2 years of operation, regulation FCAS arrangements in the NEM do not currently recognise differences in the speed or accuracy, the ‘quality’, of service delivery.
- Operational data shows that HPR provides very rapid and precise response to regulation FCAS signals, see figure right. This is in contrast to large conventional steam turbines, which can lag the Automatic Governor Control (AGC) signal by up to several minutes.
- HPR provides a high quality Regulation FCAS service. Increased deployment of such high quality frequency regulation would assist in maintaining network frequency within the 50 ± 0.15 Hz normal operating range
- **Recommendation:** implement findings from the AEMC’s 2017-18 Frequency Control Frameworks Review, which highlighted: “the best approach to the procurement of frequency services in the longer-term will need to be performance-based, dynamic and transparent”.



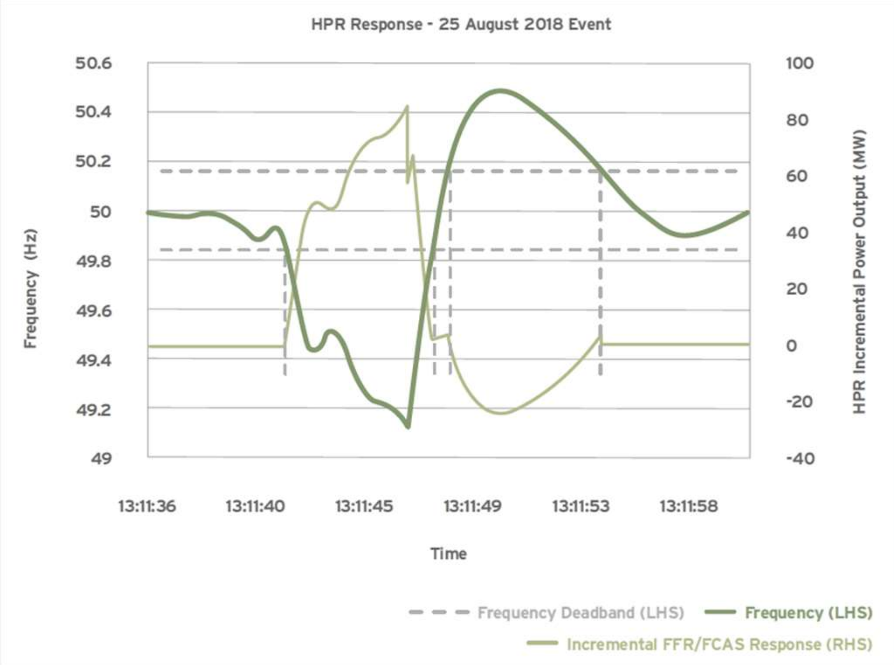
FREQUENCY STABILITY
SA ISLANDING EVENT



- The South Australian separation event provides an instructive example of the existing capabilities of battery systems to respond rapidly to provide grid support (transitioning from AEMO AGC signal to support the islanded SA grid), before playing a critical role in ensuring a smooth and seamless resynchronization could be achieved between SA and the wider NEM network
- During islanding, AEMO constrained SA batteries to zero MW output but allowed 50% state of charge to allow provision of raise and lower contingency FCAS
- Data also highlights that frequency management during the islanded and NEM connected periods were not remarkably different
- It demonstrates technical feasibility in providing system security service today, and the critical role batteries will continue to play going forward in a high renewables NEM

FAST FREQUENCY RESPONSE

- The fast frequency response from battery storage is well suited to supporting restoration of frequency and is of particular value in arresting a high Rate of Change of Frequency (RoCoF) during initial frequency disturbances. It rapidly and accurately follows the frequency deviation and provides proportional 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.
- 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 100ms, as compared to the minimum required 6 second response under existing Contingency FCAS markets. This premium service supports a reduced RoCoF and total deviation in frequency during contingency events.
- **Recommendation:** exploring appropriate incentives to value fast frequency services should be accelerated, particularly as frequency control continues to loosen across the NEM. This is increasing the occurrence of the frequency falling outside the normal operating band of 50 ± 0.15 Hz: strengthening the case for new mechanisms such as FFR to be introduced. Again, this aligns with the Frequency Control Frameworks Review recommendation from 2018: "Although FFR services could be procured through the existing six second contingency service, this does not necessarily recognise any enhanced value that might be associated with the faster response."



Source: https://www.aurecongroup.com/-/media/files/downloads-library/2018/aurecon-hornsdale-power-reserve-impact-study-2018.ashx?la=en

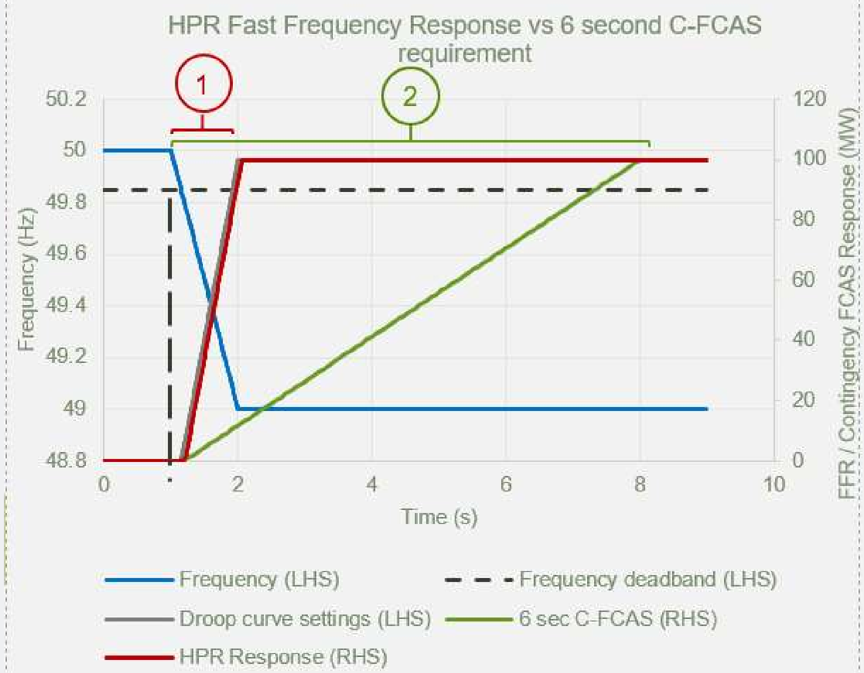
FAST FREQUENCY RESPONSE
AURECON CASE STUDY

HPR provides Fast Frequency Response more rapidly than 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 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.

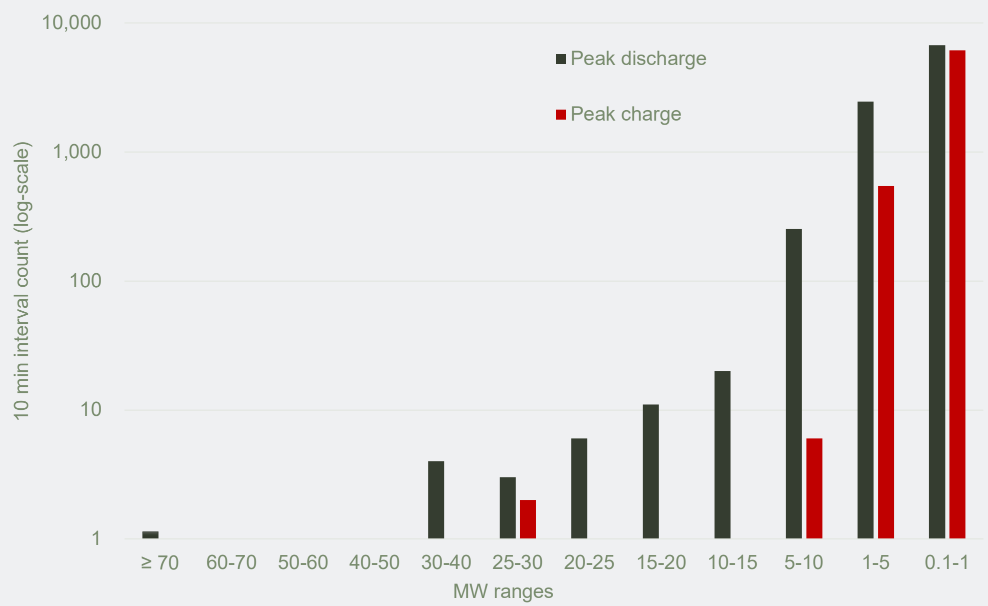


Source: https://www.aurecongroup.com/-/media/files/downloads-library/2018/aurecon-hornsdale-power-reserve-impact-study-2018.ashx?la=en

PRIMARY FREQUENCY CONTROL

- Tesla's battery energy storage systems can react automatically and almost instantaneously to locally measured changes in system frequency outside predetermined set points.
- Under existing NEM arrangements, primary frequency control services that operate outside the normal operating frequency band of the frequency operating standard are procured through the fast and slow contingency FCAS markets, with new mandates introduced for generating units to provide service within the normal operating frequency band when dispatched for energy.
- HPR is regularly responding to small frequency disturbances outside the normal operating frequency band. The demand for this frequency control is related to the effectiveness of Regulation FCAS in maintaining the frequency within the normal range.
- As discussed with AEMO, battery systems can be incentivised to tighten their frequency droop curve setting and/or deadband and provide an enduring Primary Frequency Control service. This could be a complementary service to Regulation FCAS, and should ultimately be supported through an incentive-based approach.
- **Recommendation:** early consideration of a market mechanism ahead of the mandatory PFR sunset in 2023 (as suggested under AEMC's Frequency Control Frameworks Review and the 2020 December Directions Paper).

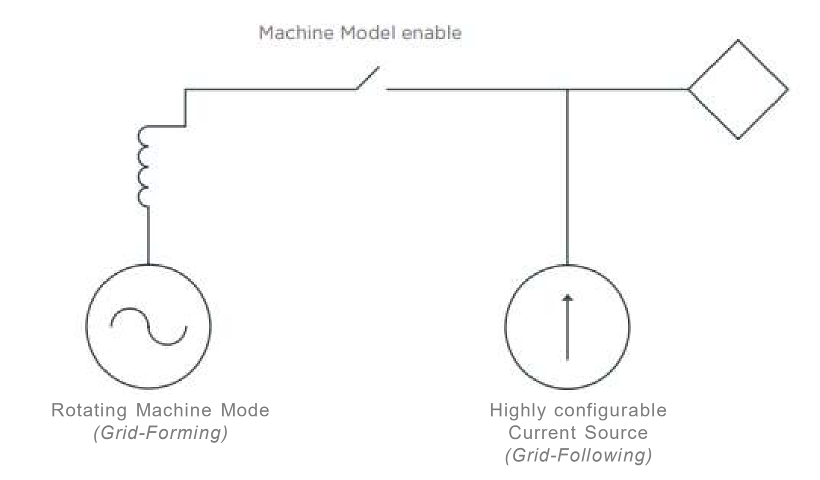
HPR Contingency response over 1st year :
HPR is regularly dispatching Contingency FCAS services for minor frequency disturbances, and responding occasionally, as required, to large contingency events



VIRTUAL INERTIA

- With increasing asynchronous generation and declining inertia from synchronous machines, there is increasing potential for batteries to provide a ‘virtual’ inertia service.
- Tesla battery systems have a virtual machine mode that can mimic the response of a traditional rotating machine to provide an inertial response. The virtual machine is a blended mode that brings dispatchability of a current source operating in parallel with the stability benefits of a voltage source.
- The flexible and fast controls in a Tesla battery inverter can replicate the response of a traditional rotating machine. As the inverter’s inertial response is created by the inverter controls the response is tunable and can be modified based on the grid’s needs (unlike traditional generators that have a fixed inertial constant based on their physical characteristics).
- The virtual machine model is a flexible feature that can be enabled or disabled as required. Its parameters such as inertial constant and impedance are fully configurable and can be tuned to obtain the desired dynamic behaviour for the grid. The inertial constant of a Tesla battery can be configured from 0.1 to 20MW.s/MVA.
- **Recommendation:** progress incentives for ‘inertia services’, defined neutrally through requirements (e.g. response time and active power level required).

Tesla Inverter Virtual Machine Mode:
A Tesla inverter can operate in Virtual Machine Mode with a configurable current source operating in parallel with a rotating machine model (voltage source).



VIRTUAL INERTIA
AMERICAN SAMOA - CASE STUDY

- The island of Ta'u in American Samoa historically relied on expensive diesel generators to supply all of their electricity needs – facing frequent outages, rationing and high emissions.
- In 2016, Tesla commissioned a renewable microgrid – using 1.4MW of solar PV paired with 750kW / 6MWh battery storage to provide affordable, reliable, and clean power to the island.
- With the battery providing all critical power system services, the microgrid now provides energy independence to the nearly 600 residents of Ta'u - allowing the island to store and use solar energy 24/7, reduce diesel costs, remove the hazards of power intermittency and make outages a thing of the past.
- The microgrid allows the island to stay fully powered for three days without sunlight, and the Tesla battery system recharges fully in seven hours – providing back-up power, peak shaving and seamless grid stability through Virtual Machine Mode (the battery operating as grid forming – setting frequency and voltage reference for the grid).
- The microgrid has <u>no</u> grid-connected synchronous generation and, whilst a small system, illustrates the capability of inverter based technologies to support the grid at all times.

VIRTUAL INERTIA
ADDITIONAL CASE STUDIES

- Since 2017, Tesla's Virtual Machine Mode has been operating on a 13MW / 52MWh energy storage facility on the island of Kaua'i, Hawaii. This system has allowed increasing renewable penetration on the island by time-shifting energy generated from solar PV and providing critical grid services including inertia and voltage smoothing.
- As part of the expansion of the Hornsdale Power Reserve to 150MW, inertia services from a grid-scale battery storage system will be demonstrated in the NEM context. Once expanded, the Hornsdale Power Reserve could provide up to 3,000MWs of inertia to the local South Australian grid.
- We note that inertia/system strength events are typically transitory events before frequency response kicks in, meaning inverter based technologies are able to provide the initial response just as well as traditional plant (and this hierarchy can be considered within the operating regime of the battery system).
- Studies by EirGrid and SONI in Ireland have also shown the benefits of incorporating virtual inertia into energy systems (lower $'s, less CO_2, reduced oscillations).