# Hornsdale Wind Farm 2 FCAS trial

**July 2018**

Knowledge sharing paper

# Important notice

## PURPOSE

This publication has been prepared by AEMO to provide information about the results of a trial conducted at Hornsdale Wind Farm 2 to establish its ability to provide frequency control ancillary services. The information in this document is current as at 6 July 2018.

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## VERSION CONTROL

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# Executive summary

**Introduction**

The Australian Energy Market Operator (AEMO) and the Australian Renewable Energy Agency (ARENA) signed a Memorandum of Understanding (MOU) in May 2017 to facilitate collaboration between the organisations in areas of mutual interest such as power system security and reliability. This report outlines the findings of a trial developed under this MOU, focusing on the first National Electricity Market (NEM) wind farm to be registered and to operate in both energy and ancillary services markets.

The Hornsdale Wind Farm 2 (HWF2) trial is the first in-market technical demonstration of a wind or solar farm providing frequency control ancillary services (FCAS) in the NEM[1]. It was undertaken by AEMO and ARENA in conjunction with NEOEN (owner and operator of the Hornsdale group of projects[2]) and Siemens-Gamesa Australia (equipment provider for the Hornsdale group of wind farms). As a result of the trial, HWF2 is the first Australian wind farm to be registered and offering FCAS in the NEM.

The relative proportion of generation sourced from wind farms in the NEM has been steadily increasing since the early 2000s, particularly in South Australia. Almost all wind farm projects built in Australia in this period have been financed based on a business model relying only on revenue from Large-scale Generation Certificates (LGCs) and sale of energy in the wholesale market. Prior to this trial, frequency control services in the NEM were only provided by thermal plant. AEMO and ARENA expect that broadening the pool of available FCAS providers and making available additional revenue streams for operating wind and solar farms will deliver value for NEM customers by improving market outcomes and increasing supply of system security services.

Consistent with its statutory objectives to improve the competitiveness of renewable energy technologies in Australia, ARENA provided partial funding for the trial, with the balance of funds provided by NEOEN. One of ARENA's central objectives in funding demonstration projects is to provide learnings that result from the projects to the broader electricity industry. To facilitate dissemination of results, a Knowledge Sharing Plan (KSP) is used in some ARENA funding agreements to specify the nature of reports and other information provided to the electricity industry and the public.

This report has been produced by AEMO as a part of the KSP for the HWF2 trial.

The concept and scope for the trial described in this report were developed in 2017 by AEMO, ARENA, the Essential Services Commission of South Australia (ESCOSA), and NEOEN, developer of Hornsdale Wind Farm (HWF)[3].

Siemens-Gamesa Australia was consulted in development of the scope of the trial. As the wind farm technology provider for HWF, it also played a major role in implementing this project, including authoring a Knowledge Sharing Article describing the process and lessons learnt from the trial.

[1] In addition to the FCAS definition on this page, Sections 2 and 3 of AEMO's *Guide to Ancillary Services in the National Electricity Market* provide a general description of FCAS, including the nature of regulation and contingency FCAS requirements, the structure of FCAS offers and their technical limits, how FCAS offers are used, and the settlement of procured FCAS.

[2] The Hornsdale group includes HWF1, HWF2, HWF3, and Hornsdale Power Reserve (HPR), the 100 megawatt (MW) Tesla battery commissioned in December 2017.

[3] HWF2 is sometimes also referred to as "HDWF2", its dispatchable unit identifier (DUID) used in AEMO's market systems.

This report is structured in three chapters:

- Chapter 1 – Project description: provides an overview of the HWF group of projects as well as the strategic drivers, objectives, and policy context for the trial project.
- Chapter 2 – Results and outcomes: provides commentary on tests and modelling required for registration and discussion of regulation and contingency FCAS performance in the market trial.
- Chapter 3 – Insights: provides discussion on outcomes from the trial that will be of interest to the broader electricity sector, in areas that were not explicitly identified in the trial objectives. This section includes a summary of areas for further work identified in this proof-of-concept.

### The Hornsdale 2 Wind Farm FCAS trial

The trial ran from August 2017 until February 2018, and was implemented in three stages:

1. Technical modelling of plant performance and demonstration of capability via on-site plant testing.
2. Review of modelling and on-site test results, leading to registration of HWF2 as an ancillary service generating unit.
3. In-market demonstration of FCAS delivery for all registered services through 48 hours of live bidding and dispatch under a range of wind conditions, referred to in this report as the 'market trial'.

Following submission of modelling and on-site capability tests, HWF2 was registered to provide six of the eight NEM FCAS products. HWF2 was not able to register for fast raise and lower contingency FCAS, after preliminary modelling suggested wind turbines were likely be in 'fault-ride-through' mode providing voltage support in the first few seconds following a frequency event. Obligations in Generator Performance Standards (GPS) for wind farms to support system voltage and prioritise provision of reactive power over active power following a fault may prevent delivery of active power within six seconds of the frequency event. The ability of other wind farm projects to provide fast FCAS and interactions between ride-through and frequency control capability will be further investigated in the upcoming Musselroe Wind Farm FCAS Trial[4].

The market trial component of this project was undertaken during the peak summer period for 2017-18. All six registered services were delivered during 48 hours of bidding from the HWF2 control room, between December 2017 and February 2018, under a variety of wind and market conditions. The market trial succeeded in meeting the scoped objectives, however the absence of a significant frequency deviation during the market trial phase of the trial meant that the full end-to-end contingency FCAS response of HWF2 couldn't be completely evaluated.

### Trial insights and market benefits

Highlights of HWF2's performance in the market trial include:

- High quality provision of regulation FCAS services.
- Operation of HWF2 FCAS in conjunction with Hornsdale Power Reserve (HPR) FCAS to reduce otherwise high FCAS prices during planned maintenance of the Heywood Interconnector on 14 January 2018. Regulation prices peaked at $248/MW on this date, compared to an average of over $9,000/MW during previous Heywood outages. Because of obligations to maintain regions of the power system in a satisfactory operating state, AEMO typically procures additional FCAS in the South Australian region when the Heywood Interconnector is subject to operation and maintenance.
- Autonomous response to a range of frequency excursions (both as a part of the market trial and during normal market operation following its conclusion).

During the market trial, to support end-to-end demonstration of service delivery HWF2 was required to bid such that it was enabled for FCAS. As a consequence of this, bidding behaviour during the market trial exercise is unlikely to reflect the longer-term economic position of HWF2. Since completion of the trial, HWF2

[4] See ARENA's website for more information, at https://arena.gov.au/news/tassie-wind-farm-trial-grid-stability-services/.

has continued to provide contingency and regulation services to the market. Other market participants with wind farms are also looking to register as ancillary service generating units.

The Market Ancillary Service Specification (MASS)[5] sets out the more detailed specification of the market ancillary services, and how market participants' performance when providing these market ancillary services is measured and verified.

As a result of this trial, AEMO has made changes to the MASS to provide additional guidance for wind and solar generators looking to provide FCAS, and is currently working with a variety of NEM stakeholders to consider options to review aspects of the MASS. A consultation process to update the MASS is expected to commence in August 2018.

This proof-of-concept trial has confirmed that inverter-connected wind plant can provide some frequency control services in accordance with the requirements of the MASS, and identified areas for further work and investigation, including:

- The ability of wind farms and other inverter-connected plant to provide fast FCAS (6-second response) following a contingency event with simultaneous voltage and frequency dips.
  - This will be further explored through ARENA's upcoming frequency control trial at Musselroe Wind Farm in Tasmania.
- Opportunities to minimise the amount of headroom or pre-curtailment necessary to ensure service delivery, through improving forecasting systems and responsiveness of active power controls. A more accurate forecast will allow a wind or solar farm to better assess their capability to deliver FCAS.
  - The potential for improvement in forecasting accuracy will be explored as a part of AEMO and ARENA's Market Participant 5-minute self-forecasting trial. This trial will be conducted from August 2018 and, if successful, will be progressively implemented in production systems from December 2018.

AEMO's power system security responsibilities under the National Electricity Rules (NER) include arranging for the dispatch of frequency control ancillary service (FCAS) from suitable generating units and loads.

AEMO seeks to maintain a balance in the market at all times between generation supplied to the market from generators and energy consumed through loads, to maintain NEM system frequency close to 50 hertz (Hz). Frequency will increase if generation exceeds load, or decrease if load is greater than generation.

FCAS is the controlled injection or withdrawal of alternating current (AC) power within a variety of timeframes (6s, 60s, 300s, or according to signals from AEMO) to maintain NEM system frequency close to 50 hertz (Hz), even if the balance of generation and load is disturbed by an unexpected but 'reasonably possible' disconnection of a generator, power line, or large load.

AEMO administers and maintains the Market Ancillary Service Specification (MASS). This is a market standard which defines the eight individual types of FCAS and details requirements for how these services must be delivered and assessed.

Under the NER, AEMO must consult with registered participants and any other interested parties before changing the MASS.

The ability for inverter-connected renewable plant to operate in ancillary services markets delivers numerous benefits to the asset operators, including:

- Additional FCAS revenues (supplementing existing energy and LGC revenues).
- The ability to hedge against potentially high FCAS regulation costs by providing FCAS regulation services.

The power system benefits from:

- Increased availability of frequency control services, which is likely to put downward pressure on prices and reduce overall FCAS market costs.
- New sources of FCAS providing greater confidence that sufficient ancillary services will be available to maintain power system security as traditional sources of FCAS reach the end of their design life and are decommissioned.

The success of this trial, and growing interest from other wind farms in providing frequency control services, demonstrate removal of barriers wind and solar farms may have faced in entering frequency control markets.

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[5] Version 5 of AEMO's MASS is available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Ancillary_Services/Market-Ancillary-Service-Specification-V50--effective-30-July-2017.pdf.

Interest from wind and solar generators in broadening their service offerings to market are also additional signs of commercial and technical maturation of these energy generation technologies. AEMO expects that utility-scale wind and solar technology will continue to take on a larger role in providing essential ancillary services in the NEM.

The ability to offer frequency control services to the market is no longer a novel concept for pilot projects; over time this capability should become an important and flexible tool in the operational kit of utility-scale renewable generators that also provides value to consumers and the power system.

### Next steps

The findings of this project will inform future trials and the evolution of some of AEMO's policies. Notable related trials and AEMO's policy consolation processes are briefly set out below:

- 2018 MASS Review – review of the MASS expected to commence in Q3 2018 (final date to be announced by AEMO), which will include consultation on the principles for registration and operation of wind FCAS. The consultation will have two key focus areas:
  - To improve power system frequency control in the NEM by better defining, and potentially amending, the frequency response required for contingency and regulating services; and
  - To amend the MASS to better facilitate the incorporation of non-traditional frequency control technologies.
- Musselroe Wind Farm FCAS trial – a trial to investigate the economic and commercial case for FCAS participation by wind farms and, if viable, enabling the frequency controllers at this Tasmanian wind farm. This project will support assessment of the business case for current and future participants seeking to participate in the FCAS market. The project will also evaluate the installation of utility-scale storage to capture energy currently not dispatched due to a combination of network and wholesale market conditions, as well as providing FCAS and other grid support services from Musselroe Wind Farm[6]. This trial is expected to have preliminary planning underway by early August 2019.
- Market Participant 5-minute Forecasting[7] – a collaboration by AEMO and ARENA, in conjunction with forecasting service providers and existing wind and solar projects. The objective of the program is to demonstrate the potential benefits of wind and solar generator self-forecasting to operation of the power system. It is anticipated that the use of self-forecasting will deliver system-wide benefits by reducing generation forecast error, and provide greater autonomy to semi-scheduled generators by allowing them to develop and use their own forecasts to set dispatch targets in National Electricity Market Dispatch Engine (NEMDE).

[6] Further information is available from https://arena.gov.au/projects/musselroe-wind-farm-fcas-trial/.

[7] Further information is available from https://www.aemo.com.au/Stakeholder-Consultation/Industry-forums-and-working-groups/Other-meetings/Market-Participant-5-Minute-Self-Forecast.

# Contents



# Tables

# Figures

# 1. Project description

This chapter provides an overview of:

- The structure and policy context of the trial.
- A description of the operating Hornsdale assets.
- A simple overview of frequency control ancillary services (FCAS).

## 1.1 Trial structure

The trial was undertaken in the following stages.

**Figure 1 Structure and stages of trial**


The 'objectives and intended outcomes' of the trial (refer to Section 1.5 for more detail) were confirmed at a summary level by AEMO, the Australian Renewable Energy Agency (ARENA), and NEOEN before being included in ARENA's funding agreement for this project. In this process, the parties defined the minimum scope by agreeing to:

i. Conduct a basic set of engineering capability tests;
ii. Simulate these tests in a power system simulation model;

iii. Register the wind farm as an ancillary services generating unit for any of the eight FCAS types for which adequate capability had been demonstrated according to the principles of AEMO's Market Ancillary Service Specification (MASS); and

iv. Participate in a 48-hour market trial via real-time submission of FCAS bids from NEOEN's HWF control room to demonstrate end-to-end service delivery and enablement/dispatch by the National Energy Market Dispatch Engine (NEMDE).

The basic tests referred to in (i) above were captured in a high-level draft test plan included with ARENA's funding agreement. This high-level plan was later augmented into the Detailed Test Plan included in Appendix A1.

As discussed further in Section 1.6, AEMO was unsure at the time the trial was scoped if Hornsdale Wind Farm (HWF) would be able to meet the requirements of the MASS and be classified to offer services in-market. If this proved infeasible for Hornsdale Wind Farm 2 (HWF2), a 'simulated' out-of-market trial would be considered to demonstrate the wind farm's ability to support power system frequency without using AEMO's bidding and market dispatch systems.

The trial demonstrated that HWF could meet MASS requirements for six of the eight FCAS products, so the market trial component could proceed as originally envisaged. A copy of the Market Trial Plan agreed between the parties is included in Appendix A2.

## 1.2 Hornsdale Wind Farm 2

This section provides a concise overview of the Hornsdale Wind Farm (HWF) group of projects.

HWF is a 99 turbine, 315 megawatt (MW) wind energy facility located in the mid-north region of South Australia near Jamestown. HWF was developed by French renewable energy company NEOEN in conjunction with international infrastructure investor John Laing. The HWF project is comprised of 99 turbines constructed in three stages, designated HWF1, HWF2, and HWF3.

All three project stages use the Siemens 3.2 MW SWT-3.2-113 direct drive wind turbine generator (WTG).

HWF is co-located with Hornsdale Power Reserve (HPR), a 100 MW/127 megawatt-hour (MWh) Tesla Powerpack battery energy storage system. HPR has been built next to the Mount Lock substation, which connects Hornsdale project assets listed in Table 1 to the 275 kilovolt (kV) ElectraNet network.

**Table 1 Hornsdale project assets**

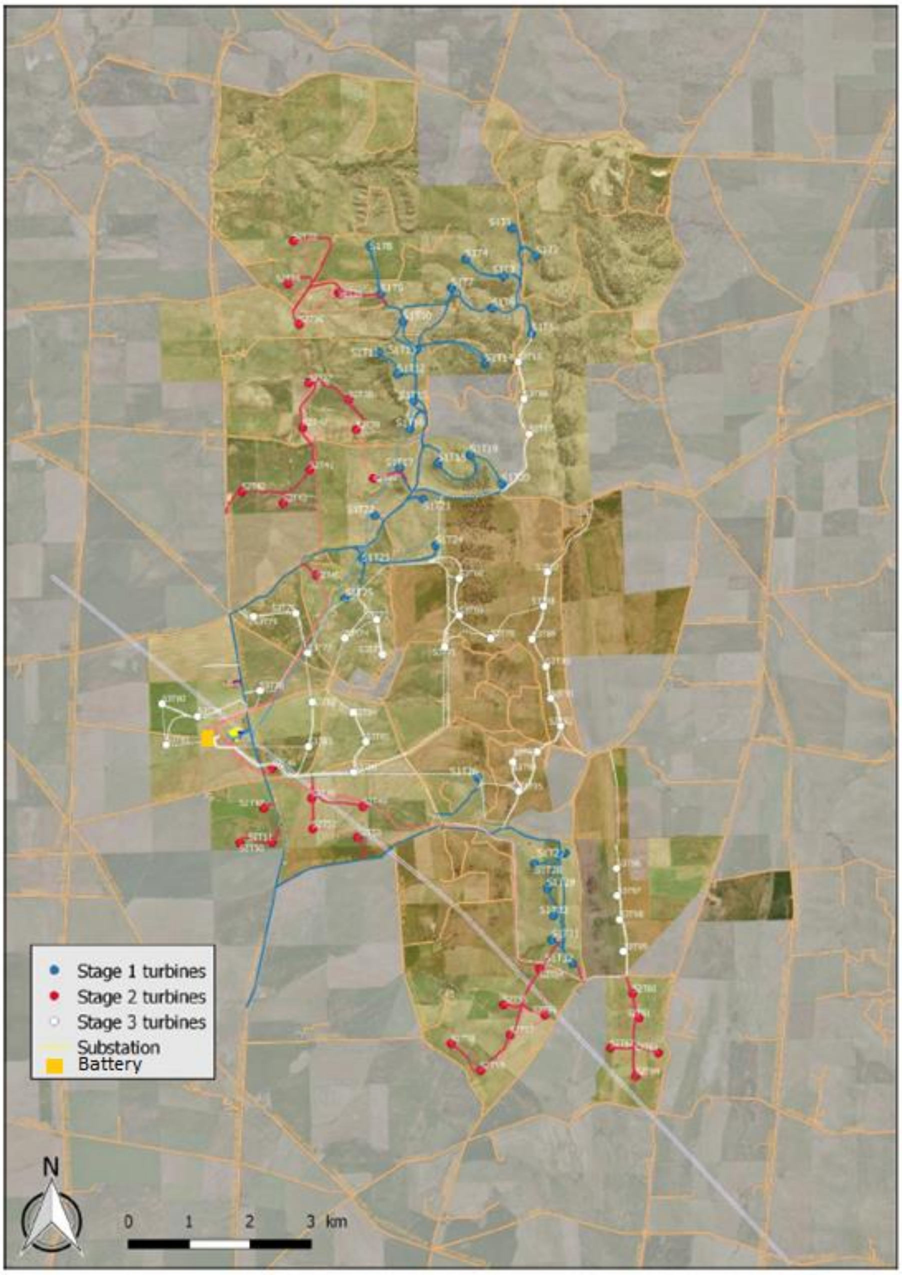
| Name | Asset type | Registered capacity | Technology provider/model |
|---|---|---|---|
| HWF1 | Wind farm | 32 WTGs- 102.4 MW | Siemens SWT-3.2-113 |
| HWF2 | Wind farm | 32 WTGs -102.4 MW | Siemens SWT-3.2-113 |
| HWF3 | Wind farm | 35 WTGs- 112 MW | Siemens SWT-3.2-113 |
| HPR | Utility-scale battery | 100 MW charge/80 MW discharge, 129 MWh | Tesla Powerpack |

Although commissioning and testing of frequency control capability from HPR was underway during the period over which the trial was conducted, only the 32 turbine HWF2 asset was involved in the trial described in this report[8].

[8] For more information on HPR and its frequency control capabilities, see AEMO's report on initial operation of this asset, at http://energylive.aemo.com.au/Innovation-and-Tech/-/media/45ACDCBA73CE46A585ACBFFB132EF9B0.ashx.

A detailed layout showing ElectraNet's 275 kV transmission line, the Mount Lock Substation, HWF1, HWF2, HWF3, and HPR is presented below in Figure 2

**Figure 2 Hornsdale Wind Farm and Hornsdale Power Reserve project layout**




## 1.3 Overview of FCAS

Frequency control is important to the security of the power system, and frequency itself acts as a measure of the instantaneous balance between supply and demand. If supply exceeds demand, frequency will increase, and vice versa. The National Electricity Market (NEM) operates at a nominal frequency of 50 Hertz (Hz).

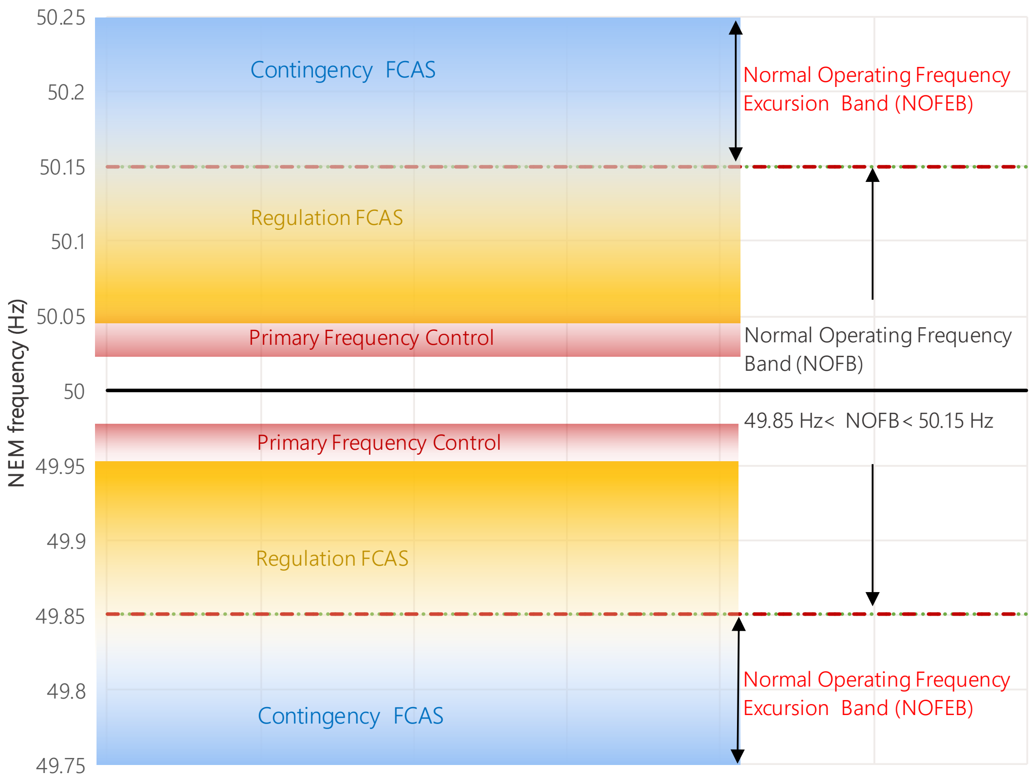
In the NEM, generation and demand are balanced through the central dispatch process, which includes the dispatch of both energy and FCAS. Provided by generation or loads, FCAS is a market product employed specifically to correct imbalances between supply and demand.

There are two types of real-time FCAS markets; for regulation services and contingency services (discussed further in Section 1.3.1). Regulation services are typically used to maintain frequency within the normal operating frequency band (NOFB)[9], while contingency services are used to return frequency to the NOFB if a contingency event occurs. The NOFB and the role of each of the services is shown below in Figure 3.

Each FCAS market is divided into two types of services:

- 'Raise' services are used to correct a deficit of generation (or excess of load).
- 'Lower' services used to correct an excess of generation (or deficit of load).

**Figure 3 FCAS and the normal operating frequency band**




## 1.3.1 Regulation and contingency FCAS

Two types of regulation service and six types of contingency service form the eight traded FCAS products described below.

### Regulation FCAS

Regulation FCAS is used to manage minor deviations in power system frequency within each 5-minute dispatch period. Regulation FCAS consists of two distinct products, each operated as a single market:

- Regulation raise/lower – changes active power in response to an Automatic Generation Control (AGC) signal. Acts to increase or decrease system frequency for raise and lower respectively.

Regulation FCAS is triggered by AEMO's AGC system sending a signal to generators that are 'enabled' to provide the services by NEMDE. AEMO does not currently manage regulation FCAS from loads via AGC, although this possibility is under consideration by AEMO and some market participants.

[9] More information on the NOFB is contained in the NEM Frequency Operating Standards, available at https://www.aemc.gov.au/sites/default/files/content/c2716a96-e099-441d-9e46-8ac05d36f5a7/REL0065-The-Frequency-Operating-Standard-stage-one-final-for-publi.pdf.

**Contingency FCAS**

Contingency FCAS is used to manage relatively material frequency deviations that might arise from larger supply-demand imbalances following contingency events. It is delivered in three timeframes: six seconds, sixty seconds, and five minutes. Providers of each service must deliver a full response by the specified time, and sustain that response sufficiently to provide an 'orderly transition' to the following frequency control service.

Contingency FCAS consists of six distinct products, each operated as a single market:

- Fast raise/lower – provides an active power response within 6 seconds of a frequency event and sustains for 60 seconds.
- Slow raise/lower – provides an active power response within 60 seconds of a frequency event and sustains for 300 seconds.
- Delayed raise/lower – provides an active power response within 300 seconds of a frequency event and sustains for 600 seconds.

Contingency FCAS is automatically triggered by generators or loads that are 'enabled' to provide services by NEMDE. These assets must autonomously monitor and respond to locally sensed frequency conditions within the 6, 60, or 300 seconds time base of the relevant contingency FCAS product.

### 1.3.2 MASS

In accordance with clause 3.11.2 (b) of the National Electricity Rules (NER), AEMO administers and maintains the Market Ancillary Service Specification (MASS).

The MASS includes:

- A detailed description of each of the eight market ancillary services.
- Performance and quality requirements that must be satisfied for each market ancillary service.

Prior to this trial, AEMO had not attempted to register a wind or solar plant as an ancillary service provider. However, the MASS is a 'technology-agnostic' specification. It describes ancillary service categories in terms of the maximum time period after an event for frequency response to occur and the minimum time for which the response must be maintained[10].

**Fast Frequency Response**

Currently there is no market framework for frequency control services faster than 6 seconds. The need for a Fast Frequency Response (FFR) service is under active consideration by AEMO and the Australian Energy Market Commission (AEMC) in their Frequency control frameworks review (refer to Section 1.4.2)[11,12].

## 1.4 Policy context

### 1.4.1 2017 Review of ESCOSA licensing conditions

Following a request in mid-2016 to support the Essential Services Commission of South Australia (ESCOSA) *Inquiry into licensing arrangements for generators in South Australia*[13], AEMO was actively engaged in a review of the Commission's licensing standards for inverter-connected generation in early 2017. AEMO's

[10] Further introductory information on FCAS and the MASS can be found in AEMO's *Guide to Ancillary Services in the National Electricity Market*, at https://www.aemo.com.au/-/media/Files/PDF/Guide-to-Ancillary-Services-in-the-National-Electricity-Market.ashx.

[11] Additional details on possible specification and applications of FFR services can be found in a working paper published by AEMO in late 2017, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017/FFR-Working-Paper---Final.pdf.

[12] Further information on the technical capability of utility-scale wind, solar and other technologies to provide FFR is available in an advisory report prepared for AEMO by General Electric (GE), at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017/2017-03-10-GE-FFR-Advisory-Report-Final---2017-3-9.pdf.

[13] Further information on ESCOSA's review is available at https://www.escosa.sa.gov.au/projects-and-publications/projects/inquiries/inquiry-into-licensing-arrangements-for-inverter-connected-generators.

recommendations[14] to ESCOSA included obligations for all new inverter-connected generation licensed in South Australia to have a minimum level of frequency control capability.

AEMO's recommended minimum level of capability included:

- The capability for new entrant inverter-connected plant to be controlled remotely by AGC signals.
  – This is the basic capability necessary to provide regulation FCAS.
- The capability for new entrant inverter-connected plant to provide an automatic active power response to locally measured frequency conditions.
  – This is the basic capability necessary to provide contingency FCAS.

AEMO consulted broadly with manufacturers across a variety of technologies in preparing this advice to ESCOSA, including wind turbine manufacturers, solar inverter manufacturers, and providers of utility-scale batteries. The consultation process concluded that the basic level of frequency control capability described above could be provided by the majority of manufacturers of each inverter-connected generation technology with little or no increase in project capital cost.

As discussed in Section 1.6, before this trial no wind or solar farm had registered to be an ancillary service provider in the NEM. Despite AEMO's finding that wind and solar plant could be equipped with frequency control capabilities without significant increases in project capital costs, end-to-end registration and testing processes with full integration into AEMO's bidding and market systems would be required to assess the degree and extent to which wind and solar generators could provide FCAS in accordance with the MASS.

NEOEN was a new entrant into the South Australian electricity market while the ESCOSA review was being finalised, and was willing to participate in this end-to-end frequency control demonstration project in collaboration with AEMO and ARENA.

### 1.4.2 Related policy development processes

This proof-of-concept was devised specifically to identify gaps and inform the evolution of policies and market arrangements in the NEM. Key current policy development processes relevant to the areas of frequency control and plant performance requirements are described below.

#### Generator technical performance standards Rule change

Following completion of ESCOSA's review of technical licensing conditions, AEMO lodged a Rule change[15] proposal on 11 August 2017 with the AEMC to align the negotiable NER connections framework with technical advice provided to ESCOSA. AEMO supports the use of a single, consistent framework for negotiation of generator performance standards in the NEM and submitted this Rule change proposal to the AEMC in accordance with recommendation 3.4 of the Finkel Review[16].

AEMO's Generator technical performance standards Rule change is still under consideration by the AEMC, with a final determination expected by 2 October 2018.

#### Frequency control frameworks review

In July 2017, the AEMC initiated a Review into NEM Frequency control frameworks[17], to assess whether current NEM regulatory arrangements were acting to effectively control of system frequency. The Review has broad Terms of Reference, including considering needs for mandatory governor response obligations, whether the

[14] AEMO's final recommendations to ESCOSA are available at https://www.escosa.sa.gov.au/ArticleDocuments/1050/20170817-Inquiry-LicensingArrangementsforGgneratorsSA-FinalReport.pdf.aspx?Embed=Y.

[15] Refer to the AEMC's website for full details of AEMO's Rule Change Proposal – Generator Technical Requirements, at https://www.aemc.gov.au/rule-changes/generator-technical-performance-standards.

[16] Finkel Review – *Independent Review into the Future Security of the National Electricity Market*, available at https://www.energy.gov.au/sites/g/files/net3411/f/independent-review-future-nem-blueprint-for-the-future-2017.pdf.

[17] Further information on Frequency control frameworks review available at https://www.aemc.gov.au/markets-reviews-advice/frequency-control-frameworks-review.

current FCAS market structure is fit for purpose, and opportunities for newer technologies (such as wind and solar) to offer services to maintain power system security.

The AEMC published a final report for this Review in July 2018.

### 1.4.3 Future trials and policy development processes

The findings of this project will inform future trials and the evolution of some of AEMO's policies. Notable related trials and AEMO policy consolation processes are briefly set out below:

- 2018 MASS Review – review of the MASS expected to commence in Q3 2018 (final date to be announced by AEMO), which will include consultation on the principles for registration and operation of wind FCAS. The consultation will have two key focus areas:
  - To improve power system frequency control in the NEM by better defining, and potentially amending, the frequency response required contingency and regulating services; and
  - To amend the MASS to provide to better facilitate the incorporation of non-traditional frequency control technologies.
- Musselroe Wind Farm FCAS trial – will investigate the economic and commercial case for FCAS participation by wind farms and, if viable, enabling the frequency controllers at this Tasmanian wind farm. This project will support assessment of the business case for current and future participants seeking to participate in the FCAS market. The project will also evaluate the installation of utility-scale storage to capture energy currently not dispatched due to a combination of network and wholesale market conditions, as well as providing FCAS and other grid support services from Musselroe Wind Farm[18].
- Market Participant 5-minute Forecasting[19] – a collaboration by AEMO and ARENA, in conjunction with forecasting service providers and existing wind and solar projects. The objective of the program is to demonstrate the potential benefits of wind and solar generator self-forecasting to operation of the power system. It is anticipated that the use of self-forecasting will deliver system-wide benefits by reducing generation forecast error, and provide greater autonomy to semi-scheduled generators by allowing them to develop and use their own forecasts to set dispatch targets in NEMDE.

## 1.5 HWF2 FCAS trial objectives

The objectives and intended outcomes agreed by AEMO, ARENA, and NEOEN for this project are presented below. These were included in the funding agreement for this project between ARENA and NEOEN. These objectives were conceived to facilitate development of frequency control capability from the renewable energy sector and to identify Rules and procedures that may require amendment as a result of the trial:

- To model, implement, and test the capability of HWF2 to be remotely controlled by AEMO to provide FCAS.
- To determine the types of FCAS for which the HWF2 can have its generating units classified in accordance with NER 2.2.6.
- To successfully complete a 48-hour trial of bidding and operating in the FCAS markets for which HWF2 can be classified, or, where HWF2 cannot be classified, successfully complete a market simulation trial. For the avoidance of doubt, successful completion of the trial means that the Recipient has fulfilled its obligations under the Detailed Test Plan.
- To determine the delayed response time and the accuracy of HWF2's response to the regulation set-point changes.
- If technical or regulatory barriers are identified that restrict the ability of HWF2 Pty Ltd to comply with the MASS or to fulfil all requirements for AEMO to classify HWF2's generating units as ancillary services

[18] Further information available from https://arena.gov.au/projects/musselroe-wind-farm-fcas-trial/.

[19] Further information available from https://www.aemo.com.au/Stakeholder-Consultation/Industry-forums-and-working-groups/Other-meetings/Market-Participant-5-Minute-Self-Forecast.

generating units under clause 2.2.6 of the NER, AEMO and NEOEN are to provide feedback to support reviewing the MASS to address identified issues, if required.

- To document and share the results of the activity in accordance with the Knowledge Sharing Plan required under this agreement.

## 1.6 Areas of focus for AEMO

AEMO looks to undertake proof-of-concept projects that reduce risks to power system security or identify and remove barriers to entry for new technologies and services that are consistent with the National Electricity Objective.

Secure operation of NEM FCAS markets requires a high level of coordination between AEMO and FCAS providers. In the case of a wind or solar farm this includes, but is not limited to:

- Estimation of available wind resource and associated power (referred to as a "Possible Power" forecast) expected to be available prior to a 5-minute dispatch interval. This is a critical factor for a wind farm or other FCAS providers to bid capacity into the FCAS markets. Wind forecasting and Possible Power are discussed further below.
- Clarity on the feasible range of operating conditions for which energy and FCAS from a registered provider can be offered to the market. This includes the ability for system security services, such as FCAS, to be provided immediately following a significant supply-demand interruption that may result in extreme or unstable voltage conditions (discussed further in Section 2.1.3).

Prior to undertaking the HWF2 trial, AEMO was unsure if information on classification, testing, and operational parameters would need to be added to the MASS to adequately cover the provision of FCAS by wind and solar farms, and provide sufficient information to support an application to classify them as ancillary service generating units. AEMO was also aware of the importance of developing guidance on operational parameters for wind and solar farms as to how much pre-curtailment (also called 'headroom') would be necessary to give confidence that security services could be provided in the presence of variations in wind and solar energy not anticipated by 5-minute ahead forecasting.

Before the trial, AEMO had limited operational familiarity in dispatching ancillary services from wind farms. AEMO focused on the following operational and procedural matters, with the specific goal of building confidence in these technologies.

**Possible Power and Unconstrained Intermittent Generation Forecast (UIGF)**

Possible Power is an estimate produced by each Market Participant of the active power available from their semi-scheduled generating units based on available wind or solar energy, subject only to technical factors affecting operation of its generation and connection assets (local limits) and excluding the impact of transmission and distribution network limits.

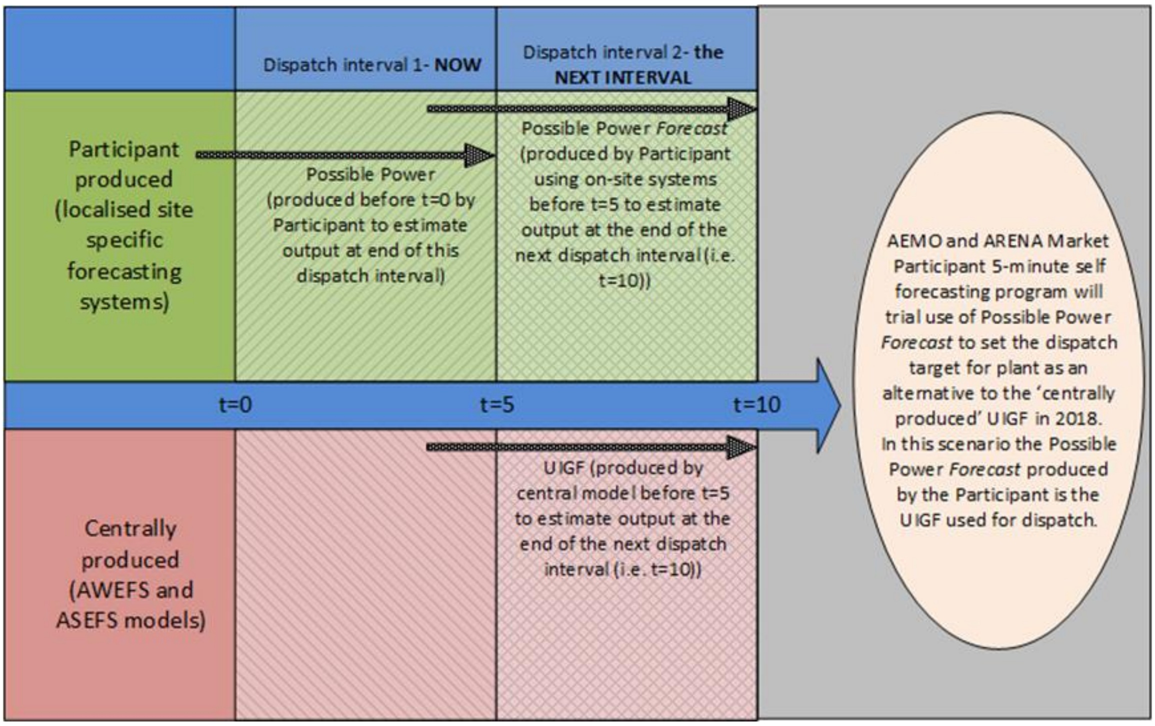
The current value of Possible Power can be provided to AEMO via supervisory control and data acquisition (SCADA) systems, and is derived from the control system of the generating units or by third-party forecasting systems.

A UIGF[20], for dispatch purposes, is a 5-minute ahead forecast of the active power from a semi-scheduled generating unit at the end of the next dispatch interval. UIGF is defined in clause 3.7A of the NER.

Currently, all values for UIGF used to set dispatch targets for semi-scheduled generators are determined by AEMO's centrally produced Australian Wind Energy Forecasting System (AWEFS) and Australian Solar Energy Forecasting System (ASEFS) models. However, as part of the Market Participant 5-minute Forecasting project, participants will be able to provide their own Possible Power Forecast to set dispatch targets, rather than using AEMO's centrally-produced values UIGF, as shown in Figure 4.

[20] This a defined term in chapter 10 of the NER, and is discussed in NER clause 3.7B. See also Section A3.2 in Appendix 3.

**Figure 4 Possible Power and UIGF**




### FCAS Classification criteria for wind and solar plant

- Test if version 5 of the MASS was suitable for FCAS provision from wind and solar farms; if amendments were required, identify and propose changes in a revised document as a part of a NER Consultation round in areas such as:
  - Pre-classification engineering capability tests – such as testing active power response to a frequency event profile fed into plant supervisory controls.
  - Plant simulation requirements – necessary to provide reasonable confidence that services which are relied upon for secure system operation can be delivered by each ancillary service generating unit.

### Operational management of FCAS from wind and solar plant

- Identification of suitable mechanisms for market participants[21] to estimate active power available to provide ancillary services on a 5-minute ahead basis. As discussed above, this Possible Power forecast is important for FCAS providers as it enables them to evaluate how much service can be reasonably provided in bids submitted to AEMO.
- Identification of suitable communications channels to provide the 5-minute ahead Possible Power forecast to NEMDE. This could be through the existing market bidding system or other means (e.g. secure Application Program Interface (API)).
- Development of basic guidance as to how much pre-curtailment (also called 'headroom') is required for reliable service delivery[22].

Discussion of how these areas of focus were addressed by AEMO during the trial is presented in Chapters 3 and 4.

[21] It is the responsibility of each market participant submitting energy and ancillary to bid in good faith such that energy and services can be provided.

[22] Consistent with requirements to bid in good faith, it is the market participant's responsibility to be maintain headroom to ensure service delivery.

# 2. Results and outcomes

## 2.1 FCAS classification

### 2.1.1 The FCAS classification

This section provides a simplified overview of the process for demonstrating FCAS capability by generation or loads prior to classification and operation in the FCAS markets.

#### Verification of communication and telemetry requirements

Prior to being registered as an ancillary service provider, proponents must provide evidence to AEMO that they have sufficient telemetry and communication and telemetry requirements in place to record the provision of FCAS for verification purposes[23].

Generally, the requirements for slow and delayed services are similar (data sampling of less than or equal to 4s per measure). Telemetry requirements for fast services are more onerous than slow or delayed services because the data sampling intervals are much smaller (at least 50 ms per sample).

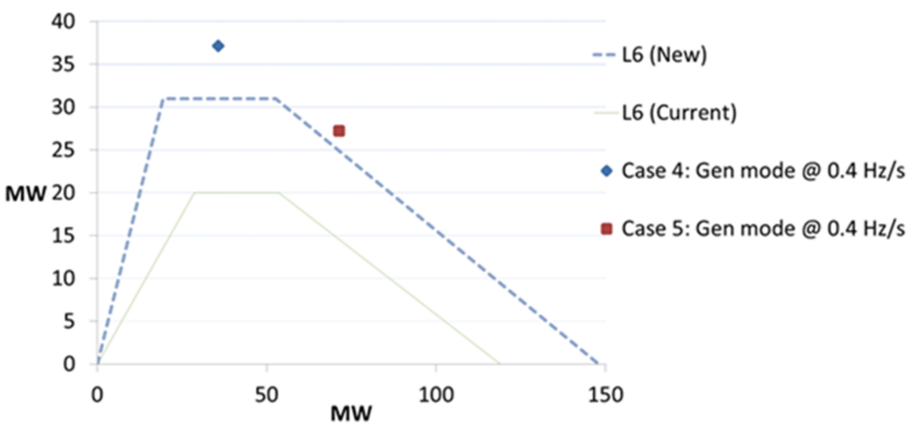
#### Assessment of FCAS capability and proposed FCAS trapezium

FCAS trapeziums are used by NEMDE to schedule FCAS by comparing its energy and contingency FCAS bids to the plant capability envelope. FCAS trapeziums represent the capability envelope of an FCAS provider to deliver energy and FCAS in each dispatch period and are discussed in further detail in Appendix A3.

A major part of the pre-classification technical assessment is to check that plant can provide FCAS per the proposed FCAS trapezium. It is critical that FCAS Trapeziums accurately reflect the actual performance of plant, as they are relied on by NEMDE to dispatch resources to maintain system security.

AEMO's process for confirming an FCAS trapezium requires the *actual capability* of the unit to be assessed for a range of representative base points (or cases) as shown in Figure 5 below.

**Figure 5 Example FCAS trapezium for assessment**




[23] For contingency FCAS, these requirements are listed in section 3.6, 4.6, and 5.6 of MASS (version 5 in effect since 30 July 2017).

**Simulations and on-site testing**

The method for generating representative base point data to evaluate the proposed FCAS trapezium will depend on the circumstances of the plant being classified, including the nature of contingency events (sometimes referred to as faults) that AEMO considers to be reasonably possible in the relevant area of the power system. Under the current version of the MASS (version 5), AEMO will accept evidence of plant performance using representative data derived from measured performance and simulations.

In the first instance, AEMO will request that a proponent looking to register in FCAS markets provide base point performance data from on-site testing using an 'injected' frequency signal. Additional modelling and data from power system simulations may be requested if AEMO believes the results from on-site frequency 'injection' tests are not representative of actual operation under reasonably expectable contingency conditions.

**Evaluation of on-site testing and simulations results**

Once the representative base point pairs have been obtained via on-site tests, or simulation results, AEMO uses the MASS FCAS Verification Tool (FCASVT)[24] to confirm that fast, slow, or delayed services have been provided according to MASS requirements.

Classification of a unit to provide FCAS may be approved once:

- Results from tests and simulations confirm the capability of the proponent to provide contingency FCAS according to their proposed FCAS trapezium; and
- Evidence has been provided to confirm that telemetry suitable for verification of FCAS is installed at the site; and
- All other information required by the AEMO application form is provided.

Further detailed information on FCAS trapezia, bidding, operation, co-optimisation, and dispatch of FCAS from wind and solar farms is provided in Appendix A3.

### 2.1.2 On-site capability testing at HWF2

Pre-classification tests were undertaken at a range of active power base points of 40, 74, and 88 MW, according to the *Detailed Test Plan* included in Appendix A1. Pre-classification tests were performed during the commissioning phase of HWF2 on 17, 24, and 27 October 2017.

Testing undertaken included standard under-/over-frequency ramp testing (according to the MASS), injection testing of non-credible contingency events, and AGC setpoint following.

AEMO was an observer to these tests, which were performed by Siemens-Gamesa Australia and NEOEN. Full detail of testing undertaken is provided in Appendix A1. Further detail on test results is available in reporting provided by Siemens-Gamesa Australia[25].

On-site tests provided acceptable results according to AEMO's evaluation methodology for six of the eight FCAS products for which HWF2 was seeking classification. AEMO requested that additional data be provided from power system simulations to assess the ability of the wind farm to provide fast FCAS. These simulation results indicated that HWF2 was unlikely to be able to provide fast services under reasonably expectable conditions. This issue is discussed further in section 2.1.3.

**Key finding: ancillary services HWF2 was classified to provide**

Based on the other evidence provided to AEMO, HWF2 was classified for raise and lower services in the regulation, slow contingency, and delayed contingency FCAS markets on 1 December 2017, however, HWF2 was unable to meet the classification requirements for fast contingency services (refer to Section 2.1.3 below).

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[24] Available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Ancillary-services/Market-ancillary-services-specifications-and-FCAS-verification.

[25] Available at https://arena.gov.au/projects/hornsdale-wind-farm-stage-2/.

### 2.1.3 Issues identified during pre-classification testing and simulations

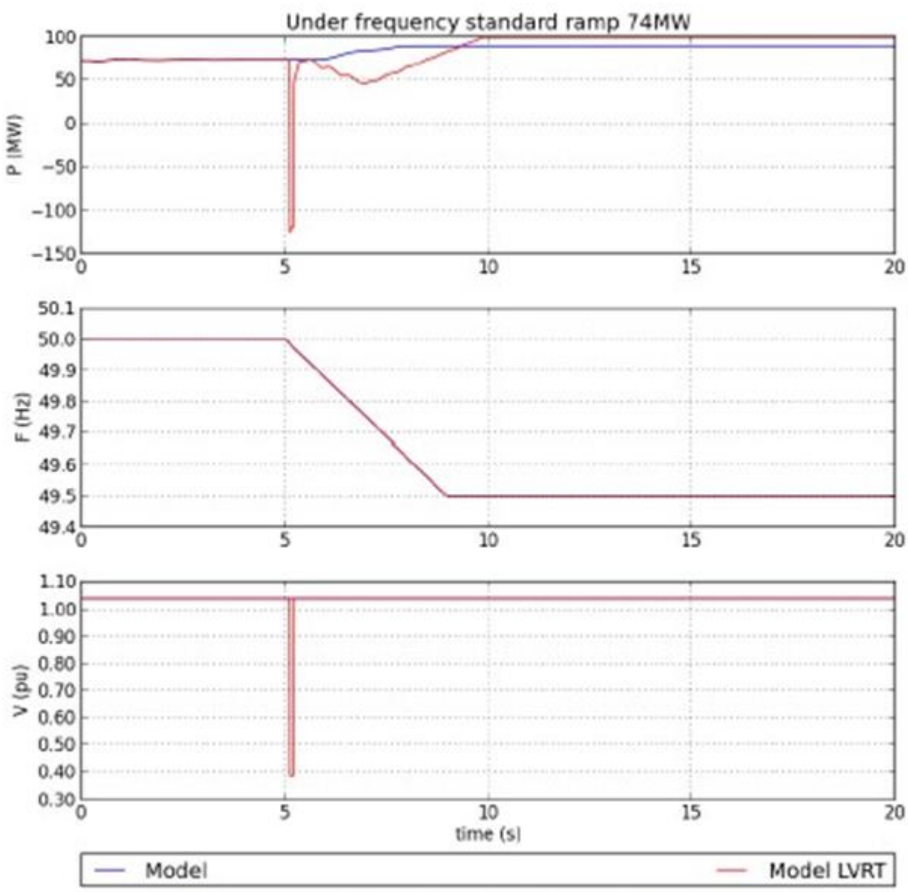
**Challenges in providing fast contingency services following voltage instability**

As part of the testing process to assess the capability of HWF2 to provide all eight FCAS services, AEMO requested that simulations be carried out to demonstrate the FCAS capabilities of the WTG following a simultaneous frequency and voltage dip. Events involving simultaneous frequency and voltage reductions have been observed in the weak grid conditions present in the South Australian power system, so the presence of these conditions is considered to be possible under some conditions.

As discussed in Siemens-Gamesa Australia's Knowledge Sharing Article[26], Low Voltage Ride Through (LVRT) is a standard control mode used by wind turbines in Australian and international grid codes to provide voltage support if voltage drops below a threshold level (normally 90% of nominal voltage at the point of connection). Operation in LVRT prioritises the provision of reactive power to the power system over active power (which is required to support system frequency) while voltage is below this threshold.

Preliminary power system simulations produced for the trial identified a conflict between the LVRT operation required for compliance with HWF2's technical Generator Performance Standard (GPS) and the wind farm's ability to provide fast raise and lower FCAS during a reasonably expectable contingency event. Figure 6 shows a typical simulation result. At 74 MW hold point, following the LVRT and recovery, the active power *reduces* substantially for 2-3 seconds before recovering to provide a raise signal.

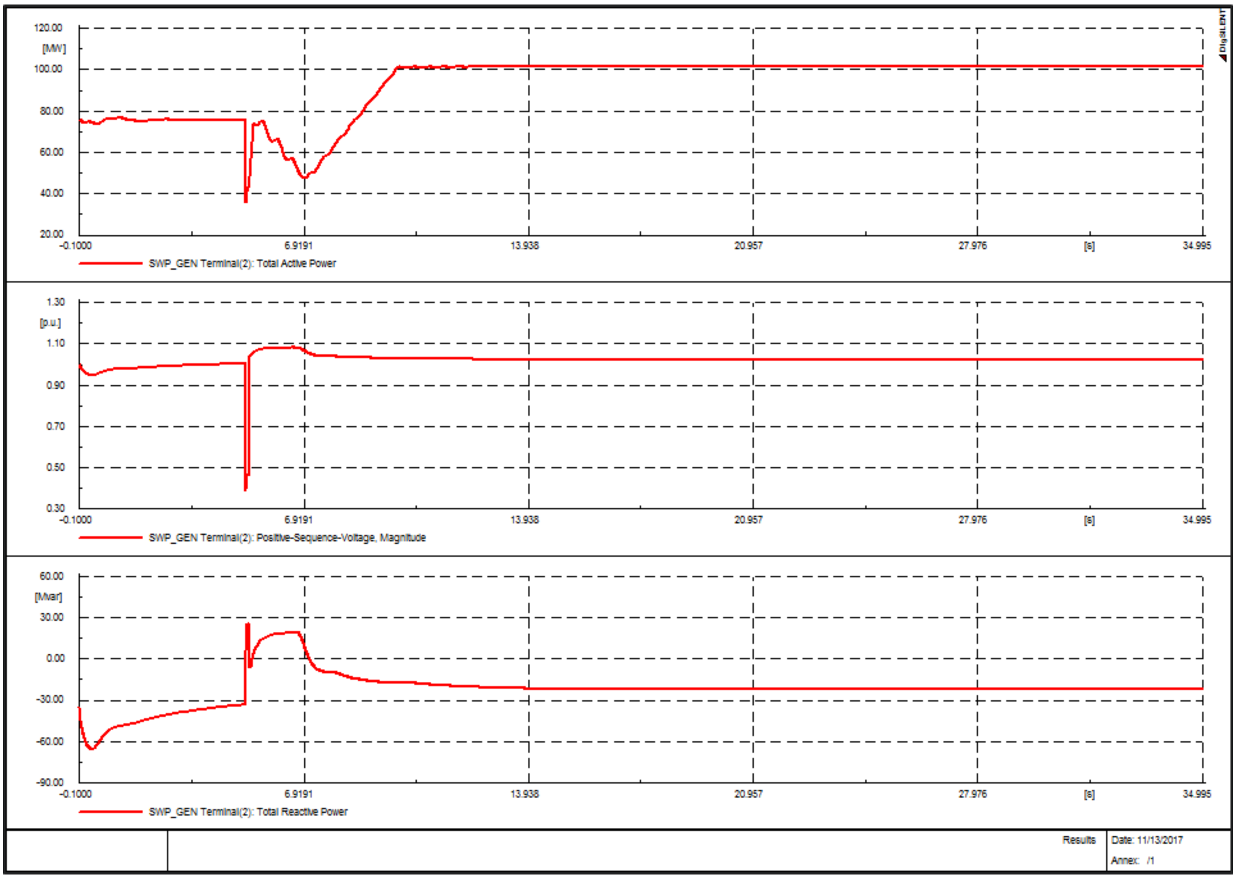
**Figure 6 Simulation of standard under-frequency ramp at 74 MW base point**




[26] Refer to section 8.1.2 of the Siemens-Gamesa report.

Siemens provided active power output data at the turbine level from simulations which confirmed the decrease in active power, as observed in Figure 7.

**Figure 7 Simulation of standard under-frequency ramp 74 MW – turbine level**




Simulation results confirmed a high reactive power injection after the fault which reduced the wind farm's ability to provide active power needed for these services. The conflicting objectives of LVRT and fast acting frequency response impeded the ability of the wind farm to reasonably provide fast raise and lower services and HWF2 could not be classified to provide fast raise and lower contingency service.

### The need for headroom

During the pre-classification technical assessment process, AEMO must consider whether an intending FCAS provider can operate in energy and FCAS markets according to their proposed FCAS trapezium. If the power system is relying on enabled ancillary services being available to the grid following occurrence of a fault, the system operator will need to be confident that these services can be provided accurately and precisely as expected. In the case of wind and solar plant, the ability of the plant operator to provide an acceptable forecast of generation in the coming dispatch interval as part of their FCAS offers (bids) becomes particularly important.

To provide AEMO with confidence in the forecasting capability, an FCAS parameter was developed to reflect a minimum headroom (or pre-curtailment) requirement for both the raise and lower services. This minimum headroom approximates a 3 standard deviation error in its 5-minute ahead generation forecast (that is, an error not exceeded for 99.7% of the time). This ensures that generator output can be steadily controlled over the 5-minute interval over which it may be enabled to provide the service. Failing to provide the service could have an adverse impact on frequency.

For HWF2, this calculation resulted in a minimum of around 10 MW of headroom to manage the risk of forecasting error (or 10% of registered capacity) across all operating conditions, measured over the period from 21 February to 18 July 2017. It is noted that this period was during the commissioning phase of the HWF2 wind farm, for which forecasting performance data was available – this minimum level of 10 MW of headroom resulted from benchmarking against actual forecast data from this period.

A detailed explanation of why a minimum level of headroom is required, and how to calculate it, is provided in Appendix A3.

**Key finding: headroom is required to ensure ancillary services can be delivered**

Based on what was learnt in establishing this trial, AEMO had developed a procedure for new wind or solar farms seeking to register for FCAS that do not have historical forecasting data to estimate forecast error. AEMO will determine a generic minimum headroom factor and allow review after six months of actual operation and assessment of forecast performance. This opportunity to review the minimum headroom factor is particularly relevant for those farms electing to provide a self-forecast, anticipated to be an improvement over AEMO's forecast. The potential for market participant self-forecasting to improve outcomes in the NEM will be investigated during AEMO and ARENA's Market Participant 5-minute Forecasting project.

## 2.2 Market trial

### 2.2.1 Process

The 48-hour market trial was conducted over a period from 19 December 2017 to 1 February 2018 following classification of HWF2 in FCAS markets on 1 December 2017. To gain the broadest possible experience and insights observing ancillary service provision from HWF2, it was agreed between the parties involved in the trial that FCAS would be offered in a variety of service combinations, each with different wind and system constraint conditions.

A summary of the range of service offerings and wind conditions is provided below in Table 2. In this table:

- RReg and LReg mean regulation raise and regulation lower FCAS.
- R5/L5 mean delayed (5-minute or 300-second) raise/lower contingency FCAS.
- R60/L60 mean slow (60-second) raise/lower contingency FCAS.
- R6/L6 mean fast (6-second) raise/lower contingency FCAS.

**Table 2 Summary of services offered during market trial period**

| Test Number | FCAS offer description | Approximate average wind speed (m/s) | Duration (hrs) | Expected outcome |
|---|---|---|---|---|
| 1 | 20 MW RReg only | 5 | 2 | Nominal operation |
| 2 | 20 MW LReg only | 5 | 2 | Nominal operation |
| 3 | 20 MW R60/R5 only | 5 | 2 | Nominal operation |
| 4 | 20 MW L60/L5 only | 5 | 2 | Nominal operation |
| 5 | 20 MW R60/R5 and 20 MW L6/L60 both enabled | 7+ | 2 | Up to 40 MW movement in combined raise and lower direction |
| 6 | 10 MW R60/R5 and 10 MW L60/L5 at $0, 10 MW R60/R5 and 10 MW L60/L5 near price-setting range | 7+ | 4 | Up to 20 MW movement in combined direction, then additional 20 MW being enabled as price moves in between bid bands |
| 7 | 20 MW RReg only | 9 | 2 | Up to 20 MW curtailment from AGC high limit at times |

| Test Number | FCAS offer description | Approximate average wind speed (m/s) | Duration (hrs) | Expected outcome |
|---|---|---|---|---|
| 8 | 20 MW LReg only | 9 | 2 | Up to 20 MW curtailment from AGC high limit at times when responding to high frequency |
| 9 | 20 MW R60/R5 only | 9 | 2 | Up to 20 MW curtailment from AGC high limit at times |
| 10 | 20 MW L60/L5 only | 9 | 2 | Up to 20 MW curtailment from AGC high limit at times when responding to high frequency |
| 11 | 20 MW LReg and 20 MW RReg both enabled | 10+ | 2 | Up to 40 MW movement in combined raise and lower direction |
| 12 | 10 MW LReg and 10 MW RReg at $0, 10 MW LReg and 10 MW Rreg near price-setting range | 10+ | 4 | Up to 20 MW movement in combined direction, then additional 20 MW being enabled as price moves in between bid bands |
| 13 | 20 MW RReg only | 13 | 2 | Nominal operation |
| 14 | 20 MW LReg only | 13 | 2 | Nominal operation |
| 15 | 20 MW R60/R5 only | 13 | 2 | Nominal operation |
| 16 | 20 MW L60/L5 only | 13 | 2 | Nominal operation |
| 17 | All services offered | 18+ | 3 | Dispatch conditions under binding conditions |
| 18 | All services offered | 18+ | 3 | No constrained conditions, but dispatch conditions under S_NIL_STRENGTH_2 (SA system strength constraint) invoked but not binding |
| 19 | All services offered | Increasing wind conditions | 3 | • Expected to utilise a 2-3 hr slow wind ramping up event, to observe AGC upper limit (mapped to actual Possible Power[A]) increasing the effective FCAS Enablement Max and the energy curtailment upper break-point.<br>• Increasing wind during the DI does not change its curtailment level (unless actually delivering FCAS response) |
| 20 | All services offered | Decreasing wind conditions | 3 | • Expected to utilise a 2-3 hr slow wind ramping down event, to observe Possible Power/AGC upper limit decreasing the effective FCAS Enablement Max and the energy curtailment upper break-point.<br>• Despite a drop in Possible Power during a DI that is not forecast, wind farm is still able to deliver its full enabled raise/lower response (because registered FCAS trapezium angles allow for 5-minute forecast error) |

A. This is an estimate of the current Possible Power.

All tests were completed according to the descriptions shown in Table 2, except for tests 17 and 18. These conditions occurred infrequently during the approximately two-month span of the market trial.

AEMO and NEOEN included basic and flexible provisions in the market trial plan for NEOEN to:

- Support system security by contacting the South Australian control room prior to commencing testing to ensure no extraordinary risks were affecting the South Australian power system; and
- Maximise the likelihood of FCAS being enabled by providing guidance on the pricing of FCAS and energy offers (discussed further in Section 2.2.4).

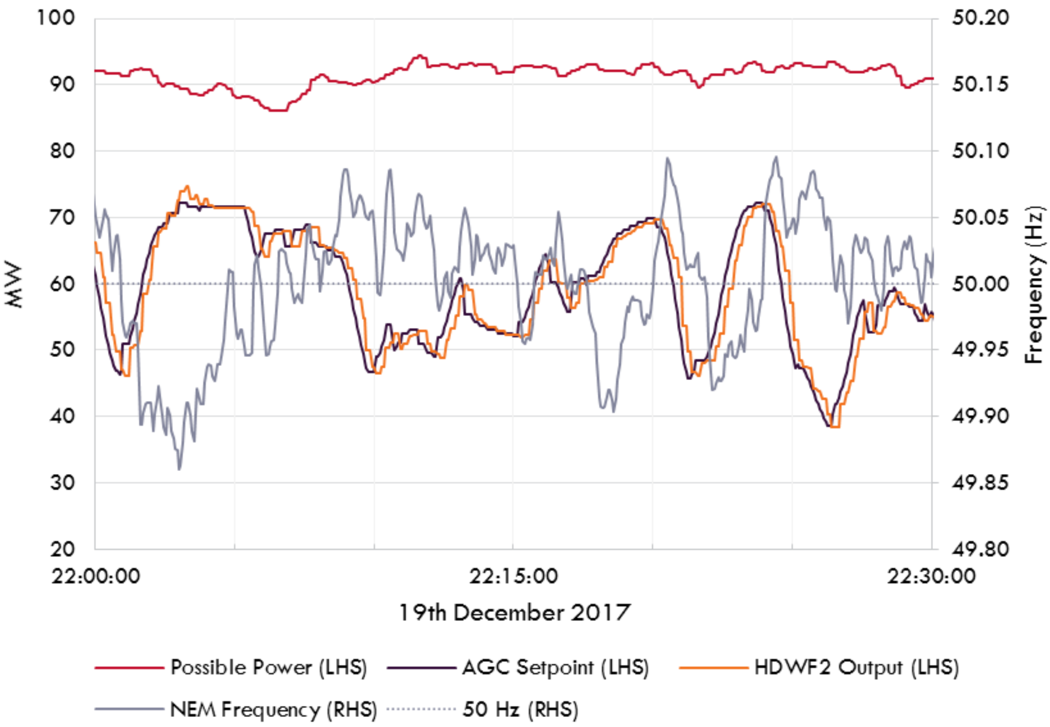
Complete information on these points can be found in the Market Trial Plan included as Appendix A1 to this report.

### 2.2.2 Delivery of raise and lower regulation FCAS

When HWF2 was enabled to provide regulation FCAS, its performance in delivering that service was generally very good.

Figure 8 below shows the performance of HWF2 between 2200 hrs and 2230 hrs on 19 December 2017 (Test 11). During this time, HWF2 offered and was enabled for 20 MW of raise regulation and 20 MW of lower regulation services. The Possible Power from HWF2 was consistent due to a steady wind speed of 10-11m/s. The output of HWF2 follows, to a high level of precision, the AGC set point in the direction to correct frequency.

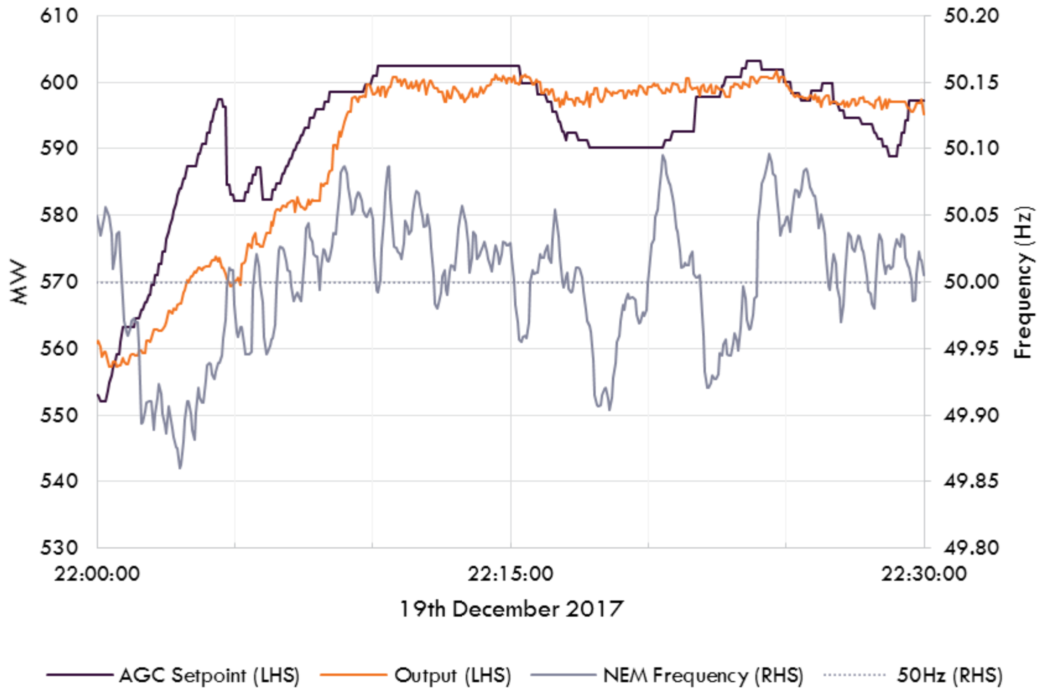
**Figure 8 HWF2 regulation FCAS performance**




For comparison, the output of a synchronous generator that was enabled for a similar amount of raise and lower regulation FCAS over the same set of dispatch periods is shown below in Figure 9.

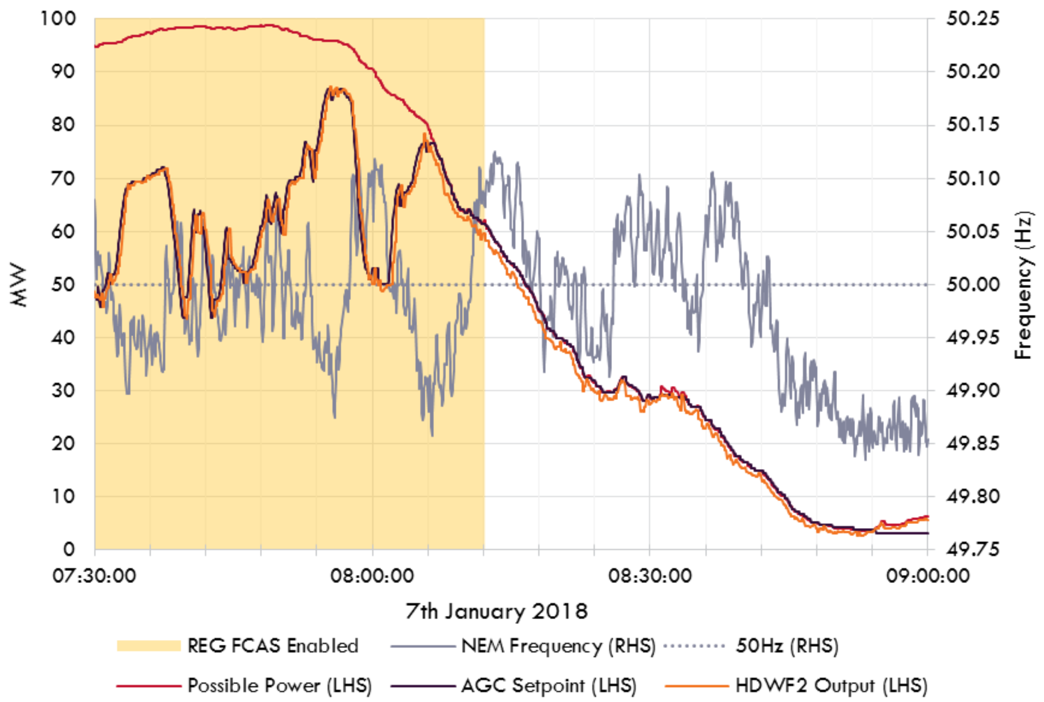
HWF2's regulation performance, as shown in Figure 8, is more precise than that of the synchronous generator providing regulation services.

**Figure 9 Comparative regulation FCAS performance by a synchronous generator**




In a separate test, HWF2 offered regulation FCAS (along with contingency FCAS) under decreasing wind conditions on 7 January 2018 (Test 20). While regulation FCAS was offered until 0900 hrs, HWF2 was only enabled for regulation FCAS until 0810 hrs, as the actual Possible Power fell due to declining wind speeds. NEMDE stopped enabling HWF2 FCAS when its output fell below its enablement minimum. When HWF2 was enabled for regulation FCAS (shown in the yellow shaded period in Figure 10), its output closely followed the AGC setpoint to correct frequency. When HWF2 was no longer enabled for regulation FCAS, its output converges with its actual Possible Power.

**Figure 10 HWF2 regulation FCAS performance during declining wind speeds**



### 2.2.3 Delivery of raise and lower contingency FCAS

The performance of HWF2 in the provision of contingency FCAS could not be fully evaluated. This was due to rarity of contingency events occurring while HWF2 was enabled by NEMDE to provide contingency FCAS.

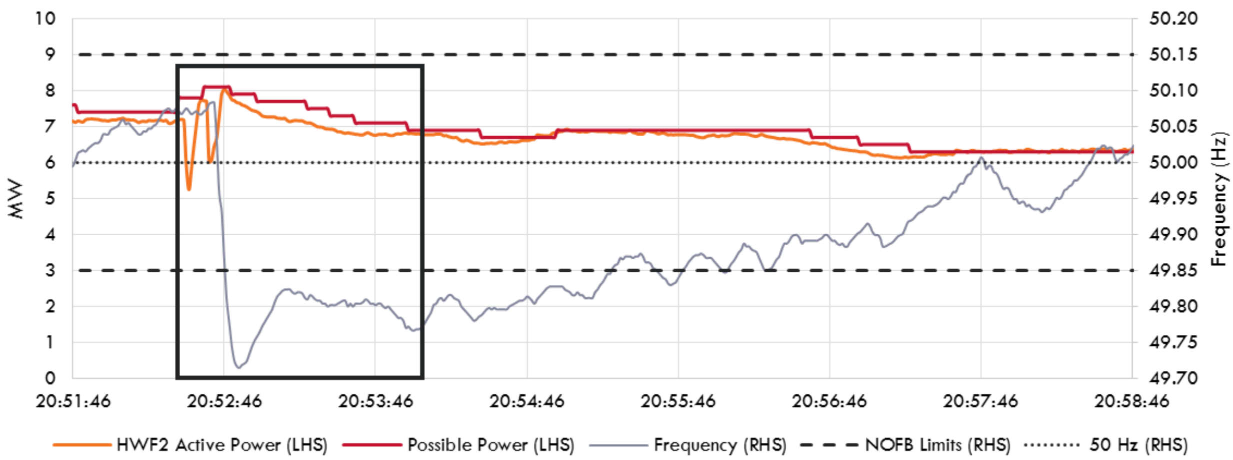
However, the droop mode for HWF2 was permanently enabled for the entire duration of the trial period. This meant that the wind farm should have responded to frequency deviations outside the Normal Operating Frequency Band (NOFB) by increasing or decreasing output, even when not enabled by NEMDE.

The graphs below show the response from HWF2 when frequency deviated from the NOFB, even when HWF2 was not enabled by NEMDE to provide contingency FCAS.

**Raise contingency services**

NEM frequency fell below the NOFB lower limit of 49.85 Hz on 26 December 2017 at approximately 20:52:46, as shown below in Figure 11. The active power output from HWF2 momentarily increased after the deviation from the NOFB, and gradually decreased as system frequency recovered.

**Figure 11 HWF2 active and Possible Power during low system frequency on 26 December 2017**

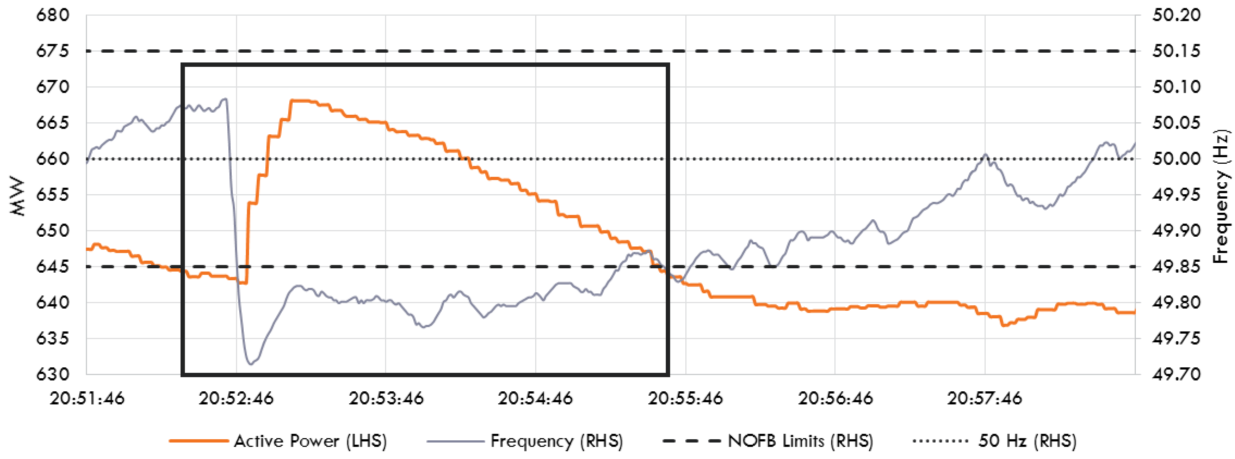



However, while system frequency was still recovering and below 49.85 Hz, HWF2 did not maintain an active power output above its initial output at the time of the frequency disturbance. Had HWF2 operated with greater headroom between its active power output and Possible Power, the raise response could potentially have been sustained[27].

For comparison, the active power output of a synchronous generator providing raise contingency FCAS using a variable controller is shown below in Figure 12.

[27] This is in part because NEMDE was using Possible Power (that is, power available now) to estimate plant output in the next dispatch interval, rather than the 5-minute ahead Possible Power *forecast*, which will be investigated through the Market Participant 5-Minute Forecasting program.

**Figure 12 Synchronous unit active power during low system frequency event on 26 December 2017**



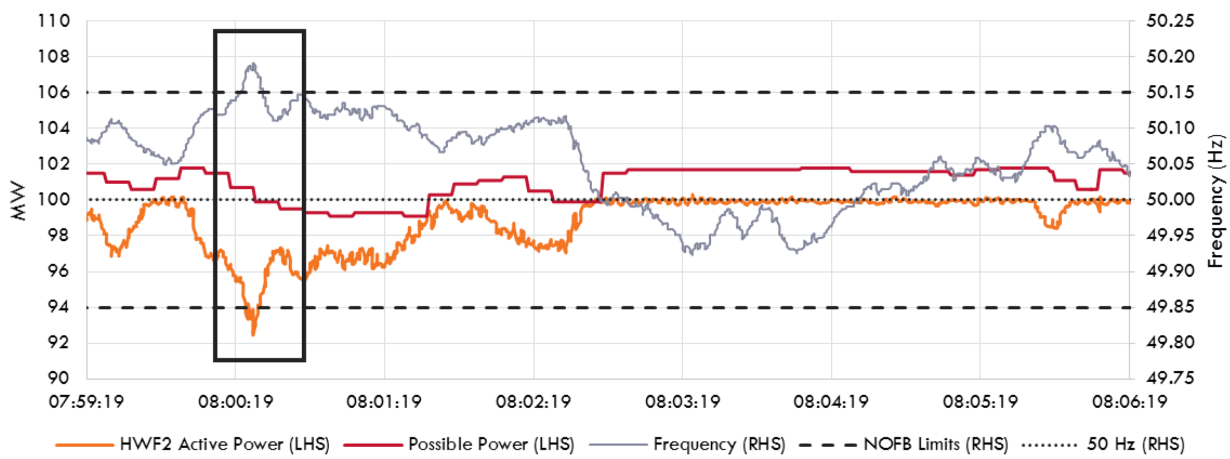

In the example shown above, the synchronous unit's active power increased when the system frequency fell below the NOFB lower limit, and the active power response was sustained until the frequency recovered.

The MASS FCAS Verification tool could not be used to confirm HWF2's ability to provide slow and delayed raise contingency FCAS, as the active power increase after the low frequency event was not sustained.

### Lower contingency services

NEM frequency exceeded the NOFB upper limit of 50.15 Hz on 16 January 2018 at approximately 08:00:19, as shown below in Figure 13. The active power output from HWF2 decreased when the system frequency exceeded 50.15 Hz and returned to its initial output as frequency recovered.

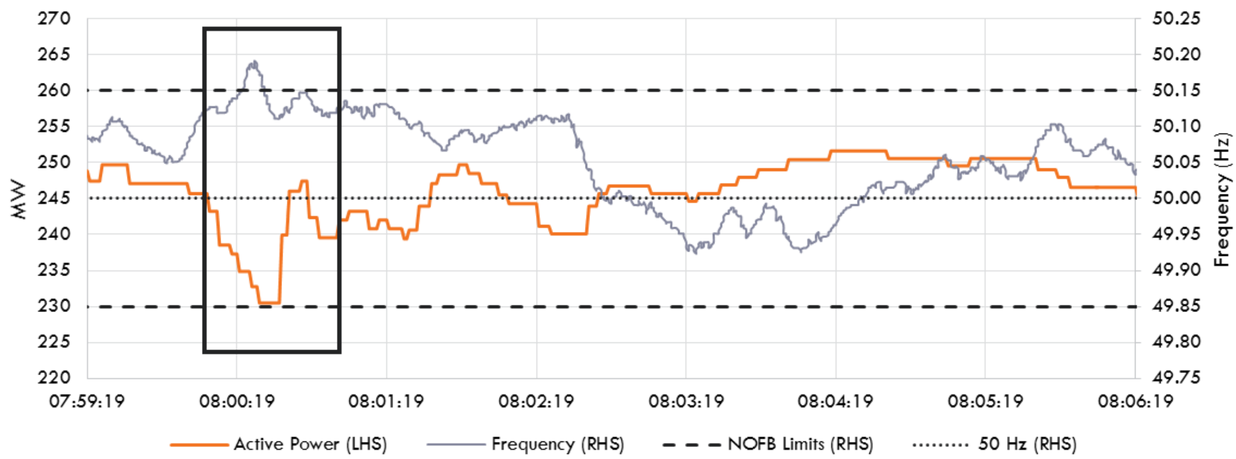
**Figure 13 HWF2 active and possible power during high system frequency event on 16 January 2018**




There was no significant change in HWF2's possible power during the frequency excursion, which indicates that the decrease in active power output was in response to the high frequency event, as opposed to falling wind speeds.

For comparison, the active power output of a synchronous generator providing lower contingency FCAS using a variable controller is shown below in Figure 14.

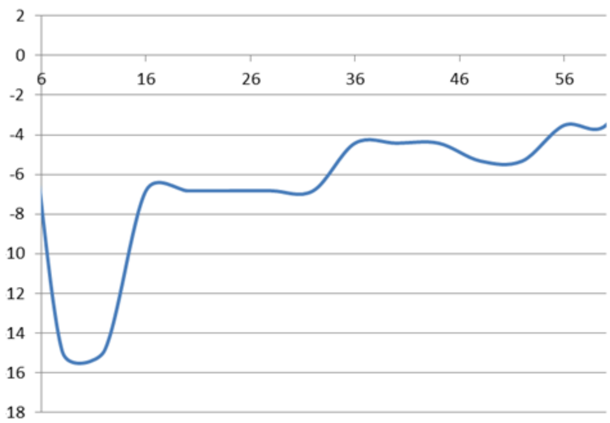
**Figure 14 Synchronous unit active power during high system frequency event on 16 January 2018**




The active power of the synchronous unit decreased when the system frequency exceeded the NOFB, and returned to its initial output once the system frequency returned to the NOFB.

HWF2's ability to provide lower contingency FCAS was confirmed using the MASS FCAS verification tool. Figure 15, from the MASS FCAS verification tool, shows the compensated lower FCAS response when the frequency exceeded the NOFB.

**Figure 15 Compensated Basic response from MASS FCAS Verification Tool (MW)**




## 2.2.4 Issues identified in the market trial

This section presents detail on issues that were not anticipated in the planning phase of this project, and which affected dispatch of FCAS in the market trial. Discussion here is intended to educate and inform other intending FCAS participants.

### Unexpected outcomes arising from FCAS co-optimisation

Plant operating in FCAS markets may find itself not being enabled for FCAS, despite offering FCAS at a price below the dispatch price – an unexpected outcome that may result from co-optimisation of energy and FCAS and operation within an FCAS trapezium. Understanding the co-optimisation of energy and FCAS is particularly important for semi-scheduled generators who want to offer FCAS, because they will typically be operating at the Enablement Max, that is, the extreme right-hand point of the FCAS trapezium, which is often limited to its Unconstrained Intermittent Generation Forecast (UIGF)[28].

Semi-scheduled generators tend to offer their entire energy availability at negative prices, and very often at the market floor price of -$1,000/MWh. In general, energy offered at negative prices will be dispatched. Consequently, semi-scheduled generators will almost always be fully dispatched in the energy market. If those generators are also offering FCAS, that means they will almost always be dispatched at Enablement Max. Furthermore, a generator operating at Enablement Max is typically unable to offer any raise FCAS, as shown in the generalised FCAS trapezium in Figure 21 in Appendix A3.

When a generator is operating at Enablement Max, and because energy and FCAS is co-optimised, the dispatch process will reduce the energy target below Enablement Max to enable FCAS only when it is cheaper overall to do so. Reducing the energy target below Enablement Max means the loss of energy must be supplied by someone else. It will be cheaper to do this only when the reduction in FCAS costs is greater than the increase in energy costs. This is unlikely to happen while a generator is offering negative energy prices.

To understand how this might work in practice, consider the following example:

- A semi-scheduled generator is offering to sell energy at -$1,000/MWh and raise regulation FCAS at $1/MWh.
- The prevailing energy price is $100/MWh and the prevailing raise regulation FCAS price is $10/MWh.
- Because the generator is offering energy at the market floor price, it is dispatched in the energy market at Enablement Max.
- The upper slope of the FCAS trapezium is 45°. This means the generator must be backed off by 1 MW in the energy market to provide 1 MW of raise regulation FCAS.
- Reducing the generator's energy output by 1 MW (at -$1,000) would require replacing it with 1 MW of energy from other sources at the prevailing energy price ($100). Because the generator's energy price is negative, the net cost is $1,100.
- Increasing the generator's FCAS enablement by 1 MW (at $1) would allow a reduction of 1 MW of raise regulation FCAS from other sources at the prevailing FCAS price ($10). The net benefit is $9.
- The overall cost of enabling the generator for 1 MW of raise regulation FCAS is therefore $1,100 - $9 = $1,091, that is, an increase. Co-optimisation of energy and FCAS would never allow this to happen.

In general, a generator will be enabled for FCAS only when the difference between their FCAS offer price and the prevailing FCAS price is greater than the difference between their energy offer price and the prevailing energy price. This is unlikely to occur if the generator is offering negative energy prices unless the prevailing FCAS price is very high.

During the FCAS trial, there were 50 dispatch intervals (or 5.8% of the time) when no FCAS was enabled for the HWF2 unit because its effective FCAS offer was uneconomic due to the relative high cost of trading off its energy target against FCAS enablement along the upper slope of its FCAS offer trapezium.

Of those uneconomic dispatch intervals, there were 37 intervals where FCAS regulation was available but not enabled, with the unit's energy target trapped at the effective FCAS Regulation Enablement Max.

As noted above, this issue is more prevalent for semi-scheduled generating units than scheduled units, because the effective FCAS Regulation Enablement Max is scaled down to its UIGF (or, if more limiting, to the SCADA AGC Upper Limit, noting that for HWF2 this was mapped to the wind farm's Possible Power). For scheduled generating units there is no UIGF, hence this dynamic scaling does not apply.

### FCAS 'stranding'

For a unit to be enabled for FCAS, it is a prerequisite that the energy being produced (or consumed) at the start of the dispatch interval lies within the maximum and minimum enablement limits of the scaled FCAS

[28] Defined in Section 1.6 of this report.

trapezium. If the initial energy operating point is outside these limits, the unit is said to be 'stranded' for that FCAS. Stranding can be a particular issue for semi-scheduled generation, which generally has less control of its output, and whose available capacity in any dispatch interval is currently forecast as its UIGF.

Consider the case when semi-scheduled generation is falling. The measured energy output at the start of the dispatch interval is likely to be greater than the UIGF for the end of the dispatch interval. Any offered FCAS will be enabled by constraining energy below its effective Enablement Max, in this case the UIGF. However, because the initial measured energy output is already greater than the UIGF, the generator will be stranded in that FCAS market, and therefore will be ineligible to provide FCAS. A similar situation could arise simply through the natural variation in the output of a semi-scheduled generator, independent of whether that output is falling over time.

Table 3 below summarises the incidence of FCAS stranding during the market trial. In this table:

- RReg and LReg mean regulation raise and regulation lower FCAS.
- R5/L5 mean delayed (5-minute or 300-second) raise/lower contingency FCAS.
- R60/L60 mean slow (60-second) raise/lower contingency FCAS.
- R6/L6 mean fast (6-second) raise/lower contingency FCAS.

There were 94 out of 863 dispatch intervals during the FCAS trial (or 11% of the time) when the HWF2 unit was stranded for one or more FCAS. Of these intervals, 50% were due to the unit initially operating above its FCAS Enablement Max/UIGF, and the other 50% were due to the unit initially operating below its FCAS Enablement Min of 20 MW.

**Table 3 Summary of FCAS stranding during market trial**

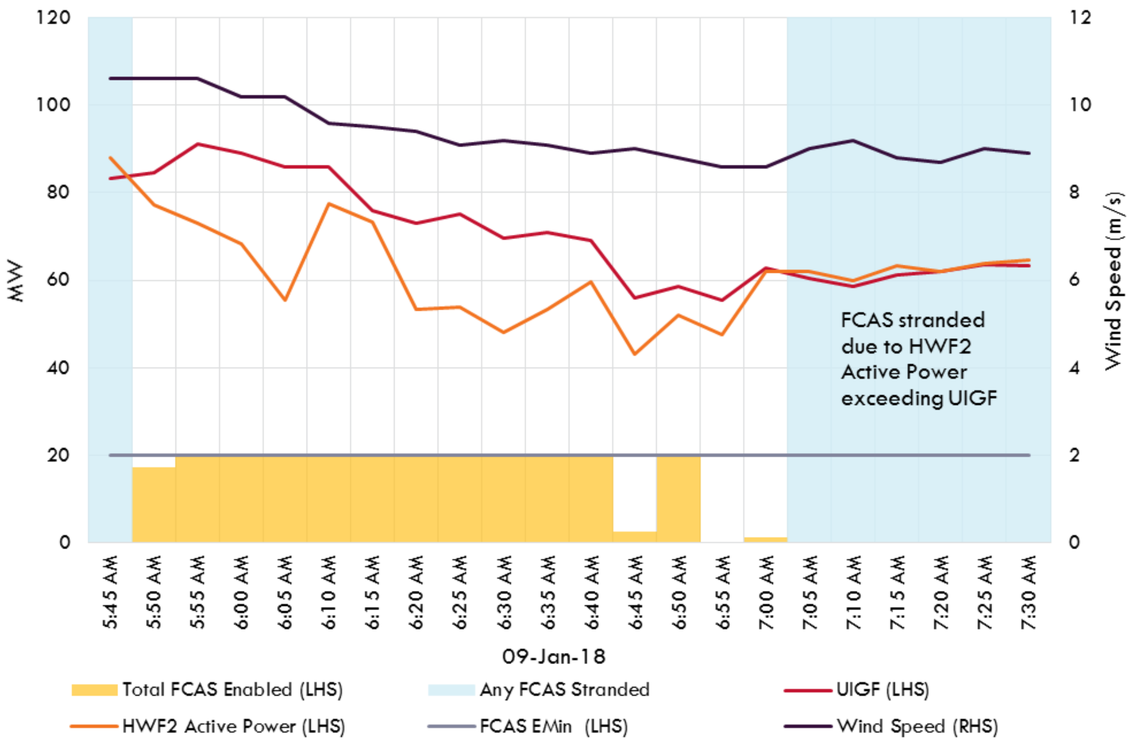
| Test | Description | Total Dispatch Interval (DIs)s | % of DIs with no FCAS enabled | % of DIs with any FCAS stranded | % of those DIs where stranded above EMaxA | % of those DIs where stranded below EMinA |
|---|---|---|---|---|---|---|
| 1 | 20 MW RReg only, energy bid at Market Floor Price (-$1,000) | 48 | 54% | 15% | 100% | 0% |
| 2 | 20 MW LReg only | 24 | 29% | 4% | 100% | 0% |
| 3 | 20 MW R60/R5 only | 24 | 33% | 33% | 0% | 100% |
| 4 | 20 MW L60/L5 only | 24 | 33% | 17% | 100% | 0% |
| 5 | 20 MW R60/R5 & 20 MW L60/L5 | 24 | 0% | 0% | 0% | 100% |
| 6 | 10 MW R60/R5 & 10 MW L60/L5 at $0<br>10 MW R60/R5 & 10 MW L60/L5 near price-setting range | 48 | 19% | 17% | 13% | 88% |
| 7 | 20 MW RReg only | 24 | 29% | 29% | 57% | 43% |
| 8 | 20 MW LReg only | 24 | 0% | 0% | 0% | 100% |
| 9 | 20 MW R60/R5 only | 24 | 0% | 0% | 0% | 100% |
| 10 | 20 MW L60/L5 only | 36 | 44% | 8% | 100% | 0% |
| 11 | 20 MW LReg & 20 MW RReg | 60 | 27% | 18% | 27% | 73% |

| Test | Description | Total Dispatch Interval (DIs)s | % of DIs with no FCAS enabled | % of DIs with any FCAS stranded | % of those DIs where stranded above EMaxA | % of those DIs where stranded below EMinA |
|---|---|---|---|---|---|---|
| 12 | 10 MW LReg & 10 MW RReg at $0<br>10 MW LReg & 10 MW RReg near price-setting range | 114 | 8% | 8% | 22% | 78% |
| 13 | 20 MW RReg only | 24 | 13% | 0% | 0% | 100% |
| 14 | 20 MW LReg only | 52 | 21% | 13% | 100% | 0% |
| 15 | 20 MW R60/R5 only | 24 | 0% | 0% | 0% | 100% |
| 16 | 20 MW L60/L5 only | 24 | 13% | 0% | 0% | 100% |
| 17 | All Services offered<br>S_NIL_STRENGTH_1 constraint binding | 84 | 1% | 2% | 50% | 50% |
| 18 | All Services offered | 53 | 8% | 4% | 100% | 0% |
| 19 | All Services offered – increasing wind | 44 | 5% | 0% | 0% | 100% |
| 20 | All Services offered – decreasing wind | 84 | 56% | 30% | 48% | 52% |
| **Total** | | 863 | 21% | 11% | 50% | 50% |

A. Refer to section A3.1 in Appendix A3 for further explanation.

Figure 16 provides an example of how HWF2 FCAS was stranded.

**Figure 16 Example of FCAS stranding**



In this case, lower regulation FCAS was available but uneconomic, so the energy target was not constrained to enable lower regulation FCAS and hence the semi-dispatch cap was not set, allowing the unit to operate to the wind which was slightly above its UIGF.

To put the FCAS stranding issue into perspective, the number of incidences of FCAS stranding for the top FCAS provider in each NEM region during the same set of dispatch intervals was generally less than for HWF2, except for the TORRB4 unit in South Australia – see Table 4 below.

**Table 4 Summary of FCAS Stranding during market trial period – top FCAS providers in each region trial**

| DUID[A] | Unit | RegionID | % of DIs with any FCAS stranded |
|---|---|---|---|
| BW03 | Bayswater 3 | NSW1 | 0.3% |
| GORDON | Gordon | TAS1 | 1.7% |
| GSTONE4 | Gladstone 4 | QLD1 | 9.2% |
| LOYYB2 | Loy Yang B2 | VIC1 | 5.0% |
| TORRB4 | Torrens Island B4 | SA1 | 12.1% |

A. DUID means Dispatchable Unit Identifier, as used in AEMO market systems.

# 3. Insights from the trial

## 3.1 Variation of wind speed across wind farms and opportunities to optimise FCAS provision

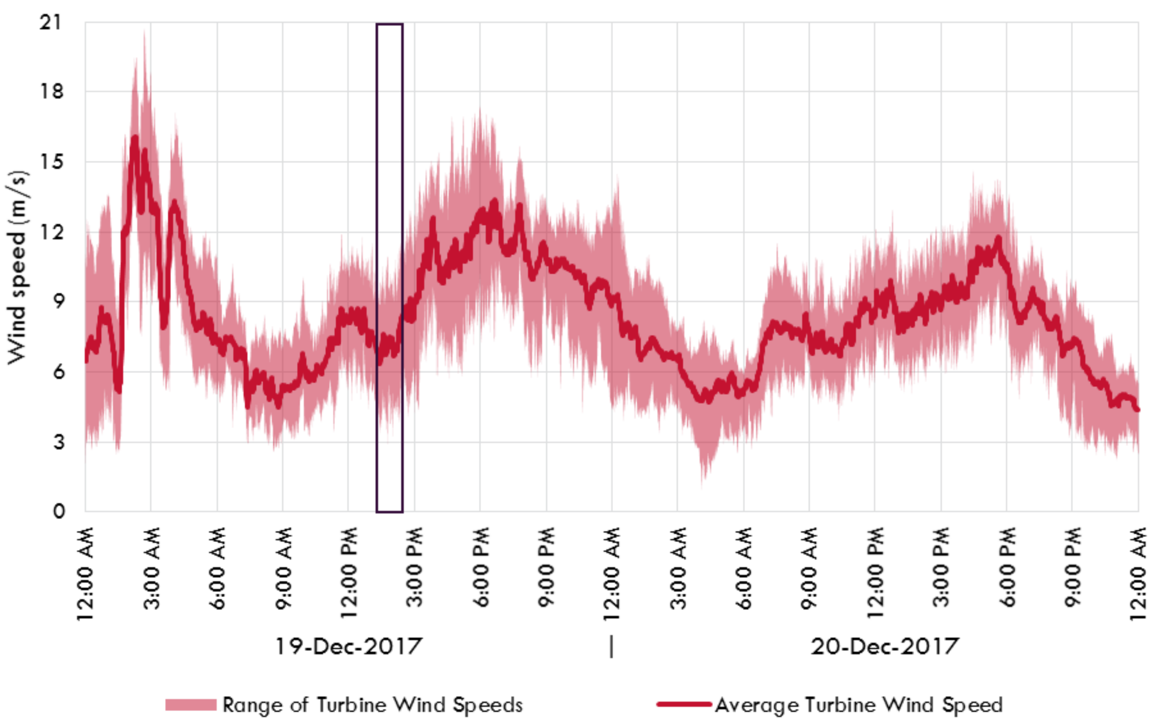
As discussed in Section 2.1.3, to ensure delivery of ancillary services, AEMO has determined that a minimum amount of FCAS headroom is required to cover uncertainty in 5-minute ahead forecasts from wind farms providing FCAS.

There is a non-linear relationship between wind speed and wind turbine output, with small errors in the forecast wind speed in the mid-wind speed range resulting in potentially large errors in the forecast output.

Forecast accuracy is further impacted by AWEFS, AEMO's wind farm forecasting model, using an estimated average wind speed from across each wind turbine to determine forecast output via the turbine power curve, rather than using wind speed forecasts for individual turbine power curves. If the number of turbines subject to higher-than-average wind speed is greater than the number implied within the average power curve, this could result in a systemic under-forecasting by the current AWEFS model.

Figure 17 below shows the variation in wind speeds across the 32 operating wind turbines at HWF2 during trial days on 19 and 20 December 2017. At 1400 hrs on 19 December (see boxed area), the average wind speed was 7.2 m/s, although the wind speed at each turbine ranged from 4.3 to 9.5 m/s. There were 15 turbines below 6.5 m/s and 13 turbines above 7 m/s.

**Figure 17 Variation of HWF2 turbine wind speeds – 19 December 2017**



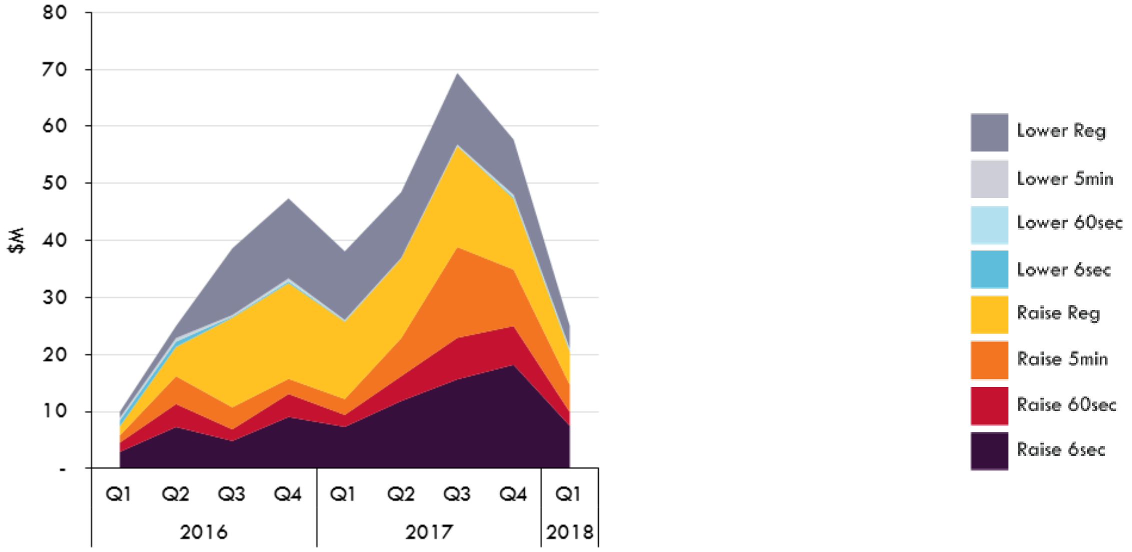
In the future, the ability for a participant to submit its own forecast, based on a more accurate summation of individual wind turbine wind and power forecasts, is expected to reduce this source of forecasting error. This capability will be explored further in future trials and enabled through AEMO's 5-minute self-forecasting project.

## 3.2 Impact on FCAS costs

Annual FCAS costs in the NEM in 2017 were the highest on record at $214 million, representing a 77% increase on 2016 levels and a 308% increase on the five-year average. This coincided with the retirement of some FCAS suppliers from the market (such as Hazelwood, Northern, and Wallerawang power stations) and an increase in the price of offers from incumbent providers.

However, in Q1 2018, this trend reversed markedly with FCAS costs across the NEM falling sharply, as shown in Figure 18, primarily due to new suppliers of FCAS entering the market.

**Figure 18 Quarterly FCAS costs by service**

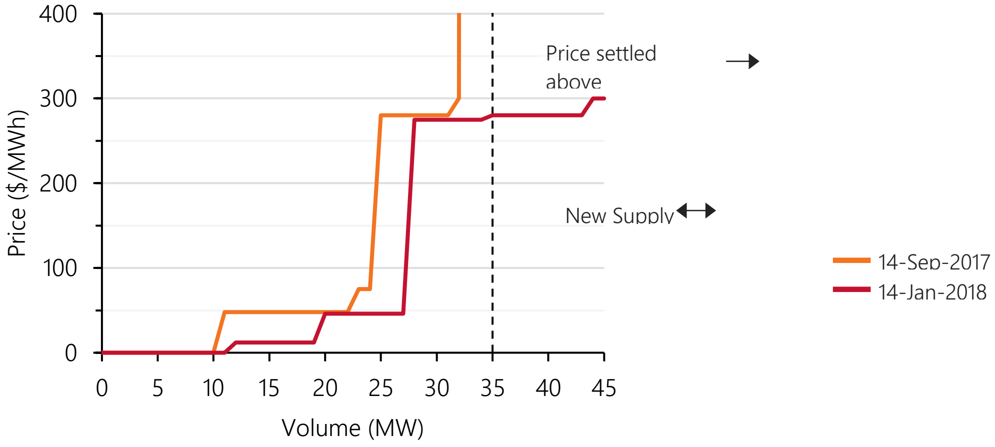



In addition to HWF2, new entrants into FCAS markets in this period include the 100 MW HPR battery co-located with HWF2, and various aggregated demand response assets under management by EnerNOC, which can offer up to 139 MW of FCAS across New South Wales, Queensland, and Victoria.

The impact of increased competition on FCAS costs is most evident when pre-contingent FCAS constraints are applied in South Australia. For system security purposes, AEMO requires 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 (when only one AC transmission interconnector is in service, or when external factors, such as bushfire, increase the risk of islanding the South Australian region). During these times, FCAS prices have been very high due to the concentrated market in South Australia.

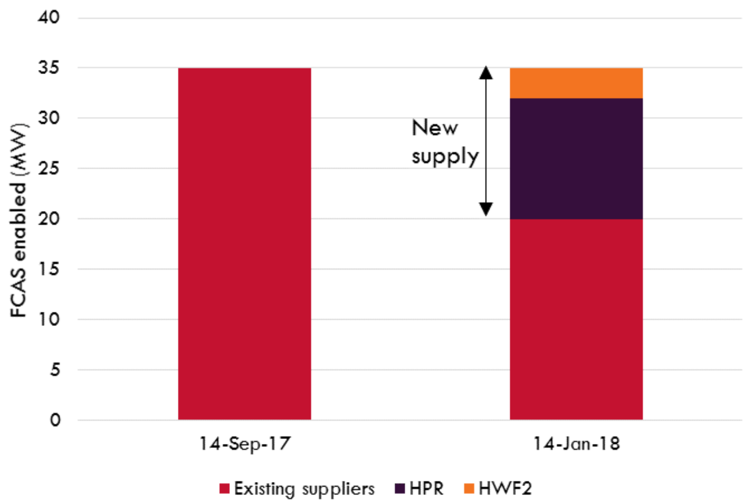
The local procurement of regulation FCAS in South Australia was required on 14 September 2017, before the entry of new FCAS supply. A similar event occurred on 14 January 2018, after the entry of new FCAS supply. The average bid curves for regulation FCAS for these two events are shown below in Figure 19.

**Figure 19** **Average raise regulation FCAS bids during local South Australian FCAS constraint, before and after entry of new supply**




During the 14 January 2018 event, additional FCAS supply was provided by HPR (12 MW) and HWF2 (3 MW). The average FCAS enablement amounts by participant during these two comparable events are shown below in Figure 20.

**Figure 20** **Provision of raise regulation FCAS during local South Australian FCAS constraint, before and after entry of new supply**




The additional supply of cheaper-priced raise regulation FCAS saw a 97% reduction in average regulation FCAS prices from approximately $9,000/MWh to $248/MWh. This is estimated to have reduced the cost of the five-hour local South Australian FCAS requirement on 14 January 2018 by approximately $3.5 million.

## 3.3 Updated wind farm testing requirements for FCAS classification

Following this trial, AEMO has developed test requirements for operators to classify wind generation as ancillary services generating units for contingency FCAS.

A wind farm operator seeking to provide contingency FCAS will be required to account for the following:

- Demonstrate the active power response to a frequency disturbance coinciding with a voltage disturbance; simulations using a sufficiently accurate model should be submitted with the FCAS classification application.
- Provide data from a frequency injection test to demonstrate the FCAS capability for standard and non-credible under-frequency and over-frequency events. The data from the test will be used to conduct the technical assessment of FCAS, and the metering facilities to comply with the MASS requirements will also be verified when the test results are provided.
- Test/simulation results are required prior to classification for the following frequency injection profiles:
  - Standard frequency ramp rate test profile for an under-frequency event when the frequency reaches the raise reference frequency and an over-frequency event when the frequency reaches the lower reference frequency.
  - 3 Hz/s profile for non-credible over-frequency and under-frequency events.
  - 1 Hz/s profile for credible over-frequency and under-frequency events.
  - Test conducted at different hold points according to the ascending section of the turbine power curve.

  Data from a suitable power system simulation package may also be required if injection testing will not deliver results representative of actual operation during a contingency event.
- Demonstrate how the headroom is calculated for raise and lower services. AEMO requires a minimum baseline % (based on 3 standard deviations) of raise and lower headroom to cover forecast uncertainty over the next five minutes. Management of headroom for contingency response and compliance with FCAS offers is the responsibility of each FCAS market participant. The baseline factor used for the headroom can be reviewed after six months based on actual forecast performance.
- A single droop setting is to be chosen if the control system to provide FCAS is a variable controller.

These test requirements will be addressed in the upcoming MASS consultation, drawing on experience following further observation of FCAS from wind farms and subsequent trials, such as the Musselroe Wind Farm FCAS trial.

# A1. Detailed Test Plan

This document is available (pdf file) on AEMO's website at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/strategic-partnerships.

# A2. Market Trial Plan

**FCAS Live-Market Trial**

**Market Plan**

**Version 4 – Final**
**14-Dec-2017**

**Background**

Hornsdale 2 Wind Farm will conduct live market trials of FCAS in the NEM in December 2017, following successful registration as an ancillary service generating unit in November 2017. During the registration process, a number of technical parameters were confirmed that have resulted in the FCAS Registration parameters shown in Table 1 below.

| Frequency Control Ancillary Services | Service provided (Y/N) | Switching controller (Y/N) | Maximum *market ancilliary service* capacity (MW) | Minimum Enablement Level (MW) | Maximum Enablement Level (MW) | Maximum Lower Angle (Deg) | Maximum Upper Angle (Deg) |
|---|---|---|---|---|---|---|---|
| Slow Raise Service (RAISE60SEC) | Y | N | 20 | 20 | 102 | 90 | 21 |
| Slow Lower Service (LOWER60SEC) | Y | N | 20 | 20 | 102 | 45 | 65 |
| Delayed Raise Service (RAISE5MIN) | Y | N | 20 | 20 | 102 | 90 | 14 |
| Delayed Lower Service (LOWER5MIN) | Y | N | 20 | 20 | 102 | 45 | 68 |
| Regulating Raise Service (RAISEREG) | Y | N | 20 | 15 | 102 | 90 | 34 |
| Regulating Lower Service (LOWERREG) | Y | N | 20 | 15 | 102 | 45 | 63 |

**Note**: At present Fast FCAS (also known as 6 Second FCAS) is not able to be technically confirmed due to a number of issues associated with modelling and actual results. Further work is being conducted by Siemens and Neoen in pursuit of the provision of these services.

**Market Test - Preparation**

During the allocated 48hr test time period, which will be spread over a number of weeks in December and January (if required, to capture ideal wind conditions), a number of strategies will be employed by Neoen to ensure adequate bids are submitted, dispatch targets generated by NEMDE and the plant allowed to follow to the NEMDE-determined levels. All tests will be preceded by:

- An indicative email to AEMO (Ops.SA@aemo.com.au) from Neoen Control Room (control.room@neoen.com ) on the afternoon before the tests (approx. 3pm) indicating:
  - the likely test MW profiles;
  - confirmation of no planned network outages; and
  - availability of any key AEMO resources (ie AGC staff).
- Confirmation email and phone call 2 hrs before the commencement once plant and market conditions are well understood. A revised bid profile will be submitted if necessary.
- Call from Neoen to AEMO control room requesting permission to commence testing.
- Call from Neoen to AEMO control room indicating tests have commenced
- Call from Neoen to AEMO control room indicating tests have finished or stopped

Note that:

- the AEMO control room may issue a request that Market Trial activities are not conducted at any time based on power system conditions. All other normal control room – to – control room communications will be maintained.
- Neoen will keep track of the hours that it believes have been utilised and send through to AEMO on a weekly basis until the 48hr period is complete.

The following key points are noted:

- HDWF2 utilises the InfoLite Generation Management System, ensuring the plant moves to prescribed dispatch targets at all times. This has been active in recent times with the S_NIL_STRENGTH_1 (1295MW) or S_NIL_STRENGTH_2 (1200MW) constraints in SA and performed satisfactorily.
- HDWF2 manual tests of the AEMO AGC system showed excellent adherence to 4sec regulation signals – the 20MW amount is expected to be fully enabled at times subject to available wind - full details of proposed services to be offered are shown in the table overleaf.
- Neoen has a 24/7 trading control room (ph: +612 6257 6842 ) that will be monitoring the FCAS trial constantly, with suitably qualified traders/operators to ensure the test objectives are fulfilled (these are the same operators who are bidding Energy and FCAS for the Hornsdale Battery Reserve)

**Market Test - Response**

The following actions will occur when it is time to test the FCAS capability:

- $0/MWh bid bands will be established for energy and FCAS prior to the tests to ensure each service is able to be dispatched;
- Test outcomes may result in some wind curtailment from the Possible Power (which is reflected in the AGC Upper Limit telemetered to AEMO, which caps the NEMDE FCAS Regulation Enablement Max and AEMO's AGC upper control range): this will be monitored by Neoen.

- Slow and Delayed Raise and Lower FCAS will be enabled after the regulation tests have been conducted, at $0/MWh bid prices for energy and FCAS, to ensure an adequate period is covered highlighting raise capability; and
- The tests should be allowed to go ahead where the SA Energy and/or FCAS prices are between $0/MWh and $300/MWh. If the price exceeds these outer limits, an assessment will be conducted mid-test to determine an alternate path/timing going forward in consultation with AEMO and ARENA.
- A revenue management application/process will be in place to ensure revenue losses are minimised where possible and will be used to monitor the hours of testing conducted and MWh curtailed. This will be made available to AEMO and ARENA only as per the KSP

**Planned Testing Sequence**

| Test Number | Tested FCAS | Approx Wind (m/s) | Likely Dur'n (hrs) | Expected Outcome |
|---|---|---|---|---|
| 1 | 20MW Raise Reg only | 5 | 2 | |
| 2 | 20MW Lower Reg only | 5 | 2 | |
| 3 | 20MW R60/R5 only | 5 | 2 | |
| 4 | 20MW L60/L5 only | 5 | 2 | |
| 5 | 20MW R60/R5 and 20MW L6/L60 both enabled | 7+ | 2 | Up to 40MW movement in combined raise and lower direction |
| 6 | 10MW R60/R5 and 10MW L60/L5 at $0, 10MW R60/R5 and 10MW L60/L5 near price setting range | 7+ | 4 | Up to 20MW movement in combined direction, then additional 20MW being enabled as price moves in between bid bands |
| 7 | 20MW Raise Reg only | 9 | 2 | Up to 20MW curtailment from AGC high limit at times |
| 8 | 20MW Lower Reg only | 9 | 2 | Up to 20MW curtailment from AGC high limit at times when responding to high frequency |
| 9 | 20MW R60/R5 only | 9 | 2 | Up to 20MW curtailment from AGC high limit at times |
| 10 | 20MW L60/L5 only | 9 | 2 | Up to 20MW curtailment from AGC high limit at times when responding to high frequency |
| 11 | 20MW Lower and 20MW Raise Reg both enabled | 10+ | 2 | Up to 40MW movement in combined raise and lower direction |
| 12 | 10MW Lower and 10MW Raise at $0, 10MW Lower and 10MW Raise near price setting range | 10+ | 4 | Up to 20MW movement in combined direction, then additional 20MW being enabled as price moves in between bid bands |
| 13 | 20MW Raise Reg only | 13 | 2 | |
| 14 | 20MW Lower Reg only | 13 | 2 | |
| 15 | 20MW R60/R5 only | 13 | 2 | |
| 16 | 20MW L60/L5 only | 13 | 2 | |
| 17 | All Services offered | 18+ | 3 | Dispatch conditions under S_NIL_STRENGTH_1 binding conditions |

| | | | | |
|---|---|---|---|---|
| 18 | All Services offered | 18+ | 3 | No constrained conditions, but Dispatch conditions under S_NIL_STRENGTH_2 invoked but not binding |
| 19 | All Services offered | Increasing wind conditions | 3 | Expected to utilise a 2-3 hr slow wind ramping up event, to observe possible power/AGC upper limit increasing the effective FCAS Enablement Max and the energy curtailment upper break-point. Increasing wind during the DI does not change its curtailment level (unless actually delivering FCAS response) |
| 20 | All Services offered | Decreasing wind conditions | 3 | As above<br>Expected to utilise a 2-3 hr slow wind ramping down event, to observe possible power/AGC upper limit decreasing the effective FCAS Enablement Max and the energy curtailment upper break-point.<br><br>Despite an unforecast drop in available wind during a DI, wind farm is still able to deliver its full enabled raise/lower response (because registered FCAS trapezium angles allow for 5-minute forecast error) |

The following notation is used in the table above:

- R6 / L6 are the Fast FCAS contingency services in raise and lower respectively
- R60 / L60 are the Slow FCAS contingency services in raise and lower respectively
- R5/L5 are the Delayed contingency services in raise and lower respectively
- RReg and LReg are the FCAS Regulation services in raise and lower respectively

The actual sequence and outcome of the market trial elements described in the table above may vary based on wind resource availability, network or market conditions in the December and January period.

A number of experienced resources will be on standby to assist Neoen if required, including:

- AEMO (Market and FCAS specialists)
- GHD (Registration and Technical Experts)
- Greenview Strategic Consulting (Market and Technical Experts)\

# A3. Guide to FCAS bidding and headroom calculation

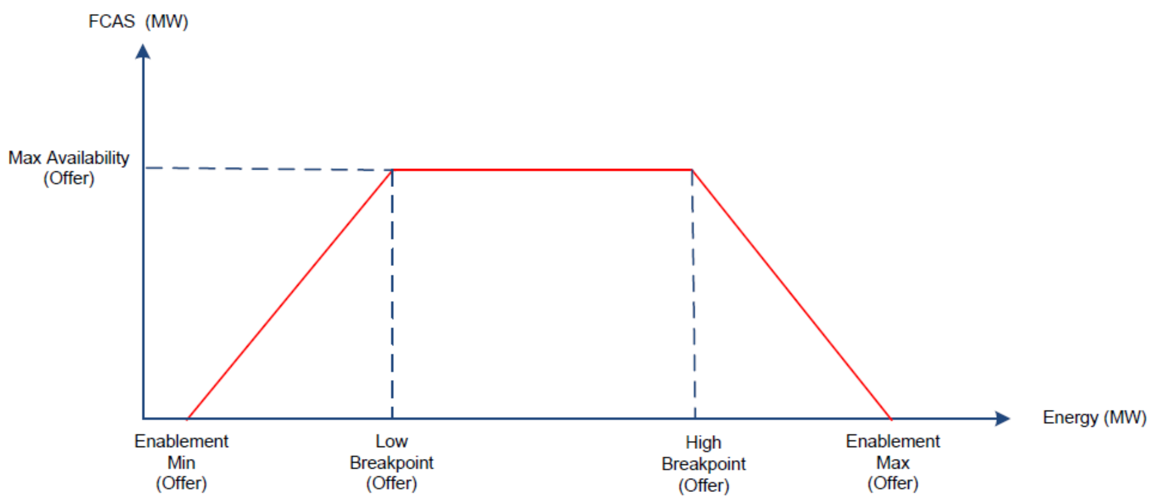
## A3.1 FCAS offer trapezium

The goal of the central dispatch process is to co-optimise the dispatch of energy and FCAS offers at overall least cost subject to security constraints.

FCAS offers are characterised by the volumes of FCAS offered and their associated prices, just as in the energy market. However, FCAS offers are also characterised by a trapezium that represents the physical relationship between the amount of energy being produced (or consumed) and the amount of FCAS that can be delivered at each energy level.

This is most easily explained diagrammatically. Figure 21 shows a generalised FCAS trapezium.

**Figure 21 Generalised FCAS trapezium**




The shape of the trapezium is defined by five parameters, all of which are submitted as part of the FCAS offer:

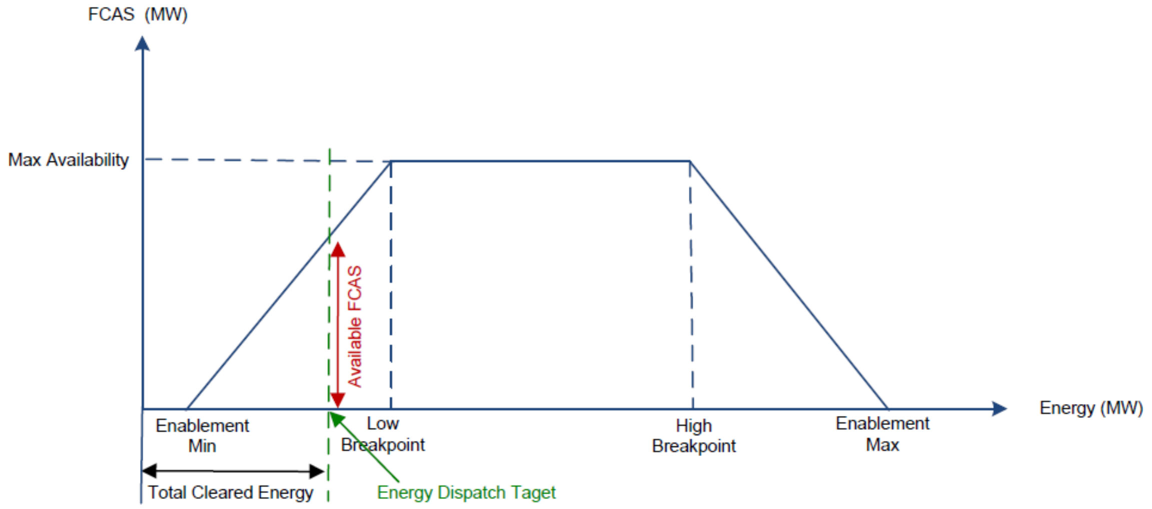
- Max Availability.
- Enablement Min (EMin).
- Low Breakpoint.
- High Breakpoint.
- Enablement Max (EMax).

Below a minimum energy level, known as "Enablement Min", the unit is incapable of providing any FCAS. This may be the case of a thermal generating unit unable to deliver lower FCAS below its minimum stable load.

Above a maximum energy level, known as "Enablement Max", the unit is again incapable of providing any FCAS. This would be the case of a generating unit unable to deliver raise FCAS above its maximum energy output as there is no spare capacity.

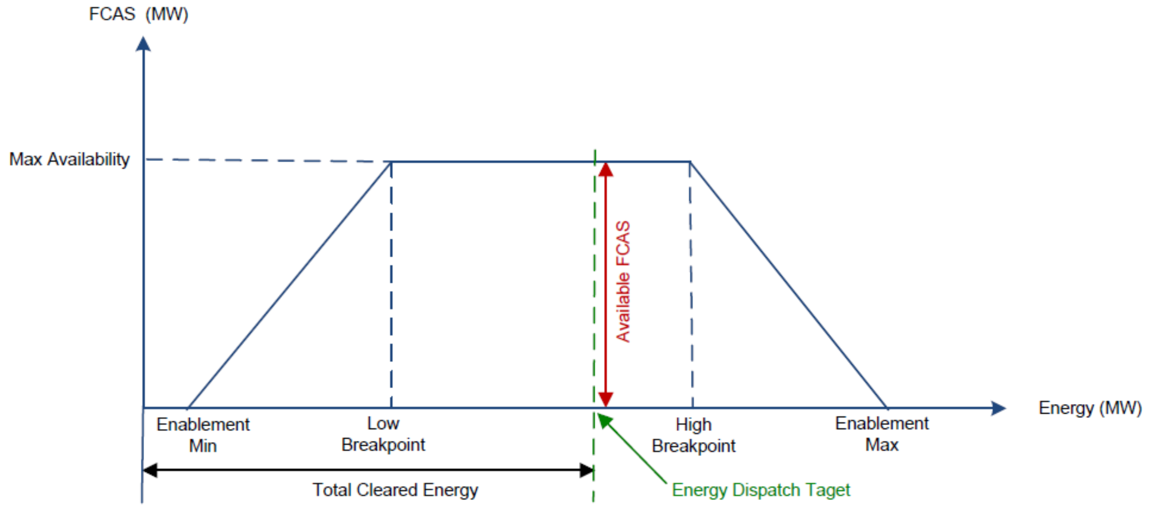
Between Enablement Min and the Low Breakpoint, the amount of FCAS available increases with the amount of energy being produced (or consumed), as shown in Figure 22.

**Figure 22 Energy between Enablement Min and Low Breakpoint**



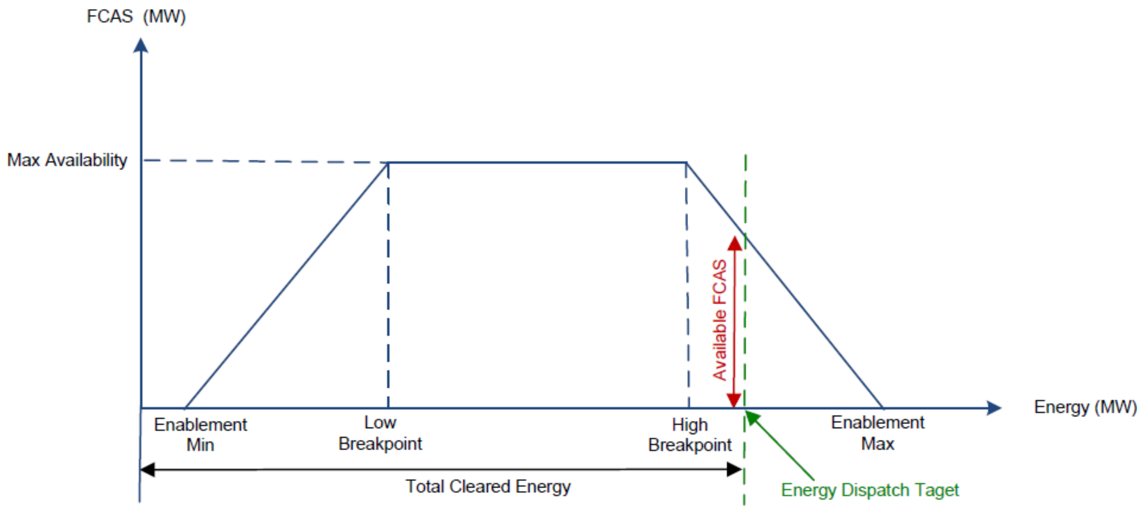

Between the Low Breakpoint and the High Breakpoint, the Max Availability of FCAS is available, as shown in Figure 23. Max Availability is the maximum amount of FCAS that can be delivered as part of the offer, independent of the amount of energy being produced (or consumed).

**Figure 23 Energy between Low Breakpoint and High Breakpoint**



Between the High Breakpoint and Enablement Max, the amount of FCAS available decreases with the amount of energy being produced (or consumed), as shown in Figure 24

**Figure 24 Energy between High Breakpoint and Enablement Max**




## A3.2 Scaling of FCAS offer trapeziums

The FCAS trapezium submitted in an FCAS offer may be subsequently modified by the central dispatch process prior to co-optimisation, depending on the prevailing system conditions. This is done to ensure that the FCAS trapezium used in dispatch is physically realistic.

AEMO takes a snapshot of the power system immediately before the start of each dispatch interval. This snapshot contains information on the current status of each dispatchable generator and load. In particular:

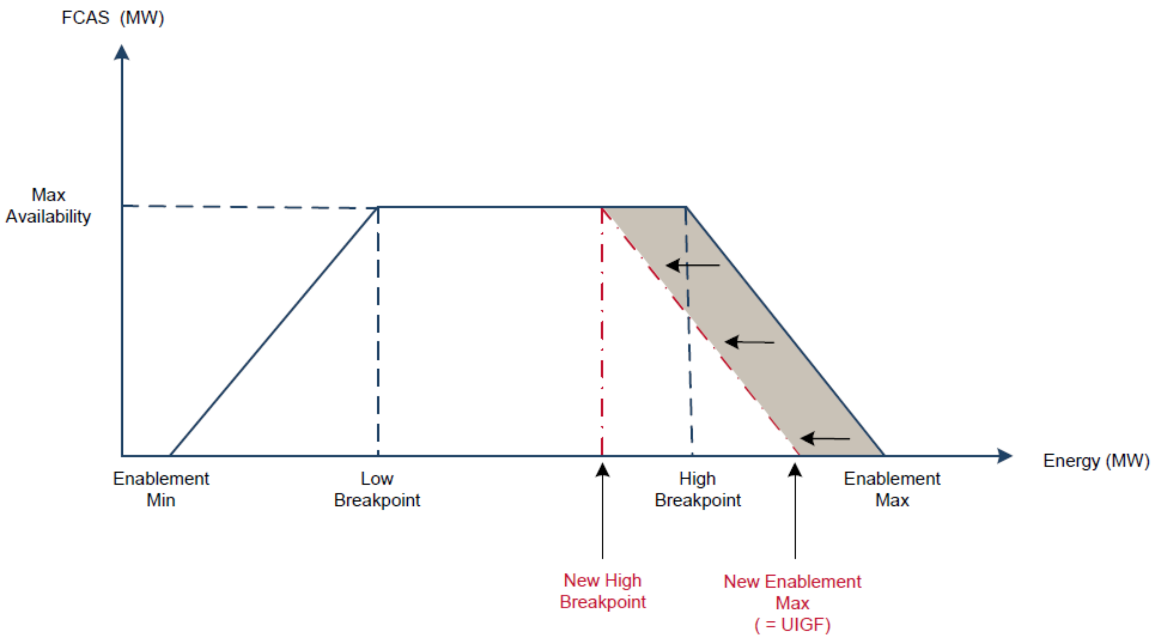
- For semi-scheduled units, AWEFS and ASEFS provide forecasts of unit availability. ASEFS and AWEFS outputs are referred to as a unit's Unconstrained Intermittent Generation Forecast (UIGF)[29].
- For units providing regulation FCAS, the unit's Automatic Generation Control system (AGC) provides updates on the actual ramp rate and maximum and minimum enablement limits.

### Scaling for UIGF

Dispatch uses the more restrictive of the offered Enablement Max and the UIGF for any FCAS offered by semi-scheduled generators. The effect of this scaling on the offered FCAS trapezium is shown in Figure 25.

[29] This a defined term in chapter 10 of the NER, and is discussed in NER clause 3.7B. See Section 1.6 in the paper for more information about UIGF.

**Figure 25 FCAS trapezium scaling by UIGF**



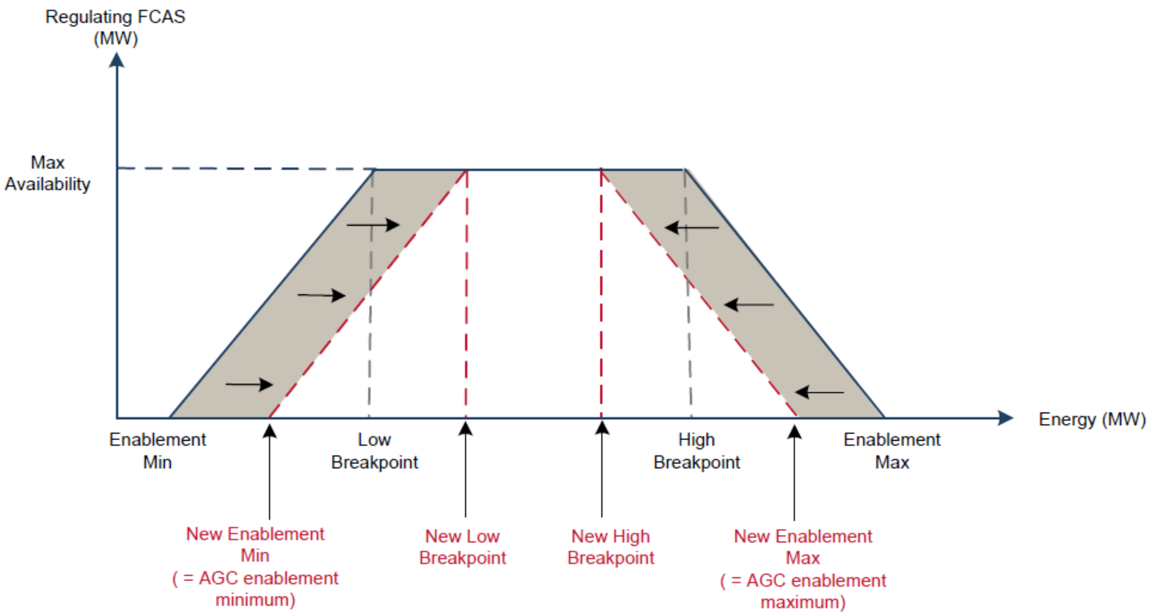

If the UIGF is more restrictive than the offered Enablement Max, the trapezium is scaled by making the UIGF the effective Enablement Max, adjusting the High Breakpoint to maintain the trapezium angles. If the offered Enablement Max is more restrictive than the UIGF, no scaling is applied.

### Scaling for AGC

Any units enabled for regulation FCAS must be on remote AGC. AGC informs the dispatch process of the current ramp rates and maximum and minimum enablement limits of those units.

Dispatch uses the most restrictive of the offered enablement limits and the real-time AGC enablement limits for scaling any regulation FCAS offers. The effect of this scaling on the offered FCAS trapezium is shown in Figure 26.

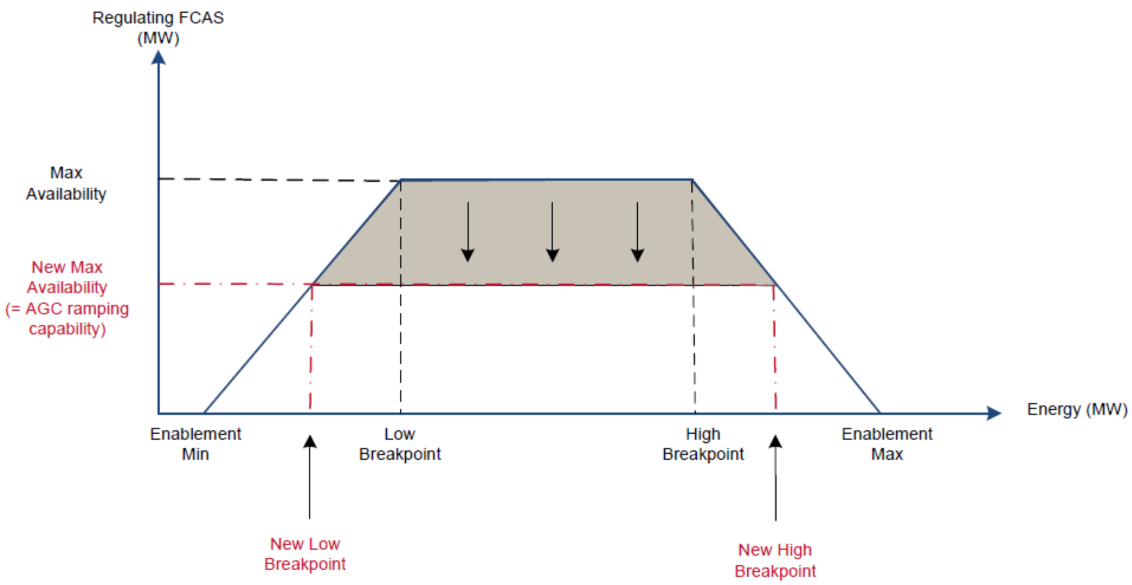
**Figure 26 Regulation FCAS trapezium scaling by AGC enablement limits**




If the real-time AGC limits are more restrictive than the offered enablement limits, the trapezium is scaled by making the AGC enablement limits the effective maximum and minimum enablement limits, and adjusting the trapezium breakpoints to maintain the trapezium angles. If the offered enablement limits are more restrictive than the real-time AGC limits (or the AGC enablement limits are zero or absent), no scaling is applied.

Dispatch also uses the more restrictive of the offered Max Availability and the real-time AGC ramping capability for any regulation FCAS offers. The effect of this scaling on the offered FCAS trapezium is shown in Figure 27.

**Figure 27 Regulation FCAS trapezium scaling by AGC ramp rates**




The AGC ramping capability is calculated as the AGC ramp rate multiplied by the time interval. For example, if the AGC ramp rate is 5 MW/min, the AGC ramping capability for a 5-minute dispatch interval is 25 MW. If the

AGC ramping capability is more restrictive than the offered Max Availability, the trapezium is scaled by making the AGC ramping capability the effective Max Availability, and adjusting the trapezium breakpoints to maintain the trapezium angles. If the offered Max Availability is more restrictive than the AGC ramping capability (or the AGC ramp rate is zero or absent), no scaling is applied.

## A3.3 Co-optimisation of energy and FCAS offers

The objective of dispatch is to minimise the cost of supplying the energy and FCAS needs of the power system. At times this requires co-optimisation between a unit's energy and FCAS offers.

Consider the case of a generator operating on the upper slope of an FCAS trapezium, as shown in Figure 24. In this situation, the dispatch process might choose to reduce the generator's energy target to enable more FCAS, if it is cheaper overall to do so. Conversely, the dispatch process might choose to reduce the generator's FCAS enablement to produce more energy, again if it is cheaper overall to do so. This trade-off is known as co-optimisation. It arises because of the relationship between energy dispatch and FCAS enablement that is defined in the FCAS trapezium.

Energy and FCAS co-optimisation is a complex optimisation task that can result in non-intuitive outcomes:

- Dispatch by NEMDE not only co-optimises energy and FCAS across a large number of market participants, but also between the different FCAS markets. Because of the complexity of these multiple co-optimisations, it is seldom possible to know beforehand exactly how energy and FCAS will be traded off to meet the needs of the power system at the lowest available cost.
- Between the Low Breakpoint and the High Breakpoint there is no trade-off between the amount of energy that can be produced (or consumed) and the amount of FCAS that can be delivered; the maximum amount of FCAS can be delivered independent of the energy operating point. Therefore, energy and FCAS co-optimisation only occurs on the upper and lower slopes of the FCAS trapezium.

## A3.4 FCAS headroom calculation

The maximum upper angles in the FCAS trapezium for the raise and lower services registered for both regulation and contingency FCAS have to be calculated to account for a change in wind speed over the next five minutes.

The need for a margin of safety to cover forecast uncertainty is demonstrated by Figure 28 to Figure 31 below.

In these charts, UIGF from the wind farm represents the forecast generation at the end of each 5-minute interval, whereas Possible Power represents instantaneous 'actual' generation.

**Figure 28 Headroom – increasing wind conditions over a dispatch interval**

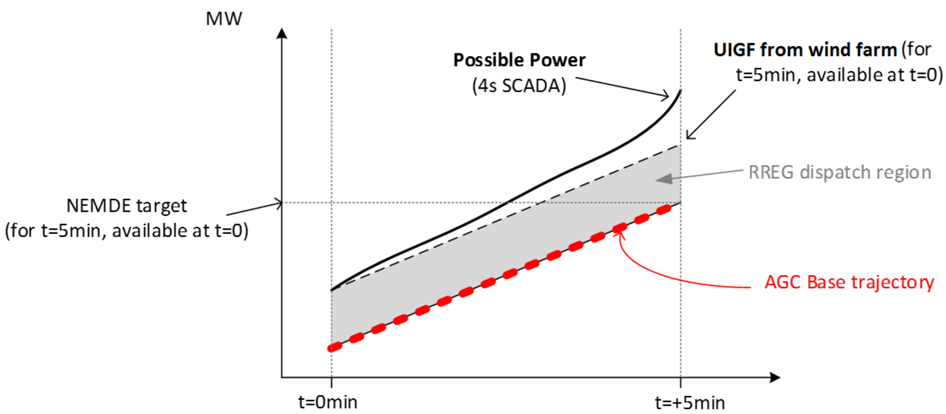


**Figure 29 Headroom – decreasing wind conditions over a dispatch interval**

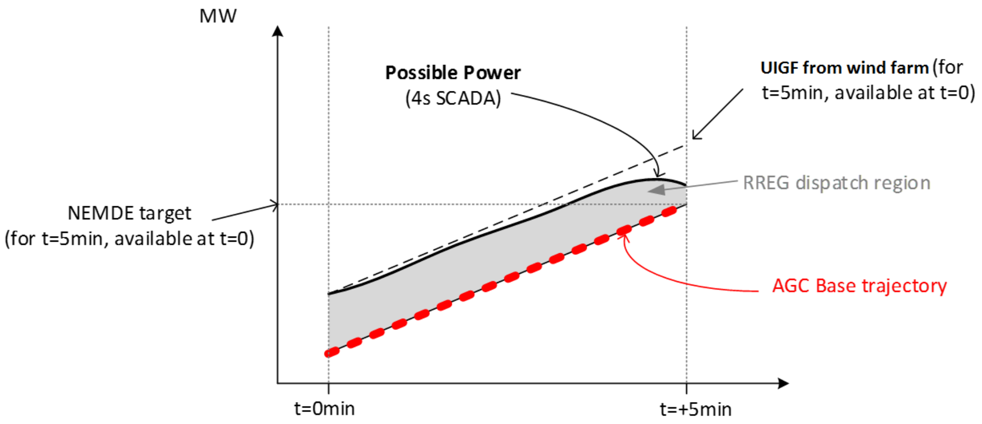
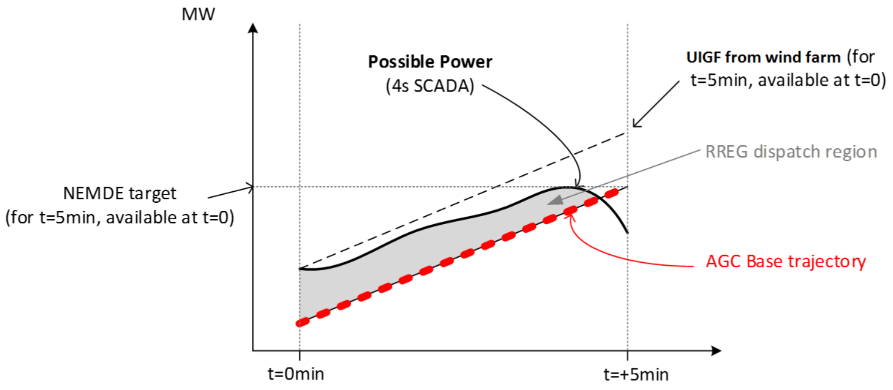



**Figure 30 Headroom – wind condition variation**

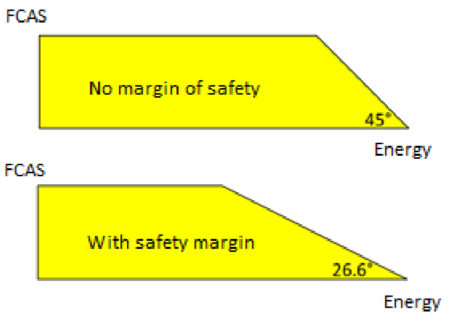



The maximum lower angles for raise services remained at $90^0$ and $45^0$ for lower services.

The Energy to FCAS ratio used was 2:1. To provide 1 MW of FCAS, the basepoint of the wind farm has to move by 2 MW. Since the registered maximum market ancillary service capacity was 20 MW, the forecast error margin for all services was assumed to be 10 MW.

Figure 31 below shows the regulation FCAS trapeziums with and without the safety margin.

**Figure 31 Headroom – energy v/s FCAS trapeziums**

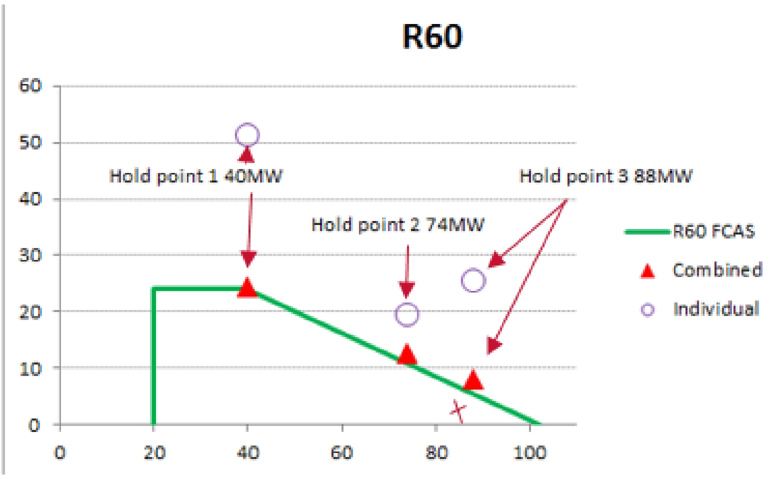



The final maximum upper angles were updated after data from the frequency injection test was provided.

To determine the maximum upper of the FCAS trapezium for contingency FCAS, the steps below were followed:

1. The results from the modelling data and the frequency injection test were plotted on a graph.
2. The minimum enablement level for a service was plotted against the maximum market ancillary service capacity for that service.
3. The amount of FCAS delivered from the three frequency injection tests at different hold points was added to the graph.
4. The maximum upper angle was calculated to match the results from the frequency injection test.

**Figure 32 FCAS trapezium for the slow raise service**




As shown in Figure 32, the maximum upper angle, shown above as a red 'x', was calculated after a line was drawn from the maximum enablement level to hold point 1.