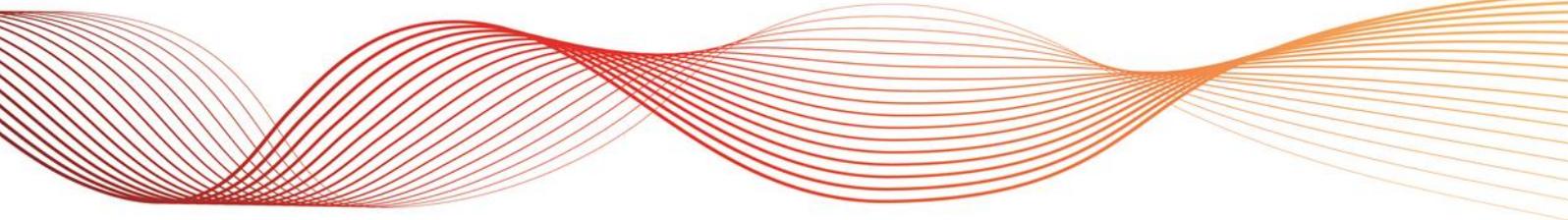




# FAST FREQUENCY RESPONSE IN THE NEM

WORKING PAPER

FUTURE POWER SYSTEM SECURITY PROGRAM





# IMPORTANT NOTICE

## Purpose

AEMO has prepared this document to provide information about possible fast frequency response services that may be valuable in future, as at the date of distribution. This document or the information in it may be subsequently updated or amended.

## Disclaimer

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# EXECUTIVE SUMMARY

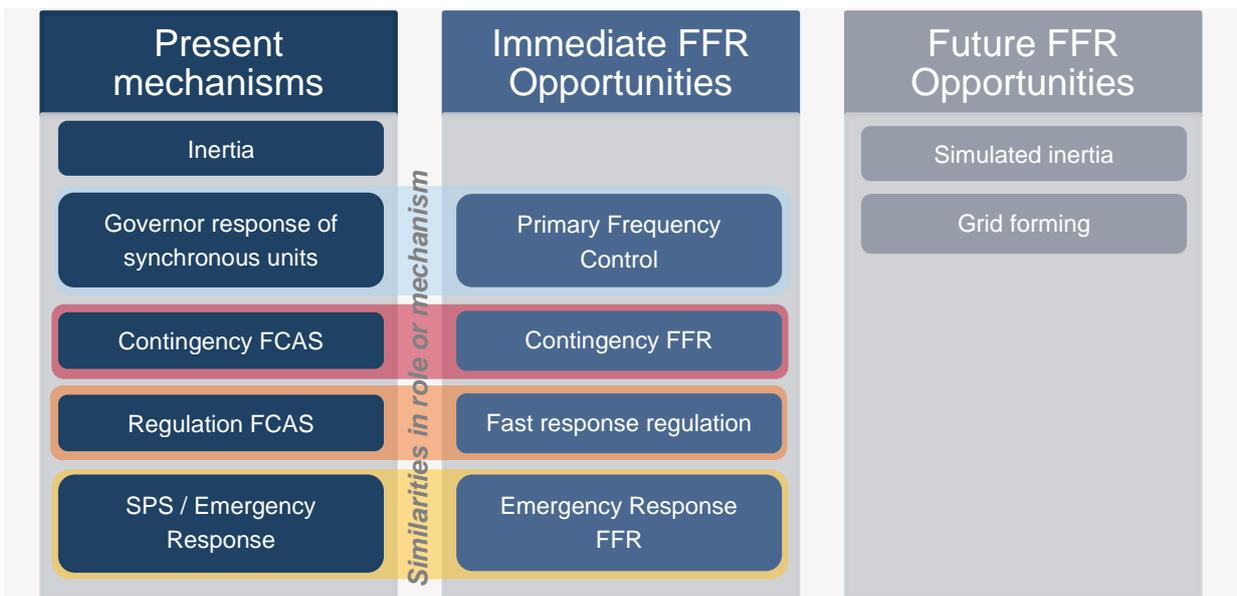
As the energy market transforms, the nature of frequency control in the National Electricity Market (NEM) will change as new services are likely to be needed to complement existing mechanisms. This provides opportunities for applications of fast frequency response (FFR) to play a role in complementing existing frequency control.

The breadth and speed of technological change in the power industry is unprecedented and parts of the NEM are leading the world in terms of new generation penetration. Thus whilst urgency is needed, research and analysis is still evolving in how these new technologies can be best applied to large, complex power systems.

This report aims to develop a common language for discussion across industry, and provide early guidance on the suite of FFR services that may be valuable in future to assist in the efficient management of power system security. In this context, AEMO invites stakeholder feedback. Figure 1 summarises the opportunities identified for FFR and how they relate to existing frequency control mechanisms in the NEM. In this way, FFR may be beneficial in:

- Delivering faster frequency control and lower cost.
- Reducing constraints on power flow imposed by risks of high rates of change of frequency.
- A more efficiency delivery of current frequency control services.

**Figure 1 Relationship of described FFR services with existing frequency control services**



## What is Fast Frequency Response?

FFR generally refers to the delivery of a rapid active power increase or decrease by generation or load in a timeframe of two seconds or less, to correct a supply-demand imbalance and assist in managing power system frequency. Many inverter-connected technologies, such as wind, photovoltaics (PV), batteries and other types of storage have the capability to deliver FFR, as well as by demand-side resources.

Given FFR can act quicker than current frequency control services in the NEM, they may also assist in managing challenges related to high rates of change of frequency (RoCoF).

FFR has had limited application internationally to date. As with any new technology, or application of it, much effort is required to understand the range of capabilities and benefits offered, and the optimal way to utilise those capabilities. International power systems that currently or are proposing to use FFR, have generally defined FFR by a specific intended application. AEMO has identified a range of FFR services that are available via different technologies and is keen to explore opportunities for expanded applications in future.

These discussions need to be underpinned by the following considerations:

- **FFR and inertia are different services.** It is unhelpful to view FFR as a substitute for inertia. Although FFR has the potential to assist with frequency management at lower levels of system inertia, FFR and inertia are delivered via different physical mechanisms, and play roles that are not directly interchangeable.

*Inertia from synchronous units provides an inherent response to slow the RoCoF, but cannot act to restore power system frequency.*      ≠      *FFR can inject active power to correct the imbalance and restore system frequency, but does not inherently slow RoCoF in the same manner.*

Importantly, as FFR is highly tuneable it can be designed to provide a broader range of possible responses than synchronous units, making it inefficient to narrow the application of FFR to mimic the response of synchronous units.

- **Faster responses are not necessarily better.** FFR technologies can respond at different rates, and some manufacturers have indicated to AEMO that total response times of 10-20 milliseconds (ms) are possible. Very rapid responses of the scale may not be appropriate or desirable in all power system conditions:
  - Slower response times allow for more robust measurement and identification of power system events, minimising false triggering.
  - Slower response times enable better coordination between frequency control providers, and facilitate greater breadth of participation in the provision of frequency control services.
  - Some frequency control services require slower responses.

The response time required will depend upon the nature of the service being delivered.

- **Flywheels are non-synchronous.** Although flywheels store kinetic energy in a rapidly rotating mass, they are typically connected to the power system via an inverter and therefore do not provide inertia.

As illustrated in Figure 1, frequency control in the NEM is currently achieved via a combination of frequency control services which act over different timescales and have different roles. They are also activated via different mechanisms. For example, following a contingency event, inertia *slows* the RoCoF, allowing time for governor response and contingency Frequency Control Ancillary Services (FCAS) to *arrest* the frequency change. Slower types of contingency FCAS and regulation FCAS then act to *restore* the frequency to its nominal value of 50 Hertz (Hz). Emergency response mechanisms such as Under Frequency Load Shedding (UFLS) and Special Protection Schemes (SPS) are designed to counter more extreme events such as the separation of a region from the rest of the NEM.

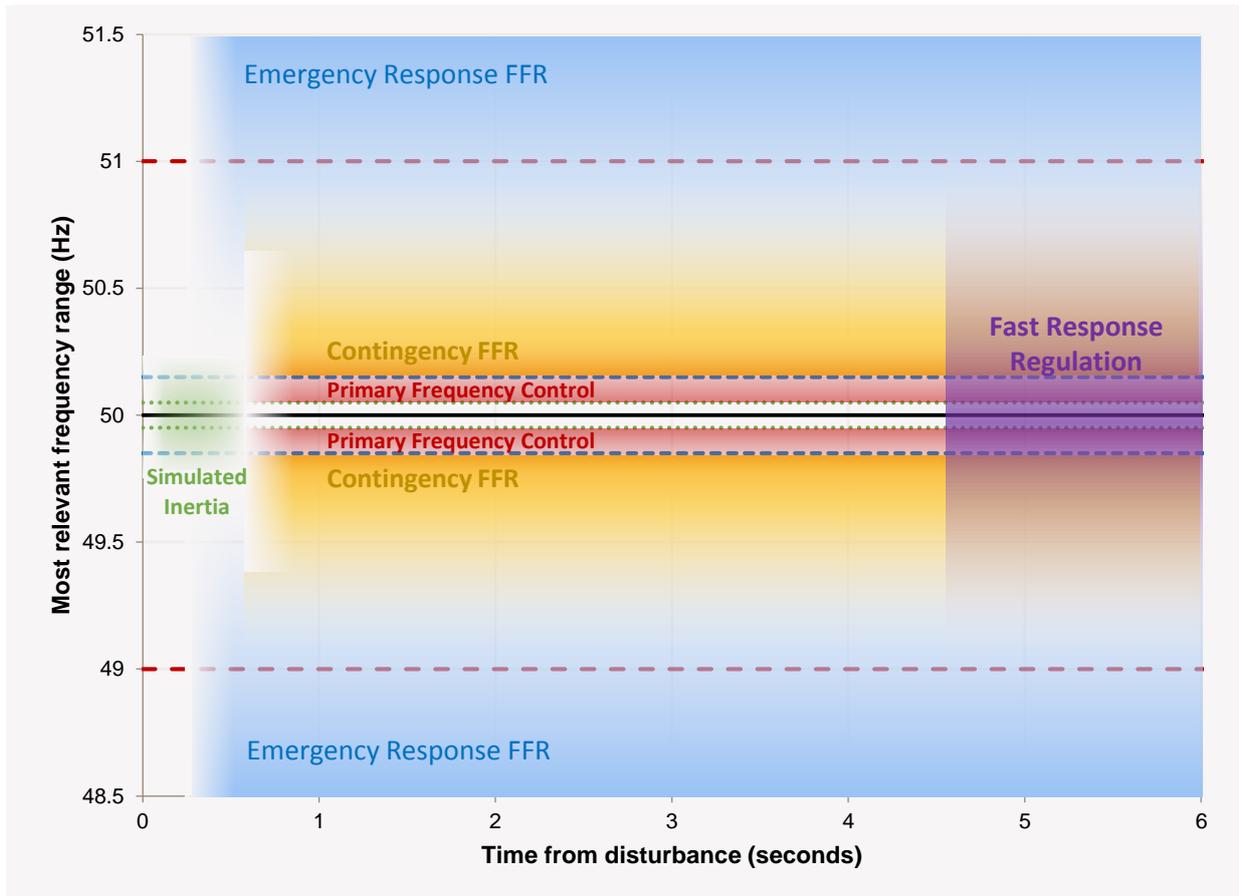
In Figure 1, the services identified as immediate FFR opportunities either fulfil similar roles or utilise similar mechanisms but on faster timeframes to existing services. In general, these particular FFR services will not act as a replacement but rather complement the existing services due to their different properties.

In the longer term, innovations may enable an even wider range of FFR services from inverter-connected resources. Two such examples that are currently in the realm of research are:

- “Simulated inertia” with the potential to be able to mimic the inertial response of synchronous units and thereby displace some quantity of system inertia (although a need for some synchronous capacity is likely to remain).
- “Grid forming” technologies may be able to set and maintain power system frequency to enable the operation of large power systems with no synchronous capacity.

A possible mapping of these identified FFR-type services, in terms of the frequency ranges where each is most relevant and the timescales over which they might operate, is given in Figure 2.

**Figure 2 Possible mapping of proposed FFR services (frequency ranges and response times)**



The approximate order in which AEMO’s analysis suggests FFR may become valuable in the NEM based on anticipated power system needs is:

- Emergency response FFR is being implemented immediately as a part of the SPS under development to protect against or prevent the loss of the Heywood interconnector connecting South Australia to Victoria.
- Contingency FFR and primary frequency control show promise in the near term.
- Fast response regulation may become important in future, and is technically feasible at present.
- Simulated inertia and grid-forming technologies are not yet commercially demonstrated.

Work will be required to determine how these services are provided, the appropriate coordination and co-optimisation between these services, and other relevant services such as inertia, and FCAS. To build confidence in the capability of FFR to deliver the frequency control services required in the NEM, AEMO is looking at facilitated proof of concept projects.



AEMO is furthering work on FFR to understand the types of services, as well as potential adaptation to FCAS frameworks. In addition, AEMO is currently:

- Collaborating with the Australian Energy Market Commission (AEMC) in its System Security Market Frameworks Review, providing technical advice on the implementation of FFR services<sup>1</sup>.
- Collaborating with the AEMC on its frequency control frameworks review that was initiated following the system security review<sup>2</sup>.
- Undertaking a trial of frequency control services delivered by Hornsdale 2 wind farm<sup>3</sup>.
- Working with the Australian Renewable Energy Agency (ARENA) and the Clean Energy Finance Corporation (CEFC) to identify opportunities to trial FFR capabilities in new projects.
- Progressing a rule change proposal for enhanced technical standards from all new entrants, including requirements for frequency control capabilities, and possibly FFR capabilities where the unit is able. These are based upon AEMO's recent advice to the Essential Services Commission of South Australia (ESCOSA) on generator licensing conditions<sup>4</sup>.
- Responding to the final recommendations by the expert panel in the "Independent Review into the Future Security of the National Electricity Market"<sup>5</sup>, some of which relate to FFR.

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<sup>1</sup> <http://www.aemc.gov.au/Markets-Reviews-Advice/System-Security-Market-Frameworks-Review>

<sup>2</sup> <http://www.aemc.gov.au/Markets-Reviews-Advice/Frequency-control-frameworks-review>.

<sup>3</sup> <http://aemo.com.au/Media-Centre/AEMO-and-ARENA-looking-to-evolve-traditional-electricity-market>.

<sup>4</sup> AEMO (31 March 2017), Recommended Technical Standards for Generator Licensing in South Australia. Available at: <http://www.escosa.sa.gov.au/ArticleDocuments/1048/20170331-Inquiry-RecommendedTechnicalStandardsGeneratorLicensingSA-AEMOadvice.pdf.aspx?Embed=Y>

<sup>5</sup> *Independent Review into the Future Security of the National Electricity Market: Blueprint for the Future*, Commonwealth of Australia 2017, available at <http://www.environment.gov.au/energy/publications/electricity-market-final-report>



# CONTENTS

<b>EXECUTIVE SUMMARY</b>	<b>3</b>
<b>1. INTRODUCTION</b>	<b>9</b>
<b>2. EMERGING FREQUENCY CONTROL CHALLENGES</b>	<b>12</b>
2.1 Frequency Control in the NEM	12
2.2 Frequency control schemes	13
2.3 Emerging frequency control challenges	14
<b>3. OPPORTUNITIES FOR NEW FREQUENCY CONTROL SERVICES</b>	<b>17</b>
3.1 What is Fast Frequency Response?	17
3.2 Technologies capable of FFR	17
3.3 Important clarifications	19
3.4 Opportunities for FFR in the NEM	21
3.5 Need for trials	21
<b>4. MULTIPLE ROLES FOR FFR</b>	<b>23</b>
4.1 Emergency response FFR	26
4.2 Contingency FFR	27
4.3 Primary Frequency Control	28
4.4 Fast Response Regulation	30
4.5 Simulated Inertia	31
4.6 Grid Forming	32
<b>5. NEXT STEPS</b>	<b>33</b>
<b>MEASURES AND ABBREVIATIONS</b>	<b>34</b>
Units of measure	34
Abbreviations	34

## TABLES

Table 1	Types of control schemes for frequency control services	13
Table 2	Some examples of types of inverter-connected technologies that can deliver FFR	18
Table 3	Potential FFR services in the NEM	24
Table 4	Considerations in utilising FFR for primary frequency control	29

## FIGURES

Figure 1	Relationship of described FFR services with existing frequency control services	3
Figure 2	Possible mapping of proposed FFR services (frequency ranges and response times)	5
Figure 3	Types of frequency control services	14
Figure 4	Mainland NEM: Negative RoCoF exposure for credible contingency events	15
Figure 5	Queensland: RoCoF exposure for the non-credible loss of QNI interconnector	16
Figure 6	Relationship of potential FFR services with existing services	21
Figure 7	Possible mapping of proposed FFR services (frequency ranges and response times)	23





# 1. INTRODUCTION

## Purpose of this report

AEMO is releasing this paper to help inform a discussion with stakeholders on the various opportunities for fast frequency response (FFR) services that may be valuable in future in the National Electricity Market (NEM). It emphasises the importance of not restricting the definition or application of FFR services so that the full value of their capability can be leveraged.

An understanding of FFR opportunities is relevant for a number of stakeholders, including:

- Project developers engaged in project design at present, with the potential to incorporate FFR capabilities.
- The Australian Energy Market Commission (AEMC), to inform FFR implementation frameworks considered in its System Security Market Frameworks Review<sup>6</sup>, and its frequency control frameworks review<sup>7</sup>.
- The federal government as FFR was given consideration in the Independent Review into the Future Security of the National Electricity Market (Finkel Review).
- Other stakeholders with influence over the capabilities sought from new projects, such as government bodies, the Australian Renewable Energy Agency (ARENA), the Clean Energy Finance Corporation (CEFC), and the Essential Services Commission of South Australia (ESCOSA).
- Market participants and other stakeholders interested in engaging with AEMO on the design of new system services, and the operation of the future power system.

This report may be read in conjunction with AEMO's broader recommendations on technical standards, as outlined in the recent advice to ESCOSA<sup>8</sup>. AEMO has submitted a rule change proposal which would broaden these recommendations to apply in all NEM regions via the National Electricity Rules (NER).

This report is not intended to provide a detailed specification of FFR services rather it represents an important intermediate step, prior to extensive further analysis that will be required to develop detailed specifications of the capabilities required in the NEM. It aims to provide a starting point for discussion with stakeholders, outlining initial high level proposals on how FFR can be of value, and establishing a common language as a basis for consultation.

This approach is consistent with the views expressed by the expert panel in the final report on the Finkel Review, which stated "*further refinement is needed to ensure a well-designed solution... The market design would need to incorporate the desired technical parameters of an FFR service, including the response speed, sustain times and control systems.*"<sup>9</sup>

## Scope and limitations

Every effort has been made to ensure this document reflects the best knowledge at present, but given the current pace of change in the energy market, it is inevitable that some aspects will evolve. In particular, this work will influence, and be influenced by, a number of open consultations and processes, including:

- The rule change exploring implementation frameworks for FFR-type services and inertia services that resulted from the AEMC's System Security Market Frameworks Review.
- The AEMC's Frequency Control Frameworks Review.

<sup>6</sup> <http://www.aemc.gov.au/Markets-Reviews-Advice/System-Security-Market-Frameworks-Review>

<sup>7</sup> <http://www.aemc.gov.au/Markets-Reviews-Advice/Frequency-control-frameworks-review>

<sup>8</sup> AEMO (31 March 2017), Recommended Technical Standards for Generator Licensing in South Australia. Available at: <http://www.escosa.sa.gov.au/ArticleDocuments/1048/20170331-Inquiry-RecommendedTechnicalStandardsGeneratorLicensingSA-AEMOadvice.pdf.aspx?Embed=Y>

<sup>9</sup> *Independent Review into Future Security of the National Electricity Market. Blueprint for the Future*, Commonwealth of Australia 2017, p57. Available at: <http://www.environment.gov.au/system/files/resources/1d6b0464-6162-4223-ac08-3395a6b1c7fa/files/electricity-market-review-final-report.pdf>



- AEMO's work on future system services program, which is seeking input from stakeholders via the Ancillary Services Technical Advisory Group (AS-TAG)<sup>10</sup>.
- The Reliability Panel's Review of the NEM Frequency Operating Standard (FOS)<sup>11</sup>.
- AEMO's continued work on developing greater understanding of new services and capabilities, including working with trial projects through a memorandum of understanding with ARENA.
- The response to the Finkel Review final report,<sup>12</sup> which includes recommendations relating to FFR.

This report does not directly address issues related to the procurement of inertia. The technical characteristics of inertia are better understood, and relatively simpler to specify, and the frameworks for its procurement are being addressed under the AEMC's System Security Market Frameworks Review. For further details, stakeholders are directed to AEMO's submissions to that process<sup>13</sup>.

This document aims to define *technical* aspects of services that may become valuable in maintaining security in the future power system. Although there is some discussion on potential implementation frameworks, this document does not make any assumptions or provide any assurances regarding the establishment of revenue streams associated with delivery of these services.

## Context

AEMO has been exploring FFR as part of its Future Power System Security (FPSS) program<sup>14</sup>, which identified the potential for high rate of change of frequency (RoCoF) as a high priority challenge (see Chapter 2).<sup>15</sup> Specifically, 'supply-demand imbalances due to any disturbance will cause larger and more rapid frequency deviations that will be increasingly hard to manage'.

As inverter-connected generation (such as wind and photovoltaics) displace synchronous generation (such as coal and gas), the inertia of the power system reduces. Inertia acts to slow the RoCoF, meaning that a lower inertia system will experience higher RoCoF following a disturbance on the power system. In time, the various mechanisms traditionally used to maintain the FOS may no longer be adequate, with faster frequency services required to maintain the FOS at lower inertia levels. AEMO has thus identified FFR as a potential option for managing high RoCoF.

As part of the FPSS program AEMO commissioned two pieces of work:

- An International Review of Frequency Control Adaptation<sup>16</sup>, examining examples of FFR implementation internationally.
- Analysis by GE Consulting to explore the potential value of FFR services in the NEM, and to provide advice on how such services should be specified. This report<sup>17</sup> and AEMO's short response<sup>18</sup> are now publicly available.

This report is intended to disseminate our findings to date and encourage discussion around the role of FFR, in particular as AEMO sees an:

- **Emerging challenge** – High RoCoF is a growing challenge in the NEM. FFR could contribute to cost effective solutions, assisting with managing frequency within the FOS as inertia levels decline.
- **Emerging opportunity** – Significant investment is anticipated in the coming years in many types of inverter-connected technologies, such as wind, photovoltaics, batteries, and other types of

<sup>10</sup> <https://www.aemo.com.au/Stakeholder-Consultation/Industry-forums-and-working-groups/Other-meetings/Ancillary-Services-Technical-Advisory-Group>

<sup>11</sup> <http://www.aemc.gov.au/Markets-Reviews-Advice/Review-of-the-Frequency-Operating-Standard#>

<sup>12</sup> <http://www.environment.gov.au/energy/publications/electricity-market-final-report>

<sup>13</sup> AEMO Submission to AEMC System Security Market Frameworks Review Direction Paper (26 April 2017). Available at: <http://www.aemc.gov.au/getattachment/917b38b1-2f61-4601-a72e-f084cba0e2ce/AEMO.aspx>

<sup>14</sup> <http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability>

<sup>15</sup> AEMO's FPSS program overview. Available at: <http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability>.

<sup>16</sup> DGA Consulting report to AEMO (14 Oct 2016), International Review of Frequency Control Adaptation. Available at: [https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security\\_and\\_Reliability/Reports/FPSS---International-Review-of-Frequency-Control.pdf](https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/FPSS---International-Review-of-Frequency-Control.pdf)

<sup>17</sup> GE Energy Consulting report to AEMO (9 March 2017), Technology Capabilities for Fast Frequency Response. Available at: [https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security\\_and\\_Reliability/Reports/2017-03-10-GE-FFR-Advisory-Report-Final---2017-3-9.pdf](https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017-03-10-GE-FFR-Advisory-Report-Final---2017-3-9.pdf)

<sup>18</sup> AEMO (15 March 2017), Fast Frequency Response Specification. Available at: [https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security\\_and\\_Reliability/Reports/FFR-Coversheet-2017-03-10a.pdf](https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/FFR-Coversheet-2017-03-10a.pdf)



storage. These technologies have the potential to deliver many kinds of FFR, and inclusion of these capabilities in the initial installation is likely to be less expensive than a later retrofit. This creates a need to define and specify the types of FFR services which may provide value in future to direct this investment.

### Structure of report

This report is structured as follows:

- Chapter 2 provides an introduction to frequency control, including the FOS, the use of Frequency Control Ancillary Services (FCAS), and types of control schemes. Emerging challenges in frequency control are discussed, highlighting the timelines over which FFR services of different types may have a role.
- Chapter 3 introduces the concept of FFR, providing background on international experiences, and the types of technologies that can deliver FFR.
- Chapter 4 presents details on different types of FFR that might be of value in future.
- Chapter 5 outlines AEMO's next steps.

While this report focuses on the NEM, the concepts and issues are pertinent to the South West interconnected system (SWIS) in Western Australia.

### Inviting stakeholder comment

The NEM, and particularly South Australia, are at the global forefront of integrating high levels of variable renewable energy into the grid. This report is informed by research and analysis by AEMO and consultants, GE. AEMO recognises that this is an emerging field and there are differing views on the capability and opportunities afforded by FFR.

AEMO welcomes evidence-based feedback on the technical findings set out in this report, preferably supported by analysis. Views on potential FFR services are also invited. All feedback will inform AEMO's forward work program as outlined in Chapter 5, and stakeholders wanting to provide input can:

- Email submissions to [ancillaryservices@aemo.com.au](mailto:ancillaryservices@aemo.com.au) by 29 September 2017.



## 2. EMERGING FREQUENCY CONTROL CHALLENGES

### 2.1 Frequency Control in the NEM

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

The FOS are set by the Reliability Panel and prescribe allowable frequency ranges for different types of events, allowing these to be managed appropriately. The FOS reflects the appropriate frequency bounds in which equipment connected to the power system can operate safely, with wear and tear limited to acceptable levels, and appropriate durations. The FOS sets the frequency range of  $50 \pm 0.15$  Hz as the Normal Operating Frequency Band, with frequency required to remain within this range 99% of the time under normal operating conditions<sup>19</sup>.

#### 2.1.1 Types of events covered by the FOS

The FOS provide for wider frequency operating bands to apply temporarily when different contingencies occur. These can be events defined in the NER as either credible or non-credible contingency events, and also include protected events<sup>20</sup>:

- **Credible contingency events** are defined under the NER as events that are unexpected, but reasonably possible given the state of the power system at a given time. Examples of credible contingency events include the sudden loss of a single generating unit, load or single transmission line. AEMO is expected to maintain frequency within the relevant FOS bands during and after a credible contingency event, and takes action pre-emptively to do so.
- **Non-credible contingency events** are rare, but potentially have more severe impacts on the power system. Examples include the loss of a double circuit interconnector, or the simultaneous loss of two transmission lines. As the probability of these events is very low and their management can involve a very high cost to consumers, under the NEM framework involuntary load shedding is considered an acceptable response. AEMO has no authority under the NER to take pre-emptive action to reduce the frequency impact of a non-credible contingency event, other than by assessing automatic under-frequency load shedding capability.<sup>21</sup> The NER require AEMO to take all reasonable action *following* the occurrence of such an event to return the power system to a secure operating state.
- **Protected events** are a new category of events arising from a recent rule change as part of the AEMC's System Security Market Frameworks Review<sup>22</sup>. On AEMO's advice, the Reliability Panel can declare a specified high impact non-credible contingency event (such as the loss of a specific double circuit interconnector) to be a protected event, together with a defined standard for management of the event by AEMO. This may include the design of an appropriate Emergency Frequency Control Scheme (EFCS), such as a Special Protection Scheme (SPS). For a protected event, AEMO can act pre-emptively to manage the impacts of a particular event if the Reliability Panel determines that a proposed set of pre-emptive management measures is technically and economically feasible, applying cost-benefit criteria set out in the NER. AEMO is currently planning for its inaugural Power System Risk Review for the NEM, which will inform any request to the Reliability Panel for the declaration of initial protected events.

<sup>19</sup> The FOS is under review by the AEMC Reliability Panel at present. AEMO is contributing technical information to this review. <http://www.aemc.gov.au/Markets-Reviews-Advice/Review-of-the-Frequency-Operating-Standard#>

<sup>20</sup> The interim FOS for protected events is set out in clause 11.97.2 of the NER.

<sup>21</sup> Governments can direct alternative actions; for example, the South Australian Government has directed AEMO to implement a constraint on flows on the Heywood Interconnector to limit RoCoF to less than 3 Hz/s in the event of non-credible loss of the interconnector.

<sup>22</sup> AEMC (6 April 2017), Rule Changes: Completed: Emergency Frequency Control Schemes. Available at: <http://www.aemc.gov.au/Rule-Changes/Emergency-frequency-control-schemes-for-excess-gen#>

### 2.1.2 Frequency Control Ancillary Services

In the NEM, generation and demand are balanced through the central dispatch process, which includes the dispatch of both energy and Frequency Control Ancillary Services (FCAS). Provided by generation or load, FCAS are a market mechanism employed specifically to correct imbalances between supply and demand which cannot be addressed through the central dispatch process which follows the forecast average demand movement.

There are two types of FCAS markets.

- Regulation FCAS is used to manage minor deviations in power system frequency within the five minute dispatch periods.
- Contingency FCAS is used to manage relatively material frequency deviations that might arise from larger supply-demand imbalances following credible contingency events. It is delivered in three timeframes: six seconds, sixty seconds and five minutes.

Each FCAS market is divided into two types of services: “Raise” services used to correct a deficit of generation (or excess of load), and “Lower” services used to correct an excess of generation (or deficit of load). 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.

## 2.2 Frequency control schemes

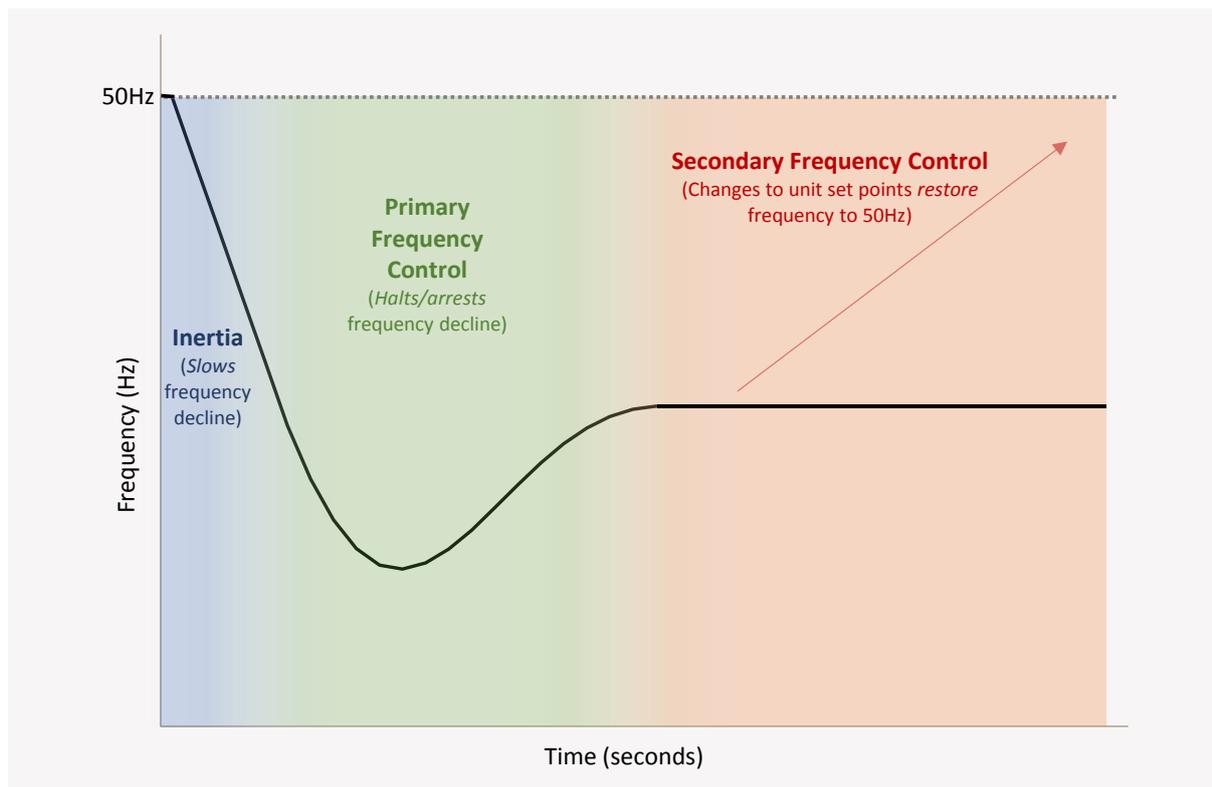
In exploring opportunities for FFR it’s important to think broader than the current FCAS frameworks and assess the various control schemes for the delivery of frequency control services. Table 1 lists four different types of control schemes with examples of the current use of each in the NEM.

Each of the control schemes has different merits with their different contributions to frequency control illustrated in Figure 3. For example, inertia is the only service that can slow frequency changes immediately following a disturbance. However, inertia can neither halt the frequency change nor restore frequency to 50 Hz. Restoring frequency to 50 Hz is achieved by changes to unit set points. Coordination of set point changes on multiple units is managed centrally via AEMO’s Automatic Generation Control (AGC) system. The AGC system detects the power system frequency, and sends control signals to generators to adjust the set points of the governors, thereby increasing or decreasing generator output.

**Table 1 Types of control schemes for frequency control services**

	Typical delivery	What it does	What it <i>can't</i> do	Examples of formal services in the NEM
<b>Inertia</b>	Automatic physical property of synchronous rotating machines	Slows frequency changes	<ul style="list-style-type: none"> <li>• Halt/arrest frequency changes</li> <li>• Restore frequency to 50 Hz</li> </ul>	Automatically delivered by all synchronous units
<b>Primary Frequency Control</b>	Controlled response to local frequency measurement. Often delivered as a droop response. Eg. Governor response of synchronous units.	Halts/arrests frequency changes	<ul style="list-style-type: none"> <li>• Slow frequency changes instantly following the disturbance</li> <li>• Fully restore frequency to 50 Hz</li> </ul>	6s and 60s contingency FCAS
<b>Changes to unit set points</b>	Automatic Generation Control (AGC)	Restores frequency to close to 50 Hz	<ul style="list-style-type: none"> <li>• Act quickly. Total response times are limited by minimum AGC cycle time of 5-10 seconds.</li> </ul>	Regulation FCAS (via AGC), and 5min contingency FCAS (autonomous changes to unit set points) Dispatch
<b>Direct event trigger</b>	Triggered by detection of a specific event, such as the loss of an interconnector. Typically “pre-armed” to ensure accurate quantity of response is delivered.	Rapidly corrects imbalance for specific event	<ul style="list-style-type: none"> <li>• Respond to general frequency disturbances.</li> </ul>	SPS protecting against loss of Basslink interconnector

**Figure 3 Types of frequency control services**



## 2.3 Emerging frequency control challenges

AEMO has analysed the risk of potential exposure to high RoCoF across the NEM following credible and non-credible contingency events. The objective of this analysis was to provide an indication of the timing of challenges in maintaining the FOS due to high RoCoF, illuminating some of the potential opportunities for different FFR services.

The analysis was based upon the generation mix projected in the 2016 National Transmission Network Development Plan (NTNDP).<sup>23</sup> As such, the timing of the identified opportunities may change if there is more rapid uptake of non-synchronous generation than that projected.

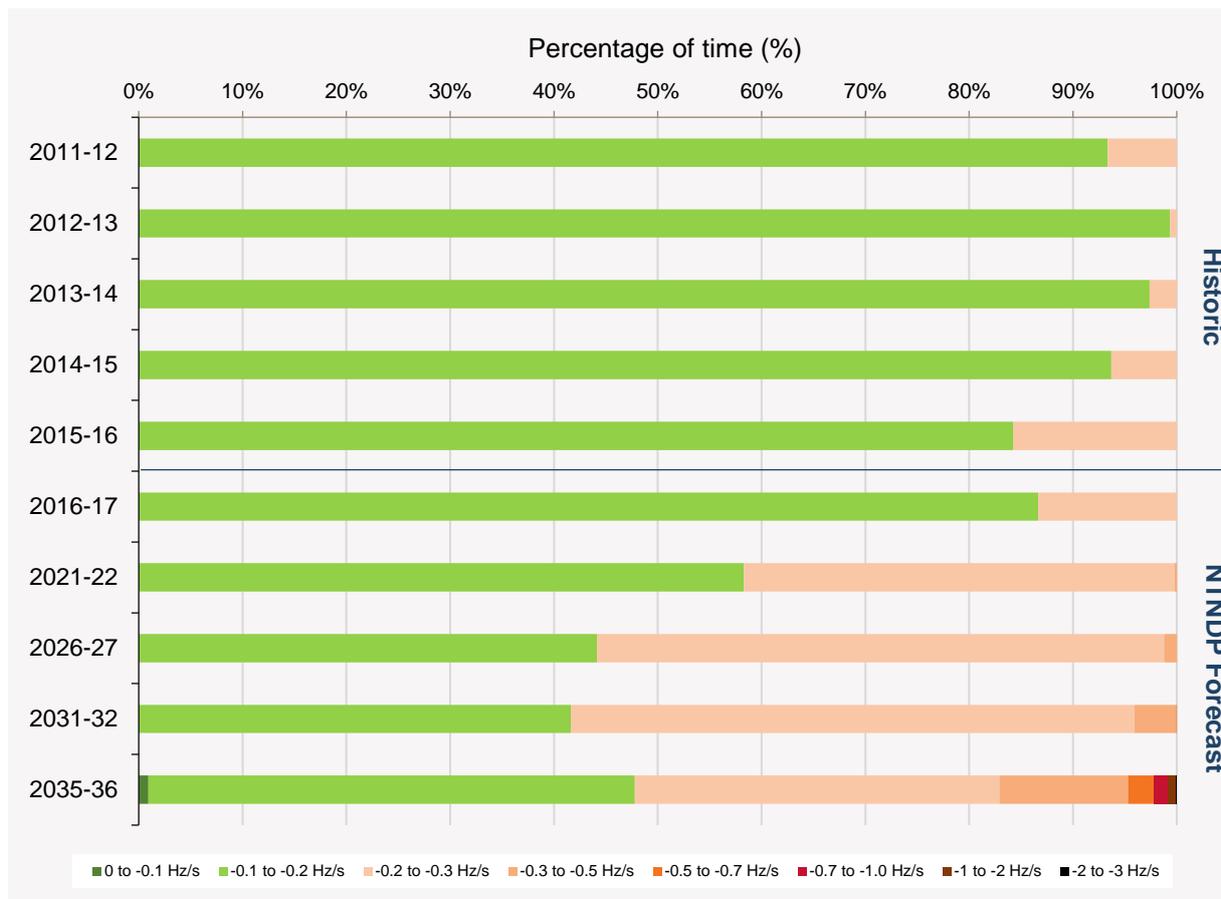
### 2.3.1 Managing credible contingency events

Figure 4 shows the projected RoCoF exposure related to credible contingency events for the NEM mainland. It shows that RoCoF levels could be in the range of 0.2-0.3 Hz/s for more than 40% of the time by 2021-22. At this level of RoCoF, there is less than two seconds for primary frequency control actions to arrest the frequency decline before frequency leaves the containment band. This is quicker than the commonly observed response from many synchronous governors, suggesting that the FOS may not be met in these cases.

This implies an increasing need for faster frequency services which, by 2021-22, could provide value on the NEM mainland in assisting with the management of credible contingency events. Potential services such as “Contingency FFR” described in section 4.2 are particularly relevant for these kinds of events.

<sup>23</sup> AEMO. 2016 National Transmission Network Development Plan. Available at: [http://aemo.com.au/-/media/Files/Electricity/NEM/Planning\\_and\\_Forecasting/NTNDP/2016/Dec/2016-NATIONAL-TRANSMISSION-NETWORK-DEVELOPMENT-PLAN.pdf](http://aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NTNDP/2016/Dec/2016-NATIONAL-TRANSMISSION-NETWORK-DEVELOPMENT-PLAN.pdf)

**Figure 4 Mainland NEM: Negative RoCoF exposure for credible contingency events**



### 2.3.2 Managing non-credible contingency events

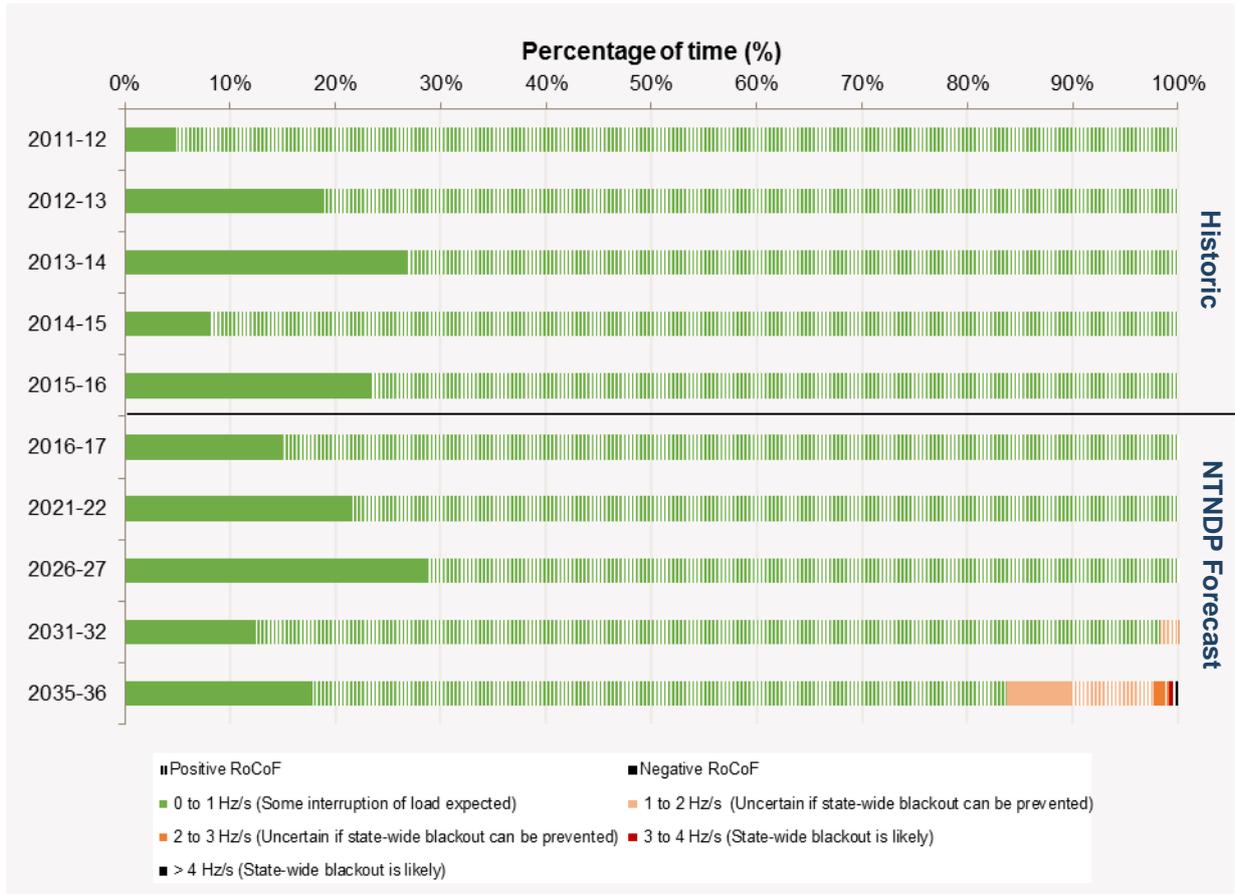
High RoCoF following non-credible contingencies presents a number of risks to managing the power system including:

- The increased likelihood of UFLS meaning more customers will be tripped. However, if the RoCoF is too high, the relays on UFLS may not be able to respond fast enough to prevent a cascading failure.
- Generators may not be able to ride through the frequency changes associated with high RoCoF, exacerbating the problem and the amount of UFLS required.

The potential non-credible loss of the Heywood Interconnector connecting South Australia to Victoria has been identified as an important risk for South Australia. Upon loss of the interconnector, South Australia becomes a synchronous island, and must survive the separation event with local reserves of inertia. AEMO directly manages flows on the Heywood Interconnector to limit RoCoF in the event of separation. A SPS (incorporating demand response FFR, and possibly other kinds of FFR) is currently under design by ElectraNet, in collaboration with AEMO, to provide a more cost effective long term option for managing this risk.

With projected growth in non-synchronous generation, Queensland may eventually require similar control mechanisms. Figure 5 illustrates the RoCoF exposure related to the non-credible loss of the QNI interconnector which connects Queensland to New South Wales. From 2035-36, RoCoF exposure is in the range of 1-2 Hz/s or higher more than 15% of the time, indicating an increasing risk to power system security. A SPS may be appropriate from that time (possibly incorporating emergency response FFR, as outlined in Section 4.1). If there is significant growth in non-synchronous generation beyond the levels projected for this analysis or earlier retirement of synchronous plant, higher RoCoF levels could occur earlier.

**Figure 5 Queensland: RoCoF exposure for the non-credible loss of QNI interconnector**



## 3. OPPORTUNITIES FOR NEW FREQUENCY CONTROL SERVICES

The current suite of frequency control measures as outlined in chapter 2 were not designed to operate in a power system with very low levels of inertia, and hence potentially high RoCoF. As the generation mix changes, the potential level of RoCoF that may follow imbalance events in the NEM highlights a need for faster frequency control services, this suite of services typically referred to as FFR.

### 3.1 What is Fast Frequency Response?

FFR does not have a single definition but refers to a broad range of capabilities and applications. While internationally the term has a wide range of interpretations based on their applications, for the purposes of this report FFR is defined as:

*Any type of rapid active power increase or decrease by generation or load, in a timeframe of less than two seconds, to correct supply-demand imbalances and assist with managing frequency.*

AEMO's international review<sup>24</sup> identified the following applications of FFR:

- **Hydro-Québec** (in Canada) has a mandatory requirement for all wind farms connecting to its system to provide inertia-based FFR (IBFFR), also often called synthetic inertia. Ontario and Brazil have more recently introduced similar mandatory requirements.
- **National Grid** (in Great Britain) has tendered for a one second *Enhanced Frequency Response* service, to be delivered by batteries from 2018. This service is to be delivered via a droop response with a narrow dead band, similar to a primary frequency response delivered by synchronous governors.
- **PJM** (in the USA) uses batteries and flywheels for dynamic regulation services, responding to AGC signals. Suppliers are paid a price scaled by how rapidly they respond, encouraging faster response.
- **New Zealand** has a one second contingency service delivered by demand response.
- **ERCOT** (in Texas) also has a fast demand response service. The introduction of a half second FFR service was proposed but was rejected by stakeholders because it was seen as complex and unnecessary at this time. It may be given further consideration in future.
- **EirGrid** (in Ireland) has proposed the introduction of a one to two second FFR service, with a payment “scalar” to incentivise faster delivery. The specification of this service is under development at present and will be informed by a qualification trial process.
- **Special protection schemes** are commonly used to manage rare, extreme events, typically utilising demand response (load shedding). For example, there is an operational SPS in Arizona, USA that is sensitive to the loss of two of the three nuclear generators at the Palo Verde Nuclear Power Station<sup>25</sup>.

The diversity in international experiences supports AEMO's view that FFR can provide a range of services that are beneficial to the power system.

### 3.2 Technologies capable of FFR

FFR services can be delivered by a wide range of technologies, some examples of which are listed in Table 2. As this is a developing field more technologies or capabilities may emerge in the near future. Table 2 outlines each technology in terms of the following characteristics:

<sup>24</sup> DGA Consulting report to AEMO (14 October 2016) International Review of Frequency Control Adaptation. Available at: [https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security\\_and\\_Reliability/Reports/FPSS---International-Review-of-Frequency-Control.pdf](https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/FPSS---International-Review-of-Frequency-Control.pdf)

<sup>25</sup> GE Energy Consulting report to AEMO (9 March 2017), Technology Capabilities for Fast Frequency Response. Available at: [https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security\\_and\\_Reliability/Reports/2017-03-10-GE-FFR-Advisory-Report-Final---2017-3-9.pdf](https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017-03-10-GE-FFR-Advisory-Report-Final---2017-3-9.pdf)

- **Sustained delivery** – Some technologies are well-suited to sustained or continuous delivery, where an ongoing injection of power or load reduction is required, such as for managing minor imbalances within dispatch intervals. Other technologies deliver a short burst of energy, and are therefore better suited to the management of larger, rarer events, such as contingency events. Larger reserves are typically required for these services, but they are only activated rarely.
- **Headroom** – Like synchronous technologies, many FFR technologies must reserve headroom to deliver FFR services. Headroom reserves the capacity to increase or decrease active power, as required for a raise or lower service. Some technologies do have the option of enabling additional capabilities that allow them to deliver raise services without the need for headroom (for example wind IBFFR and PV inverter overload capabilities). The need to reserve headroom restricts the ability for technologies to deliver other services simultaneously with the same allotment of headroom.
- **Raise versus lower services** - Discussion on FFR services is typically focused on raise services for the management of under-frequency events. However, fast lower services may also be beneficial, and can typically be supplied by wind and PV plant without any need for pre-curtailment.

**Table 2 Some examples of types of inverter-connected technologies that can deliver FFR**

	Description	Suited to sustained delivery?	Headroom required for Raise?	Headroom required for Lower?
<b>Wind inertia-based FFR (IBFFR)</b>	Often termed synthetic inertia or emulated inertia. Upon sensing a frequency disturbance, the wind turbine extracts kinetic energy from the drive train, delivering a short burst of additional active power (sustained for ~10 seconds). A recovery period often follows, during which the turbine blades must reaccelerate and active power delivery is reduced below pre-event levels (for the same wind energy).	✗	No	N/A (not applied for Lower)
<b>Wind pitch control</b>	The wind farm uses pitch control to rotate the blades to precisely follow a set point below the total available power.	✓	Yes	No
<b>PV inverter overload</b>	If the DC solar field is oversized compared to the inverter, and the inverter is designed with an appropriate short term overload capability, the PV farm can deliver a short burst of active power upon sensing a frequency disturbance if the solar irradiance is sufficient.	✗	No	N/A (not applied for Lower)
<b>PV set point operation</b>	The PV farm uses controls to precisely follow a set point below the total available power.	✓	Yes	No
<b>Batteries, flywheels</b>	Batteries and flywheels can very rapidly adjust active power supply or demand in response to a range of types of control signals.	✓	Yes	Yes
<b>Supercapacitors</b>	Supercapacitors can provide a short burst of active power (sustained for ~10 seconds)	✗	Yes	Yes
<b>Demand-side response</b>	Demand-side response can rapidly reduce consumption, providing a raise service without the need to reserve headroom.	✓	No	Yes
<b>Aggregators<sup>26</sup> (demand, DER)</b>	Aggregators can deliver changes in active power supply or demand from loads, distributed storage, and distributed energy resources (DER).	✓	Maybe	Maybe

Like the technical capabilities, the economics of each technology varies. For example, batteries and flywheels are highly flexible and capable, but wind, PV and demand-side technologies may become important providers of these services, because they can include adequate capabilities for a small incremental cost.

<sup>26</sup> Aggregators are listed as a separate category to recognise the potential contributions from aggregating large numbers of small sources.

Wind IBFFR is an important example, since it is a capability that can be incorporated into new wind farms at minimal cost, and it can deliver a fast contingency raise service without the need to reserve headroom. This means that wind IBFFR is likely to be a comparatively low cost option. However, to manage the recovery period, additional six-second FCAS may need to be scheduled when a significant proportion of contingency FFR is delivered by wind IBFFR, and the wind speeds are below maximum generation levels. Management of these situations will have operational and financial implications.

### 3.3 Important clarifications

#### 3.3.1 FFR and inertia are technically different services

FFR, especially when delivered by wind IBFFR, is often referred to as synthetic or emulated inertia. This has led to confusion about whether FFR should be considered a physical substitute for inertia. Although FFR can assist with maintaining the FOS at lower levels of inertia, it is not useful to describe substitute for inertia, for the following reasons:

##### **FFR has the potential to be more than just a substitute for inertia**

The behaviour of inverter-connected devices is highly tuneable, and can be designed to provide a much wider range of possible responses than synchronous units. Given the potential for improved services from inverter-connected devices, AEMO wants to avoid limiting FFR to mimic synchronous devices.

Framing FFR as a substitute for inertia may stifle possible future developments in the energy market. Options are necessarily benchmarked against the existing power system framework, but this can create unnecessary bias towards the status quo. AEMO's preferred approach is to examine all possible options for managing frequency to determine the optimal suite of services for future power system management at least cost. This can include a range of FFR-type services as well as inertia services co-optimised appropriately.

##### **Physical distinction between inertia and FFR**

Inertia is a physical property of synchronous units which provides an inherent response to slow the RoCoF. This provides time for an active power injection to correct the supply-demand imbalance, but it cannot act to restore power system frequency. In contrast, FFR is based upon a control system that can be tuned to operate as desired, and can inject active power to correct the imbalance, and restore power system frequency. These two services deliver different benefits to the system, and are not directly interchangeable.

##### **Complex relationships between FFR types and inertia**

The quantity and type of FFR services available to maintain a secure power system is related to the amount of inertia. This relationship does not imply that FFR and inertia are interchangeable:

- Large power systems currently require a minimum quantity of inertia, below which no quantity of FFR can be used to deliver a secure power system.
- The relationship is non-linear, needs to be determined via detailed dynamic modelling, and will depend upon a range of other operational factors.
- Different FFR services will have a different relationship between the level of power system inertia and the quantity of FFR required.

AEMO already uses a defined relationship between the amount of power system inertia, and the quantity of six second contingency FCAS procured in Tasmania. At lower inertia levels, more six second contingency FCAS is required to maintain system security. This relationship does not suggest in any way that contingency FCAS is interchangeable for inertia. Instead, there is a defined relationship used in the co-optimisation process for the two distinct services. FFR and inertia should be viewed from a similar perspective.

## A range of services from synchronous units

The term inertia is sometimes used to refer to all system services provided by synchronous units. However, inertia is just one aspect of how synchronous units interact with the power system. For example, synchronous units also contribute to system strength (injection of fault current), which assists with management of voltage disturbances, and contribute synchronising torque so that units can maintain synchronism with the power system during disturbances. These aspects must be considered in any stability analysis, and it is not always possible to clearly distinguish between each. That is, under extreme power system conditions it becomes increasingly challenging to specify precisely which of these characteristics will potentially destabilise the power system. This is particularly true when the power system is operating with very low levels of synchronous capacity online. The aim of any stability study is to determine the combination of interventions that will lead to a stable system. In these extreme cases, it is more appropriate to directly model and categorise FFR and inertia as separate services.

### 3.3.2 Faster may not always be better

- FFR technologies vary in their speed of response, and can respond very rapidly; some manufacturers have indicated to AEMO that total response times (including measurement and detection) in the realm of 20 milliseconds (ms) are possible. Response times this rapid are not appropriate or desirable in all cases because: Slower response times allow for robust measurement and identification of power system events, helping to avoid false triggering. On very short timescales frequency varies around the power system and the local frequency at a unit site may not reflect average power system frequency. This means that even the most sophisticated device will not be able to accurately distinguish between different types of disturbances if the measurement time is very short.
- The ability to coordinate between different kinds of FFR services is important. In some cases, it is better for some services to respond more slowly once the faster services have “settled”, to avoid undesired interaction.
- Extremely fast responses can in some instances reduce power system frequency performance by, for example, inhibiting the activation of synchronous plant governors and delaying the overall frequency response.
- Slower response times facilitate participation of a broader range of technologies in delivering FFR services. Some comparatively low cost technologies (such as wind IBFFR) have physical limitations that restrict the speed of response; a slower specification will allow their participation, increasing the range of providers, and potentially delivering a more competitive solution for consumers. As long as they are sufficiently fast to deliver a useful and cost effective response, their contribution should be included and encouraged.
- Following a fault in grids with low system strength, inverter-connected resources may need to recover active power more slowly to ensure power system stability. A slower FFR response time will allow resources in weak grid areas to participate more reliably.

For these reasons, AEMO is exploring response times that are only as fast as necessary for the particular application of interest to deliver the required benefit.

### 3.3.3 Flywheels are non-synchronous

Flywheels store kinetic energy in a rapidly rotating mass, the energy of which can be extracted and provided as an active power injection into the grid, delivering FFR.

It is a common misconception that flywheels are synchronous, and therefore provide inertia. In fact, flywheels are typically connected via an inverter and so not provide inertia. A “synchronous flywheel” would need to always rotate at a multiple of the grid frequency in order to be synchronously connected. This would mean that very little energy could be extracted from the flywheel while maintaining synchronism. Terminology such as “synchronous flywheel” typically refers to technology similar to a synchronous condenser which delivers inertia but cannot provide FFR.

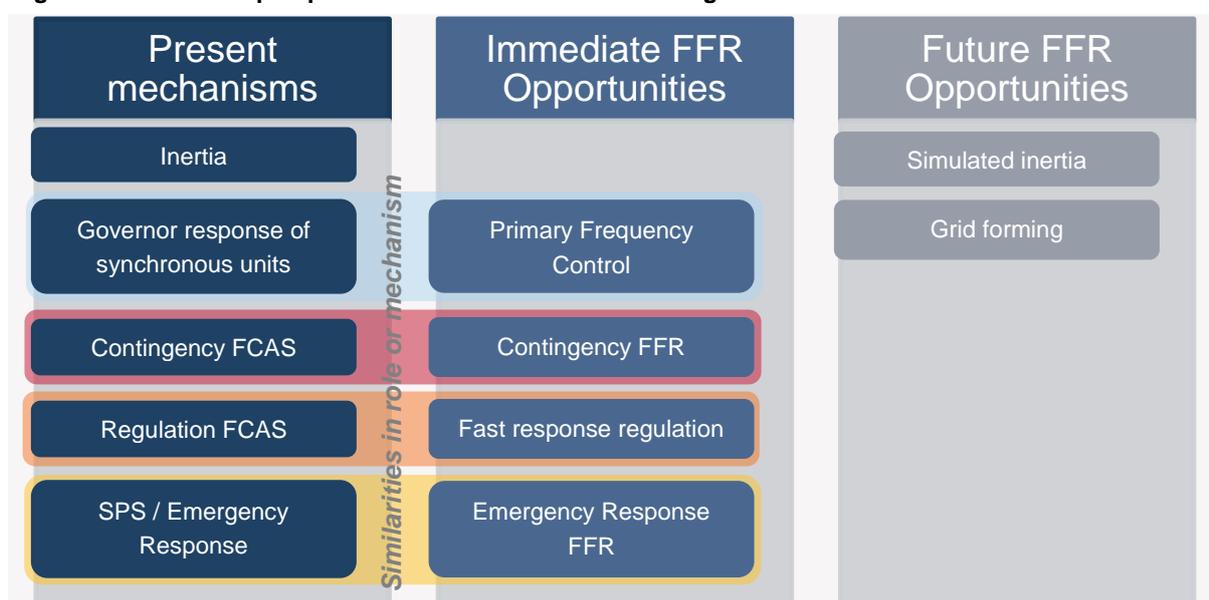
Some manufacturers are creating new and innovative products<sup>27</sup> such as “rotating stabilizers”, which use a clutch to move between operating as a flywheel (delivering FFR), and a synchronous condenser (delivering inertia). These technologies will offer increased flexibility and a larger range of options for managing power system frequency in future.

### 3.4 Opportunities for FFR in the NEM

Based on the frequency control challenges emerging in the NEM and the potential capabilities of technologies in providing FFR, AEMO has assessed what opportunities are available to complement the existing frequency control schemes. Figure 6 provides an outline of proposed FFR services and the parallels to existing services.

Some of the proposed FFR services fulfil similar roles or utilise similar mechanisms to existing frequency control approaches, but on faster timeframes, enabled by inverter-connected technologies. The proposed FFR services are intended to complement the existing services, not act as a replacement.

**Figure 6 Relationship of potential FFR services with existing services**



The characteristics of these potential FFR services and how they map across various frequency ranges and response times are detailed in the following chapter.

### 3.5 Need for trials

Work will be required to determine the appropriate coordination and co-optimisation between all of these services, and other relevant mechanisms such as inertia procurement and existing FCAS. Given the immaturity of these services, a process of learning facilitated by trials and experience is necessary. This will help to build confidence in the ability to use FFR services of different types to maintain power system security, and understand the required specifications in the design of new mechanisms, and their integration.

AEMO is pursuing collaborative opportunities with ARENA and market participants to develop trials of new services, including FFR. In May 2017, AEMO agreed a Memorandum of Understanding with ARENA to facilitate this process. AEMO intends to support 'proof of concept' projects which will allow new and emerging technologies to be deployed in the power system in the near future where those

<sup>27</sup> GE Energy Consulting report to AEMO (9 March 2017), Technology Capabilities for Fast Frequency Response. Available at: [https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security\\_and\\_Reliability/Reports/2017-03-10-GE-FFR-Advisory-Report-Final---2017-3-9.pdf](https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017-03-10-GE-FFR-Advisory-Report-Final---2017-3-9.pdf)



technologies may assist with the secure operation of the NEM. This could include demonstration of FFR type services.

The role of a proof-of-concept approach to understanding new technologies and their potential value to the power system was recognised in Recommendation 2.9 of the Finkel Review final report:

*Proof-of-concept testing of innovative grid-scale solutions will be required for as long as technology is continuing to rapidly evolve. A funding source for trials by the Australian Energy Market Operator and the Australian Renewable Energy Agency should be assured for the long-term.*

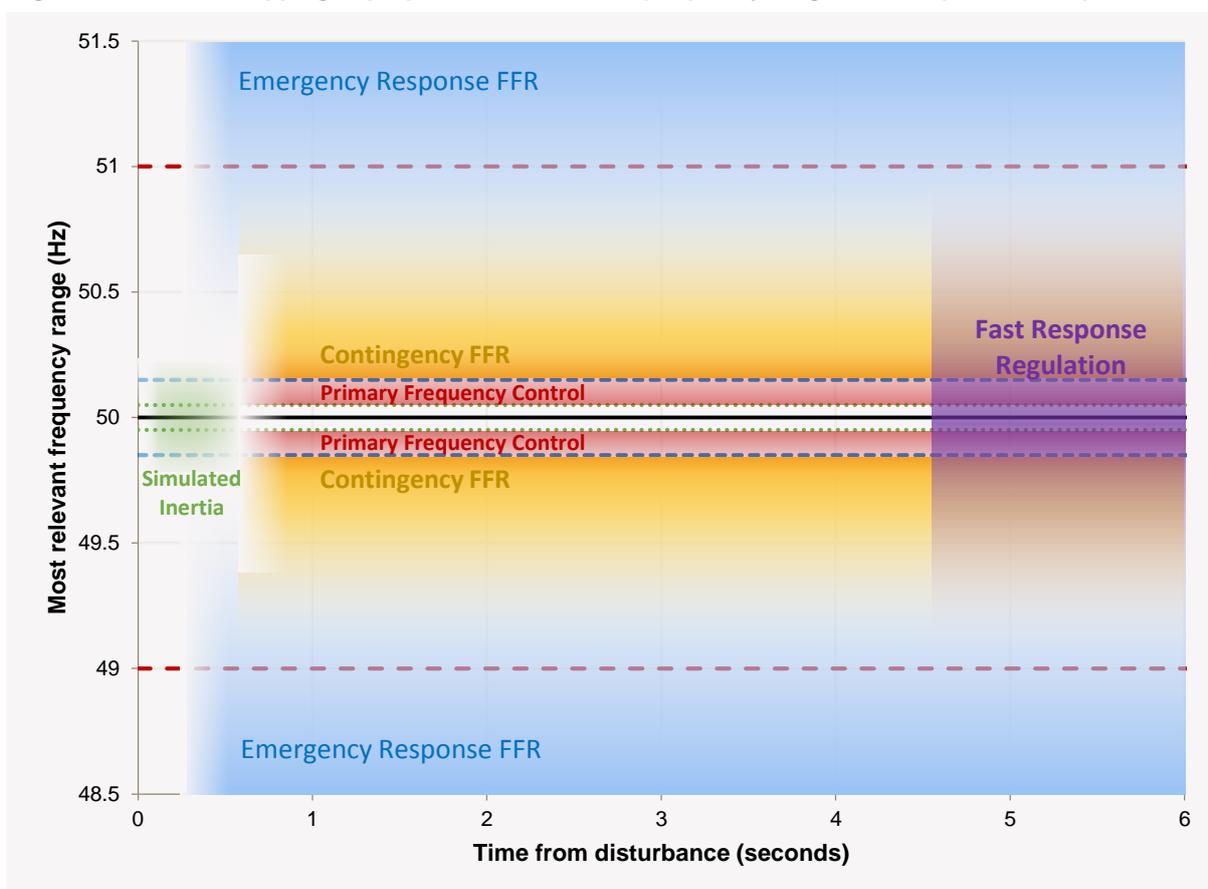
## 4. MULTIPLE ROLES FOR FFR

The range of FFR services that could assist in maintaining frequency in a future power system with lower levels of inertia are summarised in Table 3. Each type of service would be utilised to manage different kinds of frequency events, and could be managed or implemented by different parties.

As with the current suite of frequency control mechanisms, all of these FFR services could provide value in different ways, combining to provide alternative options for meeting the FOS. Figure 7 illustrates the frequency ranges over which each FFR service is most relevant, and the timescales over which they might operate. Relevant frequency bands from the FOS are illustrated for reference.

It is important to note that the Reliability Panel is currently undertaking a review of the FOS which will be conducted in two stages.<sup>28</sup> Any changes to the operating bands that may be considered in the future will affect the potential roles of all frequency control services, including FFR.

**Figure 7 Possible mapping of proposed FFR services (frequency ranges and response times)**



The FFR services in Table 3 are ordered by the approximate timeline over which AEMO believes they may become valuable or feasible in the NEM:

- Emergency response FFR is being implemented immediately as a part of the SPS under development to protect against or prevent the loss of the Heywood interconnector in South Australia.
- Contingency FFR and primary frequency control show promise in the near term.
- Fast response regulation may become important in future, and is technically feasible at present.
- Simulated inertia and grid-forming technologies are not yet commercially demonstrated.

<sup>28</sup> <http://www.aemc.gov.au/Markets-Reviews-Advice/Review-of-the-Frequency-Operating-Standard>

Table 3 Potential FFR services in the NEM<sup>29</sup>

Service	Purpose	Typical time to full response (including measurement and detection)	Trigger and control type	Possible deadbands	Maturity with inverter-connected resources	Example technologies for Raise <sup>30</sup> (non-exhaustive)	Proposed implementation
<b>Emergency response</b>	For arresting frequency following specific <b>rare, extreme events</b> such as non-credible separation of a region.	~250ms	Direct event trigger, such as part of a Special Protection Scheme (SPS)	NA	<b>Mature with demand response</b> ; used in many applications internationally. Used for managing loss of Basslink in Australia (with demand-response FFR)	<b>No headroom required:</b> Demand response  <b>Headroom required:</b> Batteries, Flywheels, Supercapacitors	Implemented by TNSPs, via the Emergency Frequency Control Scheme (EFCS) framework (similar to UFLS)
<b>Contingency FFR</b>	For arresting frequency following <b>credible contingency events</b> , such as loss of a single unit.	~0.5 - 1 second	Local frequency measurement (may include a combination of switched and proportional response)	Wide (eg. $\pm 0.15$ Hz)  Aim to trigger only when contingency events occur.	<b>Emerging.</b> Few international examples, such as mandatory wind IBFFR response by Hydro Quebec, and proposals by EirGrid and ERCOT	<b>No headroom required:</b> Wind IBFFR, PV inverter overload, Demand response.  <b>Headroom required:</b> Batteries, Flywheels, Supercapacitors, Wind pitch control, PV pre-curtailed	<b>Long term:</b> Aligned with FCAS framework  <b>Short term:</b> Fixed regulated tariff paid for all periods enabled
<b>Primary Frequency Control</b> (simulated governor response)	For fast, continuous arresting of all imbalances (minor and contingency events), <i>within</i> the normal operating frequency band.	~0.5 - 1 second (or as fast as possible whilst ensuring action is appropriate)	Local frequency measurement (droop response)  In practice, may be delivered by same controls as Contingency FFR, but with narrower deadband.	Narrow (e.g. $\pm 0.05$ Hz or less)  Used continuously for minor imbalances.	<b>Emerging.</b> Few international examples, such as Enhanced Frequency Response from batteries in Great Britain	<b>Headroom required:</b> Batteries, Flywheels, Wind pitch control, PV pre-curtailed	<b>Capability:</b> Mandate capability for all new entrants in technical standards <b>Enablement:</b> Could be mandated or paid service (like present FCAS) <b>Reserving headroom:</b> Payment framework, co-optimised with energy market

<sup>29</sup> Many of the services described in this table are routinely delivered by synchronous plant on slower timescales. In some cases, synchronous plant may also be able to deliver these services adequately fast to qualify as types of FFR. However, the focus of this report is on new types of FFR services delivered by inverter-connected plant, since this is the area with the least experience, and so comments on the novelty of FFR services relate to obtaining these services from inverter-connected plant. Demand response FFR is also included (as a more mature example), given the potential for expanding its use in the NEM.

<sup>30</sup> Raise services are addressed as an example; Lower services will also be required, and will have different headroom requirements as indicated in Table 2.



Service	Purpose	Typical time to full response (including measurement and detection)	Trigger and control type	Possible deadbands	Maturity with inverter-connected resources	Example technologies for Raise <sup>30</sup> (non-exhaustive)	Proposed implementation
<b>Fast Response Regulation</b>	For restoring frequency to 50Hz, associated with minor imbalances within 5min dispatch intervals	~1 second response to AGC signals (or as fast as possible)	4 second AGC signals (~5 second total cycle response time)	Used continuously for minor imbalances.	<b>Emerging.</b> Few international examples, such as Dynamic Regulation from batteries and flywheels in PJM	<b>Headroom required:</b> Batteries, Flywheels, Wind pitch control, PV pre-curtailed	Could be via adaptation of regulation FCAS to introduce payment for performance (reward faster response)
<b>Simulated inertia</b>	To simulate the inertial response of a synchronous unit, as closely as possible	No more than 10-20ms	Local frequency measurement	Enabled continuously	<b>Not commercially available at present.</b> May be feasible in high inertia grids in the near future. Unlikely to be feasible in low inertia grids (such as SA) for some time.	<b>Headroom required:</b> Batteries, Flywheels.	Could be via adaptation to the inertia procurement mechanism (when this becomes technically feasible).
<b>Grid forming technologies</b>	A suite of services to manage a large (>300MW) system with no synchronous capacity (100% inverter-connected)	Constant response	Unknown	NA	<b>Not technically possible at present for large (&gt;300MW) systems,</b> but under research, and likely to become possible in future with continued technology development.	May require adaptation to all units installed in the system	NA

## 4.1 Emergency response FFR

FFR can be used to assist with emergency response to extreme contingency events, potentially including the new category of low probability, high impact ‘protected events’<sup>31</sup>. This would most likely involve incorporating FFR into the design of a SPS for a specific event, such as the loss of a double-circuit interconnector. The use of inverter-connected technologies and voluntary demand response FFR would reduce the amount of involuntary UFLS utilised to manage the event, reducing customer outages.

FFR for emergency response will need to be very fast, with a total response time the order of 250 ms. This service aims to respond to extreme contingency events for which the RoCoF levels can (and have) exceeded 3 Hz/s. This allows less than 300 ms to detect and respond to the event, before the 49 Hz threshold for UFLS is reached. Similarly, an SPS on an interconnector that aims to detect imminent occurrence of a loss of synchronism would need to act very rapidly to correct the imbalance before the interconnector is tripped.

This very rapid response is achievable by many technologies, including batteries, demand-side response, supercapacitors and flywheels. Direct event detection will likely be necessary to achieve a total response time that is sufficiently rapid and robust. This would monitor the status of the relevant interconnector (or other device) and trigger emergency response FFR when a particular event is detected (such as a breaker opening on an interconnector, or an unexpected zeroing of current on the interconnector).

FFR resources for emergency response, triggered by direct event detection, do not respond directly to power system frequency. However, this service is included here as a type of FFR since it is a rapid active power injection (or load reduction) used to correct an imbalance to help manage power system frequency.

SPSs are commonly used internationally and are considered mature. In Australia, an SPS is currently used to manage the loss of the Basslink interconnector, utilising demand-response FFR from industrial customers in Tasmania. The incorporation of other types of FFR resources (such as batteries) is less mature, but does not appear to have any major technical barriers.

Some technologies may not be able to respond sufficiently rapidly to deliver emergency response FFR. For example, the rate of response of IBFFR from wind turbines is limited by tower stresses, and is more typically on the order of one to two seconds.

### 4.1.1 Implementation

Historically, the emergency response mechanism in the NEM has been UFLS. Under the recent NER changes introducing protected events, UFLS is considered part of a broader category of EFCS<sup>32</sup>. The existing UFLS scheme operates by detecting when frequency falls to 49 Hz, and progressively trips customer load blocks to arrest the frequency decline. A framework for design and implementation of Over Frequency Generation Shedding (OFGS) schemes (a type of EFCS able to trip generation to arrest an increase in frequency) has also been included in the NER.

The implementation of a SPS becomes necessary when RoCoF levels exceed the existing EFCS capability (that is, OFGS and UFLS scheme performance). AEMO modelling suggests this occurs at RoCoF levels around 2-3 Hz/s<sup>33</sup>.

Transmission Network Service Providers (TNSPs) have obligations under the NER to implement the EFCSs. They are also obliged to consider non-credible contingency events and upgrade the emergency response mechanism if required in collaboration with AEMO. This incorporates obligations

<sup>31</sup> AEMC (6 April 2017), Rule Changes: Completed: Emergency Frequency Control Schemes. Available at: <http://www.aemc.gov.au/Rule-Changes/Emergency-frequency-control-schemes-for-excess-gen#>

<sup>32</sup> AEMC (6 April 2017), Rule Changes: Completed: Emergency Frequency Control Schemes. Available at: <http://www.aemc.gov.au/Rule-Changes/Emergency-frequency-control-schemes-for-excess-gen#>

<sup>33</sup> AEMO (December 2016) Black System South Australia 28 September 2016 Third Preliminary Report. Section 3.3.3. Available at: [https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security\\_and\\_Reliability/Reports/Integrated-Third-Report-SA-Black-System-28-September-2016.pdf](https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/Integrated-Third-Report-SA-Black-System-28-September-2016.pdf)

for TNSPs to design and implement an SPS, where the existing EFCS capability may no longer be sufficient.

In the design of an SPS, a TNSP could utilise FFR resources to reduce the use of involuntary load shedding, procuring FFR as a Network Loading Control Ancillary Service (NLCAS), a form of Network Support and Control Ancillary Service (NSCAS)<sup>34</sup>. It is anticipated that TNSPs will consult with AEMO around design aspects of any SPS.

## 4.2 Contingency FFR

FFR can assist with the management of credible contingency events, such as the loss of a single generating unit, network element or load. This service complements the existing contingency FCAS, providing a faster response that becomes a potential valuable option for maintaining the FOS in a power system with lower inertia.

Contingency FFR could also assist with the management of non-credible contingency events in some cases, although the expectation is that it would be designed with control schemes and response times appropriate to target typical credible contingency events. Similarly, contingency FFR could be designed to assist with some kinds of protected events.

Contingency FFR is envisioned to have a total response time of around one second or less. A one second response time would be sufficient to complement the existing six second contingency FCAS, and allow the FOS to be maintained at lower inertia levels. Response times as short as half a second could be feasible for many technologies, while still allowing sufficient time for robust measurement of power system frequency.

Like existing contingency FCAS, contingency FFR would be triggered by local frequency measurement which is feasible and robust within a one second total response time.

In order to complement the existing FCAS framework, contingency FFR would need to sustain a response for at least six seconds, and then transition in an orderly manner (probably using proportional controls<sup>35</sup>) to the six second service. This transition will need to be carefully controlled to ensure the transition between different FCAS timeframes operates smoothly.

Careful consideration will be required to determine optimal approaches for measurement and verification of the delivery of contingency FFR. For six second contingency FCAS, a 50 ms resolution measurement device at each unit is typically used; this may not be fast enough for measurement and verification of the response for a service delivered in less than one second. Continuous sampling is typically used, with data stored only when an event is detected. Data from several seconds prior to the event is required, continuing until some period of time after the event.

International examples of contingency FFR services include the demand response services in ERCOT and New Zealand, the requirement for wind IBFFR by Hydro-Québec, and the proposed market frameworks by EirGrid and ERCOT (as discussed in Section 3.1).

### 4.2.1 Implementation

Implementing a contingency FFR service is complex and needs to consider many factors including:

- Management of the recovery period for wind IBFFR, and any other energy-negative technologies<sup>36</sup>. Additional six-second FCAS may need to be scheduled when a significant proportion of contingency FFR is delivered by wind IBFFR, and the wind speeds at those farms are below maximum generation. This will have operational and financial implications to manage.
- The specification of control schemes, including the balance between closed-loop controls to assist stable recovery (utilising feedback to deliver a proportional response), and the use of open-loop switched triggers (without a feedback loop) to allow for a rapid initial response without

<sup>34</sup> AEMO (April 2015) Guide to Ancillary Services in the National Electricity Market. Available at: <https://www.aemo.com.au/-/media/Files/PDF/Guide-to-Ancillary-Services-in-the-National-Electricity-Market.ashx>

<sup>35</sup> Closed loop controls use a system measurement (such as frequency) to scale the unit response. A droop response is an example of a closed loop control.

<sup>36</sup> Wind IBFFR is considered energy-negative for the delivery of contingency FFR, because the energy extracted from the drive train is often recovered during a period of reduced active power delivery.

the need for high gains (which can become unstable). Some technologies may be better suited to one control type; for example, demand-response is often delivered via switched controllers. A mix of control types may need to be actively managed.

- The amount of contingency FFR available will vary from period to period, since it scales with the amount of wind and PV resource in each period. Storage units may also elect to use headroom for other purposes, rather than reserving it for contingency FFR. This will need to be managed in real-time, requiring provision of real-time information on active power control settings and response modes.
- Co-optimisation with other services will need careful consideration. For example:
  - If a large FFR response is available, to what degree can the FOS be managed with a lower inertia level?
  - How much six second FCAS is required? In some regions, the amount of six second FCAS is increased during periods of low inertia; FFR availability may reduce this requirement. However, if FFR is procured from wind IBFFR operating at wind speeds below rated, the management of the recovery period will require larger quantities of six second FCAS. These relationships will need to be carefully evaluated.

In the long term, it appears plausible for contingency FFR to be implemented under the same framework as contingency FCAS. This suggests an eventual transition to a spot market arrangement (or whatever FCAS framework is in place) in the long term if feasible.

In the near term, given the novel nature of many of these services and the degree of learning required, a more simple transitional approach is warranted, with the aim to:

- Develop a large pool of potential providers that will facilitate gradual transition to align with the procurement frameworks in place for other FCAS.
- Allow AEMO and market participants to develop practical experience with the operation of contingency FFR in the NEM, ensuring operational confidence in technology capabilities, and the integration of relevant operational systems.

Mandating the inclusion of specific contingency FFR capabilities in generator performance standards is problematic, requiring detailed, technology-specific specifications for capabilities such as wind IBFFR and PV inverter overload capabilities. Furthermore, there is no equivalent performance standards for other potential providers such as the demand-side.

For this reason, AEMO proposed to the AEMC that a fixed regulated tariff should be paid initially to all service providers in periods when they are available and enabled<sup>37</sup>. This tariff should aim to cover only the small incremental costs for new entrants to include and offer this additional capability.

## 4.3 Primary Frequency Control

FFR providing primary frequency control would respond to all types of imbalances (large and small), operating with narrow dead bands within the normal frequency operating band. It is analogous to a governor response from synchronous units continuously maintaining frequency over timeframes shorter than those of existing regulation FCAS. In this context, it would assist in meeting the FOS in a lower inertia system.

### 4.3.1 Specification

Regulation FCAS has become the main mechanism available for responding to minor imbalances within five minute dispatch intervals. In the existing regulation FCAS specification, enabled units respond to an AGC signal received every four seconds but have no clear timeframe for responding to those signals. In some cases, the response may be very slow; some market participants have noted that coal-fired power stations may have delays in the order of minutes before responding to changes

<sup>37</sup> AEMO (26 April 2017) Submission to AEMC System Security Market Frameworks Review Directions Paper. Available at: <http://www.aemc.gov.au/getattachment/917b38b1-2f61-4601-a72e-f084cba0e2ce/AEMO.aspx>

in set point targets<sup>38</sup>. This may mean that imbalances are not corrected in an adequate timeframe to prevent the frequency moving outside of the normal operating band, creating a risk that the FOS may not be met if this occurs frequently enough.

Given the delays inherent in the AGC system, the fastest feasible response time from regulation FCAS providers is of the order of five to ten seconds. The existing regulation FCAS is thus designed to respond to larger, slower deviations over five minute intervals such as errors in five minute demand and semi-scheduled forecasts. Typical frequency control practices suggest that this slower response is not effective for managing small, faster deviations that occur continuously within a dispatch interval. A continuous FFR service could fill this gap under normal operating conditions although the benefits are uncertain given they have not been required to date.

Continuous FFR can respond to local frequency measurements within a timeframe of approximately one second, or faster. This could be via a droop response, similar to a governor response from synchronous units, with a small dead band to ensure the response is relatively continuous.

While many international jurisdictions mandate primary frequency control from synchronous units, examples of similar services from non-synchronous units are rare. National Grid has tendered for a one second Enhanced Frequency Response service to be delivered by batteries via an autonomous droop response from 2018.

### 4.3.2 Implementation

Table 4 outlines three aspects to the implementation of FFR for primary frequency control which could be achieved via different frameworks.

**Table 4 Considerations in utilising FFR for primary frequency control**

	Description	Costs to unit	Possible implementation
<b>Capability</b>	A sufficient proportion of units installed must have the <b>capability</b> to deliver the service.	<b>Capital cost</b> associated with incorporating capability into the unit design. Also a cost for verification and registration of the capability during installation.	Mandate from all new entrants through technical standards
<b>Enablement</b>	A sufficient proportion of units must be <b>enabled to deliver</b> this service in any particular dispatch interval.	<b>Maintenance costs</b> due to wear and tear related to continuous output adjustments may be increased, particularly if required to be enabled in all periods.	Mandate (like National Grid) or Incentivise enablement (like present FCAS)
<b>Headroom</b>	A sufficient proportion of units must have adequate <b>headroom reserved</b> to deliver this service in any particular dispatch interval.	<b>Opportunity cost</b> associated with lost energy (if pre-curtailment required), or inability to provide other services with the same headroom.	Pay for headroom (like present FCAS)

AEMO’s advice to ESCOSA<sup>39</sup> on South Australian licencing conditions suggested that the *capability* to delivery primary frequency control be mandated from all new generation entrants. Specifically, the capability must be at the fastest timescale appropriate for each technology without any intentional delay, unless necessary for stable operation. AEMO has submitted a rule change proposal to extend this requirement to all NEM regions, and apply to all new generation, that is, applying to both synchronous and non-synchronous units.

Further consideration is required to determine how best to approach *enablement*. Mandating permanent enablement of primary frequency control may have costs in the form of increased wear and tear (including factors such as battery cycling costs), even without any requirement to maintain

<sup>38</sup> Delta Electricity (19 May 2017) Amendment of the Market Ancillary Service Specification (MASS) Response to the Draft Determination. Available at: [http://www.aemo.com.au/-/media/Files/Stakeholder\\_Consultation/Consultations/Electricity\\_Consultations/2017/MASS/Delta-Electricity-MASS-Stage-2-Submission.pdf](http://www.aemo.com.au/-/media/Files/Stakeholder_Consultation/Consultations/Electricity_Consultations/2017/MASS/Delta-Electricity-MASS-Stage-2-Submission.pdf)

<sup>39</sup> AEMO (31 March 2017), Recommended Technical Standards for Generator Licensing in South Australia. Available at: <http://www.escosa.sa.gov.au/ArticleDocuments/1048/20170331-Inquiry-RecommendedTechnicalStandardsGeneratorLicensingSA-AEMOadvice.pdf.aspx?Embed=Y>

headroom. A cost-benefit analysis should be undertaken to determine whether this service is required, and if so, the appropriate approach for enablement.

Recent analysis has identified a decline in the quality of frequency control in the NEM. It has been suggested that a return to the past approach of mandating governor droop response from all units may be appropriate to address this concern. With the increasing displacement of synchronous units from dispatch, this mandatory obligation would also need to extend to non-synchronous units to ensure continued access to the service. AEMO is currently conducting further analysis on this issue and is consulting with industry through the ASTAG<sup>40</sup>.

Even if enablement is mandated, it may be appropriate to develop a mechanism to financially compensate units that deliberately reserve headroom to deliver primary frequency control (especially for a raise service). The opportunity costs associated with lost generation for reserved headroom can be significant, and will vary period to period depending upon energy prices and other factors. For this reason, consideration should be given to a spot market approach (similar to the present FCAS framework), allowing co-optimisation with energy dispatch.

## 4.4 Fast Response Regulation

Fast response regulation can assist with managing minor imbalances within five minute dispatch intervals, continuously restoring frequency to 50 Hz. It would fulfil the same role as existing regulation FCAS, but with a more rapid response to AGC signals delivering faster restoration of frequency. This will be increasingly important in a lower inertia system.

### 4.4.1 Specification

Fast response regulation differs from other FFR services in that it would be controlled via AGC signals. This allows changes to unit set points which can restore frequency to 50 Hz. It is anticipated that most inverter-connected technologies could respond to AGC signals within less than one second.

As discussed above, a whole AGC cycle, taking into account measurement and calculation of new unit set points, may take around five to ten seconds even though the unit delivering FFR may respond to those AGC signals in one second or less. This means that fast response regulation is the slowest of the FFR services described in this report (in terms of total response time). This is appropriate, with the slower response time avoiding undesired interaction with other autonomously controlled services, giving these time to have acted to arrest the frequency change.<sup>41</sup> In this way, the centrally coordinated AGC signals can direct units to change set points and fully correct the imbalance, returning the frequency to 50 Hz.

AEMO is working to determine the degree to which a faster response to AGC signals may be necessary or valuable. Given the AGC system's slower acting nature, there may be only a marginal benefit in a faster response to AGC signals. In some cases, a slower response may be preferable, to avoid step changes which could themselves become disruptive. Nevertheless the possibility of fast frequency regulation services highlights the value of including AGC capability in new inverter-connected devices which would allow them to participate in the market for regulation services.

### 4.4.2 Implementation

There are a number of different possible approaches to implementation of fast response regulation.

One approach would be to simply require a faster response time from all units providing regulation FCAS. For example, the specification of regulation FCAS could require all units to respond to AGC signals in less than two seconds when providing regulation FCAS. Steam units with technical limitations requiring a response time of minutes<sup>42</sup> would be excluded from contributing. This may be appropriate if the slower response times are too slow to deliver any significant benefit, but an

<sup>40</sup> <https://www.aemo.com.au/Stakeholder-Consultation/Industry-forums-and-working-groups/Other-meetings/Ancillary-Services-Technical-Advisory-Group>

<sup>41</sup> In some smaller systems, governors can be tuned in a bespoke manner to assist with returning the frequency to 50 Hz, reducing reliance upon the central AGC.

<sup>42</sup> Delta Electricity (19 May 2017) Amendment of the Market Ancillary Service Specification (MASS) Response to the Draft Determination. Available at: [http://www.aemo.com.au/-/media/Files/Stakeholder\\_Consultation/Consultations/Electricity\\_Consultations/2017/MASS/Delta-Electricity-MASS-Stage-2-Submission.pdf](http://www.aemo.com.au/-/media/Files/Stakeholder_Consultation/Consultations/Electricity_Consultations/2017/MASS/Delta-Electricity-MASS-Stage-2-Submission.pdf)



assessment would be required to ensure that sufficient participants are available at faster response times.

Another approach could be to define multiple regulation FCAS services, each requiring different response times to AGC signals. This would allow slower resources to continue to participate, while recognising the enhanced capabilities of faster resources in a separate market. AEMO's analysis of the variability of generation in the power system suggests that much of the current need for regulation FCAS is associated with slower changes and forecast errors over the five minute interval, rather than rapid changes within the interval. This suggests that multiple categories of regulation FCAS may be appropriate. Larger reserves of slower regulation could be enabled to manage larger, slower ramps, and a smaller proportion of faster regulation could be procured to ensure enough fast response to manage smaller, rapid ramps.

A third possible approach is to “pay for performance”, with payments to regulation providers scaled according to their speed of response. This approach has been highly successful in PJM in encouraging faster response from batteries and flywheels. This may be effective where incrementally faster responses are incrementally more valuable, and this relationship can be easily defined. This would be relatively straightforward to implement via a simple regulated tariff. However, it is unclear how this might work within a spot market framework. The NEM dispatch engine (NEMDE) calculates the least cost dispatch, ensuring adequate enablement of FCAS of each type, based upon participant offers for each service. The price is determined by the marginal cost of delivering each service. NEMDE would require additional information about the speed of response of each provider, and on the overall proportion of response required at each speed. It may ultimately be simpler to implement if different regulation services are defined, as per the second approach outlined above.

Some adjustments to the specification of regulation services are likely to be considered in the AEMC's frequency control frameworks review, and AEMO's ongoing work on future system services.

## 4.5 Simulated Inertia

To AEMO's knowledge, simulated inertia is not commercially available at present, although some manufacturers refer to development work in this area. Manufacturers have also indicated to AEMO that inverter-connected devices with sub-cycle total response times of the order of 10-20 ms may be feasible. It has been suggested that it would be possible to design these devices with control schemes that mimic the active power changes that occur due to the purely inertial response of a synchronous unit.

Most manufacturers have experience in large, highly interconnected grids internationally with levels of inertia such that RoCoF rarely exceeds  $\pm 0.1$  Hz/s. In these high inertia grids, it may be feasible to create a control scheme for an inverter-connected device that provides a reasonably accurate simulation of an inertial response from a synchronous unit.

While simulated inertia may be achievable in power systems with low RoCoF, at higher RoCoF it will become increasingly challenging to create an appropriate transient response from these devices. RoCoF in South Australia can exceed 4 Hz/s<sup>43</sup>. In these circumstances, it is expected to be extremely challenging for an inverter-connected device to remain synchronised, and hence able to provide an appropriate simulated inertia response. Even moderate RoCoF events of 1-2 Hz/s that may arise in South Australia are considered extreme in large power systems by international standards.

The application of simulated inertia devices in low inertia grids will also be limited by the nature of their technology. These devices are “grid following”, meaning that they rely upon a frequency signal created by “grid forming” units, such as synchronous units. This makes simulated inertia devices likely to only operate effectively in higher inertia systems, and unable to fully replace synchronous inertia. A certain minimum level of synchronous inertia will need to be online to keep RoCoF within the range in which simulated inertia can respond effectively, with only a limited quantity of synchronous inertia able to be displaced.

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<sup>43</sup> AEMO (March 2017), “Black System South Australia 28 September 2016”. Available at: [https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market\\_Notices\\_and\\_Events/Power\\_System\\_Incident\\_Reports/2017/Integrated-Final-Report-SA-Black-System-28-September-2016.pdf](https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2017/Integrated-Final-Report-SA-Black-System-28-September-2016.pdf)



Given these limitations, it is important to consider the suite of services inverter-connected devices can provide. An appropriately designed set of frequency control services incorporating all of the potential capabilities provides an opportunity to meet the FOS and power system security needs at least cost. As discussed in Section 3.2, this should not be limited by thinking founded in the present framework.

## 4.6 Grid Forming

Grids with zero synchronous inertia (100% power electronic connected generation) have been achieved on a small scale, with examples including distribution systems of households, ships, small island grids, and industrial applications. Offshore DC connected wind farms are another example. However, at present it is not technically feasible to operate a large (> 300 MW) power system with no synchronous inertia.

Large grids with zero synchronous inertia may become possible in future, and research is ongoing in this space<sup>44</sup>. The operation of such a grid will require a suite of new services from inverter-connected devices.

At present, inverter-connected devices sense power system frequency, and use a Phase Locked Loop (PLL) to synchronise to the grid. They are grid-following, meaning they measure frequency and adapt their current injection to provide active and reactive power with the same frequency.

In order to operate a low or no inertia grid, some or all of these devices will need to be grid forming, creating the voltage waveform independently. In a small grid, this is achieved by a single device such as a battery which sets frequency, allowing other inverter-connected devices to follow. In a larger grid, multiple devices will be required to set a stable system-wide frequency as all inverters need to be synchronised to the same frequency, regardless of grid topology, in a distributed and very robust way, even when a transient disturbance occurs. Telecommunications systems between all devices are unlikely to be adequate; innovative approaches will be required. This is an area of research focus, for example the international MIGRATE project<sup>45</sup>.

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<sup>44</sup> MIGRATE – Massive Integration of Power Electronic Devices. Available at:  
<https://www.eles.si/Portals/0/MEDNARODNI%20PROJEKTI/MIGRATE/MIGRATE-presentation.pdf>

<sup>45</sup> MIGRATE – Massive Integration of Power Electronic Devices. Available at:  
<https://www.eles.si/Portals/0/MEDNARODNI%20PROJEKTI/MIGRATE/MIGRATE-presentation.pdf>



## 5. NEXT STEPS

AEMO has identified a preliminary set of possible FFR services that could provide value in the NEM. In considering these it will be important to capture the synergies with other work currently underway related to frequency control. These include:

- **AEMC System Security Market Frameworks Review** – collaborating with the AEMC providing technical advice on the implementation of FFR services arising from the System Security Market Frameworks Review.
- **AEMC Frequency control frameworks review** – collaborating with the AEMC on its forthcoming review on frequency control frameworks which will include informing approaches to efficiently include FFR if viable.
- **AEMO Future System Services**– conducting a comprehensive assessment of future system services. This includes ongoing consultation with stakeholders through the ASTAG<sup>46</sup> and other forums. The program will continue to explore FFR type services, as well as potential adaptation to FCAS frameworks. This will provide the main forum for discussion of this report, and extension of this work to inform the AEMC’s review.
- **Review of the Frequency Operating Standards** – AEMO is engaged in the Reliability Panel’s review of the FOS, in particular stage 2 may influence the opportunities offered by FFR.
- **Proof of Concept** – AEMO is working with market participants to conduct trials of FCAS and FFR services delivered by wind, PV, and emerging technologies. This includes a demonstration of frequency control services from the Hornsdale 2 wind farm, in a collaboration between AEMO, ARENA and Neoen.
- **Identifying new trials** – working with ARENA and the CEFC to identify opportunities to trial FFR capabilities in new projects.
- **Technical Standards** – following its advice to ESCOSA on recommended changes to the technical standards in South Australian generator licencing conditions, AEMO has submitted a rule change proposal for revised technical standards for generators in all regions. The proposed technical standards include requirements for frequency control capabilities, potentially including FFR capabilities where the unit is able.
- **Finkel Review** – responding to the recommendations by the expert panel, including aspects relating to FFR.

In undertaking this work, AEMO will consider submissions received in response to this discussion paper as well as feedback received as part of the ASTAG process.

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<sup>46</sup> <https://www.aemo.com.au/Stakeholder-Consultation/Industry-forums-and-working-groups/Other-meetings/Ancillary-Services-Technical-Advisory-Group>



# MEASURES AND ABBREVIATIONS

## Units of measure

Abbreviation	Unit of measure
Hz	Hertz
ms	Millisecond
MW	Megawatt

## Abbreviations

Abbreviation	Expanded name
AC	Alternating current
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AGC	Automatic Generation Control
ASTAG	Ancillary Services Technical Advisory Group
CEFC	Clean Energy Finance Corporation
DC	Direct current
DER	Distributed Energy Resources
EFCS	Emergency Frequency Control Scheme
ESCOSA	Essential Services Commission of South Australia
FCAS	Frequency Control Ancillary Service
FFR	Fast Frequency Response
FOS	Frequency Operating Standards
FPSS	Future Power System Security (Program)
IBFFR	Inertia-based Fast Frequency Response
MASS	Market Ancillary Services Specification
NEM	National Electricity Market
NEMDE	National Electricity Market Dispatch Engine
NER	National Electricity Rules
NLCAS	Network Loading Control Ancillary Service
NSCAS	Network Support and Control Ancillary Service
OFGS	Over Frequency Generation Shedding
PLL	Phase Locked Loop
PV	Photovoltaics
RoCoF	Rate of Change of Frequency
SPS	Special Protection Scheme
TNSP	Transmission Network Service Provider
UFLS	Under Frequency Load Shedding