FCAS MODEL IN NEMDE

SCALING, ENABLEMENT, AND CO-OPTIMISATION OF FCAS BIDS IN CENTRAL DISPATCH

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Current version release details

Version	Effective date	Summary of changes
3.0	3 June 2024	Updated to include bidirectional units.

Note: There is a full version history at the end of this document.

1. Introduction

1.1. Purpose and scope

AEMO has prepared this document to provide information about the FCAS model used in NEMDE as at the date of publication.

AEMO is responsible under the National Electricity Rules (Rules) for ensuring that the power system is operated in a safe, secure and reliable manner, including managing frequency through the procurement of Frequency Control Ancillary Services (FCAS) from suitable generating units, bidirectional units, and loads.

Under the Rules, the central dispatch process aims to maximise the value of spot market trading by satisfying energy demand and all FCAS requirements using the least-cost combination of energy and FCAS bids, subject to technical limits on the provision of those services. AEMO achieves this using the National Electricity Market Dispatch Engine (NEMDE) software.

Sections 2 and 3 of AEMO's "Guide to Ancillary Services in the National Electricity Market"[1] provide a general description of FCAS, including the nature of FCAS requirements, the structure of FCAS bids and their technical limits, and the settlement of FCAS costs.

This document describes how the technical limits on FCAS provision are modelled within the NEMDE software, including:

- Limits submitted in FCAS bids.
- Limits telemetered in real-time from automatic generation control (AGC[2]) systems.
- Limits due to sharing capacity between different types of FCAS and energy.

In order to understand this document, readers should be familiar with the relevant inputs to NEMDE, such as FCAS trapeziums, bid ramp rates, AGC ramp rates, and AGC enablement limits.

1.2. Definitions and interpretation

1.2.1. Glossary

Terms defined in the National Electricity Law and the Rules have the same meanings in this document unless otherwise specified in this clause.

1 https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/guide-to-ancillary-services-in-the-national-electricity-market.pdf.

2 AGC limits are also referred to as Supervisory Control and Data Acquisition (SCADA) limits or AGC SCADA limits.

In addition, the words, phrases and abbreviations in the table below have the meanings set out opposite them when used in this document.

Term	Definition
$/MWh	Dollars per megawatt hour
AEMO	Australia Energy Market Operator
AGC	Automatic Generation Control
FCAS	Frequency Control Ancillary Service(s)
MW	Megawatt
NEMDE	National Electricity Market Dispatch Engine
Rules	National Electricity Rules
SCADA	Supervisory Control and Data Acquisition
UIGF	Unconstrained Intermittent Generation Forecast

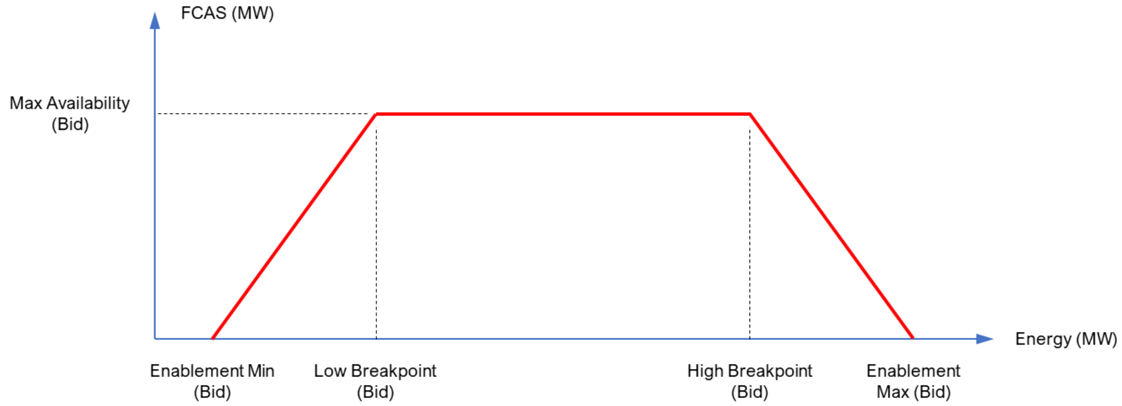
2. Structure of an FCAS bid

Under the Rules, an FCAS bid comprises:

- Ten price bands, each with a band price ($/MWh) and band availability (MW). Prices are defined for a trading day, and MW quantities are defined for each trading interval of a trading day.
- The following technical limits on providing FCAS:
  - Enablement Min (MW)
  - Low Breakpoint (MW)
  - High Breakpoint (MW)
  - Enablement Max (MW)
  - Max Availability (MW)

Together these limits form a generic FCAS bid trapezium, as illustrated in Figure 1. The FCAS trapezium defines the frequency response capability of the Ancillary Service Provider in relation to its power generation, consumption, or load reduction.[3] Power generation, consumption, or load reduction are shown on the horizontal axis (as energy), and the frequency response capability is shown on the vertical axis (as FCAS).

Figure 1 Generic FCAS bid trapezium



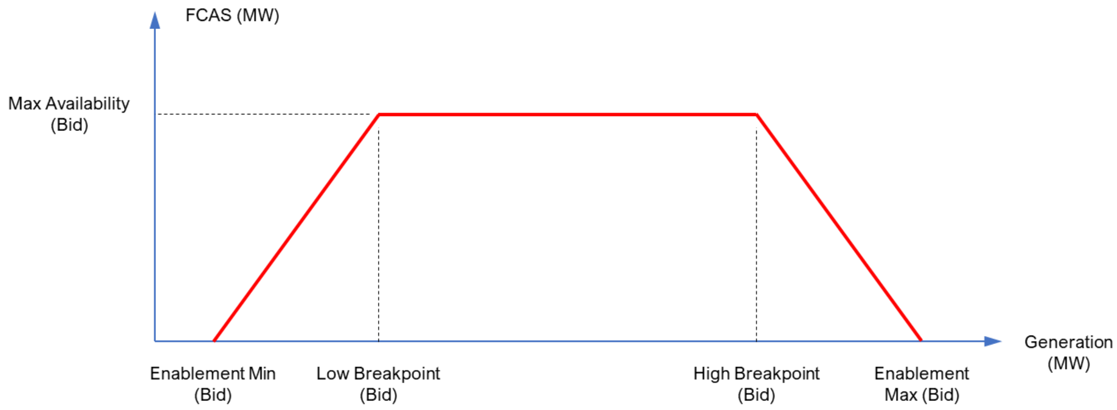
The limits submitted as part of an FCAS bid must be within the technical envelope specified by the Ancillary Service Provider when the scheduled generating unit, scheduled bidirectional unit, scheduled load, semi-scheduled generating unit, or wholesale demand response unit is registered.

[3] Power generation for scheduled and semi-scheduled generating units, power consumption for scheduled loads, and load reduction for wholesale demand response units. For bidirectional units it may be power generation or power consumption.

2.1. FCAS bids from scheduled and semi-scheduled generating units

FCAS bids from scheduled and semi-scheduled generating units form the generic trapezium illustrated in Figure 2, in which all the technical limits are positive values and power generation increases from left to right. This is identical to Figure 1 above.

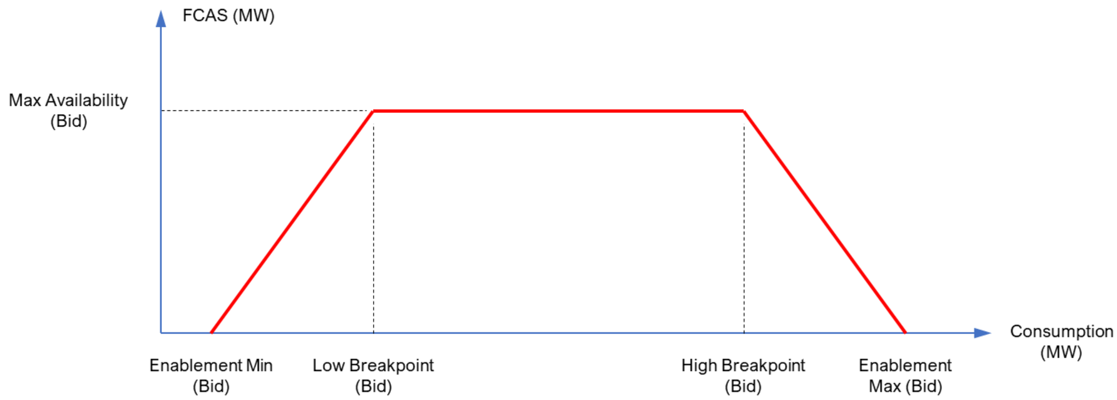
Figure 2 Scheduled and semi-scheduled generating unit FCAS trapezium



2.2. FCAS bids from scheduled loads

FCAS bids from scheduled loads form the generic trapezium illustrated in Figure 3. The technical limits are all bid as positive values and power consumption increases from left to right.

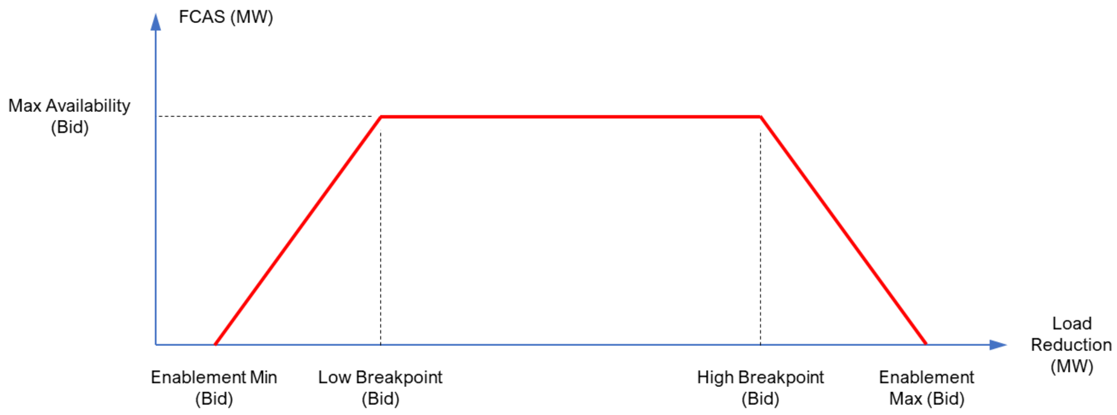
Figure 3 Scheduled load FCAS trapezium



2.3. FCAS bids from wholesale demand response units

FCAS bids from wholesale demand response units form the generic trapezium illustrated in Figure 4. All the technical limits are positive values and load reduction – which is equivalent to power generation – increases from left to right.

Figure 4 Wholesale demand response unit FCAS trapezium

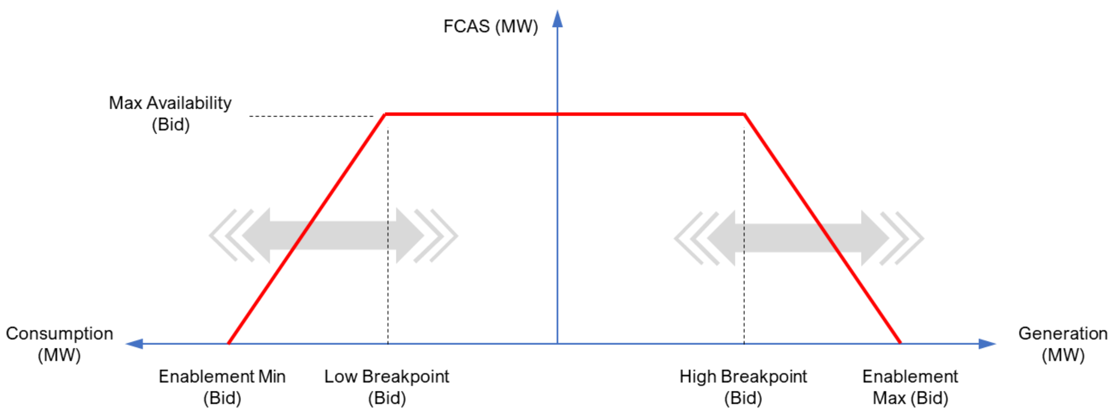


2.4. FCAS bids from bidirectional units

Interpretation of FCAS bids from bidirectional units depends on whether the bid is for contingency or regulation FCAS.

Contingency FCAS bids from bidirectional units are a bid for the entire unit, and form the generic trapezium illustrated in Figure 5. Max Availability is always positive[4], but Enablement Min, Low Breakpoint, High Breakpoint and Enablement Max may be positive or negative depending on where they lie on the energy axis, given that a bidirectional unit can both generate and consume power.

Figure 5 Scheduled bidirectional unit contingency FCAS trapezium

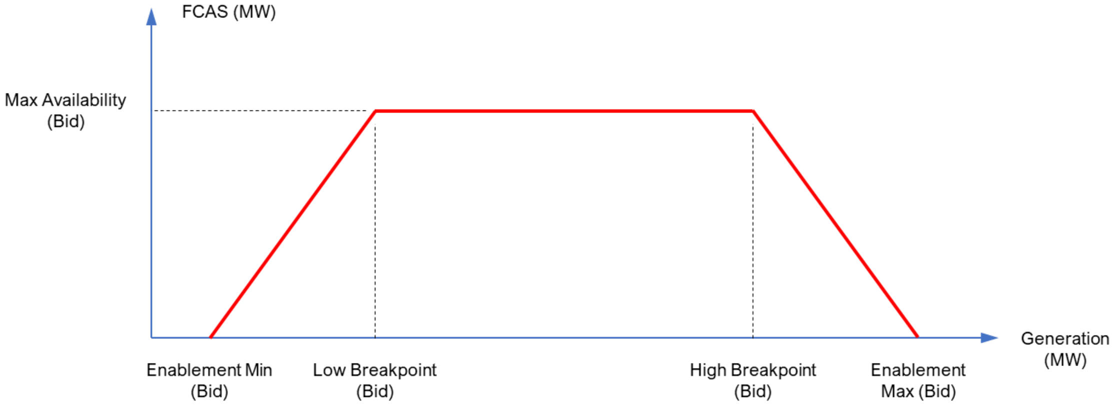


[4] Strictly speaking, Max Availability is always non-negative, but zero Max Availability means that no FCAS is available for enablement.

Regulation FCAS bids from bidirectional units may consist of:

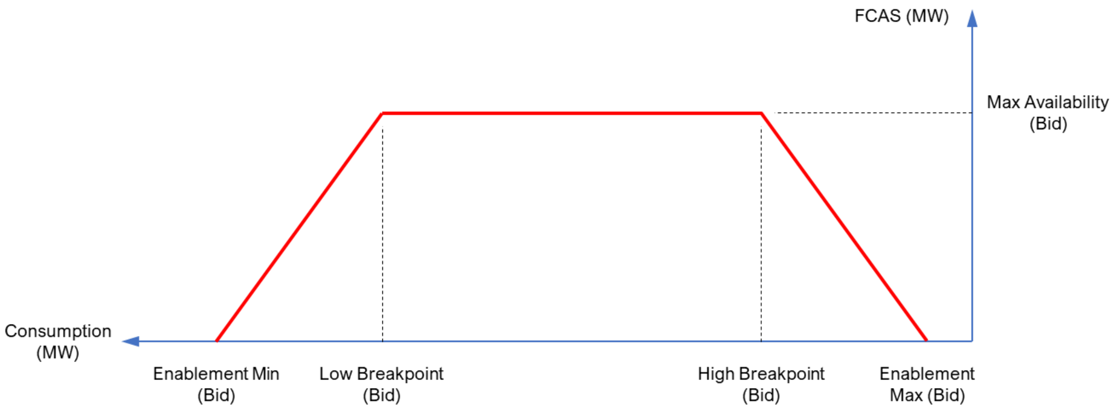
- one bid for the generation side, in which all the technical limits are non-negative, as shown in Figure 6[5];

Figure 6 Scheduled bidirectional unit regulation FCAS trapezium – generation side only



- or one bid for the load side, in which all the enablement limits and breakpoints are non-positive, as shown in Figure 7;

Figure 7 Scheduled bidirectional unit regulation FCAS trapezium – load side only



- or bids for both the generation and load sides, as shown in Figure 8 and Figure 9, along with their combined trapeziums.[6] Regulation FCAS bids from both sides of a bidirectional unit are optimised individually within NEMDE, but are amalgamated for the following purposes:
  - for FCAS bid validation, to ensure that the combined FCAS bid is within the technical envelope specified by the Ancillary Service Provider when registering the BDU for FCAS – this is a pre-processing check before the bids are used as inputs to NEMDE;

[5] This is the same as an FCAS bid from a scheduled or semi-scheduled generating unit, as shown in Figure 2.

[6] Figures 8 and 9 represent typical regulation raise trapeziums. Typical regulation lower trapeziums would be mirror images of Figures 8 and 9.

- to ensure that the initial operating point of the BDU is within the enablement limits of the combined trapezium – this is one of the preconditions for FCAS enablement in NEMDE [see Section 5];
- when calculating whether the BDU is “trapped” or “stranded” [see Sections 5, 6.2 and 6.3] – this calculation is performed within NEMDE but is effectively a post-processing step after optimisation; and
- and when calculating actual FCAS availability [see Section 7] – this is a post-processing step performed outside of NEMDE after optimisation.

Figure 8 Scheduled bidirectional unit combined regulation FCAS trapezium I

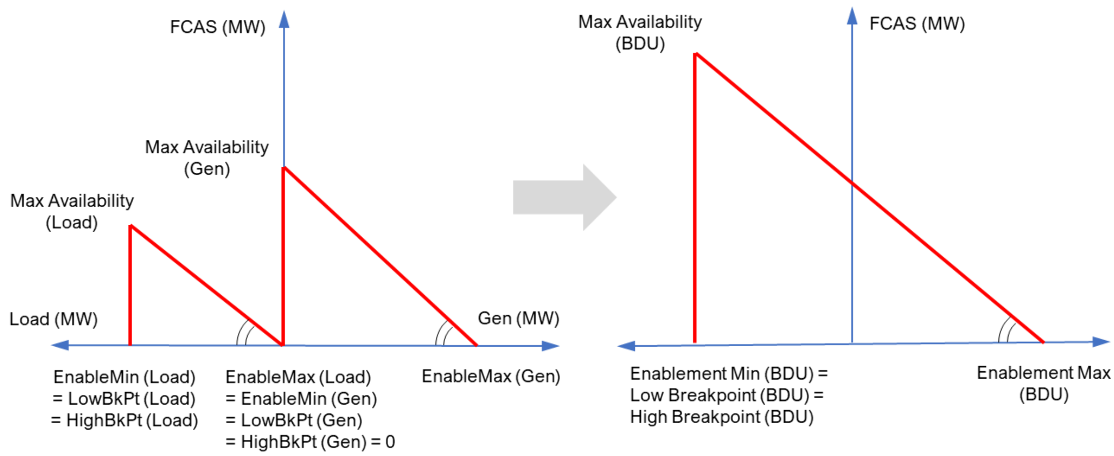
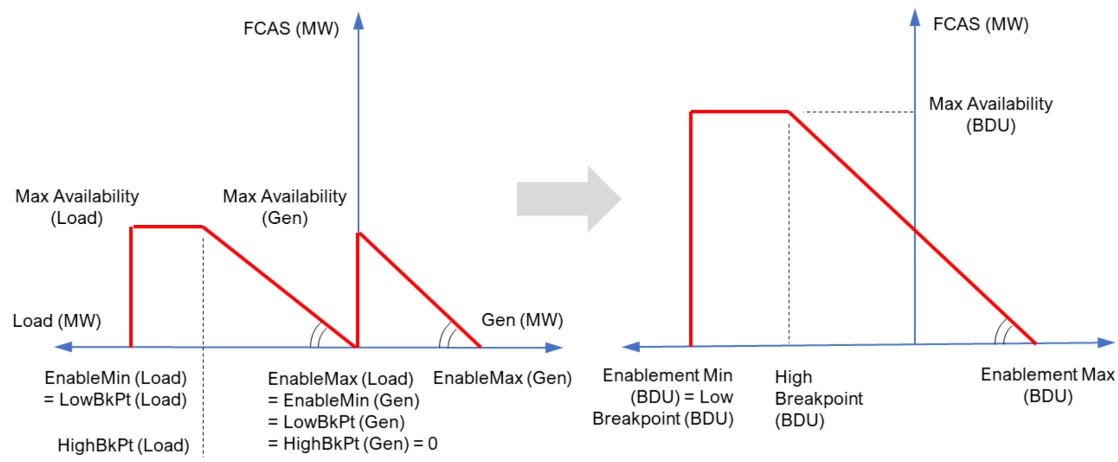


Figure 9 Scheduled bidirectional unit combined regulation FCAS trapezium II



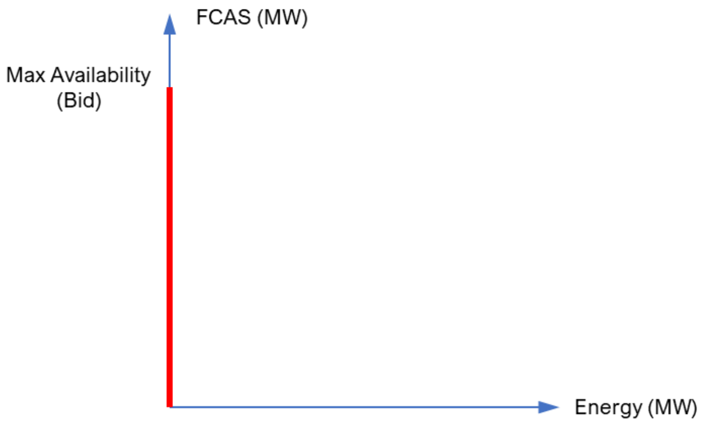
There are further rules that must be obeyed if there are regulation FCAS bids for both sides of a bidirectional unit:

- the bids must be contiguous, so that $EnablementMax_{Load}$ = 0 = $EnablementMin_{Gen}$
- both trapeziums must have the same upper angle
- both trapeziums must have the same lower angle
- if the upper angle is less than 90° then $HighBreakpoint_{Gen}$ = $LowBreakpoint_{Gen}$ = 0 i.e. the trapezium on the generation side becomes a triangle
- if the lower angle is less than 90° then $HighBreakpoint_{Load}$ = $LowBreakpoint_{Load}$ = 0 i.e. the trapezium on the load side becomes a triangle

2.5. FCAS bids from FCAS-only units

If an Ancillary Service Provider is registered for FCAS only, and does not participate in the energy market, then its FCAS bid trapezium would be a vertical line, as shown in Figure 10. In this case its frequency response capability in central dispatch is independent of its energy level because there is no energy dispatched by NEMDE.

Figure 10 FCAS bid "trapezium" – FCAS provision only

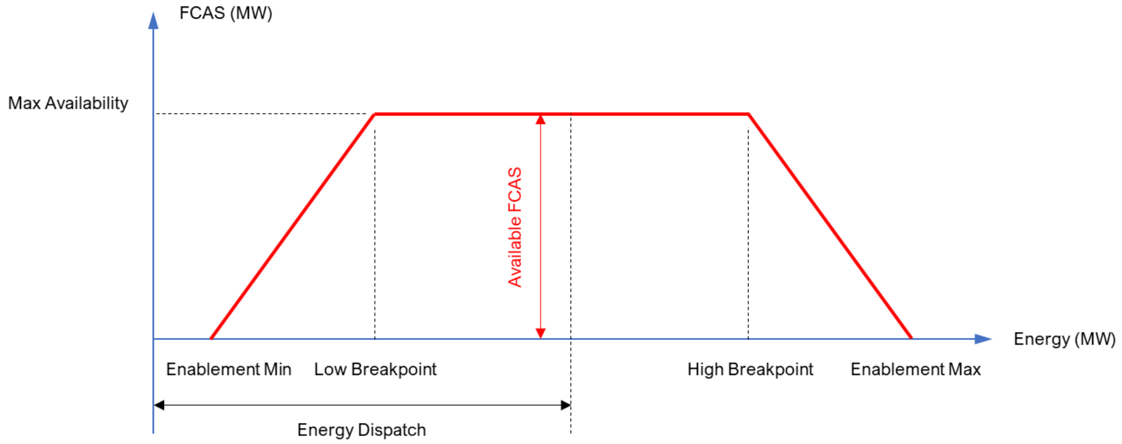


3. Application of an FCAS bid

The amount of FCAS that can be enabled is bounded by the FCAS bid trapezium for that service.

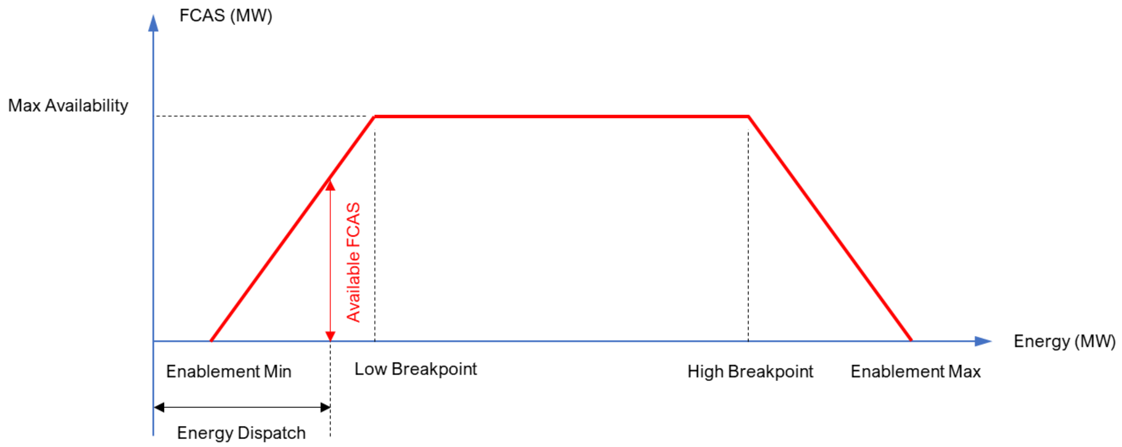
For example, if a unit is dispatched in the energy market between its Low Breakpoint and High Breakpoint, the maximum available FCAS that can be enabled equals its Max Availability, as shown by the vertical red line in Figure 11.

Figure 11 Energy target between breakpoints



If a unit is dispatched in the energy market between its Enablement Min and Low Breakpoint, the available FCAS is bound by the lower trapezium slope[7] as shown in Figure 12.

Figure 12 Energy target between Low Breakpoint and Enablement Min



If a unit is dispatched in the energy market between its High Breakpoint and Enablement Max, the available FCAS is bound by the upper trapezium slope[8] as shown in Figure 13.

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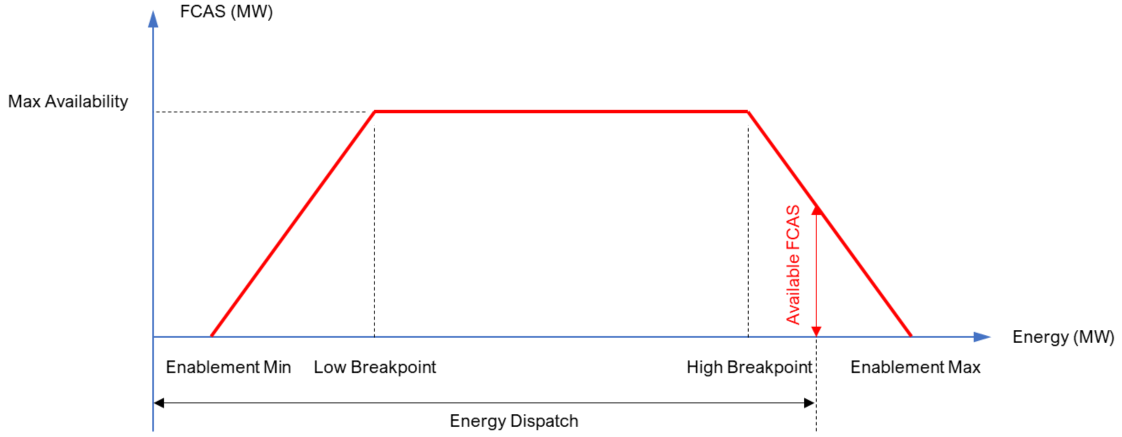
7 Upper trapezium slope in the case of scheduled loads.

8 Lower trapezium slope in the case of scheduled loads.

Figure 13 Energy Target between High Breakpoint and Enablement Max



If a unit is operating below its Enablement Min or above its Enablement Max, the available FCAS that can be enabled is zero.

4. Scaling the FCAS bid within technical limits

The bounds of an FCAS bid trapezium used by NEMDE may be more restrictive than those submitted in the FCAS bid from a provider, depending on the technical limits of the plant at the time.

- For regulating services, NEMDE scales the FCAS bid trapezium to within the telemetered AGC enablement and availability limits. This scaling does not apply to contingency services.
- For semi-scheduled generating units, the FCAS bid trapezium is also scaled to within the unconstrained intermittent generation forecast (UIGF) for both regulating and contingency services.

This process is called FCAS trapezium scaling. FCAS trapezium scaling occurs in a pre-processing step within NEMDE before optimisation occurs. If no scaling is applied, the FCAS trapezium used by NEMDE is the same as the bid FCAS trapezium.

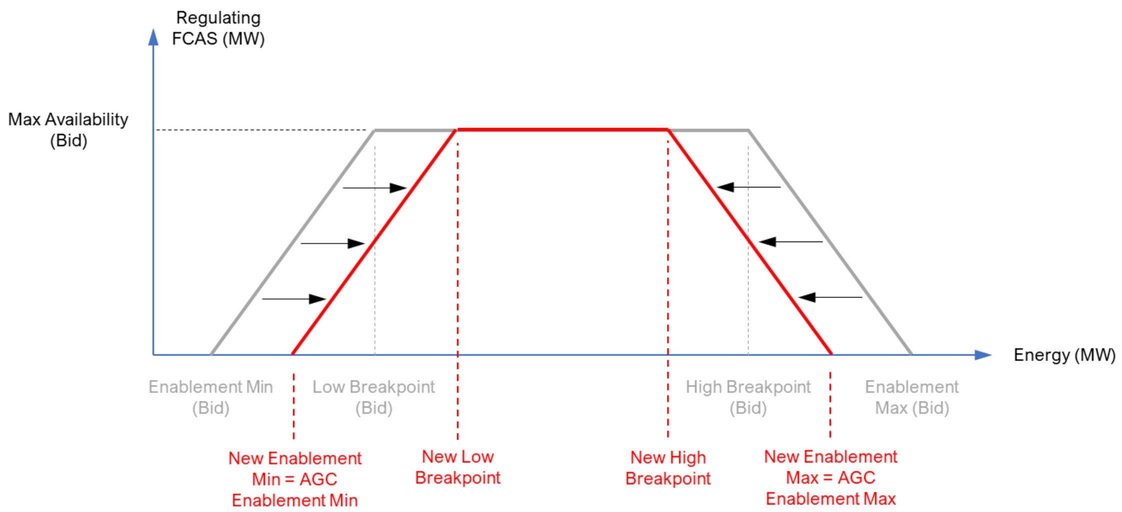
Note that no FCAS trapezium scaling is applied to contingency FCAS bids from scheduled units. For example, if an Ancillary Service Provider reduces the maximum availability of their unit in the energy market to below the Enablement Max of any of their FCAS bids, NEMDE does not automatically scale the Enablement Max (and High Breakpoint) of those FCAS bids.

4.1. Scaling for AGC enablement limits

NEMDE uses the more restrictive of bid enablement limits and AGC enablement limits for regulating services. If the AGC limits are more restrictive than the bid enablement limits, NEMDE scales the bid trapezium by making the AGC enablement limits the effective enablement limits, and adjusting the trapezium break points to maintain the trapezium angles. If the bid enablement limits are more restrictive than the AGC limits, this scaling has no impact and the bid trapezium enablement limits are used in NEMDE. If the AGC enablement limit is zero or absent, no scaling is applied.

Scaling by AGC enablement limits is shown in Figure 14.

Figure 14 FCAS trapezium scaling by AGC enablement limits

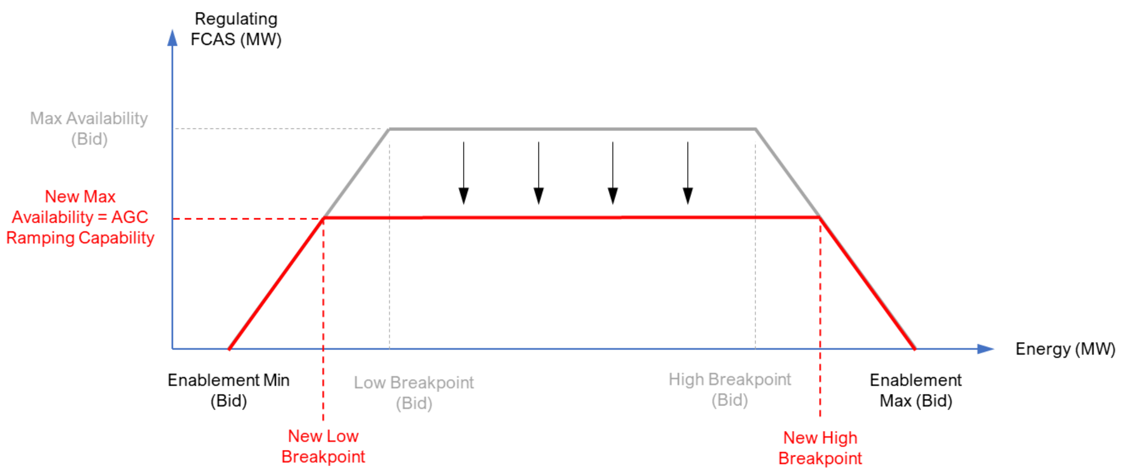


4.2. Scaling for AGC ramp rates

NEMDE uses the more restrictive of bid Max Availability and AGC ramping capability for regulating services. The AGC ramping capability is calculated as the AGC ramp rate multiplied by the trading interval time period. For example, if the AGC ramp rate is 5MW/min, then the AGC ramping capability for a 5-minute trading interval is 25MW (i.e. 5MW/min x 5 minutes = 25MW). If the AGC ramping capability is more restrictive than the bid Max Availability, NEMDE scales the trapezium by using the AGC ramping capability as the effective Max Availability, and adjusts the trapezium break points to maintain the trapezium angles. If the AGC ramping capability is higher than the bid Max Availability, the scaling has no impact. If the AGC ramp rate is zero or absent, no scaling is applied.

Scaling by AGC ramp rates is shown in Figure 15.

Figure 15 FCAS trapezium scaling by AGC ramp rates

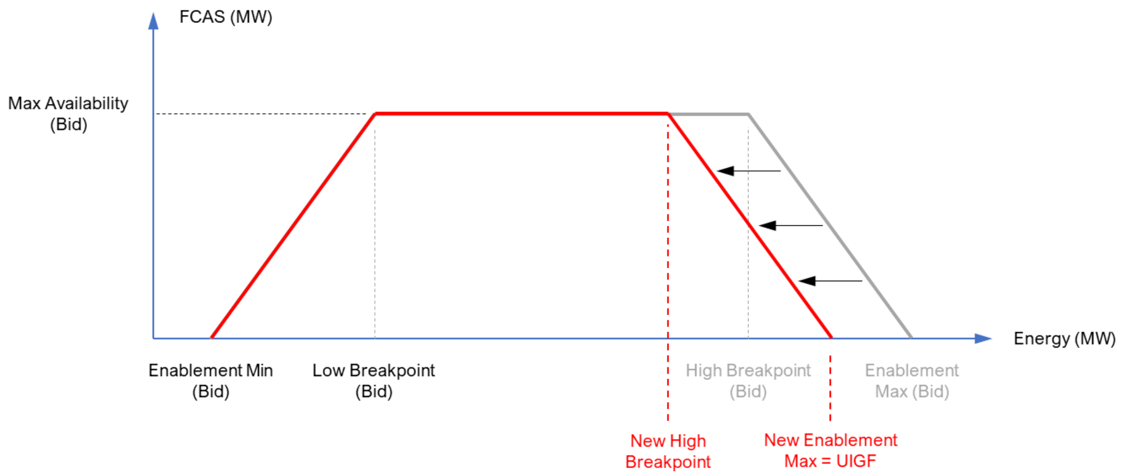


4.3. Scaling for UIGF

NEMDE uses the more restrictive of bid Enablement Max and the UIGF for all FCAS services provided by semi-scheduled units. If the UIGF is more restrictive than the bid Enablement Max, NEMDE scales the bid trapezium by making the UIGF the effective maximum enablement limit and adjusting the trapezium upper break point to maintain the trapezium angles. If the bid Enablement Max is more restrictive than the UIGF, this scaling has no impact.

FCAS trapezium scaling by UIGF is shown in Figure 8.

Figure 16 FCAS trapezium scaling by UIGF



4.4. Application of FCAS trapezium scaling in dispatch, 30-minute pre-dispatch and 5-minute pre-dispatch

The application of FCAS trapezium scaling discussed in sections 4.1 to 4.3 may cause a "shrinkage" of the original FCAS bid trapezium, as shown in Figure 9.

Figure 17 FCAS trapezium scaling

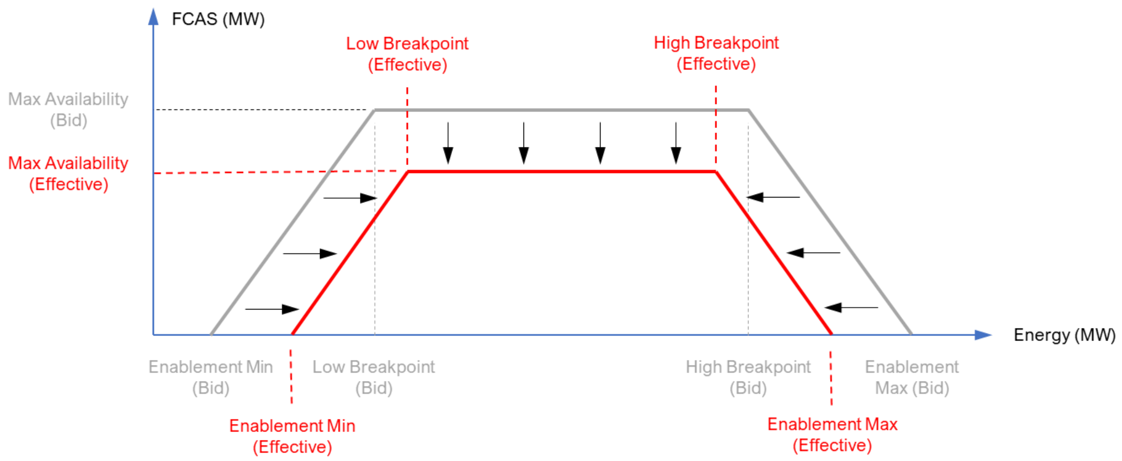


Table 1 summarises the range of intervals over which FCAS trapezium scaling applies in the dispatch, 30-minute pre-dispatch and 5-minute pre-dispatch processes.

Table 1 Intervals over which FCAS trapezium scaling applies in central dispatch

	Intervals to which scaling applies		
	Dispatch	***5-minute Pre-dispatch***	***Pre-dispatch***
Scaling for AGC enablement limits	All	First	First
Scaling for AGC ramp rates	All	First	None
Scaling for UIGF	All	All	All

If scaling is applied, NEMDE uses the scaled (effective) trapezium in the optimisation process.

5. Pre-conditions for enabling FCAS

After FCAS trapezium scaling, a scheduled or semi-scheduled generating unit, scheduled bidirectional unit, scheduled load, or wholesale demand response unit is considered for enablement for a particular FCAS in NEMDE if the following conditions are met:

- The maximum availability for the service is greater than zero:

  $$FCAS\ Max\ Availability > 0$$

- At least one of the bid price bands has a capacity greater than zero.
- The FCAS Enablement Max is generally non-negative, with some exceptions for bidirectional units.

  For regulation FCAS bids on the load side of bidirectional units:

  $$FCAS\ Enablement\ Min_{LOAD} \leq 0$$

  For regulation FCAS bids on the generation side of bidirectional units, and for all FCAS bids from non-bidirectional units:

  $$FCAS\ Enablement\ Max \geq 0$$

  For contingency FCAS bids from bidirectional units, FCAS Enablement Min and FCAS Enablement Max may be negative, positive, or zero.

- The energy maximum availability allows the unit to operate within the FCAS trapezium for the service. This generally means that the energy maximum availability is greater than or equal to the FCAS enablement minimum. However, there are exceptions for semi-scheduled generating units and bidirectional units.

  For scheduled generating units, scheduled loads and wholesale demand response units:

  $$Energy\ Max\ Availability \geq FCAS\ Enablement\ Min$$

  For semi-scheduled generating units:

  $$min\ [Energy\ Max\ Availability,\ UIGF] \geq FCAS\ Enablement\ Min$$

  For bidirectional units offering regulation FCAS on the load side:

  $$-\ Energy\ Max\ Availability_{LOAD} \leq FCAS\ Enablement\ Max_{LOAD}$$

  For bidirectional units offering regulation FCAS on the generation side:

  $$Energy\ Max\ Availability_{GEN} \geq FCAS\ Enablement\ Min_{GEN}$$

  For bidirectional units offering contingency FCAS:

  $$-\ Energy\ Max\ Availability_{LOAD} \leq FCAS\ Enablement\ Max$$

  and

  $$Energy\ Max\ Availability_{GEN} \geq FCAS\ Enablement\ Min$$

- The unit is operating between the FCAS enablement minimum and maximum at the start of the interval.

  For scheduled and semi-scheduled generating units, scheduled loads and wholesale demand response units:

  $$FCAS\ Enablement\ Min \leq Max[Initial\ MW, 0] \leq FCAS\ Enablement\ Max$$

For bidirectional units offering regulation FCAS on both the generation and load sides of the unit:

$$FCAS\ Enablement\ Min_{LOAD} \leq Initial\ MW \leq FCAS\ Enablement\ Max_{GEN}$$

For all other types of FCAS bids from bidirectional units:

$$FCAS\ Enablement\ Min \leq Initial\ MW \leq FCAS\ Enablement\ Max$$

One consequence of this pre-condition is that units operating at an energy level outside the Enablement Min and Enablement Max of an FCAS trapezium at the start of an interval cannot be enabled for that FCAS. This phenomenon is referred to as "stranded outside the FCAS trapezium", or simply "stranded".

- In real time dispatch, the first interval of 5-minute pre-dispatch, and the first interval of 30-minute pre-dispatch, the unit must be on AGC to be enabled for regulation FCAS.
- In 30-minute pre-dispatch, if the unit is daily energy constrained then there must be sufficient remaining energy in each period to allow the unit to operate within the FCAS trapezium for the service.

  For scheduled and semi-scheduled generating units, scheduled loads, and wholesale demand response units with a daily energy limit:

$$\frac{Energy\ Available}{DispPeriod} > FCAS\ Enablement\ Min$$

where *DispPeriod* is the length of the pre-dispatch period in hours i.e. DispPeriod = 0.5.

For bidirectional units with a profiled energy limit where PreviousStorage, i.e. energy storage at the end of the previous interval, is not NULL:

If FCAS bid direction = "LOAD"

$$min\left\{0,\left[\left\{\frac{(Previous\ Storage - Max\ Storage) * 2}{DispPeriod * ImportEfficiencyFactor}\right\} - Initial\ MW\right]\right\} < FCAS\ Enablement\ Max_{LOAD}$$

else if FCAS bid direction = "GEN"

$$max\left\{0,\left[\left\{\frac{(Previous\ Storage - Min\ Storage) * 2 * ExportEfficiencyFactor}{DispPeriod}\right\} - Initial\ MW\right]\right\} > FCAS\ Enablement\ Min_{GEN}$$

else

$$min\left\{0,\left[\left\{\frac{(Previous\ Storage - Max\ Storage) * 2}{DispPeriod * ImportEfficiencyFactor}\right\} - Initial\ MW\right]\right\} < FCAS\ Enablement\ Max$$

and

$$max\left\{0,\left[\left\{\frac{(Previous\ Storage - Min\ Storage) * 2 * ExportEfficiencyFactor}{DispPeriod}\right\} - Initial\ MW\right]\right\} > FCAS\ Enablement\ Min$$

where ImportEfficiencyFactor and ExportEfficiencyFactor represent losses in importing and exporting energy from the bidirectional unit.

6. Joint energy and FCAS constraints

After FCAS trapezium scaling, and if a scheduled or semi-scheduled generating unit, scheduled bidirectional unit, scheduled load, or wholesale demand response unit is considered for enablement for a particular FCAS in NEMDE, further constraints will be imposed within NEMDE to ensure that the unit can physically deliver all the energy for which it has been dispatched, and all the FCAS for which it has been enabled.

An FCAS trapezium defines the maximum frequency response that a unit can provide for that service only. The actual maximum response may be less than the level defined by the trapezium if the unit is providing multiple services.

To ensure that the combined energy dispatch and FCAS enablement is within a unit's technical capability, NEMDE creates intrinsic "joint ramping", "joint capacity", "energy and regulating FCAS capacity", and "BDU regulating FCAS SCADA ramping" constraints to represent the unit's combined ramping and capacity capabilities.

- The joint ramping constraint is applied to regulating services and ensures that the combined amount of increase or decrease of energy and regulating services is within the real-time AGC ramp rates telemetered from the unit.
- The joint capacity constraint is applied to each contingency service and affects both regulating and contingency services. It ensures that the maximum amount of contingency service that a unit can provide is offset by the amounts of regulating service for which the unit is enabled and energy for which it is dispatched.
- The energy and regulating FCAS capacity constraint is applied to regulating services and ensures that the maximum amount of regulating FCAS that a unit can provide is offset by the amount of energy for which it is dispatched. This is similar to the joint capacity constraint but involves only regulating FCAS and energy.
- The BDU regulating FCAS SCADA ramping constraint is applied solely to regulating services from bidirectional units and ensures that the SCADA ramp rate limit is not "double-counted" when there are regulating FCAS bids on both sides of the BDU.

As a group these NEMDE intrinsic constraints are referred to as "unit FCAS constraints". Table 2 summarises the application of the unit FCAS constraints to regulating and contingency services.

Table 2 Application of unit FCAS constraints to different services

	Regulating service	Contingency service
Joint ramping constraint	Applied	Not applied
Joint capacity constraint	Applied	Applied
Energy and regulating FCAS capacity constraint	Applied	Not applied
BDU regulating FCAS SCADA ramping constraint	Applied (to BDUs only)	Not applied

NEMDE applies the unit FCAS constraints simultaneously during the optimisation process and searches for the optimum solution that satisfies all constraints concurrently.

6.1. Joint ramping constraints

NEMDE applies joint ramping constraints to ensure that any combined change in energy output and regulating service delivery is within the relevant AGC ramp rate.[9] This prevents infeasible dispatch outcomes in which a unit is enabled for regulating FCAS but unable to fully deliver it.

Joint ramping constraints are based on the telemetered AGC ramping capability at the initial generation, consumption, or load reduction level for each unit, and are applied if a unit has an energy bid, is enabled for regulating services, and the AGC ramp up or down rate is greater than zero.

- The joint ramping constraint equations for scheduled or semi-scheduled generating units, scheduled bidirectional units, and wholesale demand response units are:

$$Energy\ Dispatch\ Target + Raise\ Regulation\ FCAS\ Target \leq Initial\ MW + SCADA\ Ramp\ Up\ Rate * Time\ Period^{10}$$

$$Energy\ Dispatch\ Target - Lower\ Regulation\ FCAS\ Target \geq Initial\ MW - SCADA\ Ramp\ Down\ Rate * Time\ Period$$

- The joint ramping constraint equations for scheduled loads are:

$$Energy\ Dispatch\ Target + Lower\ Regulation\ FCAS\ Target \leq Initial\ MW + SCADA\ Ramp\ Up\ Rate * Time\ Period$$

$$Energy\ Dispatch\ Target - Raise\ Regulation\ FCAS\ Target \geq Initial\ MW - SCADA\ Ramp\ Down\ Rate * Time\ Period$$

where

$$Time\ Period = 5\ minutes^{11}$$

$Initial\ MW$ is the generation, consumption, or load reduction of the unit at the start of the period

Figure 18 depicts a joint ramping constraint applied to a regulating raise service trapezium from a scheduled generating unit with a typical 45° upper slope.[12] The AGC Ramp Up Capability is the SCADA Ramp Up Rate * Time Period. As the constraint also has a 45° slope, it runs parallel to the right-hand-side trapezium slope. The constraint reduces the feasible solution space by truncating the area under the upper trapezium slope.

[9] AEMO's AGC cannot physically dispatch a unit beyond its telemetered AGC ramp rate limits.

[10] The constraint equations in this document are simplified versions of the NEMDE constraints and do not include constraint surplus and deficit terms. Terms in *blue* are "dispatchable entities", or variables that can be controlled by NEMDE. Their values are optimised by NEMDE and published as part of the NEMDE solution.

[11] Because joint ramping constraints are not applied in 30-minute pre-dispatch.

[12] This illustration also applies to semi-scheduled generating units, scheduled bidirectional units, and wholesale demand response units. For scheduled loads, this illustration would be applicable to the regulating lower service if the Energy axis was relabelled "Consumption".

Figure 18 Joint ramping constraint – 45° angle upper slope

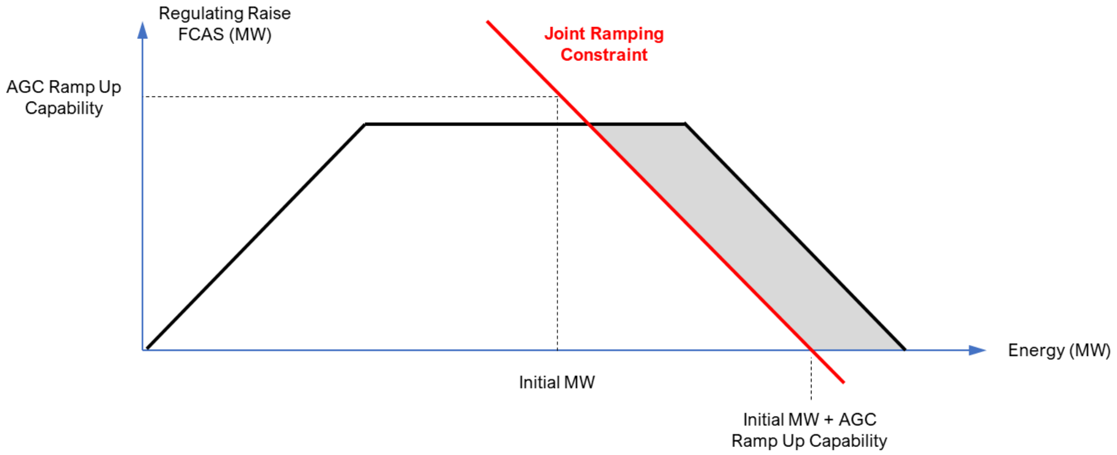
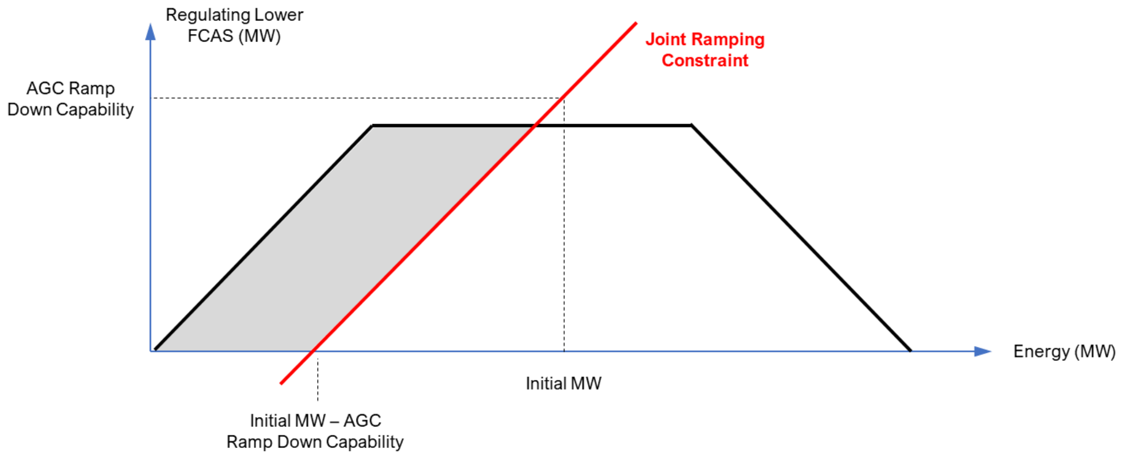


Figure 19 depicts the analogous situation for the regulating lower service from a scheduled generating unit.[13] The AGC Ramp Down Capability is the SCADA Ramp Down Rate * Time Period. For the regulating lower service, the joint ramping constraint truncates the feasible solution space under the left-hand-side trapezium slope.

Figure 19 Joint ramping constraint – 45° angle lower slope



6.2. Joint capacity constraints

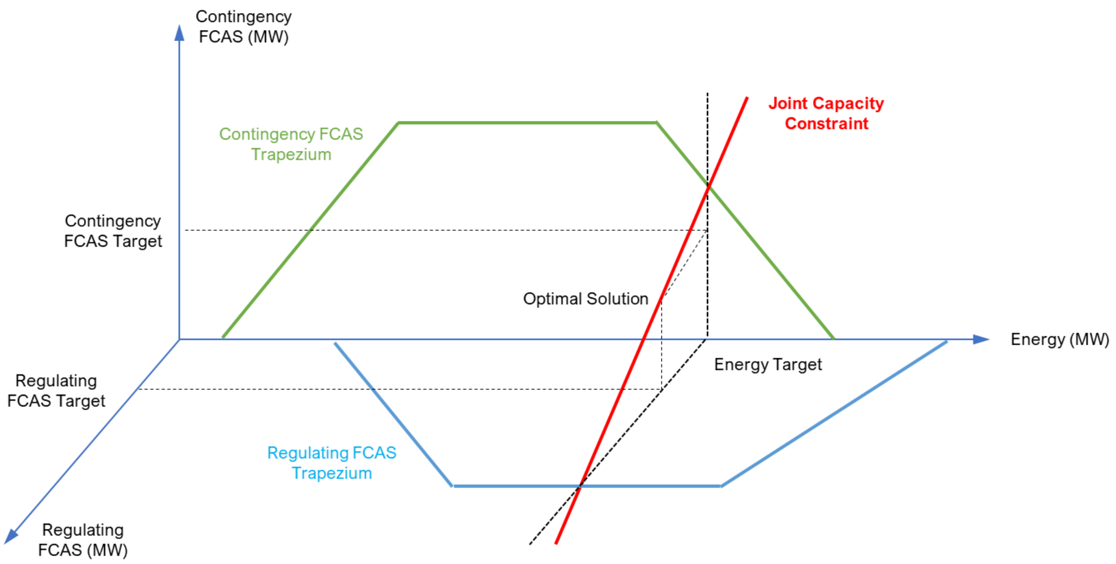
The maximum contingency service response that a unit can physically provide following a contingency may be reduced if the unit has already provided a regulation frequency response. NEMDE applies joint capacity constraints to co-optimise the dispatch of energy and the enablement of regulating services and contingency services from a unit. NEMDE does this to avoid infeasible dispatch outcomes in which a unit is enabled for both regulating and contingency services but is unable to fully deliver both following a contingency.

Figure 20 shows an example of the co-optimisation of energy, regulating FCAS and contingency FCAS. For a particular energy target, the combined availability of regulating and contingency

[13] This illustration also applies to semi-scheduled generating units, scheduled bidirectional units, and wholesale demand response units. For scheduled loads, this illustration would be applicable to the regulating raise service if the Energy axis was relabelled "Consumption".

services is limited by the relevant joint capacity constraint, shown as a solid red line. The feasible solution space for a given energy target is the area underneath the red line on the contingency FCAS – regulating FCAS plane, and the optimum solution lies on the red line.

Figure 20 Joint capacity constraint in 3D



The 3D relationship illustrated in Figure 20 can be simplified to two dimensions by recognising that energy and the regulating services have a 1:1 relationship. For example, a 1MW reduction in energy output can potentially increase a generating unit's regulating raise service availability by 1MW and decrease its regulating lower service availability by 1MW. Conversely, a 1MW increase in energy output can potentially reduce its regulating raise service availability by 1MW and increase its regulating lower service availability by 1MW.

This simplification is performed for a scheduled generating unit in Figure 21 and Figure 22.[14] The regulating FCAS trapezium has been removed, and the regulating FCAS target is shown on the horizontal axis along with the energy target. This is possible because the 1:1 relationship between energy and regulating FCAS allows them to be drawn to the same scale on the same plane. A joint capacity constraint now runs parallel to the contingency FCAS trapezium slope.

[14] These illustrations also apply to semi-scheduled generating units, scheduled bidirectional units, and wholesale demand response units. For scheduled loads, these illustrations should have the regulating raise and lower services swapped and the Energy axis relabelled as "Consumption".

Figure 21 Joint capacity constraint in 2D – regulating raise

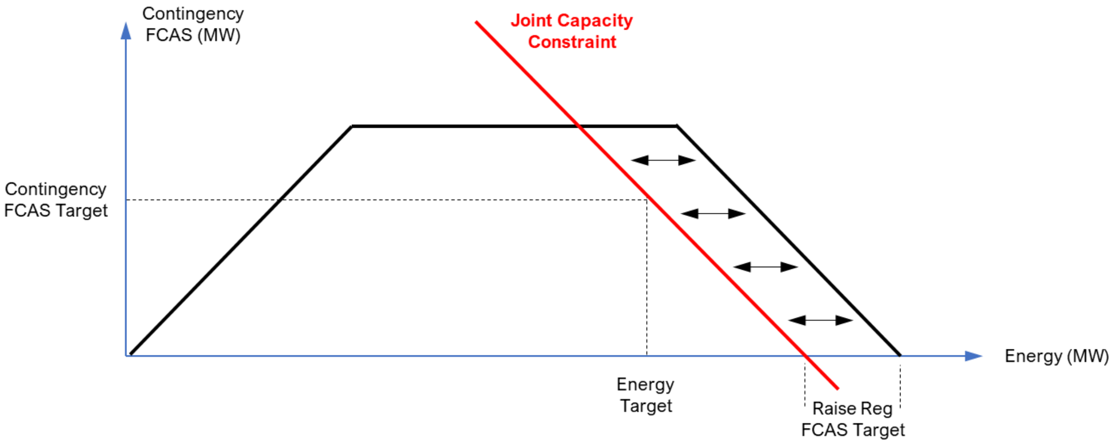
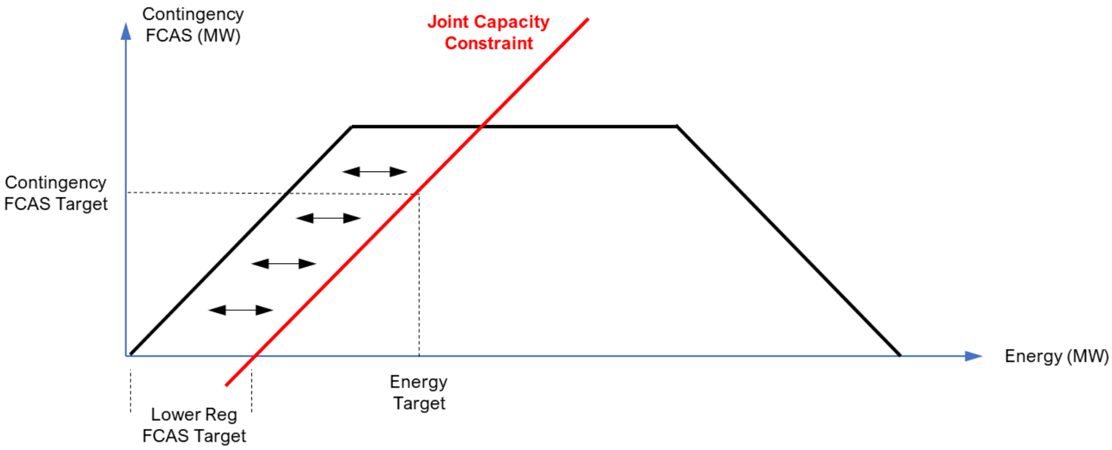


Figure 22 Joint capacity constraint in 2D – regulating lower



Joint capacity constraints are created for all units with an energy bid and which are enabled for a contingency service. One set of constraints is created for each contingency service (very fast raise, fast raise, slow raise, delayed raise, very fast lower, fast lower, slow lower, or delayed lower) for which the unit is enabled.

- The joint capacity constraint equations for each type of contingency FCAS for scheduled or semi-scheduled generating units, scheduled bidirectional units, and wholesale demand response units are:

$$Energy\ Dispatch\ Target + Upper\ Slope\ Coeff * Contingency\ FCAS\ Target \\ + [Raise\ Regulation\ FCAS\ Enablement\ Status] \\ * Raise\ Regulation\ FCAS\ Target \leq EnablementMax$$

$$Energy\ Dispatch\ Target - Lower\ Slope\ Coeff \times Contingency\ FCAS\ Target \\ - [Lower\ Regulation\ FCAS\ Enablement\ Status] \\ \times Lower\ Regulation\ FCAS\ Target \geq EnablementMin$$

- The joint capacity constraint equations for each type of contingency FCAS for scheduled loads are:

$$\begin{aligned} Energy\ Dispatch\ Target &+ Upper\ Slope\ Coeff * Contingency\ FCAS\ Target \\ &+ [Lower\ Regulation\ FCAS\ Enablement\ Status] \\ &* Lower\ Regulation\ FCAS\ Target \leq EnablementMax \end{aligned}$$

$$\begin{aligned} Energy\ Dispatch\ Target &- Lower\ Slope\ Coeff \times Contingency\ FCAS\ Target \\ &- [Raise\ Regulation\ FCAS\ Enablement\ Status] \\ &\times Raise\ Regulation\ FCAS\ Target \geq EnablementMin \end{aligned}$$

where

$$Upper\ Slope\ Coeff = \frac{EnablementMax - HighBreakPoint}{MaxAvail}$$

$$Lower\ Slope\ Coeff = \frac{LowBreakPoint - EnablementMin}{MaxAvail}$$

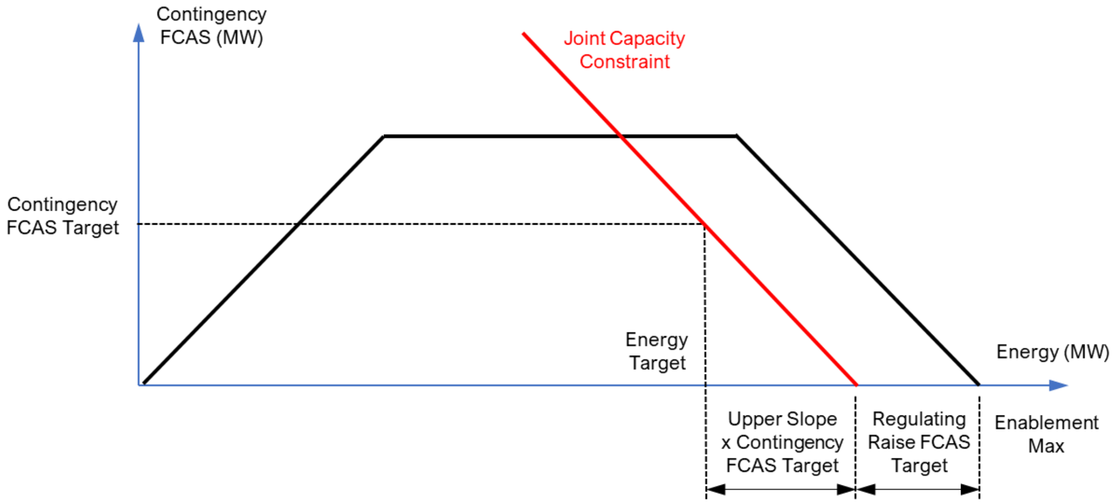
$[Raise\ Regulation\ FCAS\ Enablement\ Status]$ = 1 if the regulating raise service is enabled for the unit, otherwise 0.

$[Lower\ Regulation\ FCAS\ Enablement\ Status]$ = 1 if the regulating lower service is enabled for the unit, otherwise 0.

One consequence of these constraints is that the energy dispatch target is bounded by Enablement Min and Enablement Max whenever a unit is enabled for contingency FCAS. This phenomenon is referred to as “trapped within the FCAS trapezium”, or simply “trapped”.

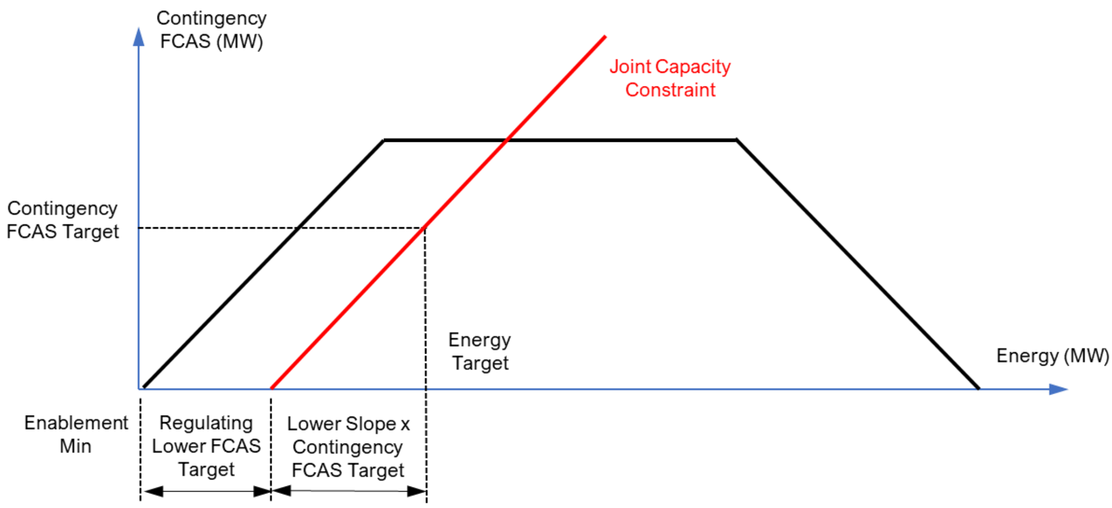
The elements of the joint capacity constraint equations for a scheduled generating unit are depicted in Figure 23 and Figure 24.[15]

Figure 23 Joint capacity constraint equation – energy dispatch target + upper slope x contingency FCAS target + regulating raise FCAS target ≤ Enablement Max



[15] These illustrations also apply to semi-scheduled generating units, scheduled bidirectional units, and wholesale demand response units. For scheduled loads, these illustrations should have the regulating raise and lower services swapped, the upper and lower slopes swapped, and the Energy axis relabelled as “Consumption”.

Figure 24 Joint capacity constraint equation – energy dispatch target – lower slope x contingency FCAS target – lower regulating FCAS target ≥ Enablement Min



6.3. Energy and regulating FCAS capacity constraints

NEMDE applies energy and regulating FCAS capacity constraints to ensure that the dispatch of energy and enablement of regulating services is co-optimised within the bounds specified by the regulating service trapezium.

Energy and regulating FCAS capacity constraints are created for all units with an energy bid and which are enabled for regulating services. The energy and regulating FCAS capacity constraint equations are:

$$Energy\ Dispatch\ Target + Upper\ Slope\ Coeff \times Regulating\ FCAS\ Target \leq EnablementMax$$

$$Energy\ Dispatch\ Target - Lower\ Slope\ Coeff \times Regulating\ FCAS\ Target \geq EnablementMin$$

where

$$Upper\ Slope\ Coeff = \frac{EnablementMax - HighBreakPoint}{MaxAvail}$$

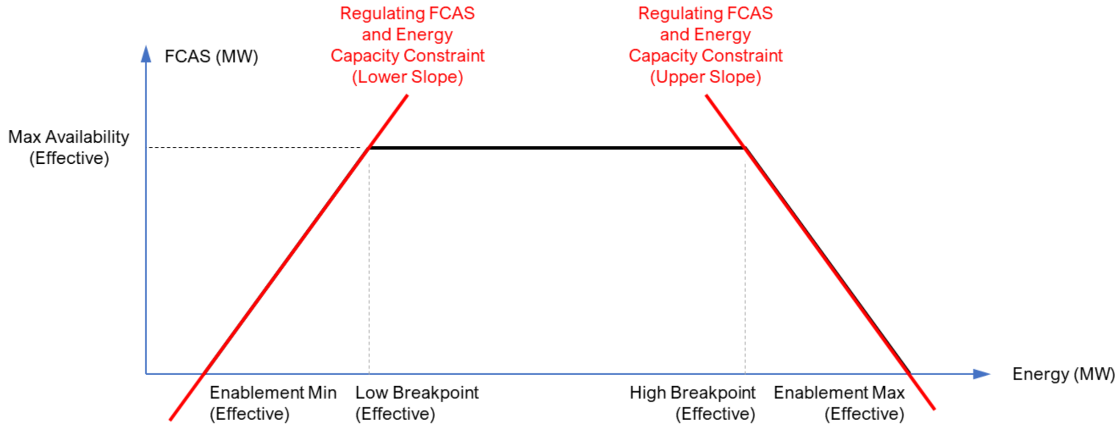
$$Lower\ Slope\ Coeff = \frac{LowBreakPoint - EnablementMin}{MaxAvail}\ {}_{16}$$

The energy and regulating FCAS capacity constraint equations are depicted for a scheduled generating unit in Figure 25.[17] The constraints enforce the limits specified by the regulating FCAS trapezium slopes.

[16] In the case of bidirectional units, NEMDE creates a pair of energy and regulating FCAS capacity constraints for the generation side of the unit, the load side of the unit, or for both sides of the unit depending on whether the bidirectional unit has provided a regulating FCAS bid for just the generation side, just the load side, or for both sides of the unit.

[17] This illustration also applies to semi-scheduled generating units, scheduled bidirectional units, and wholesale demand response units. For scheduled loads, the Energy axis should be relabelled as “Consumption”.

Figure 25 Energy and regulating FCAS capacity constraints



One consequence of these constraints is that the energy dispatch target is bound by the Enablement Min and the Enablement Max when a unit is enabled for regulating FCAS. As with contingency FCAS, this phenomenon is referred to as "trapped within the FCAS trapezium", or simply "trapped".

6.4. BDU regulating FCAS SCADA ramping constraints

NEMDE applies BDU regulating FCAS SCADA ramping constraints to bidirectional units to ensure that the SCADA ramp rate limit is not "double-counted" when there are regulating FCAS bids on both sides of the BDU. BDU regulating FCAS SCADA ramping constraints are created for all bidirectional units with an energy offer that are enabled for regulating FCAS.

Bidirectional units can bid regulating FCAS on both sides of the BDU. Scaling for AGC ramp rates [see Section 4.2] is applied to each of the generation and load side trapeziums, which are then optimised individually within NEMDE. In some circumstances the BDU might be enabled for regulating FCAS up to the SCADA ramp rate limit on both sides of the unit, even though the SCADA ramp rate applies to the unit as a whole. BDU regulating FCAS SCADA ramping constraints are applied to the unit to prevent this possible "double-counting" of the SCADA ramp rate.

The BDU regulating FCAS SCADA ramping constraint equations are:

$$Raise\ Regulation\ FCAS\ Target \leq SCADA\ Ramp\ Up\ Rate * Time\ Period$$

$$Lower\ Regulation\ FCAS\ Target \leq SCADA\ Ramp\ Down\ Rate * Time\ Period$$

where

$$Time\ Period = 5\ minutes^{18}$$

[18] Because BDU regulating FCAS SCADA ramping constraints are not applied in 30-minute pre-dispatch.

6.5. Application of unit FCAS constraints in dispatch, 5-minute pre-dispatch, and 30-minute pre-dispatch

Table 3 summarises the range of intervals over which the unit FCAS constraints apply in the dispatch, 5-minute pre-dispatch, and 30-minute pre-dispatch processes.

Table 3 Intervals over which unit FCAS constraints apply in central dispatch

Constraints	Intervals to which the constraint applies		
	Dispatch	*5-minute pre-dispatch*	*Pre-dispatch*
Joint ramping constraint	All[19]	First	None
Joint capacity constraint	All	All	All
Energy and regulating FCAS capacity constraint	All	All	All
BDU regulating FCAS SCADA ramping constraint	All	First	None

[19] Excludes the 1st Pass Fast Start Commitment and 2nd Pass Dispatch solves for Fast Start units initially in Fast Start Inflexibility Modes 0, 1 or 2.

7. FCAS availability

If a unit is enabled for a particular FCAS, then its FCAS availability is calculated by finding the constraint that most limits the unit's frequency response capability at a given energy target. This is often less than the FCAS Max Availability that was bid.

FCAS availability is based on energy dispatch targets and the amounts of FCAS enabled in each trading interval, rather than the quantities of FCAS bid into the market, because FCAS trapezium scaling, the pre-conditions for FCAS enablement, and unit FCAS constraints can all restrict the amounts of FCAS that can feasibly be delivered by an FCAS provider.

The FCAS availability for a unit at a given energy target is the maximum amount of the service that the unit can provide when it is fully delivering the amounts of all other services for which it is enabled at that energy target. For example, the regulating service availability of a unit in a particular direction (raise or lower) is the maximum regulating response that the unit is able to deliver when it is generating (for scheduled and semi-scheduled generating units or scheduled bidirectional units) or consuming (for scheduled loads or bidirectional units) or reducing load (for wholesale demand response units) at its energy target and fully delivering any simultaneously enabled contingency service. Conversely, the contingency service availability of a unit in a particular direction is the maximum contingency response that the unit is able to deliver when it is generating or consuming or reducing load at its energy target and fully delivering any simultaneously enabled regulating service.

The FCAS availability for a unit for a particular FCAS is set to 0 MW if the unit cannot be enabled for that service due to the failure of one or more of the pre-conditions specified in Section 5.

AEMO must publish information on the actual availability of each type of FCAS.[20] AEMO meets this requirement by publishing the maximum available quantity of each type of FCAS on a region-aggregate basis after each dispatch and pre-dispatch run, and publishing the maximum available quantity of each type of FCAS on a per-unit basis at the end of each trading day.[21]

The FCAS availability calculation is performed as a post-processing step at the time of loading the NEMDE solution into the Electricity Market Management System (EMMS) database. In rare cases this can produce anomalous outcomes for bidirectional units, which can bid energy in both generation and load directions, as well as regulation FCAS on the generation side, the load side, or both the generation and load side (in which case the regulation FCAS trapeziums are treated independently during the NEMDE optimisation but are amalgamated into one aggregate trapezium for the availability calculations).

7.1. Calculation of FCAS availability

If a unit's Initial MW is outside its enablement limits, then its FCAS availability is 0 MW because the unit will not be enabled for FCAS. Otherwise, the FCAS availability for a given energy target is set by the most restrictive relevant constraint. There are five constraint types that can limit FCAS availability. These constraint types are marked from (1) to (5) below for later reference.

[20] Rules clauses 3.13.4(f)(4) and 3.13.4(p).

[21] Unit FCAS availability is provided confidentially to the relevant participant after each dispatch and pre-dispatch run.

FCAS Availability =

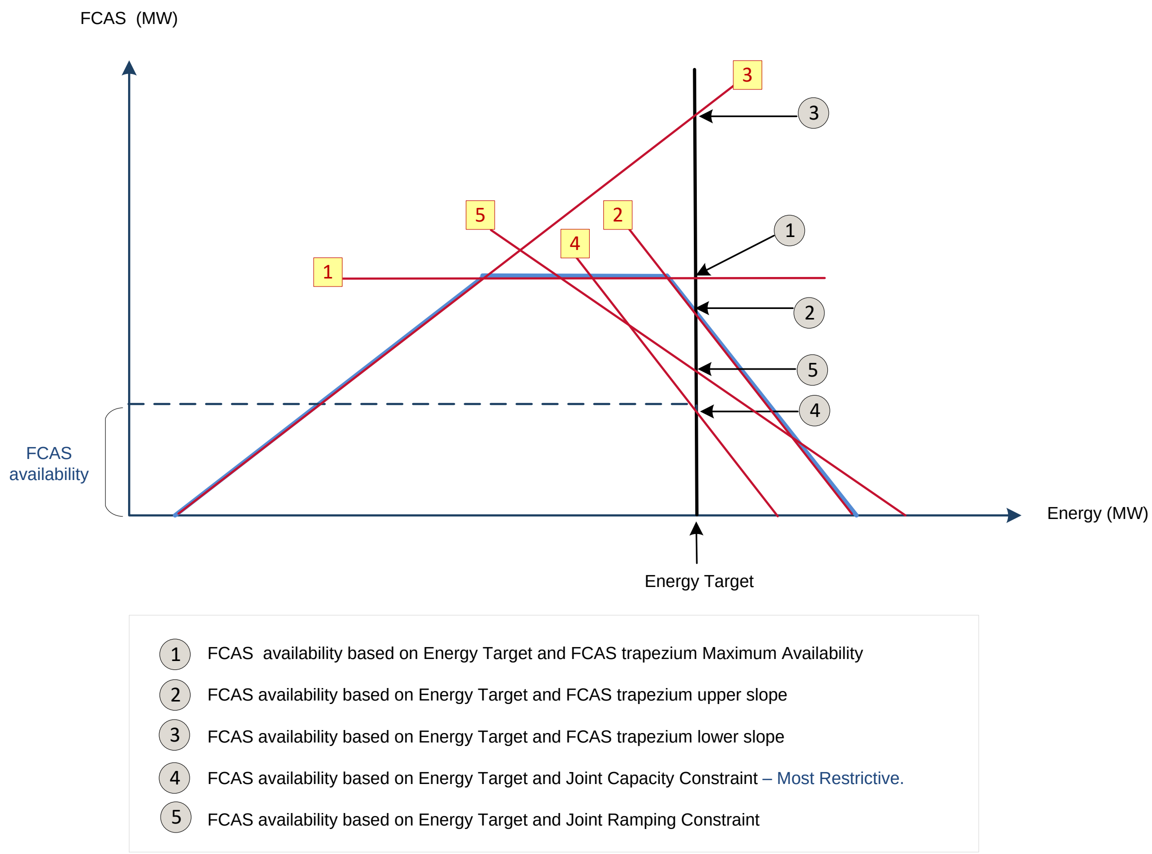
MINIMUM of [

- FCAS availability set by the FCAS trapezium Max Availability (1)
- FCAS availability set by the FCAS trapezium upper slope (2)
- FCAS availability set by the FCAS trapezium lower slope (3)
- FCAS availability set by the joint capacity constraint (4)
- FCAS availability set by the joint ramping constraint (5)[22]]

where the FCAS trapezium is the scaled (effective) FCAS trapezium from Section 4. For the regulating service availability calculation, there can be multiple type (4) joint capacity constraints because a joint capacity constraint is created for each contingency service for which the unit is enabled.

Figure 26 is an example showing how the constraints are applied. In this example, the constraint resulting in the most restrictive FCAS availability for the given energy target is a joint capacity constraint (4).

Figure 26 FCAS actual availability calculation



[22] For regulating FCAS only.

FCAS availability for each type of FCAS can be calculated using the formulas below.[23] For each limiting term, the corresponding constraint type is marked from (1) to (5).

Regulating Raise FCAS Availability =

WHEN >0, MINIMUM of [

1. *Effective RReg FCAS MaxAvail* ....(1)
2. *(Effective RReg EnablementMax - Energy Target) / Upper Slope Coeff RReg* ....(2)
3. *(Energy Target - Effective RReg EnablementMin) / Lower Slope Coeff RReg* ....(3)
4. *Bid R1 EnablementMax - Energy Target - (Upper Slope Coeff R1 x R1 Target)* ....(4)
5. *Bid R6 EnablementMax - Energy Target - (Upper Slope Coeff R6 x R6 Target)* ....(4)
6. *Bid R60 EnablementMax - Energy Target - (Upper Slope Coeff R60 x R60 Target)* ....(4)
7. *Bid R5 EnablementMax - Energy Target - (Upper Slope Coeff R5 x R5 Target)* ....(4)
8. *Bid L1 EnablementMax - Energy Target - (Upper Slope Coeff L1 x L1 Target)* ....(4)
9. *Bid L6 EnablementMax - Energy Target - (Upper Slope Coeff L6 x L6 Target)* ....(4)
10. *Bid L60 EnablementMax - Energy Target - (Upper Slope Coeff L60 x L60 Target)* ....(4)
11. *Bid L5 EnablementMax - Energy Target - (Upper Slope Coeff L5 x L5 Target)* ....(4)
12. *JointRampRaiseMax - Energy Target* ....(5)]

Regulating Lower FCAS Availability =

WHEN >0, MINIMUM of [

1. *Effective LReg FCAS MaxAvail* ....(1)
2. *(Effective LReg EnablementMax - Energy Target) / Upper Slope Coeff LReg* ....(2)
3. *(Energy Target - Effective LReg EnablementMin) / Lower Slope Coeff LReg* ....(3)
4. *Energy Target - Bid R1 EnablementMin - (Lower Slope Coeff R1 x R1 Target)* ....(4)
5. *Energy Target - Bid R6 EnablementMin - (Lower Slope Coeff R6 x R6 Target)* ....(4)
6. *Energy Target - Bid R60 EnablementMin - (Lower Slope Coeff R60 x R60 Target)* ....(4)
7. *Energy Target - Bid R5 EnablementMin - (Lower Slope Coeff R5 x R5 Target)* ....(4)
8. *Energy Target - Bid L1 EnablementMin - (Lower Slope Coeff L1 x L1 Target)* ....(4)
9. *Energy Target - Bid L6 EnablementMin - (Lower Slope Coeff L6 x L6 Target)* ....(4)
10. *Energy Target - Bid L60 EnablementMin - (Lower Slope Coeff L60 x L60 Target)* ....(4)
11. *Energy Target - Bid L5 EnablementMin - (Lower Slope Coeff L5 x L5 Target)* ....(4)
12. *Energy Target - JointRampLowerMin* ....(5)]

[23] Please note that these formulas have been developed for scheduled generating units. Given the complexity of the "basic" formulas, any additional refinements – such as for UIGF scaling, or load versus generation – have not been explicitly applied.

Contingency Raise FCAS Availability for service Rxx =

WHEN >0, MINIMUM of [

1. *Bid Rxx FCAS MaxAvail* ....(1)
2. *(Bid Rxx EnablementMax - Energy Target - RReg Target) / Upper Slope Coeff Rxx*..................(4)
3. *(Energy Target - Bid Rxx EnablementMin - LReg Target) / Lower Slope Coeff Rxx* ....(4)]

Contingency Lower FCAS Availability for service Lxx =

WHEN >0, MINIMUM of [

1. *Bid Lxx FCAS MaxAvail* .... (1)
2. *(Bid Lxx EnablementMax - Energy Target - RReg Target) / Upper Slope Coeff Lxx* .... (4)
3. *(Energy Target - Bid Lxx EnablementMin - LReg Target) / Lower Slope Coeff Lxx* ....(4)]

where

*Effective RReg FCAS MaxAvail = Min [Bid RReg FCAS MaxAvail, AGC Ramp Up Rate * Time Period]*

Effective RReg EnablementMax = Min [Bid RReg EnablementMax, AGC Upper Limit]

Effective RReg EnablementMin = Max [Bid RReg EnablementMin, AGC Lower Limit]

*Effective LReg FCAS MaxAvail = Min [Bid LReg FCAS MaxAvail, AGC Ramp Down Rate * Time Period]*

Effective LReg EnablementMax = Min [Bid LReg EnablementMax, AGC Upper Limit]

Effective LReg EnablementMin = Max [Bid LReg EnablementMin, AGC Lower Limit]

*JointRampRaiseMax = Initial MW + (AGC Ramp Up Rate * Time Period)*

*JointRampLowerMin = Initial MW – (AGC Ramp Down Rate * Time Period)*

$$Lower\ Slope\ Coeff\ xx = \frac{Bid\ xx\ LowBreakPoint - Bid\ xxEnablementMin}{Bid\ xx\ MaxAvail}\ \forall FCAS\ xx^{24}$$

$$Upper\ Slope\ Coeff\ xx = \frac{Bid\ xx\ EnablementMax - Bid\ xx\ HighBreakPoint}{Bid\ xx\ MaxAvail}\ \forall FCAS\ xx^{25}$$

Time Period = 5 minutes for dispatch and 5-minute pre-dispatch

30 minutes for 30-minute pre-dispatch

Examples of FCAS availability calculations are provided in Appendix A.

[24] Bid trapezium parameters can be used to calculate *Lower Slope Coeff* and *Upper Slope Coeff* for regulating FCAS because the trapezium angles are maintained during any FCAS trapezium scaling. If Lower Slope Coeff = 0 the corresponding availability limit is ignored to avoid dividing by zero.

[25] If Upper Slope Coeff = 0 then the corresponding availability limit is ignored to avoid dividing by zero.

7.2. Publication of FCAS availability

Table 4 summarises the content and timing of FCAS availability information published to the EMMS Data Model.

Table 4 FCAS availability publication

<table>
<tr><th>Column name</th><th>Table name</th><th>Information</th><th>Publication time</th></tr>
<tr><td rowspan="4">Raise1SecActualAvailability
Raise6SecActualAvailability
Raise60SecActualAvailability
Raise5MinActualAvailability
RaiseRegActualAvailability
Lower1SecActualAvailability
Lower6SecActualAvailability
Lower60SecActualAvailability
Lower5MinActualAvailability
LowerRegActualAvailability</td><td>DispatchLoad</td><td>Unit FCAS availability for dispatch</td><td>Available to the relevant participant every 5 minutes. Available to public next trading day.</td></tr>
<tr><td>DispatchRegionSum</td><td>Regional FCAS availability for dispatch</td><td>Every 5 minutes</td></tr>
<tr><td>PredispatchLoad</td><td>Unit FCAS availability for 30-minute pre-dispatch</td><td>Available to the relevant participant every 30 minutes. Available to public next trading day.</td></tr>
<tr><td>PredispatchRegionSum</td><td>Regional FCAS availability for 30-minute pre-dispatch</td><td>Every 30 minutes</td></tr>
</table>

Appendix A. Examples – FCAS Availability (Generator)

A.1 Base case

Assume the following base case conditions:

- Region Energy price = $30/MWh
- Region FCAS prices = $3/MWh for all FCAS

GEN01 unit is a slow-start generating unit, with all energy offered at $10/MWh, any FCAS offered at $1/MWh, and the following offer profile:

GEN01		Max Availability (MW)	Ramp Up Rate (MW/min)	Ramp Down Rate (MW/min)	Enablement Minimum (MW)	Low Break Point (MW)	High Break Point (MW)	Enablement Maximum (MW)
GEN01 Offer	Energy	690	5	5				
	Raise 1 Sec	66			234	234	624	690
	Raise 6 Sec	66			234	234	624	690
	Raise 60 Sec	66			234	234	575	690
	Raise 5 Min	66			290	300	624	690
	Regulating Raise	100			300	300	590	680
	Lower 1 Sec	66			234	300	690	690
	Lower 6 Sec	66			234	300	690	690
	Lower 60 Sec	66			234	300	690	690
	Lower 5 Min	76			290	366	690	690
	Regulating Lower	100			300	400	690	690

Real-time SCADA telemetry gives the following values for GEN01:

GEN01 SCADA	GEN01 SCADA values
AGC Ramp Up Rate	3 MW/min
AGC Ramp Down Rate	2 MW/min
AGC Lower Limit	280 MW
AGC Upper Limit	670 MW
AGC Status	ON

Consequently, FCAS trapezium scaling during pre-processing gives the following parameters for regulating FCAS from GEN01:

GEN01 FCAS Parameter	Regulating Raise	Regulating Lower
Effective Max Availability	15	10
Effective Enablement Max	670	670
Effective Enablement Min	300	300
Effective Low Break Point	300	310
Effective High Break Point	656.5	670

A.2 Scenario 1: Regulating and 5-minute FCAS available

Initial MW = 450 MW

Only RaiseReg, Raise5Min, LowerReg and Lower5Min FCAS offered

The *Initial MW* of 450 MW is between the enablement limits of all the offered FCAS so both the joint ramping and joint capacity constraints are automatically invoked by NEMDE for raise and lower FCAS services.

Joint Ramping Constraints (section 6.1):

$Energy\ Target + RaiseReg\ Target \leq JointRampRaiseMax$

$Energy\ Target - LowerReg\ Target \geq JointRampLowerMin$

where

$JointRampRaiseMax \quad = Initial\ MW + (AGC\ Ramp\ Up\ Rate * 5)$

$= 450 + (3*5)$

$= 465\ MW$

$JointRampLowerMin = Initial\ MW - (AGC\ Ramp\ Down\ Rate * 5)$

$= 450 - (2*5)$

$= 440\ MW$

<u>Joint Capacity Constraints (Section 6.2):</u>

$Energy\ Target + Upper\ Slope\ Coeff_{R5MI} * Raise5Min\ Target + RaiseReg\ Target \leq Raise5Min\ Enablement\ Max$

$Energy\ Target + Upper\ Slope\ Coeff_{L5MI} * Lower5Min\ Target + RaiseReg\ Target \leq Lower5Min\ Enablement\ Max$

$Energy\ Target - Lower\ Slope\ Coeff_{R5MI} * Raise5Min\ Target - LowerReg\ Target \geq Raise5Min\ Enablement\ Min$

$Energy\ Target - Lower\ Slope\ Coeff_{L5MI} * Lower5Min\ Target - LowerReg\ Target \geq Lower5Min\ Enablement\ Min$

where

$Raise5min\ Enablement\ Max = 690\ MW$

$Lower5min\ Enablement\ Max = 690\ MW$

$Raise5min\ Enablement\ Min = 290\ MW$

$Lower5min\ Enablement\ Min = 290\ MW$

$$Upper\ Slope\ Coeff_{R5MI} = \frac{(Raise5min\ Enablement\ Max - Raise5min\ High\ Break\ Point)}{Raise5min\ Max\ Availability} = \frac{(690-624)}{66} = 1$$

$$Upper\ Slope\ Coeff_{L5MI} = \frac{(Lower5min\ Enablement\ Max - Lower5min\ High\ Break\ Point)}{Lower5min\ Max\ Availability} = \frac{(690-690)}{76} = 0$$

$$Lower\ Slope\ Coeff_{R5MI} = \frac{(Raise5min\ Low\ Break\ Point - Raise5min\ Enablement\ Min)}{Raise5min\ Max\ Availability} = \frac{(300-290)}{66} = 0.152$$

$$Lower\ Slope\ CoeffL_{5MI} = \frac{(Lower5min\ Low\ Break\ Point - Lower5min\ Enablement\ Min)}{Lower5min\ Max\ Availability} = \frac{(366-290)}{76} = 1$$

Substituting into the joint capacity constraints:

$Energy\ Target + Raise5min\ Target + RaiseReg\ Target \leq 690$

$Energy\ Target + RaiseReg\ Target \leq 690$

$Energy\ Target - 0.152 * Raise5min\ Target - LowerReg\ Target \geq 290$

$Energy\ Target - Lower5min\ Target - LowerReg\ Target \geq 290$

GEN01 Solution

Energy target	= 465 MW
RaiseReg target	= 0 MW
Raise5Min target	= 66 MW
LowerReg target	= 10 MW
Lower5Min target	= 76 MW

GEN01 unit's energy target is binding at the *JointRampRaiseMax* of the unit's joint ramping constraints, resulting in a RaiseReg target of zero. The full amount of LowerReg, Lower5Min and Raise5Min can be dispatched.

A.3 Scenario 2: Regulating FCAS unavailable

Initial MW = 680 MW

The *Initial MW* of 680 MW is outside the regulating FCAS enablement limits, so the unit cannot be enabled for regulating FCAS. (The unit is "stranded".) In this case the pre-processing logic creates neither joint capacity constraints nor joint ramping constraints.

This unit is reported as "stranded" for regulating FCAS.

A.4 Scenario 3: Availability calculation

The following set of FCAS availability calculations is based on Scenario 1, with some changes to the GEN01 unit targets.

Assumptions:

Initial MW	= 450 MW
Energy target	= 455 MW
RaiseReg target	= 10 MW
LowerReg target	= 10 MW
Raise5Min target	= 50 MW
Lower5Min target	= 50 MW

Substituting the unit energy and FCAS targets to determine the unit FCAS availabilities (section 7.1):

RaiseReg Availability

*= Min [15, (670 – 455) / 1.1, ignore: lower slope coeff = 0, ignore: no Raise6Sec offered, ignore: no Raise60Sec offered, (690 – 455 – (1 * 50)), (465 – 455)]*

= Min [15, 193.5, ignore, ignore, ignore, 185, 10]

= 10 MW

LowerReg Availability

*= Min [10, ignore: upper slope coeff = 0, (455 – 300) / 1, ignore: no Lower6Sec offered, ignore: no Lower60Sec offered, (455 – 290 – (1 * 50)), (455 – 440)]*

= Min [10, ignore, 155, ignore, ignore, 115, 15]

= 10 MW

Raise5Min Availability

= Min [66, (690 – 455) / 1, (455 – 290) / 0.15, (690 – 455 – 10) / 1]

= Min [66, 235, 1089, 225]

= 66 MW

Lower5Min Availability

= Min [76, ignore: upper slope coeff = 0, (455 – 290) / 1, (455 – 290 – 10) / 1]

= Min [76, ignore, 165, 155]

= 76 MW

Version release history

Version	Effective date	Summary of changes
3.0	3 June 2024	Updated to include bidirectional units.
2.0	9 October 2023	Updated to include Very Fast Contingency FCAS. New template. Minor edits.
1.0	3 November 2021	First issue in updated template