AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

FCAS MODEL IN NEMDE

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

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Current version release details

Version	Effective date	Summary of changes
2.0	9 October 2023	Updated to include Very Fast Contingency FCAS. New template. Minor edits.

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 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 Service (FCAS) from suitable generating 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 at least cost using 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, how FCAS bids are used, and the settlement of procured FCAS.

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 NER have the same meanings in this document unless otherwise specified in this clause.

Terms defined in the NER are intended to be identified in this document by italicising them, but failure to italicise a defined term does not affect its meaning.

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

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.

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

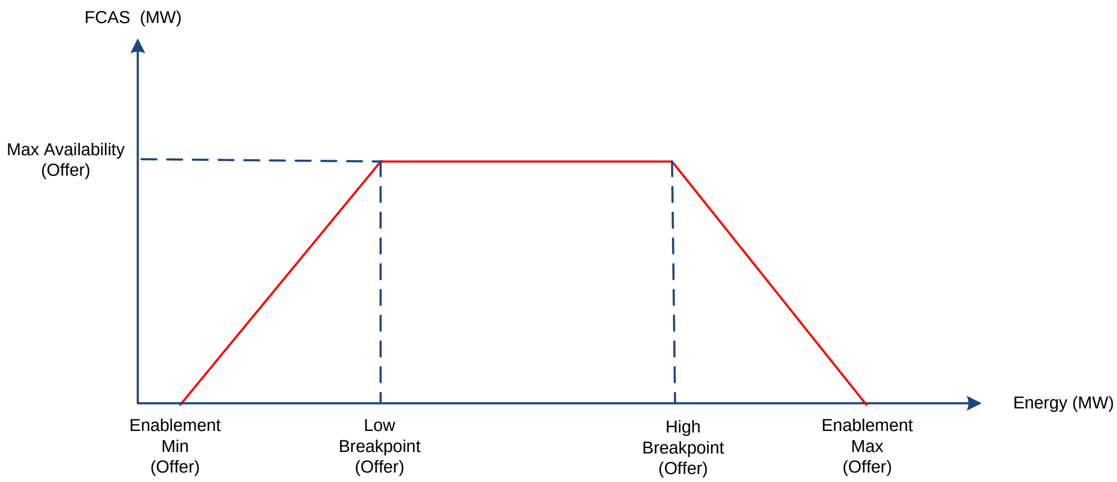
2. Structure of an FCAS Bid

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 the provision (or enabling) of that FCAS:
  - Enablement Min (MW)
  - Low Breakpoint (MW)
  - High Breakpoint (MW)
  - Enablement Max (MW)
  - Max Availability (MW)

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

Figure 1 FCAS bid trapezium – energy and FCAS capability relationship

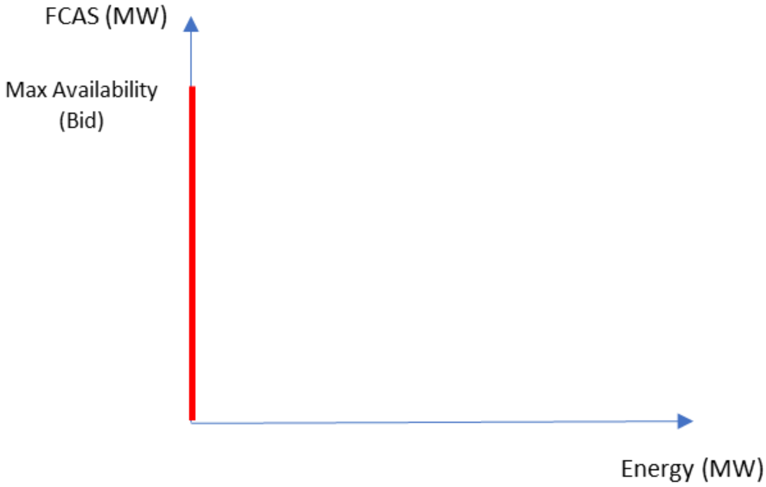


[3] Power generation level for scheduled and semi-scheduled generating units, power consumption level for scheduled loads, load reduction level for wholesale demand response units.

The technical limits submitted as part of an FCAS bid must be within the bounds of the technical envelope specified during registration of that provider for that FCAS.

If a provider is registered for FCAS only, and does not participate in the energy market as a scheduled or semi-scheduled generating unit, scheduled load or wholesale demand response unit, then its FCAS bid trapezium would be a vertical line, as shown in Figure 2. 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 2 FCAS bid trapezium – FCAS provision only



3. Application of an FCAS Bid

The maximum 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 3.

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, as shown in Figure 4.

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, as shown in Figure 5.

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

Figure 3 Energy target between breakpoints

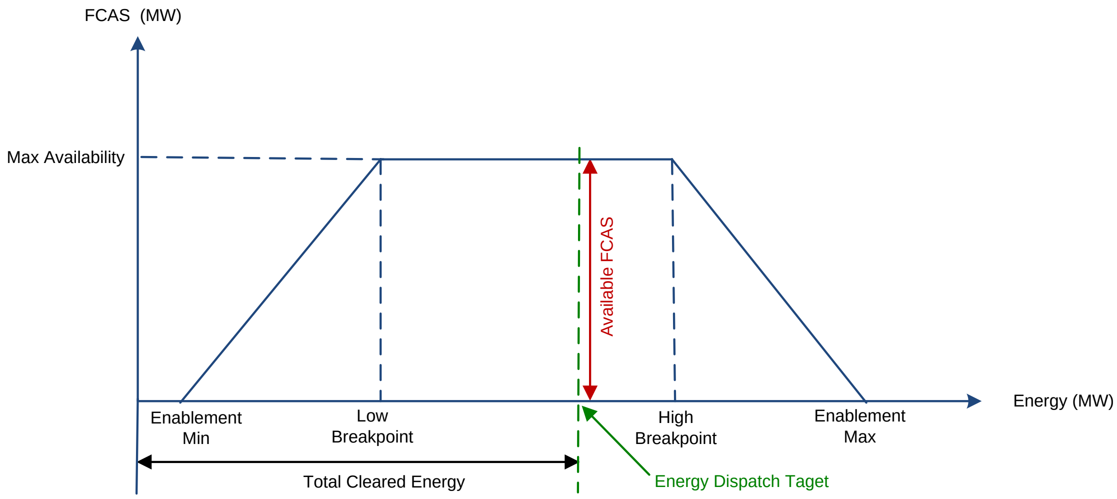


Figure 4 Energy target between Low Breakpoint and Enablement Min

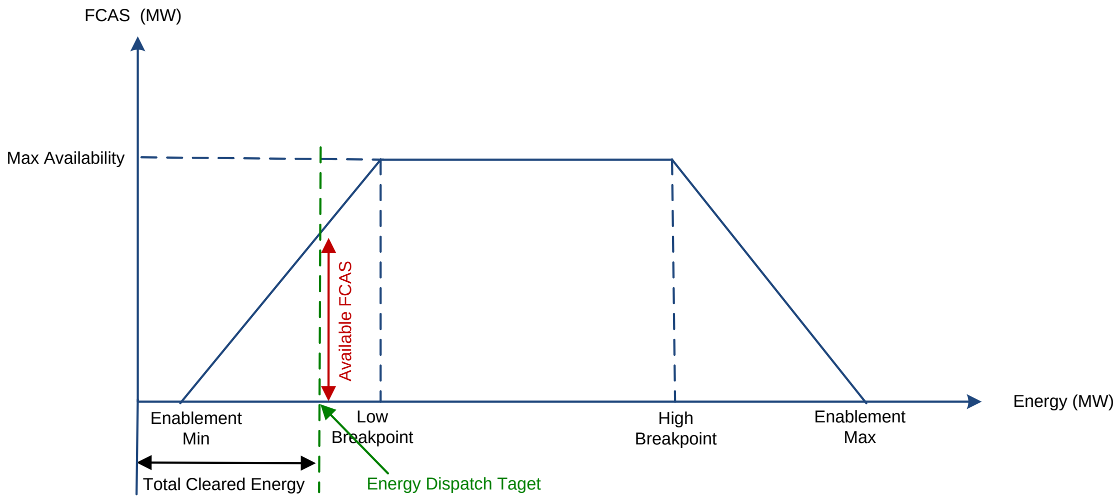
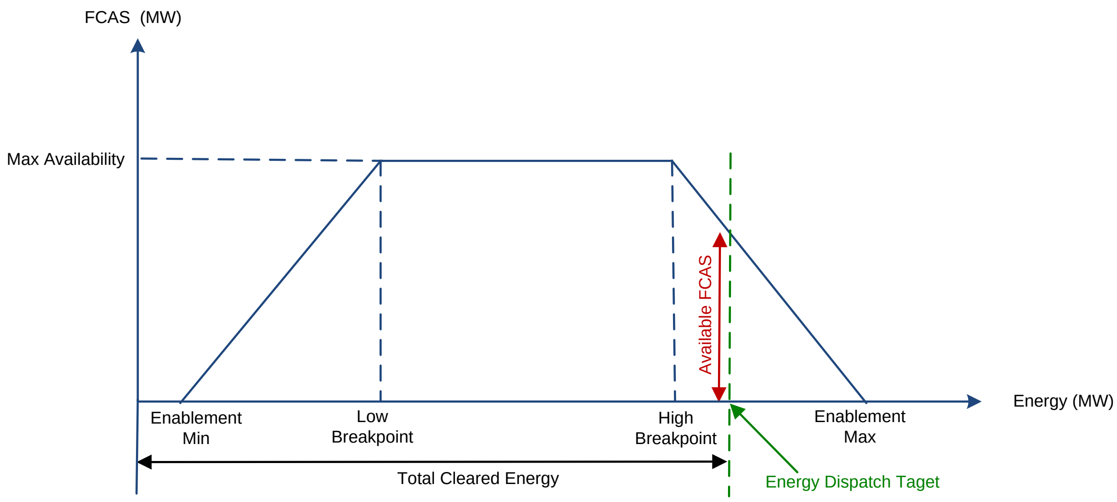


Figure 5 Energy Target between High Breakpoint and Enablement Max



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 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.

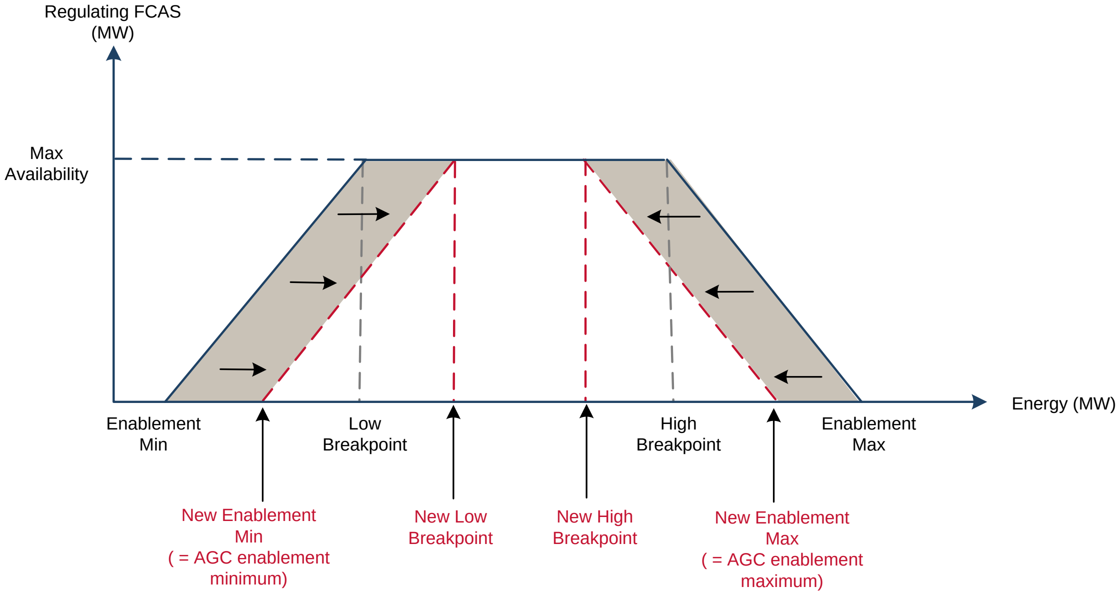
> Note that no FCAS trapezium scaling is applied to contingency FCAS bids from scheduled units. For example, if an FCAS provider reduces the maximum availability of their unit in the energy market to below the Enablement Max of any of their FCAS bids, NEMDE does not automatically scale the Enablement 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 6.

Figure 6 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 the maximum availability of 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 7.

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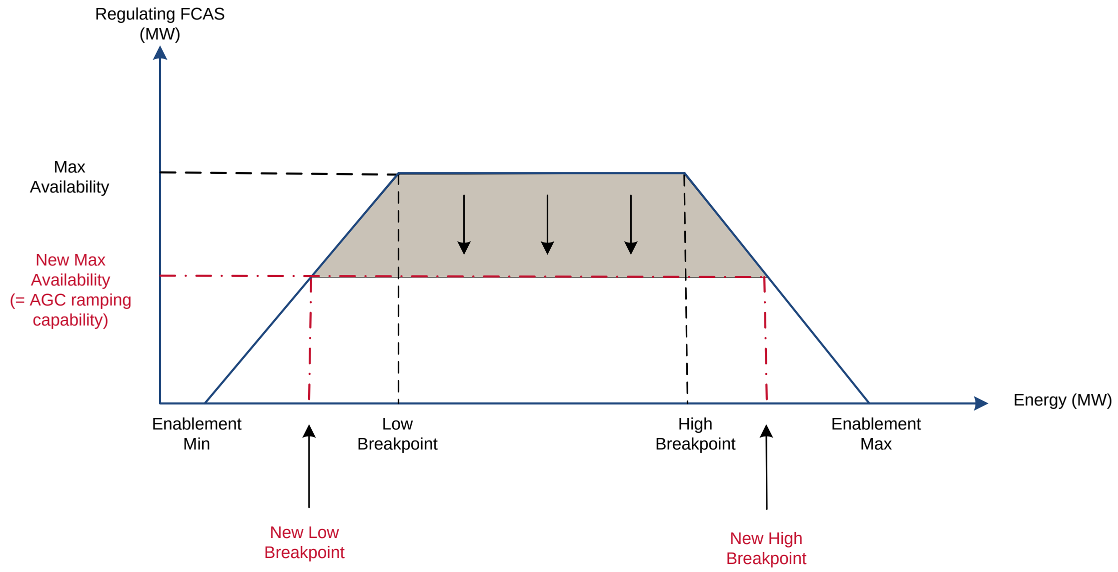
Figure 7 FCAS trapezium scaling by AGC ramp rates

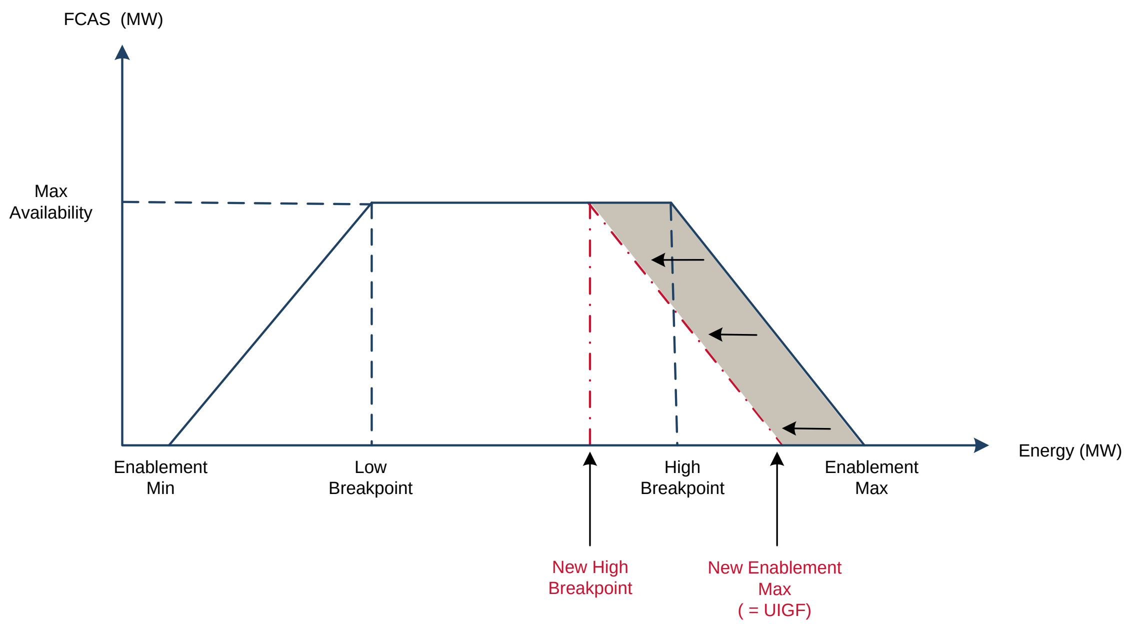


4.3. Scaling for UIGF

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 maximum limit is more restrictive than the UIGF, this scaling has no impact.

FCAS trapezium scaling by UIGF is shown in Figure 8.

Figure 8 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 9 FCAS trapezium scaling

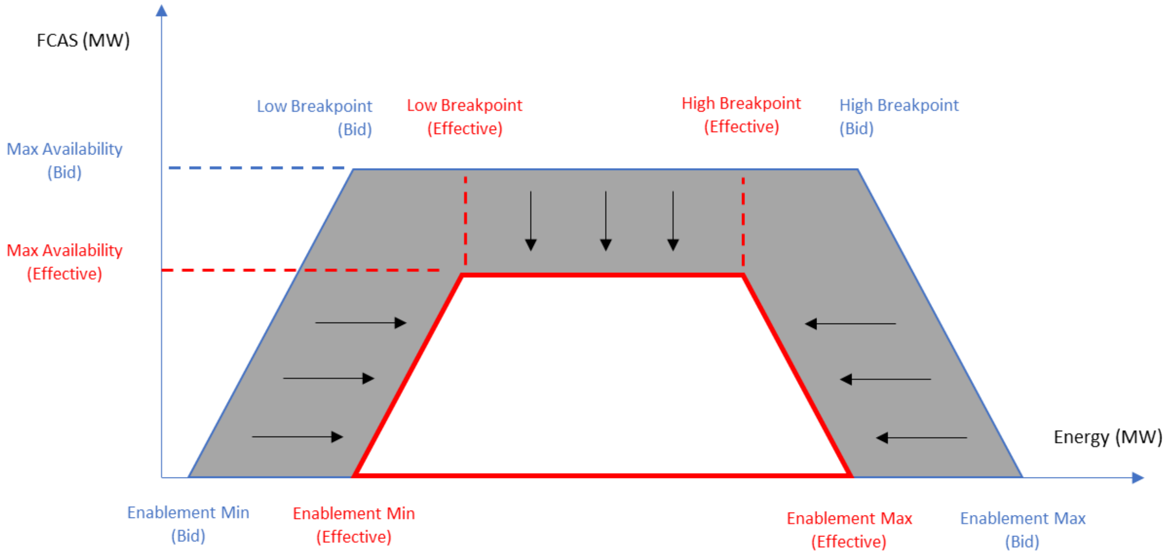


Table 1 summarises the range of intervals over which FCAS trapezium scaling applies in the Dispatch, 30-minute Pre-dispatch and 5-minute Pre-dispatch processes.

Table 1 Intervals over which FCAS trapezium scaling applies

Constraints	Intervals to which the constraint 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

The FCAS trapezium that NEMDE uses for the optimisation process is the scaled (effective) trapezium.

5. Pre-Conditions for enabling FCAS

After FCAS trapezium scaling, a scheduled or semi-scheduled generating 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 bid 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 for the service.
- The energy availability is greater than or equal to the FCAS trapezium enablement minimum of the service.

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

- The FCAS trapezium enablement maximum of the service is greater than or equal to zero.

  $FCAS\ Enablement\ Max \geq 0$

- The unit is initially operating between the FCAS trapezium enablement minimum and maximum of the service.

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

  One consequence of this pre-condition is that units operating at an energy level less than the Enablement Min or more than the Enablement Max of an FCAS trapezium cannot be enabled for that FCAS. This phenomenon is referred to as “stranded outside the FCAS trapezium”.

- In 30-minute pre-dispatch, if the unit is energy constrained then the remaining energy for the day must be above the FCAS trapezium enablement minimum for the service.

  $2\ x\ remaining\ energy\ available > FCAS\ Enablement\ Min$

In addition to the above conditions, for Dispatch and the first interval of 30-minute Pre-dispatch and 5-minute Pre-dispatch, regulating FCAS is enabled only if the following condition is met:

- AGC Status is “On”.

6. Joint Energy and FCAS Constraints

After FCAS trapezium scaling, and if a scheduled or semi-scheduled generating 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 particular 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", and "energy and regulating FCAS capacity" constraints to represent the unit's joint 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.

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

	Regulating service	Contingency service
Joint ramping constraint	Applied	Not applied
Joint capacity constraint	Applied	Applied
Energy and regulating FCAS capacity constraint	Applied	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

If a unit's energy dispatch is already constrained at its telemetered AGC ramp rate, it leaves no spare ramping capability for frequency regulation in the same direction. NEMDE co-optimises the joint dispatch of energy and enablement of regulating service from the unit so that, if required, the unit's AGC is physically able to deliver both, up to the unit's relevant telemetered AGC ramp rate limit.

NEMDE applies joint ramping constraints to ensure that any combined change in energy output and regulating service delivery is within the AGC ramp rates.[4] Joint ramping constraints are based on the telemetered AGC ramping capability at the initial generation or consumption 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 are:

$$\begin{aligned} &Energy\ Dispatch\ Target + Raise\ Regulating\ FCAS\ Target \\ &\quad \leq Initial\ MW + SCADA\ Ramp\ Up\ Capability \end{aligned}$$[5]

if $SCADA\ Ramp\ Up\ Rate > 0$

$$\begin{aligned} &Energy\ Dispatch\ Target - Lower\ Regulating\ FCAS\ Target \\ &\quad \geq Initial\ MW - SCADA\ Ramp\ Down\ Capability \end{aligned}$$

if $SCADA\ Ramp\ Down\ Rate > 0$

where

$SCADA\ Ramp\ Up\ Capability = SCADA\ Ramp\ Up\ Rate * Time\ Period$

$SCADA\ Ramp\ Down\ Capability = SCADA\ Ramp\ Down\ Rate * Time\ Period$

$Initial\ MW$ is the output or consumption of the unit at the beginning of the dispatch interval

Figure 10 depicts a joint ramping constraint applied to a typical regulating raise service trapezium with a 45° upper slope. As the constraint also has a 45° slope, it runs parallel to the right-hand-side trapezium slope. It shows how the constraint reduces the feasible solution area by truncating the area under the upper trapezium slope.

Figures 11 and 12 show how the feasible solution area is truncated by a joint ramping constraint if the trapezium does not have a 45° upper slope.

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

5 The constraint equations in this document are simplified version of the NEMDE constraints and do not include constraint surplus and deficit terms. Terms in *blue* are "dispatchable entities" and their values are determined by NEMDE and published as part of the NEMDE solution.

Figure 10 Joint ramping constraint – 45° angle upper slope

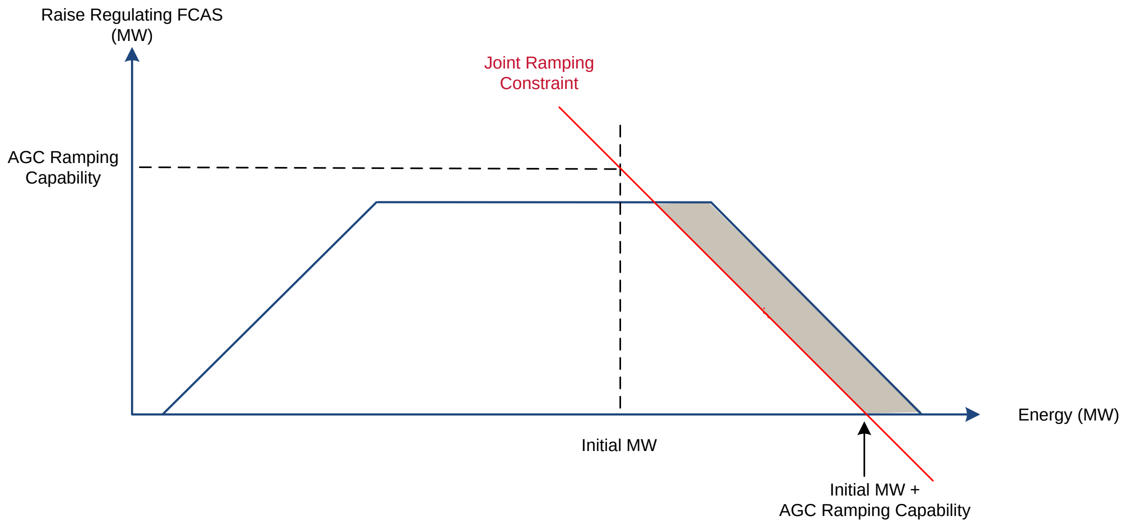


Figure 11 Joint ramping constraint – steep upper slope

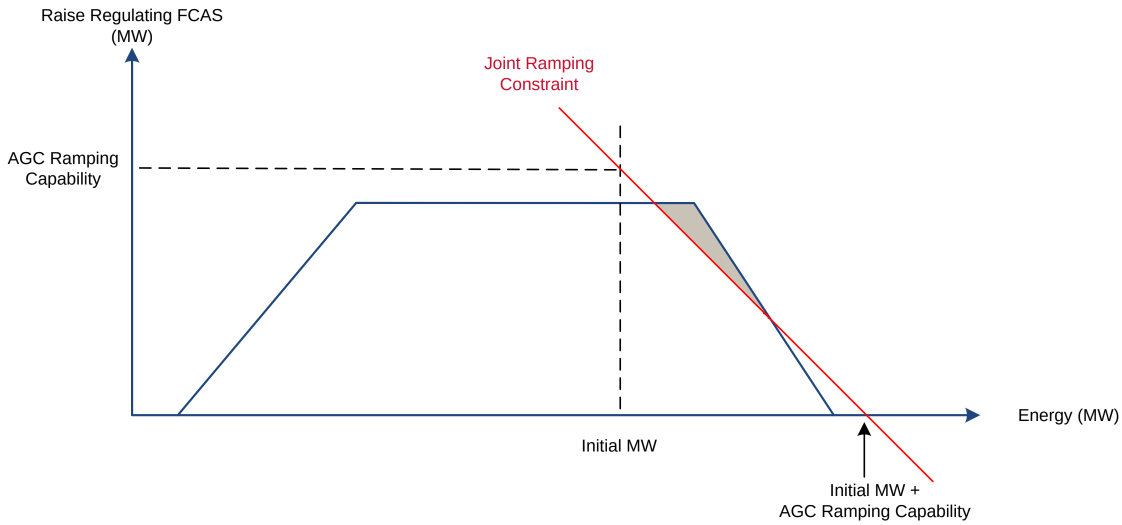
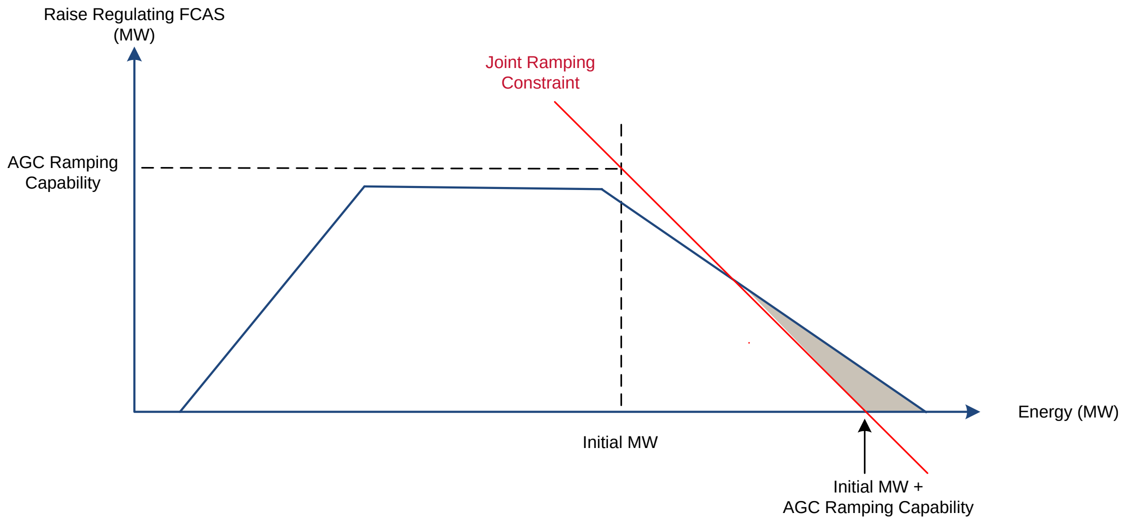


Figure 12 Joint ramping constraint – shallow upper slope



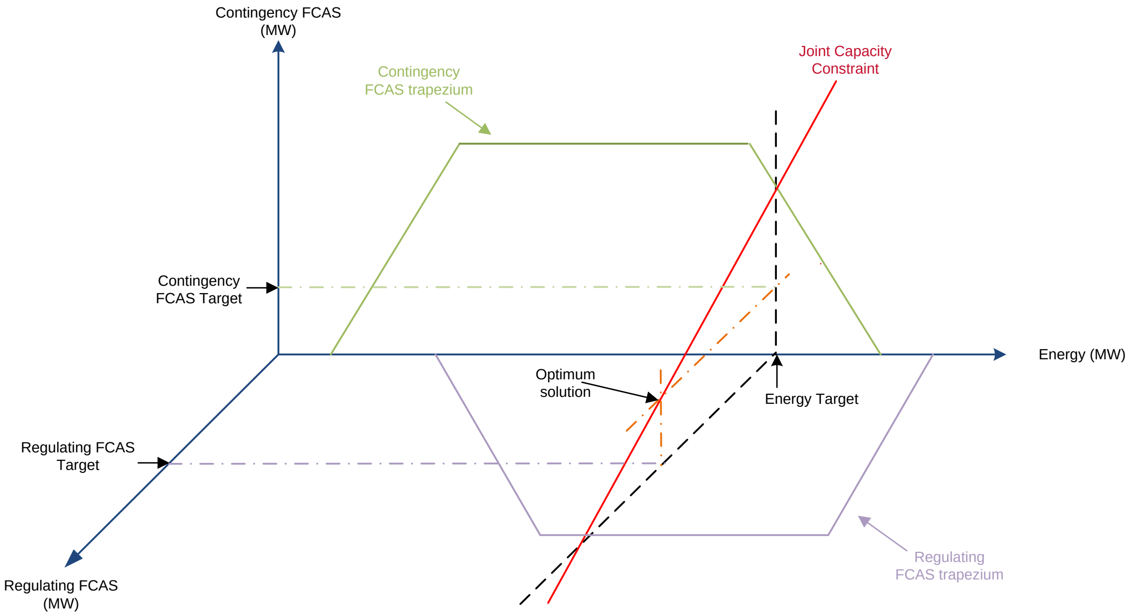
Similar diagrams can be drawn for the regulating lower service. For the regulating lower service, the joint ramping constraint would truncate the feasible solution area under the left-hand-side trapezium slope.

6.2. Joint capacity constraints

The maximum contingency service response that a unit can physically provide following a contingency event 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 unable to fully deliver both following a contingency event.

Figure 13 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 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 13 Joint capacity constraint in 3D

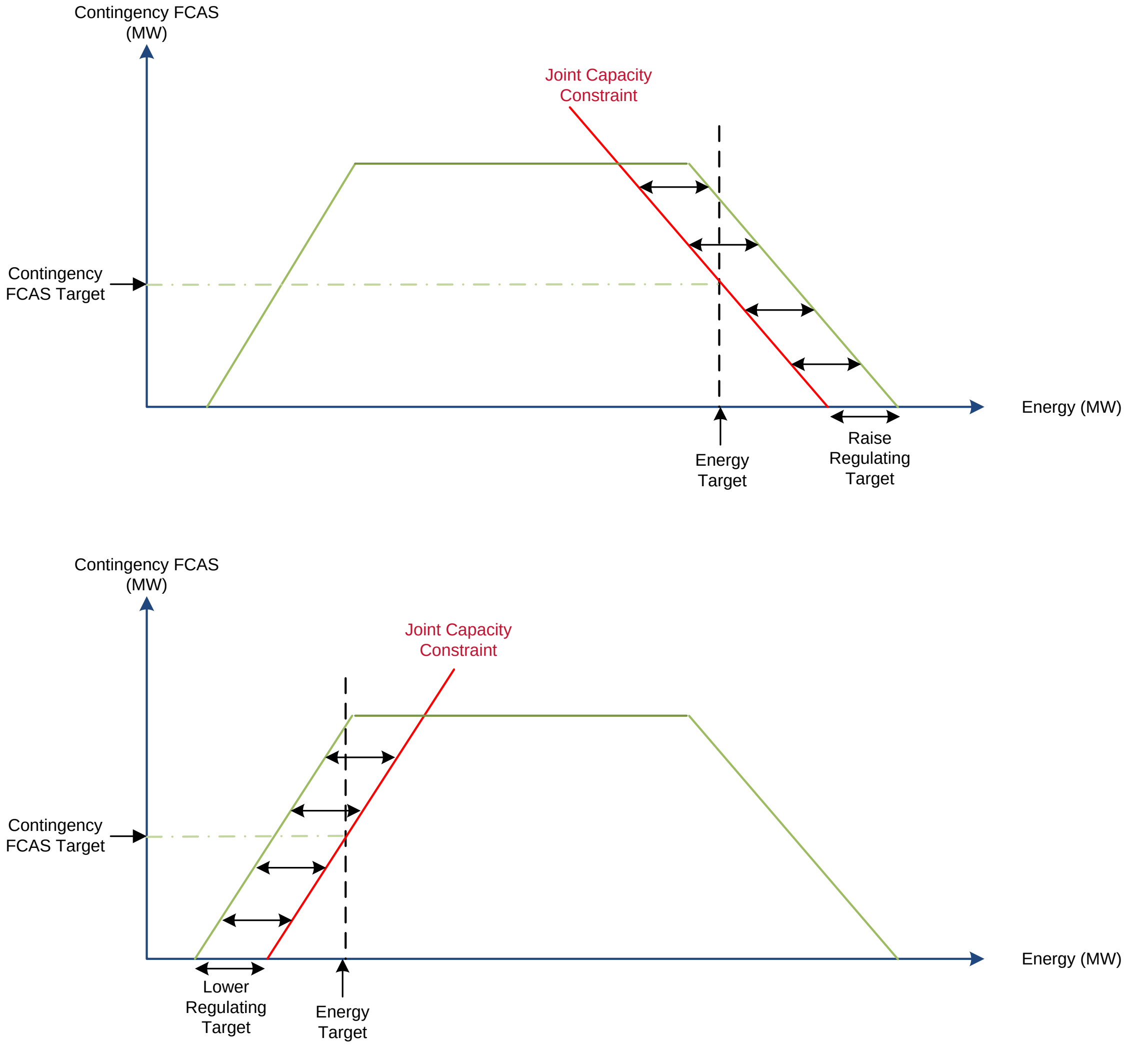


The 3D relationship illustrated in Figure 13 can be simplified by recognising that energy and the regulating services have a one-to-one relationship. For example, a 1MW reduction in energy output can potentially increase a generating unit's regulating raise service availability by 1 MW and decrease its regulating lower service availability by 1 MW. Conversely, a 1MW increase in energy output can potentially reduce its regulating raise service availability by 1 MW and increase its regulating lower service availability by 1 MW.

This relationship allows the 3D diagram to be simplified in 2D, as shown in Figure 14. Note that the regulating FCAS trapezium has been removed in the 2D diagram, and that the regulating FCAS target is shown on the horizontal axis along with the energy target.[6] A joint capacity constraint now runs parallel to the contingency FCAS trapezium slope.

[6] Energy and regulating FCAS can be drawn on the same scale and the same plane because of their one-to-one relationship.

Figure 14 Joint capacity constraint in 2D



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 are:

$$\begin{aligned}\mathit{Energy\ Dispatch\ Target} &+ \mathit{Upper\ Slope\ Coeff} \times \mathit{Contingency\ FCAS\ Target} \\ &+ [\mathit{Raise\ Regulation\ FCAS\ enablement\ status}] \\ &\times \mathit{Raise\ Regulating\ FCAS\ Target} \leq \mathit{EnablementMax}^{7}\end{aligned}$$

$$\begin{aligned}\mathit{Energy\ Dispatch\ Target} &- \mathit{Lower\ Slope\ Coeff} \times \mathit{Contingency\ FCAS\ Target} \\ &- [\mathit{Lower\ Regulation\ FCAS\ enablment\ status}] \\ &\times \mathit{Lower\ Regulating\ FCAS\ Target} \geq \mathit{EnablementMin}^{8}\end{aligned}$$

[7] To ensure that the sum of the contingency and regulating raise service availabilities are capped by the contingency service trapezium when operating on the upper slope of that trapezium.

[8] To ensure that the sum of the contingency and regulating lower service availabilities are capped by the contingency service trapezium when operating on the lower slope of that trapezium.

where

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

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

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

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

These joint capacity constraint equations are depicted in Figures 15 and 16.

Figure 15 Joint capacity constraint equation – energy dispatch target + upper slope x contingency FCAS target + regulating raise FCAS target ≤ Enablement Max

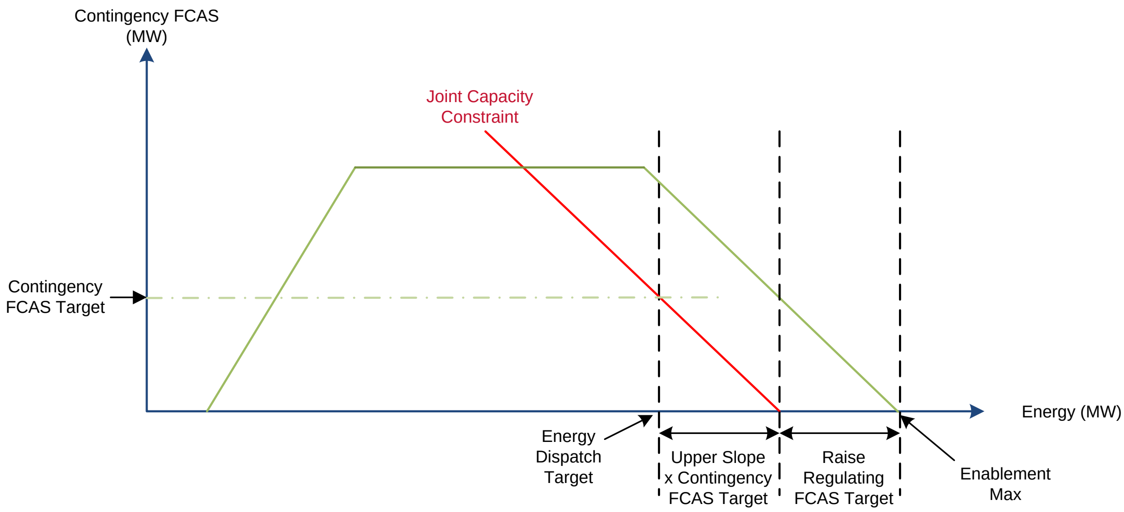
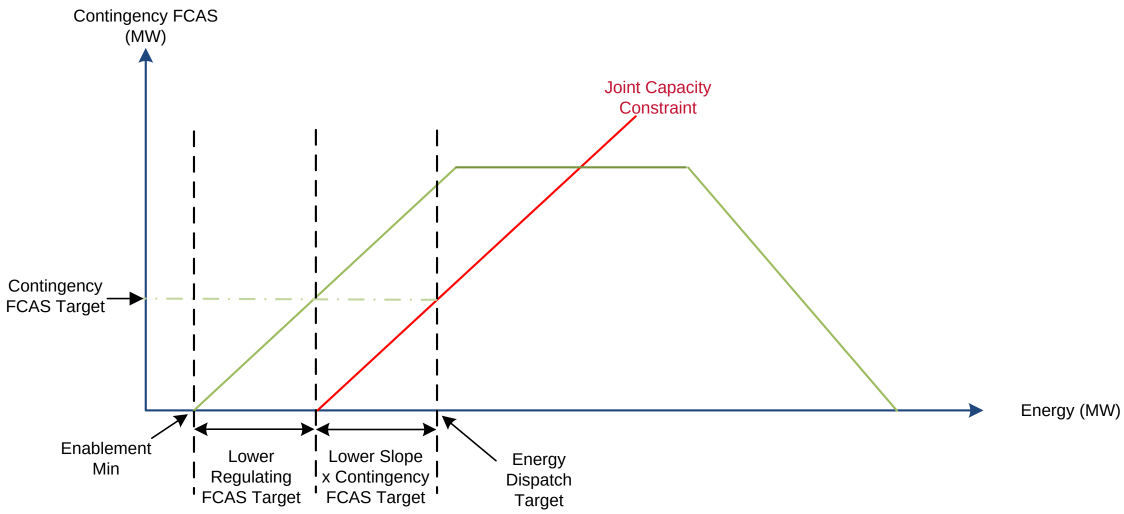


Figure 16 Joint capacity constraint equation – energy dispatch target – lower slope x contingency FCAS target – lower regulating FCAS target ≥ Enablement Min



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 contingency FCAS. This phenomenon is referred to as “trapped within the FCAS trapezium”.

6.3. Energy and regulating FCAS capacity constraint

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. This prevents infeasible dispatch outcomes in which a unit is enabled for regulating FCAS but unable to fully deliver it.

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:

$$Energy\ Dispatch\ Target + Upper\ Slope\ Coeff \times Regulating\ FCAS\ Target \leq EnablementMax$$ [9]

$$Energy\ Dispatch\ Target - Lower\ Slope\ Coeff \times Regulating\ FCAS\ Target \geq EnablementMin$$ [10]

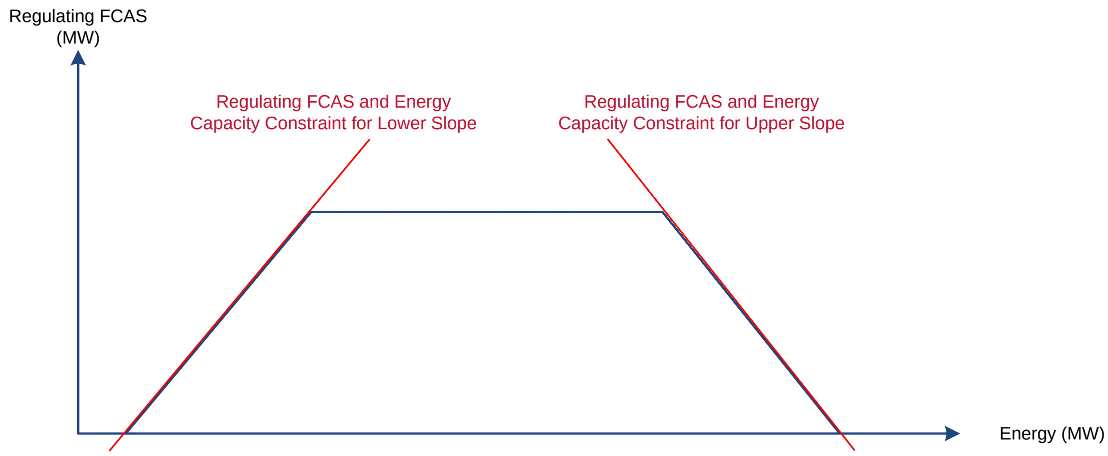
where

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

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

These energy and regulating FCAS capacity constraint equations are depicted in Figure 17. The constraints simply enforce the limits specified by the regulating FCAS trapezium slopes.

Figure 17 Energy and regulating FCAS capacity constraint



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”.

[9] To ensure that the regulating FCAS availability is capped by the regulating FCAS trapezium when operating on the upper slope of the trapezium.

[10] To ensure that the regulating FCAS availability is capped by the regulating FCAS trapezium when operating on the lower slope of the trapezium.

6.4. 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

Constraints	Intervals to which the constraint applies		
	Dispatch	***5-minute Pre-dispatch***	***Pre-dispatch***
Joint ramping constraint	All[11]	First	None
Joint capacity constraint	All	All	All
Energy and regulating FCAS capacity constraint	All	All	All

[11] 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 most restrictive constraint that limits the unit's frequency response capability at a given energy target.

FCAS availability is based on energy dispatch targets and the amounts of FCAS enabled, 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 consuming (for scheduled loads) or reducing load (for wholesale demand response units) at its energy target and fully delivering any enabled contingency service in the same direction. 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 enabled regulating service in the same direction.

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 0.

AEMO must also publish actual quantities of each type of FCAS every year.[12] AEMO meets this requirement by publishing the maximum available quantity of each FCAS on a region-aggregate basis after each Dispatch and Pre-dispatch run, and publishing the maximum available quantity of each FCAS on a per-unit basis at the end of each trading day.[13] 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.

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 $\boxed{1}$ to $\boxed{5}$ below for later reference.

[12] Required under clause 3.13.4A(b1) of the Rules.

[13] Unit FCAS availability is provided confidentially to the relevant participant after each Dispatch and Pre-dispatch run. This information is made public at the end of each trading day.

FCAS Availability =

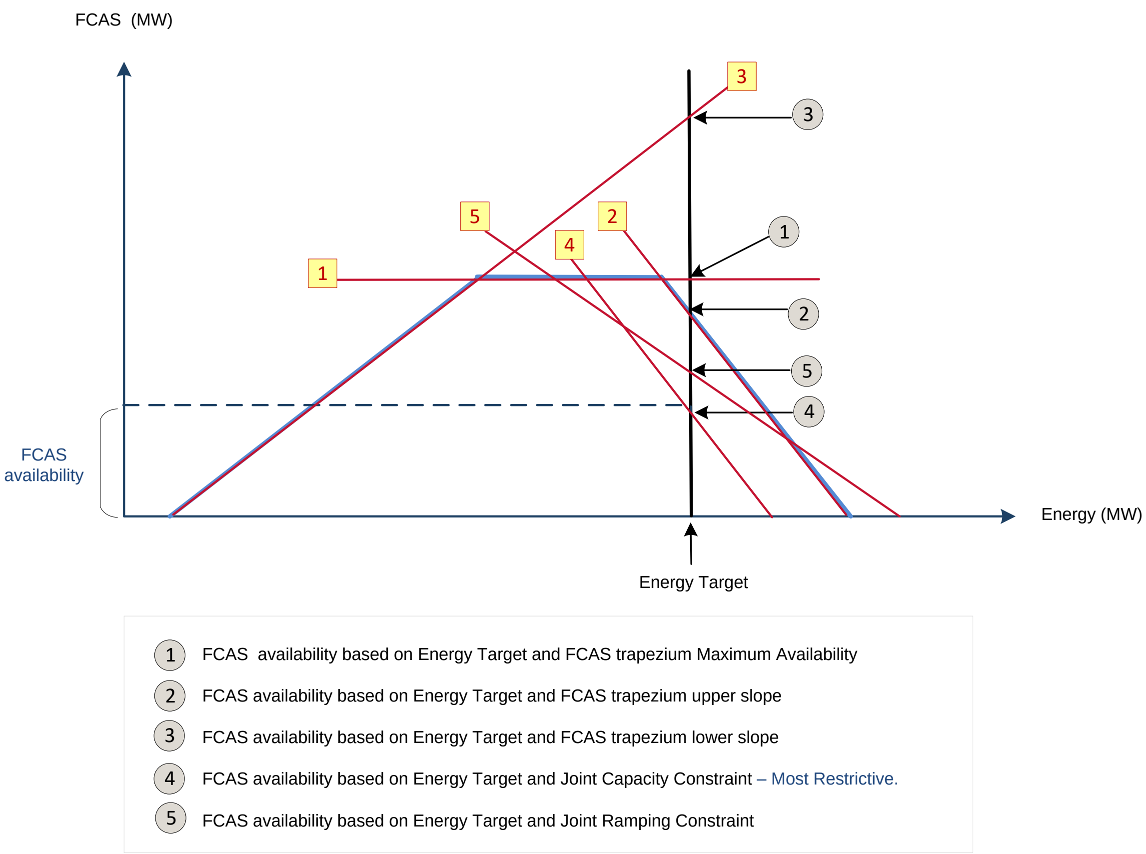
MINIMUM of [

- 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 – for Regulating services only (5)]

where the FCAS trapezium is the scaled (effective) FCAS trapezium from Section 0. 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 18 is an example showing how the constraints are applied. In this particular example, the constraint resulting in the most restrictive FCAS availability for the given energy target is the joint capacity constraint.

Figure 18 FCAS availability



FCAS availability for each FCAS can be calculated using the formula below.[14] For each limit equation, 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 - LRegTarget) / 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. *JointRampRaiseMax - Energy Target* 5

]

Regulating Lower FCAS Availability =

WHEN >0, MINIMUM of [

1. *Effective LReg FCAS MaxAvail* 1
2. *(Effective LReg EnablementMax - Energy Target - RRegTarget) / Upper Slope Coeff LReg* 2
3. *(Energy Target - Effective LReg EnablementMin) / Lower Slope Coeff LReg* 3
4. *Energy Target – Bid L1 EnablementMin - (Lower Slope Coeff L1 x L1 Target)* 4
5. *Energy Target – Bid L6 EnablementMin - (Lower Slope Coeff L6 x L6 Target)* 4
6. *Energy Target – Bid L60 EnablementMin - (Lower Slope Coeff L60 x L60 Target)* 4
7. *Energy Target – Bid L5 EnablementMin - (Lower Slope Coeff L5 x L5 Target)* 4
8. *Energy Target – JointRampLowerMin* 5

]

[14] Please note that these formulae have been developed for scheduled generation. Slightly different formulae may apply to semi-scheduled generation, scheduled load, and wholesale demand response units. Given the complexity of the "basic" formulae, 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. *(Energy Target - Bid Rxx EnablementMin - LReg Target) / Lower Slope Coeff Rxx* 4
3. *(Bid Rxx EnablementMax - Energy Target - RReg Target) / Upper 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)*

$$Lower\ Slope\ Coeff^{15}\ xx = \frac{Bid\ xx\ LowBreakPoint - Bid\ xxEnablementMin}{Bid\ xx\ MaxAvail}$$

$$Upper\ Slope\ Coeff^{16\ 17}\ xx = \frac{Bid\ xx\ EnablementMax - Bid\ xx\ HighBreakPoint}{Bid\ xx\ MaxAvail}$$

[15] If Lower Slope Coeff = 0 then the corresponding availability limit is ignored

[16] If Upper Slope Coeff = 0 then the corresponding availability limit is ignored

[17] When calculating the *Lower Slope Coeff* and *Upper Slope Coeff* for regulating FCAS, the bid trapezium parameters produce the same outcome as the effective trapezium parameters because the trapezium angles are maintained during any FCAS trapezium scaling.

Examples of FCAS availability calculation are provided in Appendix A.

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

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

$= 450 + (3*5)$

$= 465\ MW$

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

$= 450 - (2*5)$

$= 440\ MW$

Joint Capacity Constraints (Section 6.2):

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

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

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

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

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
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