

FCAS Verification Tool User Guide

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Contents	Current version release details	3
1. Introduction		4
1.1. Purpose and scope		4
1.2. Definitions and interpretation		4
1.3. Related documents		7
2. Description of verification tool process		7
2.1. Verification of Very Fast Raise Service and Very Fast Lower Service		7
2.2. Verification of Fast Raise Service and Fast Lower Service		12
2.3. Verification of Slow Raise Service and Slow Lower Service		18
2.4. Verification of Delayed Raise Service and Delayed Lower Service		23
3. Setup		26
3.1. Software pre-requisites		26
3.2. Downloading the application		26
3.3. Installation		26
4. Structure and flow of the FCASVT		26
4.1. Navigating the FCASVT		26
4.2. Data and control flow		28
4.3. “Raise” tabs		28
5. Using the FCASVT		30
5.1. User interaction		30
5.2. Input data		31
5.3. Results		36
5.4. Worked example		37
6. Understanding the calculation steps in FCASVT		38
7. Support and information		39
Appendix A. Calculation of time average		40
Version release history		41

Tables

Table 1	Tab descriptions.....	27
Table 2	Input parameters.....	33

Figures

Figure 1	MASS VT icon	26
Figure 2	Worksheet tabs.....	26
Figure 3	FCAS VT calculation process – Raise.....	29
Figure 4	Standard Frequency Ramp for Tasmania – Lower.....	30

Figure 5 List of tabs in FCASVT spreadsheet..... 31

Figure 6 Parameter inputs..... 32

Figure 7 High and low speed data inputs..... 36

Figure 8 FCAS VT Results..... 37

Figure 9 Calculation layout..... 38

Figure 10 Calculation analysis 39

Figure 11 Visual representation of calculation of FCAS delivery 40

Current version release details

Version	Effective date	Summary of changes
6.2	28 June 2024	Updates to reflect National Electricity Amendment (Integrating energy storage systems into the NEM) Rule 2021 No.13 and National Electricity Amendment (Implementing integrated energy storage systems) Rule 2023 No.2

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

1. Introduction

1.1. Purpose and scope

The FCAS Verification Tool (FCASVT) is an Excel spreadsheet that has been made available to NEM Participants to calculate frequency control ancillary services (FCAS) delivered by their plant offering such services to the National Electricity Market (NEM). The FCASVT will calculate Very Fast Raise (R1), Fast Raise (R6), Slow Raise (R60), Delayed Raise (R5), Very Fast Lower (L1), Fast Lower (L6), Slow Lower (L60) and Delayed Lower (L5) delivered in accordance with the Market Ancillary Services Specification (MASS). The FCASVT also permits the user to inspect in detail how the input data is processed in order to arrive at a result.

This document provides an overview of the FCASVT and a description on how to use the spreadsheet application. It does not include information or explanation on the definitions and specifications of FCAS services. Nor does it include reasoning behind why any particular calculation is done. The MASS provides the complete definition and specification of FCAS, and users of the FCASVT and this guide are assumed to have a good understanding of the MASS.

1.2. Definitions and interpretation

1.2.1. Glossary

Terms defined in the National Electricity Law or the NER have the same meanings in the MASS unless otherwise specified in this section. NER defined terms are intended to be identified in the MASS by italicising them, but failure to italicise a defined term does not affect its meaning.

The words, phrases and abbreviations in the table below have the meanings set out opposite them when used in these Procedures.

Term	Definition
Aggregated Ancillary Service Facility	The <i>ancillary service units</i> aggregated by an FCAS Provider under clause 3.8.3 of the NER for the purpose of providing FCAS.
Aggregated Generation Amount	The aggregate Generation Amounts through one or more <i>connection points</i> of an Aggregated Ancillary Service Facility.
Aggregated Load Amount	The aggregate Load Amounts through one or more <i>connection points</i> of an Aggregated Ancillary Service Facility.
Ancillary Service Facility	The <i>ancillary service unit</i> used to deliver FCAS.
Contingency FCAS	A term used to refer to <i>fast raise service, fast lower service, slow raise service, slow lower service, delayed raise service and delayed lower service</i> collectively.
Controlled Quantity	A quantity of <i>generation or load</i> that is: (a) controlled by Raise Signals and Lower Signals; (b) measured at the relevant connection point
Frequency Control Ancillary Services (FCAS)	<i>market ancillary services</i> , commonly referred to as “frequency control ancillary services”.
Frequency Control Ancillary Service Ancillary Service Verification Tool (FCASVT)	Frequency Control Ancillary Service Ancillary Service Verification Tool: An Excel spreadsheet used to verify the delivery of Contingency FCAS.

Term	Definition
FOS	The <i>frequency operating standard</i> .
Frequency Deadband	The range of Local Frequency through which a Variable Controller will not operate.
Frequency Deviation Setting(s)	The setting allocated to an Ancillary Service Facility by AEMO within the range shown in Table 5 of the MASS for the Mainland and Table 6 of the MASS for the Tasmania <i>region</i> .
Frequency Disturbance	An occasion when System Frequency is outside the NOFB.
Frequency Disturbance Time (FDT)	The time ¹ when Local Frequency is outside the NOFB following a Frequency Disturbance, as determined by AEMO.
Frequency Operating Standards	Has the meaning given in the NER, as applicable to the <i>region</i> in which the relevant Ancillary Service Facility is located.
Frequency Ramp Rate	0.125 Hz/s for the Mainland or 0.4 Hz/s for Tasmania.
Frequency Rate of Change Multiplier	See Table 5 for the Mainland, or Table 6 for Tasmania.
Frequency Recovery	The first change in Local Frequency to occur after a Frequency Disturbance from above 50.15 Hz to below 50.1 Hz, or below 49.85 Hz to above 49.9 Hz.
Frequency Setting(s)	The level of <i>frequency</i> or a combined level of <i>frequency</i> and <i>frequency</i> rate of change determined by AEMO in accordance with section 6 of the MASS for use by an Ancillary Service Facility's Switching Controller.
Generation Amount	The amount of <i>active power flow</i> through the <i>connection point</i> of an Ancillary Service Facility into the <i>transmission network</i> or <i>distribution network</i> to which it is <i>connected</i> , expressed as a positive value in MW.
Generation Event	As defined in the FOS.
Inertial Response	The change in Generation Amount or Load Amount due to the impact of an Ancillary Service Facility's <i>inertia</i> .
Initial Value	The Generation Amount or Load Amount immediately prior to a <i>frequency disturbance time</i> .
Load Amount	The amount of <i>active power flow</i> through the <i>connection point</i> of an Ancillary Service Facility into the <i>transmission network</i> or <i>distribution network</i> to which it is <i>connected</i> , expressed as a negative value in MW.
Load Event	As defined in the FOS.
Local Frequency	The <i>frequency</i> measured by an FCAS Provider at the <i>connection point</i> of the FCAS Provider's Ancillary Service Facility or Aggregated Ancillary Service Facility, in Hz.
Lower Control Limit	The lowest level to which a Controlled Quantity may be controlled in response to Lower Signals, subject to the enablement amount.
Lower Rate Limit	The highest rate at which a Controlled Quantity may be controlled in response to Lower Signals, subject to the enablement amount.
Lower Reference Frequency	The upper value in the 'containment band' for Load Events, as specified in Section A.1 of the FOS (A.2.1 for Tasmania).
Lower Response	The decrease in Generation Amount or increase in Load Amount as compared with its Initial Value.
Lower Signal	An AGC control signal sent by or on behalf of AEMO to request delivery of a Regulating Lower Response.
Mainland	All <i>regions</i> other than Tasmania.
MASS	The <i>market ancillary service specification</i> .

¹ The *frequency disturbance time* is referred to in the equations in the MASS as occurring at $t = 0$.

Term	Definition
NER	National Electricity Rules.
NOFB	The <i>normal operating frequency band</i> that applies under normal operating conditions, namely the values in Column 2 of Table A.1 in the FOS.
OFTB	The <i>operational frequency tolerance band</i> .
Raise Control Limit	The highest level to which a Controlled Quantity may be controlled in response to Raise Signals, subject to the enablement amount.
Raise Rate Limit	The highest rate at which a Controlled Quantity may be controlled in response to Raise Signals, subject to the enablement amount.
Raise Reference Frequency	The containment frequency below 50 Hz for Generation Events, as given in the relevant Frequency Operating Standards
Raise Response	The increase in Generation Amount or decrease in Load Amount with respect to the corresponding Initial Value
Raise Signal	An AGC a control signal sent by or on behalf of AEMO to request delivery of a Regulating Raise Response
Regulating Lower Response	The decrease in Generation Amount or increase in Load Amount delivered in response to one or more Lower Signals
Regulating Raise Response	The increase in Generation Amount or decrease in Load Amount delivered in response to one or more Raise Signals
Standard Frequency Ramp	A linear change of Local Frequency from one level to another at the applicable Frequency Ramp Rate and then sustained, as shown in Appendix A of the MASS.
Switching Controller	A <i>control system</i> that delivers a specific amount of FCAS by either switching <i>generation</i> or <i>load</i> on or off (as applicable) or rapidly and automatically altering an Ancillary Service Facility's output when its Frequency Settings are detected.
System Frequency	The <i>frequency</i> of the <i>power system</i> , as measured by AEMO.
Time Average	For a Raise Response or Lower Response and a time interval, the average value of that Raise Response or Lower Response over that time interval, determined as the integral of the Raise Response or Lower Response over the time interval divided by the duration of the time interval.
Trigger Range	The <i>frequency</i> range for which an Ancillary Service Facility with one or more switching controllers must record and store data regarding its performance, commencing 0.2Hz either side of 50 Hz for the Mainland, and 0.8Hz for Tasmania.
Trigger Rate	0.05 Hz/s for the Mainland and 0.15 Hz/s for Tasmania
Variable Controller	A <i>control system</i> that is used by an Ancillary Service Facility to deliver FCAS upon the commencement of the Frequency Disturbance in proportion to the size of the frequency excursion.

1.2.2. Interpretation

The following principles of interpretation apply to these Procedures unless otherwise expressly indicated:

- (a) The MASS is subject to the principles of interpretation set out in Schedule 2 of the National Electricity Law.
- (b) References to time are references to Australian Eastern Standard Time

1.3. Related documents

The FCASVT and User Guide are implementations of the principles set out in the MASS. If there is any inconsistency between the FCASVT and the MASS, the MASS will prevail to the extent of that inconsistency.

All references in this document refer to MASS Version 8.2 unless stated otherwise.

Title	Location
Market Ancillary Services Specification	http://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/market-ancillary-services-specification-and-fcas-verification-tool
FCAS Verification Tool	
Guide to Ancillary Services in the National Electricity Market	http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Ancillary-services

2. Description of verification tool process

Clauses 5.3 and 6.6 of the MASS contain the principles that must be followed in verifying the response of *ancillary service units* enabled to provide Contingency Services. These clauses detail the steps taken verifying this response. These steps are embodied in the FCASVT. If there is any inconsistency between this tool and the MASS, the MASS will prevail to the extent of that inconsistency.

2.1. Verification of Very Fast Raise Service and Very Fast Lower Service

For the purpose of verifying the amount of *very fast raise service* or *very fast lower service* delivered in response to a change in *local frequency*, the amount of service to be compared with the *enabled price bands* or maximum capability of the relevant *market ancillary service offer* must be determined using the recordings made under clause 5.3 of the MASS as follows:

- (a) Perform the following steps:
 - (i) for the purpose of paragraph 2.1(a)(ii), if the *ancillary service unit* is *scheduled* or *semi-scheduled* then determine its reference trajectory as the successive straight line interpolations between two consecutive energy market dispatch targets. The reference trajectory is to start with the dispatch target at the beginning of the trading interval in which the frequency deviation occurs and is to continue for the succeeding trading intervals².
 - (ii) determine a set of values RT such that:

if the *ancillary service unit* is a *scheduled generating unit* or *scheduled load* or *semi-scheduled generating unit* respectively, RT_i is equal to:

² For example if a frequency event occurs at 01:04 hrs then the associated reference trajectory will be the linear trajectory between the dispatch targets for the 01:05, 01:10, 01:15 and 01:20 *trading intervals*.

RT0 minus the value of the reference trajectory at time t_i , corresponding to the power measurement P_i

where: RT0 is the value of the reference trajectory at the *frequency disturbance time*

- (iii) adjust each power measurement (P_i at time interval i) before the *frequency disturbance time* for changing *dispatch* targets by first adding to it:

the maximum of RT_i and 0 if *local frequency* was below 50 Hz at the *frequency disturbance time*

the minimum of RT_i and 0 if *local frequency* was above 50 Hz at the *frequency disturbance time*

- (iv) add to each adjusted power measurement an amount of:

$$IR_i = 4 \pi^2 I f_{local,i} df/dt_i$$

where IR_i is the *inertial response* at time t_i ,

I is the effective moment of inertia of the *ancillary service unit* as agreed between AEMO and the relevant *Market Participant*,

$f_{local,i}$ is the measurement of *local frequency* at time t_i corresponding to the power measurement at time t_i ,

df/dt_i is the rate of change of offset smoothed *local frequency* at time t_i

$$df/dt_i = \frac{2 \times f_{i+2}^{offset-smoothed} + f_{i+1}^{offset-smoothed} - f_{i-1}^{offset-smoothed} - 2 \times f_{i-2}^{offset-smoothed}}{5 \times t_{i+1} - 5 \times t_{i-1}},$$

$f_i^{offset-smoothed}$ is the offset smoothed *local frequency* at time t_i given by

$$f_i^{offset-smoothed} = f_{i+9}^{smoothed}, \text{ and}$$

$f_{i+9}^{smoothed}$ is the smoothed *local frequency* at time t_{i+9} given by

$$f_{i+9}^{smoothed} = 0.9 * f_{i+8}^{smoothed} + 0.1 * f_{local,i+9}$$

- (v) determine the value VA such that:

VA is the *time average* of the adjusted power measurements made during the period between 4 seconds and 2 seconds before the *frequency disturbance time*,. VA may be specified manually using the *Manual Basepoint Override* value where the time average is not deemed to provide an accurate representation of pre-disturbance output.

- (vi) determine the basic response measurements by subtracting value VA from each adjusted power measurement after the *frequency disturbance time*;

- (vii) determine the values VP and VS such that:

VS is the amount of the basic response delivered by *switching controller*, and VP is the amount of the basic response delivered by *variable controller*. If a discrete combination of *switching controller* and *variable controller* is used (refer clause 6.5.2 of the MASS) then VS is determined by separate metering or appropriate control system data, and VP is determined by subtracting VS from the total basic response.

- (viii) determine Required Proportional Response (RPR) for a *variable controller* by:

$$RPR = \frac{(f_{raise\ DB} - f_{local})}{ABS(f_{raise\ DB} - f_{ref})} \times \text{Very Fast Enablement}$$

if f_{local} less than 50 Hz, or:

$$RPR = \frac{ABS(f_{lower\ DB} - f_{local})}{ABS(f_{lower\ DB} - f_{ref})} \times (-1) \times \text{Very Fast Enablement}$$

if f_{local} greater than 50 Hz

- (ix) If *LOCAL* (the default) is selected as the frequency trace option, compensate each value of VP after the frequency disturbance time for frequency change by multiplying it by the following factor, disregarding any measurement at or after a frequency recovery:

$$MIN \left(3, MIN \left(MAX \left(1, \frac{ABS(f_{raise\ DB} - f_{resp-rate})}{ABS(f_{raise\ DB} - f_{local})} \right), (f_{raise\ DB} - f_{ref}) \times 1000 \right) \times G \right)$$

if f_{local} less than 50 Hz, or:

$$MIN \left(3, MIN \left(MAX \left(1, \frac{ABS(f_{lower\ DB} - f_{resp-rate})}{ABS(f_{lower\ DB} - f_{local})} \right), (f_{lower\ DB} - f_{ref}) \times 1000 \right) \times G \right)$$

if f_{local} greater than 50 Hz

If *RAMP* is selected as the frequency trace option, compensate each value of VP after the *frequency disturbance time* for frequency change by multiplying the minimum of VP and RPR by the following factor, disregarding any measurement at or after a *frequency recovery* and, in the case where VP is greater than RPR, adding VP minus RPR to the total:

$$MIN \left(MAX \left(1, \frac{ABS(f_{raise\ DB} - f_{resp-rate})}{ABS(f_{raise\ DB} - f_{local})} \right), (f_{raise\ DB} - f_{ref}) \times 1000 \right) \times G$$

if f_{local} less than 50 Hz, or:

$$MIN \left(MAX \left(1, \frac{ABS(f_{lower\ DB} - f_{resp-rate})}{ABS(f_{lower\ DB} - f_{local})} \right), (f_{lower\ DB} - f_{ref}) \times 1000 \right) \times G$$

if f_{local} greater than 50 Hz

where f_{local} is the *local frequency* measurement coincident with the basic response measurement being compensated,

$f_{raise\ DB}$ is the lower frequency of the controller's *frequency dead-band*

$f_{lower\ DB}$ is the higher frequency of the controller's *frequency dead-band*

if f_{local} less than 50 Hz then

$$\text{frequency reference time} = \frac{49.85 - f_{ref}}{\text{frequency ramp rate}}$$

if f_{local} greater than 50 Hz then

$$\text{frequency reference time} = \frac{f_{ref} - 50.15}{\text{frequency ramp rate}}$$

if time after the event is between 0 and *frequency reference time* and f_{local} less than 50 Hz then:

$$f_{\text{resp-rate}} = 49.85 - t * \text{frequency ramp rate}$$

if time after the event is between 0 and *frequency reference time* and f_{local} greater than 50 Hz then:

$$f_{\text{resp-rate}} = 50.15 + t * \text{the appropriate frequency ramp rate}$$

if time after the event is greater than *frequency reference time* and f_{local} less than 50 Hz then:

$$f_{\text{resp-rate}} = \text{the appropriate raise reference frequency}$$

if time after the event is greater than *frequency reference time* and f_{local} greater than 50 Hz then:

$$f_{\text{resp-rate}} = \text{the appropriate lower reference frequency}$$

f_{ref} is the appropriate *raise or lower reference frequency*

frequency ramp rate is the appropriate MASS defined *frequency ramp rate*

MIN (x,y) means the function of the minimum of x and y,

MAX (x,y) means the function of the greater of x and y, and

ABS(x) means the function of the absolute value of x;

$$G = T_{\text{reg}}/T_{\text{act}}$$

T_{reg} is the maximum capacity corresponding to the relevant registered FCAS trapezium

T_{act} is the maximum capacity corresponding to the maximum availability of the trapezium appropriate for the measured maximum rate of change of frequency that actually occurred. *Market participants* supplying *market ancillary services* would need to provide relevant information to AEMO needed to calculate T_{act} .

- (x) compensate VS by multiplying it by:

$$\text{MAX} (1, (1 - \text{frequency setting time})/(1 - t_{\text{initiate}} + t_{\text{step}}))$$

where t_{initiate} is time after the event when the *local frequency* measurement reaches the relevant *frequency setting*

t_{step} is equal to the time interval between power flow measurements during the first second after the *frequency disturbance time*.

- (xi) determine the adjusted response as VS plus VP;
- (xii) determine value VB as twice the *time average* of the adjusted response measurements (after any necessary compensation) made between the *frequency disturbance time* and one second after the *frequency disturbance time*, disregarding measurements made at or after a *frequency recovery*, calculated using the trapezoidal rule to find the integral and adjusted for the integral of the time offset due to estimating FDT via interpolation of *frequency* between points t_{-1} and t_0 ³.
- (xiii) determine value VC as twice the *time average* of the adjusted response measurements (after any necessary compensation), made between one and six seconds after the *frequency disturbance time*, disregarding measurements made

³ See Appendix A for further information.

at or after a *frequency recovery*, calculated using the trapezoidal rule to find the integral and adjusted for the integral of the time offset due to estimating FDT via interpolation of *frequency* between points t_{-1} and t_0 ⁴.

- (b) Determine the amounts of *very fast raise response* and *very fast lower response* from the values of VB and VC as follows:
- (i) Round the values of VB and VC to the nearest 0.1 MW;
 - (ii) If the local frequency recovered between the *frequency disturbance time* and one second after the *frequency disturbance time*, the amount of *very fast raise response* is:
 - the lesser of the value of VB and the maximum Compensated Basic Response measurement between the *frequency disturbance time* and one second after the *frequency disturbance time*.
 - Otherwise, the amount of *very fast raise response* is taken as the lesser of (A) and (B):
 - (A) the lesser of the value of VB and the maximum Compensated Basic Response measurement between the *frequency disturbance time* and one second after the *frequency disturbance time*.
 - (B) the lesser of the value of VC and the maximum Compensated Basic Response measurement between one second and six seconds after the *frequency disturbance time*.
 - (iii) If the local frequency recovered between the *frequency disturbance time* and one second after the *frequency disturbance time*, the amount of *very fast lower response* is:
 - the greater of the value of VB and the minimum Compensated Basic Response measurement between the *frequency disturbance time* and one second after the *frequency disturbance time*.
 - Otherwise, the amount of *very fast lower response* is taken as the greater of (A) and (B):
 - (A) the greater of the value of VB and the minimum Compensated Basic Response measurement between the *frequency disturbance time* and one second after the *frequency disturbance time*.
 - (B) the greater of the value of VC and the minimum Compensated Basic Response measurement between one second and six seconds after the *frequency disturbance time*.
 - (iv) For the purposes of paragraph 2.2(b), value VD is:
 - (A) If the power system frequency was below 50 Hz at the *frequency disturbance time*,

$$VD = VC - \text{MIN}(VC, V_{enb}); \text{ and}$$

⁴ See Appendix A for further information.

- (B) If the power system frequency was above 50 Hz at the *frequency disturbance time*,

$$VD = VC - \text{MAX}(VC, -V_{enb})$$

where V_{enb} is the amount of very fast raise/lower service enabled by *dispatch*,

MIN (x,y) means the function of the minimum of x and y, and

MAX (x,y) means the function of the greater of x and y.

- (c) If two or more *ancillary service units* that share a common *connection point* were *enabled* for the same *market ancillary service* at the time of the *frequency disturbance*, allocate the responses determined in paragraphs (b)(i) and (b)(ii) above to each of them in proportion to the corresponding amounts of *raise response* or *lower response* that they should have delivered taking into account:
- (i) the amounts for which they were *enabled*; and
 - (ii) if the ancillary service units use switching controllers, the actual frequency trajectory compared with the frequency setting of each relevant switching controller.

2.2. Verification of Fast Raise Service and Fast Lower Service

For the purpose of verifying the amount of *fast raise service* or *fast lower service* delivered in response to a change in *local frequency*, the amount of service to be compared with the *enabled price bands* or maximum capability of the relevant *market ancillary service offer* must be determined using the recordings made under clause 5.3 of the MASS as follows:

- (a) Perform the following steps:
- (i) for the purpose of paragraph 2.22(a)(ii), if the *ancillary service unit* is *scheduled* or *semi-scheduled* then determine its reference trajectory as the successive straight line interpolations between two consecutive energy market dispatch targets. The reference trajectory is to start with the dispatch target at the beginning of the trading interval in which the frequency deviation occurs and is to continue for the succeeding trading intervals⁵.
 - (ii) determine a set of values RT such that:

if the ancillary service unit is a scheduled generating unit or scheduled load or semi-scheduled generating unit respectively, RT_i is equal to:

RT_0 minus the value of the reference trajectory at time t_i , corresponding to the power measurement P_i

where: RT_0 is the value of the reference trajectory at the *frequency disturbance time*

⁵ For example if a frequency event occurs at 01:04 hrs then the associated reference trajectory will be the linear trajectory between the dispatch targets for the 01:05, 01:10, 01:15 and 01:20 trading intervals.

- (iii) adjust each power measurement (P_i at time interval i) before the *frequency disturbance time* for changing *dispatch* targets by first adding to it:
 - the maximum of RT_i and 0 if *local frequency* was below 50 Hz at the *frequency disturbance time*
 - the minimum of RT_i and 0 if *local frequency* was above 50 Hz at the *frequency disturbance time*

- (iv) add to each adjusted power measurement an amount of:

$$IR_i = 4 \pi^2 I f_{local,i} df/dt_i$$

where IR_i is the *inertial response* at time t_i ,

I is the effective moment of inertia of the *ancillary unit* as agreed between AEMO and the relevant *Market Participant*,

$f_{local,i}$ is the measurement of *local frequency* at time t_i corresponding to the power measurement at time t_i ,

df/dt_i is the rate of change of offset smoothed *local frequency* at time t_i

$$df/dt_i = \frac{2 \times f_{i+2}^{offset-smoothed} + f_{i+1}^{offset-smoothed} - f_{i-1}^{offset-smoothed} - 2 \times f_{i-2}^{offset-smoothed}}{5 \times t_{i+1} - 5 \times t_{i-1}},$$

$f_i^{offset-smoothed}$ is the offset smoothed *local frequency* at time t_i given by

$$f_i^{offset-smoothed} = f_{i+9}^{smoothed}, \text{ and}$$

$f_{i+9}^{smoothed}$ is the smoothed *local frequency* at time t_{i+9} given by

$$f_{i+9}^{smoothed} = 0.9 \times f_{i+8}^{smoothed} + 0.1 \times f_{local,i+9}$$

- (v) determine the value FA such that:

FA is the *time average* of the adjusted power measurements made during the period between 4 seconds and 2 seconds before the *frequency disturbance time*. FA may be specified manually using the *Manual Basepoint Override* value where the time average is not deemed to provide an accurate representation of pre-disturbance output

- (vi) determine the basic response measurements by subtracting value FA from each adjusted power measurement after the *frequency disturbance time*;

- (vii) determine the values FP and FS such that:

FS is the amount of the basic response delivered by *switching controller*, and FP is the amount of the basic response delivered by *variable controller*. If a discrete combination of *switching controller* and *variable controller* is used (refer clause 6.5.2 of the MASS) then FS is determined by separate metering or appropriate control system data, and FP is determined by subtracting FS from the total basic response.

- (viii) determine Required Proportional Response (RPR) for a *variable controller* by:

$$RPR = \frac{(f_{raise\ DB} - f_{local})}{ABS(f_{raise\ DB} - f_{ref})} \times Fast\ Enablement$$

if f_{local} less than 50 Hz, or:

$$RPR = \frac{ABS(f_{lower\ DB} - f_{local})}{ABS(f_{lower\ DB} - f_{ref})} \times (-1) \times Fast\ Enablement$$

if f_{local} greater than 50 Hz

- (ix) If LOCAL (the default) is selected as the frequency trace option, compensate each value of VP after the frequency disturbance time for frequency change by multiplying it by the following factor, disregarding any measurement at or after a frequency recovery:

$$MIN \left(3, MIN \left(MAX \left(1, \frac{ABS(f_{raise\ DB} - f_{resp-rate})}{ABS(f_{raise\ DB} - f_{local})} \right), (f_{raise\ DB} - f_{ref}) \times 1000 \right) \times G \right)$$

if f_{local} less than 50 Hz, or:

$$MIN \left(3, MIN \left(MAX \left(1, \frac{ABS(f_{lower\ DB} - f_{resp-rate})}{ABS(f_{lower\ DB} - f_{local})} \right), (f_{lower\ DB} - f_{ref}) \times 1000 \right) \times G \right)$$

if f_{local} less than 50 Hz

If RAMP is selected as the frequency trace option, compensate each value of FP after the frequency disturbance time for frequency change by multiplying the minimum of FP and RPR by the following factor, disregarding any measurement at or after a frequency recovery and, in the case where FP is greater than RPF, adding FP minus RPR to the total:

$$MIN \left(MAX \left(1, \frac{ABS(f_{raise\ DB} - f_{resp-rate})}{ABS(f_{raise\ DB} - f_{local})} \right), (f_{raise\ DB} - f_{ref}) \times 1000 \right) \times G$$

if f_{local} less than 50 Hz, or:

$$MIN \left(MAX \left(1, \frac{ABS(f_{lower\ DB} - f_{resp-rate})}{ABS(f_{lower\ DB} - f_{local})} \right), (f_{raise\ DB} - f_{ref}) \times 1000 \right) \times G$$

if f_{local} greater than 50 Hz

where f_{local} is the *local frequency* measurement coincident with the basic response measurement being compensated,

$f_{raise\ DB}$ is the lower frequency of the controller's *frequency dead-band*

$f_{lower\ DB}$ is the higher frequency of the controller's *frequency dead-band*

if f_{local} less than 50 Hz then

$$frequency\ reference\ time = \frac{49.85 - f_{ref}}{frequency\ ramp\ rate}$$

if f_{local} greater than 50 Hz then

$$frequency\ reference\ time = \frac{f_{ref} - 50.15}{frequency\ ramp\ rate}$$

if time after the event is between 0 and *frequency reference time* and f_{local} less than 50 Hz then:

$$f_{resp-rate} = 49.85 - t * frequency\ ramp\ rate$$

if time after the event is between 0 and *frequency reference time* and f_{local} greater than 50 Hz then:

$$f_{resp-rate} = 50.15 + t * \text{the appropriate frequency ramp rate}$$

if time after the event is greater than *frequency reference time* and f_{local} less than 50 Hz then:

$$f_{resp-rate} = \text{the appropriate raise reference frequency}$$

if time after the event is greater than *frequency reference time* and f_{local} greater than 50 Hz then:

$$f_{resp-rate} = \text{the appropriate lower reference frequency}$$

f_{ref} is the appropriate *raise* or *lower reference frequency*

frequency ramp rate is the appropriate MASS defined *frequency ramp rate*

MIN (x,y) means the function of the minimum of x and y,

MAX (x,y) means the function of the greater of x and y, and

ABS(x) means the function of the absolute value of x;

$$G = T_{reg}/T_{act}$$

T_{reg} is the maximum capacity corresponding to the relevant registered FCAS trapezium

T_{act} is the maximum capacity corresponding to the maximum availability of the trapezium appropriate for the measured maximum rate of change of frequency that actually occurred. *Market participants* supplying *market ancillary services* would need to provide relevant information to AEMO needed to calculate T_{act} .

- (x) compensate FS by multiplying it by:

$$\text{MAX} (1, (6 - \text{frequency setting time}) / (6 - t_{initiate} + t_{step}))$$

where $t_{initiate}$ is time after the event when the *local frequency* measurement reaches the relevant *frequency setting*

t_{step} is equal to the time interval between power flow measurements during the first six seconds after the *frequency disturbance time*.

- (xi) determine the adjusted response as FS plus FP;
- (xii) determine value FB as twice the *time average* of the adjusted response measurements (after any necessary compensation) made between one and six seconds after the *frequency disturbance time*, disregarding measurements made at or after a *frequency recovery*, calculated using the trapezoidal rule to find the integral and adjusted for the integral of the time offset due to estimating FDT via interpolation of *frequency* between points t_{-1} and t_0 ⁶.

⁶ See Appendix A for further information.

- (xiii) determine value FC as twice the *time average* of the adjusted response measurements (after any necessary compensation), made between six and sixty seconds after the *frequency disturbance time*, disregarding measurements made at or after a *frequency recovery*, calculated using the trapezoidal rule to find the integral and adjusted for the integral of the time offset due to estimating FDT via interpolation of *frequency* between points t_{-1} and t_0 ⁷.
- (b) Determine the amounts of *fast raise response* and *fast lower response* from the values of FB and FC as follows:
- (i) Round the values of FB and FC to the nearest 0.1 MW;
 - (ii) If the local frequency recovered between one and six seconds after the *frequency disturbance time*, the amount of *fast raise response* is:
 - if Very Fast Enablement is zero, the lesser of the value of FB and the maximum Compensated Basic Response measurement between one and six seconds after the *frequency disturbance time*.
 - if Very Fast Enablement is greater than zero, the lesser of the value of VD and the maximum Compensated Basic Response measurement between one and six seconds after the *frequency disturbance time*.

Otherwise, the amount of *fast raise response* is:

 - if Very Fast Enablement is zero, taken as the lesser of (A) and (B):
 - (A) the lesser of the value of FB and the maximum Compensated Basic Response measurement between one and six seconds after the *frequency disturbance time*.
 - (B) the lesser of the value of FC and the maximum Compensated Basic Response measurement between six and sixty seconds after the *frequency disturbance time*.
 - if Very Fast Enablement is greater than zero, taken as the lesser of (A) and (B):
 - (A) the lesser of the value of VD and the maximum Compensated Basic Response measurement between one and six seconds after the *frequency disturbance time*.
 - (B) the lesser of the value of FC and the maximum Compensated Basic Response measurement between six and sixty seconds after the *frequency disturbance time*.
 - (iii) If the local frequency recovered between one and six seconds after the *frequency disturbance time*, the amount of *fast lower response* is:
 - if Very Fast Enablement is zero, the greater of the value of FB and the minimum Compensated Basic Response measurement between one and six seconds after the *frequency disturbance time*.

⁷ See Appendix A for further information.

- if Very Fast Enablement is greater than zero, the greater of the value of VD and the minimum Compensated Basic Response measurement between one and six seconds after the *frequency disturbance time*.

Otherwise, the amount of *fast lower response* is:

- if Very Fast Enablement is zero, taken as the greater of (A) and (B):
 - (A) the greater of the value of FB and the minimum Compensated Basic Response measurement between one and six seconds after the *frequency disturbance time*.
 - (B) the greater of the value of FC and the minimum Compensated Basic Response measurement between six and sixty seconds after the *frequency disturbance time*.
- if Very Fast Enablement is greater than zero, taken as the greater of (A) and (B):
 - (A) the greater of the value of VD and the minimum Compensated Basic Response measurement between one and six seconds after the *frequency disturbance time*.
 - (B) the greater of the value of FC and the minimum Compensated Basic Response measurement between six and sixty seconds after the *frequency disturbance time*.
- (iv) For the purposes of paragraph 2.3(b), value FD is:
 - (A) If the power system frequency was below 50 Hz at the *frequency disturbance time*,

$$FD = FC - \text{MIN}(FC, F_{enb});$$
 and
 - (B) If the power system frequency was above 50 Hz at the *frequency disturbance time*,

$$FD = FC - \text{MAX}(FC, -F_{enb})$$

where F_{enb} is the amount of fast raise/lower service enabled by *dispatch*,
 MIN (x,y) means the function of the minimum of x and y, and
 MAX (x,y) means the function of the greater of x and y.

- (c) If two or more *ancillary service units* that share a common *connection point* were *enabled* for the same *market ancillary service* at the time of the *frequency disturbance*, allocate the responses determined in paragraphs (b)(i) and (b)(ii) above to each of them in proportion to the corresponding amounts of *raise response* or *lower response* that they should have delivered taking into account:
 - (i) the amounts for which they were *enabled*; and
 - (ii) if the ancillary service units use switching controllers, the actual frequency trajectory compared with the frequency setting of each relevant switching controller.

2.3. Verification of Slow Raise Service and Slow Lower Service

For the purpose of verifying the amount of *slow raise service* or *slow lower service* delivered in response to a change in *local frequency*, the amount of service to be compared with the *enabled price bands* or maximum capacity of the relevant *market ancillary service offer* must be determined using the recordings made under clause 5.3 of the MASS as follows:

- (a) Perform the following steps:
- (i) for the purpose of paragraph 2.3(a)(ii), if the *ancillary service unit* is *scheduled* or *semi-scheduled* then determine its reference trajectory as the successive straight line interpolations between two consecutive energy market dispatch targets. The reference trajectory is to start with the dispatch target at the beginning of the trading interval in which the frequency deviation occurs and is to continue for the succeeding trading intervals⁸.
 - (ii) determine a set of values RT such that:

if the *ancillary service unit* is a *scheduled generating unit* or *scheduled load* or *semi-scheduled generating unit* respectively, RT_i is equal to:

$$RT_0 \text{ minus the value of the reference trajectory at time } t_i, \text{ corresponding to the power measurement } P_i$$

where: RT_0 is the value of the reference trajectory at the *frequency disturbance time*
 - (iii) adjust each power measurement (P_i at time interval i) before the *frequency disturbance* for changing *dispatch* targets by first adding to it:

the maximum of RT_i and 0 if *local frequency* was below 50 Hz at the *frequency disturbance time*

the minimum of RT_i and 0 if *local frequency* was above 50 Hz at the *frequency disturbance time*
 - (iv) determine the value SA such that:

SA is the *time average* of the adjusted power measurements made during the period between 20 seconds and 8 seconds before the *frequency disturbance time*. SA may be specified manually using the *Manual Basepoint Override* value where the time average is not deemed to provide an accurate representation of pre-disturbance output.
 - (v) determine the basic response measurements by subtracting value SA from each power measurement (as adjusted) after the *frequency disturbance time*;
 - (vi) determine the values SP and SS such that:

SS is the amount of the basic response delivered by *switching controller*, and SP is the amount of the basic response delivered by *variable controller*. If a

⁸ For example if a frequency event occurs at 01:04 hrs then the associated reference trajectory will be the linear trajectory between the dispatch targets for the 01:05, 01:10, 01:15 and 01:20 trading intervals.

discrete combination of *switching controller* and *variable controller* is used (refer clause 6.5.2 of the MASS) then SS is determined by separate metering or appropriate *control system* data, and SP is determined by subtracting SS from the total basic response.

- (vii) determine Required Proportional Response (RPR) for a *variable controller* by:

$$RPR = \frac{(f_{raise\ DB} - f_{local})}{(f_{raise\ DB} - f_{ref})} \times Slow\ Enablement$$

if f_{local} less than 50 Hz, or:

$$RPR = \frac{(f_{lower\ DB} - f_{local})}{(f_{lower\ DB} - f_{ref})} \times (-1) \times Slow\ Enablement$$

if f_{local} greater than 50 Hz

- (viii) If *LOCAL* is selected as the frequency trace option, compensate each value of VP after the frequency disturbance time for frequency change by multiplying it by the following factor, disregarding any measurement at or after a frequency recovery:

$$MIN \left(3, MIN \left(MAX \left(1, \frac{ABS(f_{raise\ DB} - f_{resp-rate})}{ABS(f_{raise\ DB} - f_{local})} \right), (f_{raise\ DB} - f_{ref}) \times 1000 \right) \times G \right)$$

if f_{local} less than 50 Hz, or:

$$MIN \left(3, MIN \left(MAX \left(1, \frac{ABS(f_{lower\ DB} - f_{resp-rate})}{ABS(f_{lower\ DB} - f_{local})} \right), (f_{lower\ DB} - f_{ref}) \times 1000 \right) \times G \right)$$

if f_{local} greater than 50 Hz

If *RAMP* is selected as the frequency trace option, compensate each value of SP after the frequency disturbance for *frequency* change by multiplying the minimum of SP and RPR by the following factor, disregarding measurements made at or after a *frequency recovery* and, in the case where SP is greater than RPR, adding SP minus RPR to the total:

$$MIN \left(MAX \left(1, \frac{ABS(f_{raise\ DB} - f_{resp-rate})}{ABS(f_{raise\ DB} - f_{local})} \right), (f_{raise\ DB} - f_{ref}) \times 1000 \right) \times G$$

if f_{local} less than 50 Hz, or:

$$MIN \left(MAX \left(1, \frac{ABS(f_{lower\ DB} - f_{resp-rate})}{ABS(f_{lower\ DB} - f_{local})} \right), (f_{lower\ DB} - f_{ref}) \times 1000 \right) \times G$$

if f_{local} greater than 50 Hz

where f_{local} is the *local frequency* measurement coincident with the basic response measurement being compensated,

$f_{raise\ DB}$ is the lower frequency of the controller's *frequency dead-band*

$f_{lower\ DB}$ is the higher frequency of the controller's *frequency dead-band*

if f_{local} is less than 50 Hz then

$$\text{frequency reference time} = \frac{49.85 - f_{ref}}{\text{frequency ramp rate}}$$

if f_{local} is greater than 50 Hz then

$$\text{frequency reference time} = \frac{f_{ref} - 50.15}{\text{frequency ramp rate}}$$

if time after the event is between 0 and *frequency reference time* and f_{local} less than 50 Hz then:

$$f_{\text{resp-rate}} = 49.85 - t * \text{frequency ramp rate}$$

if time after the event is between 0 and *frequency reference time* and f_{local} greater than 50 Hz then:

$$f_{\text{resp-rate}} = 50.15 + t * \text{the appropriate frequency ramp rate}$$

if time after the event is greater than *frequency reference time* and f_{local} less than 50 Hz then:

$$f_{\text{resp-rate}} = \text{the appropriate raise reference frequency}$$

if time after the event is greater than *frequency reference time* and f_{local} greater than 50 Hz then:

$$f_{\text{resp-rate}} = \text{the appropriate lower reference frequency}$$

f_{ref} is the appropriate *raise* or *lower reference frequency*

frequency ramp rate is the appropriate MASS defined *frequency ramp rate*

MIN (x,y) means the function of the minimum of x and y,

MAX (x,y) means the function of the greater of x and y, and

ABS(x) means the function of the absolute value of x;

$$G = T_{reg}/T_{act}$$

T_{reg} is the maximum capacity corresponding to the relevant registered FCAS trapezium

T_{act} is the maximum capacity corresponding to the maximum availability of the trapezium appropriate for the measured maximum rate of change of frequency that actually occurred. *Market participants* supplying *market ancillary services* would need to provide relevant information to AEMO needed to calculate T_{act} .

- (ix) determine the adjusted response as SS plus SP;
- (x) determine value SB as twice the *time average* of the adjusted response measurements (after any necessary compensation), made between six and sixty seconds after the *frequency disturbance time*, disregarding measurements made at or after a *frequency recovery*, calculated using the trapezoidal rule to find the

integral and adjusted for the integral of the time offset due to estimating FDT via interpolation of *frequency* between points t_{-1} and t_0 ⁹.

- (xi) determine value SC as twice the *time average* of the adjusted response measurements (after any necessary compensation), made between sixty seconds and five minutes after the *frequency disturbance time*, disregarding measurements made at or after a *frequency recovery* or after a *service cancellation*, calculated using the trapezoidal rule to find the integral and adjusted for the integral of the time offset due to estimating FDT via interpolation of *frequency* between points t_{-1} and t_0 ¹⁰.
- (b) Determine the amounts of *slow raise response* and *slow lower response* from the values of SB and SC as follows:
 - (i) Round the values of SB and SC to the nearest 0.1 MW;
 - (ii) If the local frequency recovered between six and sixty seconds after the *frequency disturbance time*, the amount of *slow raise response* is:
 - If Fast Enablement is zero, the lesser of the value of SB and the maximum Compensated Basic Response measurement between six and sixty seconds after the *frequency disturbance time*.
 - if Fast Enablement is greater than zero, the lesser of the value of FD and the maximum Compensated Basic Response measurement between six and sixty seconds after the *frequency disturbance time*.

Otherwise, the amount of *slow raise response* is:

 - if Fast Enablement is zero, taken as the lesser of (A) and (B):
 - (A) the lesser of the value of SB and the maximum Compensated Basic Response measurement between six and sixty seconds after the *frequency disturbance time*.
 - (B) the lesser of the value of SC and the maximum Compensated Basic Response measurement between sixty seconds and five minutes after the *frequency disturbance time*.
 - if Fast Enablement is greater than zero, taken as the lesser of (A) and (B):
 - (A) the lesser of the value of FD and the maximum Compensated Basic Response measurement between six and sixty seconds after the *frequency disturbance time*.
 - (B) the lesser of the value of SC and the maximum Compensated Basic Response measurement between sixty seconds and five minutes after the *frequency disturbance time*.
 - (iii) If the local frequency recovered between six and sixty seconds after the *frequency disturbance time*, the amount of *slow lower response* is:

⁹ See Appendix A for further information.

¹⁰ See Appendix A for further information.

- If Fast Enablement is zero, the greater of the value of SB and the minimum Compensated Basic Response measurement between six and sixty seconds after the *frequency disturbance time*.
- if Fast Enablement is greater than zero, the greater of the value of FD and the minimum Compensated Basic Response measurement between six and sixty seconds after the *frequency disturbance time*.

Otherwise, the amount of *slow lower response* is:

- if Fast Enablement is zero, taken as the greater of (A) and (B):
 - (A) the greater of the value of SB and the minimum Compensated Basic Response measurement between six and sixty seconds after the *frequency disturbance time*.
 - (B) the greater of the value of SC and the minimum Compensated Basic Response measurement between sixty seconds and five minutes after the *frequency disturbance time*.
- if Fast Enablement is greater than zero, taken as the greater of (A) and (B):
 - (A) the greater of the value of FD and the minimum Compensated Basic Response measurement between six and sixty seconds after the *frequency disturbance time*.
 - (B) the greater of the value of SC and the minimum Compensated Basic Response measurement between sixty seconds and five minutes after the *frequency disturbance time*.

(iv) For the purposes of paragraph 2.4(b), value SD is:

- (A) If the power system frequency was below 50 Hz at the *frequency disturbance time*,

$$SD = SC - \text{MIN}(SC, S_{enb}); \text{ and}$$

- (B) If the power system frequency was above 50 Hz at the *frequency disturbance time*,

$$SD = SC - \text{MAX}(SC, -S_{enb})$$

where S_{enb} is the amount of slow raise/lower service enabled by *dispatch*,

MIN (x,y) means the function of the minimum of x and y, and

MAX (x,y) means the function of the greater of x and y.

- (c) If two or more *ancillary service units* that share a common *connection point* were *enabled* for the same service at the time of the *frequency disturbance*, allocate the responses determined in paragraphs (b)(i) and (b)(ii) above to each of them in proportion to the corresponding amounts of *raise response* or *lower response* that they should have delivered taking into account:
 - (i) the amounts for which they were *enabled*; and

- (ii) if the *ancillary service units* have switching controllers, the actual *frequency trajectory* compared with the *frequency setting* of each relevant *switching controller*.

2.4. Verification of Delayed Raise Service and Delayed Lower Service

For the purpose of verifying the amount of *delayed raise service* or *delayed lower service* delivered in response to a change in *local frequency*, the amount of service to be compared with the *enabled price bands* or maximum capacity of the relevant *market ancillary service offer* must be determined using the recordings made under clause 5.3 of the MASS as follows:

- (a) Perform the following steps:
 - (i) for the purpose of paragraph 2.4(a)(ii), if the *ancillary service unit* is *scheduled* or *semi-scheduled* then determine its reference trajectory as the successive straight line interpolations between two consecutive energy market dispatch targets. The reference trajectory is to start with the dispatch target at the beginning of the trading interval in which the frequency deviation occurs and is to continue for the succeeding trading intervals¹¹.
 - (ii) determine a set of values RT such that:

if the *ancillary service unit* is a *scheduled generating unit* or *scheduled load* or *semi-scheduled generating unit* respectively, RT_i is equal to:

RT_0 minus the value of the reference trajectory at time t_i , corresponding to the power measurement P_i

where: RT_0 is the value of the reference trajectory at the *frequency disturbance time*

- (iii) adjust each power measurement (P_i at time interval i) before the *frequency disturbance* for changing *dispatch* targets by first adding to it:
 - the maximum of RT_i and 0 if *local frequency* was below 50 Hz at the *frequency disturbance time*
 - the minimum of RT_i and 0 if *local frequency* was above 50 Hz at the *frequency disturbance time*
- (iv) determine the value DA such that:
 - DA is the *time average* of the power measurements made during the period between 20 seconds and 8 seconds before the *frequency disturbance time*. DA may be specified manually using the *Manual Basepoint Override* value where the time average is not deemed to provide an accurate representation of pre-disturbance output.

¹¹ For example if a frequency event occurs at 01:04 hrs then the associated reference trajectory will be the linear trajectory between the dispatch targets for the 01:05, 01:10, 01:15 and 01:20 trading intervals.

- (v) determine the basic response measurements by subtracting value DA from each power measurement after the *frequency disturbance time*;
 - (vi) determine value DB as twice the *time average* of the basic response measurements, made between one and five minutes after the *frequency disturbance time*, disregarding measurements made at or after a *frequency recovery* or after *service cancellation*, calculated using the trapezoidal rule and subtracting an amount equivalent to the time offset between FDT as determined by interpolation between points t_{-1} and t_0 ¹².
 - (vii) determine value DC as the *time average* of the basic response measurements, made between five minutes and ten minutes after the *frequency disturbance time*, disregarding measurements made at or after a *frequency recovery* or after *service cancellation*, calculated using the trapezoidal rule and subtracting an amount equivalent to the time offset between FDT as determined by interpolation between points t_{-1} and t_0 ¹³.
- (b) Determine the amounts of *delayed raise response* and *delayed lower response* from the values of DB and DC as follows:
- (i) Round the values of DB and DC to the nearest 0.1 MW;
 - (ii) If the local frequency recovered between sixty seconds and five minutes after the *frequency disturbance time*, the amount of *delayed raise response* is:
 - If Slow Enablement is zero, the lesser of the value of DB and the maximum Basic Response measurement between sixty seconds and five minutes after the *frequency disturbance time*.
 - if Fast Enablement is greater than zero, the lesser of the value of SD and the maximum Basic Response measurement between sixty seconds and five minutes after the *frequency disturbance time*.

Otherwise, the amount of *delayed raise response* is:

 - if Fast Enablement is zero, taken as the lesser of (A) and (B):
 - (A) the lesser of the value of DB and the maximum Basic Response measurement between sixty seconds and five minutes after the *frequency disturbance time*.
 - (B) the lesser of the value of DC and the maximum Basic Response measurement between five and ten minutes after the *frequency disturbance time*.
 - if Fast Enablement is greater than zero, taken as the lesser of (A) and (B):
 - (A) the lesser of the value of SD and the maximum Basic Response measurement between sixty seconds and five minutes after the *frequency disturbance time*.

¹² See Appendix A for further information.

¹³ See Appendix A for further information.

- (B) the lesser of the value of DC and the maximum Basic Response measurement between five and ten minutes after the *frequency disturbance time*.
- (iii) If the local frequency recovered between sixty seconds and five minutes after the *frequency disturbance time*, the amount of *delayed lower response* is:
 - If Slow Enablement is zero, the greater of the value of DB and the minimum Basic Response measurement between sixty seconds and five minutes after the *frequency disturbance time*.
 - if Fast Enablement is greater than zero, the greater of the value of SD and the minimum Basic Response measurement between sixty seconds and five minutes after the *frequency disturbance time*.

Otherwise, the amount of *delayed lower response* is:

 - if Fast Enablement is zero, taken as the greater of (A) and (B):
 - (A) the greater of the value of DB and the minimum Basic Response measurement between sixty seconds and five minutes after the *frequency disturbance time*.
 - (B) the greater of the value of DC and the minimum Basic Response measurement between five and ten minutes after the *frequency disturbance time*.
 - if Fast Enablement is greater than zero, taken as the greater of (A) and (B):
 - (A) the greater of the value of SD and the minimum Basic Response measurement between sixty seconds and five minutes after the *frequency disturbance time*.
 - (B) the greater of the value of DC and the minimum Basic Response measurement between five and ten minutes after the *frequency disturbance time*.
- (c) If two or more *ancillary service units* that share a common *connection point* were *enabled* for the same service at the time of the *frequency disturbance*, allocate the responses determined in paragraphs (b)(i) and (b)(ii) above to each of them in proportion to the corresponding amounts of response that they should have delivered taking into account:
 - (i) the amounts for which they were *enabled*; and
 - (ii) if the *ancillary service units* have switching controllers, the actual *frequency trajectory* compared with the *frequency setting* of each relevant *switching controller*.

3. Setup

3.1. Software pre-requisites

The FCASVT is an Excel spreadsheet and requires Microsoft Excel 2010 or a later version to be installed on the user’s PC.

3.2. Downloading the application

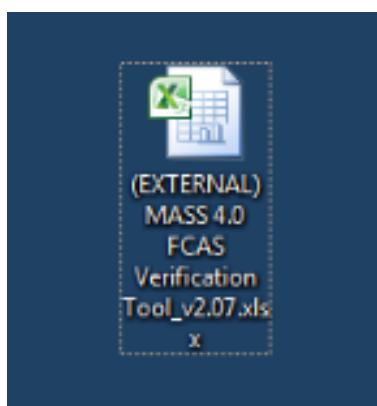
The FCASVT can be downloaded from AEMO’s website at:

<https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/market-ancillary-services-specification-and-fcas-verification-tool>

3.3. Installation

There is no specific installation for the FCASVT. Once the spreadsheet is downloaded and saved on the user’s PC, it can be opened by double-clicking the FCASVT icon or opening the spreadsheet from Excel.

Figure 1 MASS VT icon

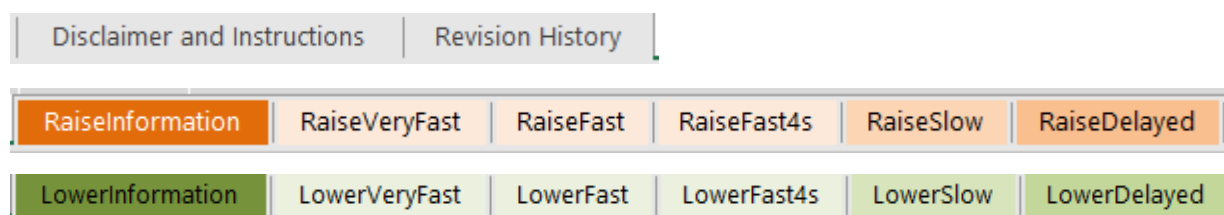


4. Structure and flow of the FCASVT

4.1. Navigating the FCASVT

The FCASVT consists of 14 worksheet tabs as seen below.

Figure 2 Worksheet tabs



Note that for ease of use, the six “Raise” tabs are in different shades of **orange**, whereas the six “Lower” tabs are in different shades of **green**.

Table 1 Tab descriptions

Worksheet tab	Description
Disclaimer and Instructions	Contains AEMO disclaimer and brief instructions on how to use the FCASVT
Revision History	Contains software updates made for each version
RaiseInformation	For Raise FCAS, the user should enter input data in this tab. Once input data is entered, the calculated R1, R6, R60 and R5 FCAS output is displayed
RaiseVeryFast	<i>This tab is for information only and no user interaction is required.</i> This tab contains the detailed steps to process the input data to calculation of R1 services.
RaiseFast	<i>This tab is for information only and no user interaction is required.</i> This tab contains the detailed steps to process the input data to calculation of R6 services.
RaiseFast4s	<i>This tab is for information only and no user interaction is required.</i> This tab contains calculations for the sole purpose of estimating the FD parameter when high speed data is unavailable. No other information from this tab is relevant
RaiseSlow	<i>This tab is for information only and no user interaction is required.</i> This tab contains the detailed steps to process the input data to calculation of R60 services.
RaiseDelayed	<i>This tab is for information only and no user interaction is required.</i> This tab contains the detailed steps to process the input data to calculation of R5 services.
LowerInformation	For Lower FCAS, the user should enter input data in this tab. Once input data is entered, the calculated L1, L6, L60 and L5 FCAS output is displayed
LowerVeryFast	<i>This tab is for information only and no user interaction is required.</i> This tab contains the detailed steps to process the input data to calculation of L1 services.
LowerFast	<i>This tab is for information only and no user interaction is required.</i> This tab contains the detailed steps to process the input data to calculation of L6 services.
LowerFast4s	<i>This tab is for information only and no user interaction is required.</i>

Worksheet tab	Description
	This tab contains calculations for the sole purpose of estimating the FD parameter when high speed data is unavailable. No other information from this tab is relevant
LowerSlow	<p><i>This tab is for information only and no user interaction is required.</i></p> <p>This tab contains the detailed steps to process the input data to calculation of L60 services.</p>
LowerDelayed	<p><i>This tab is for information only and no user interaction is required.</i></p> <p>This tab contains the detailed steps to process the input data to calculation of L5 services.</p>

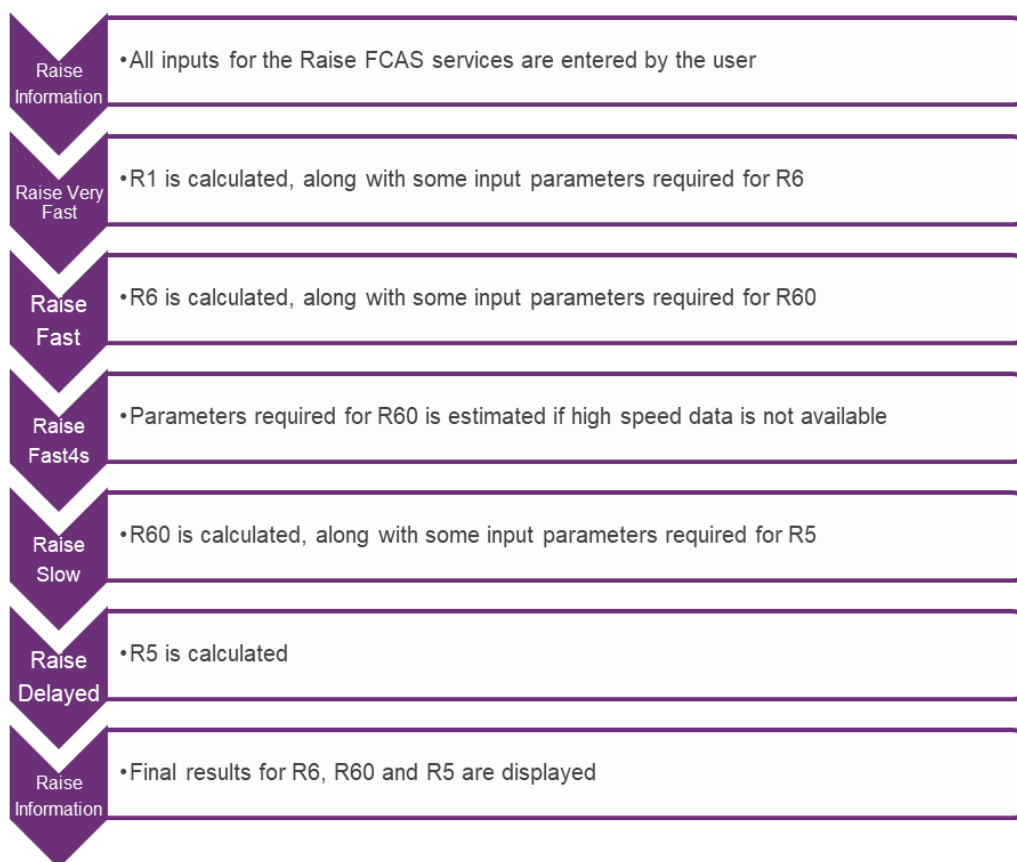
4.2. Data and control flow

The six “Raise” tabs work together, as do the six “Lower” tabs. There is no interaction between the “Raise” and “Lower” tabs, since either a Raise or a Lower service, but not both, is delivered for a given contingency.

4.3. “Raise” tabs

The “Raise” tabs reference each other in the following order to produce the results.

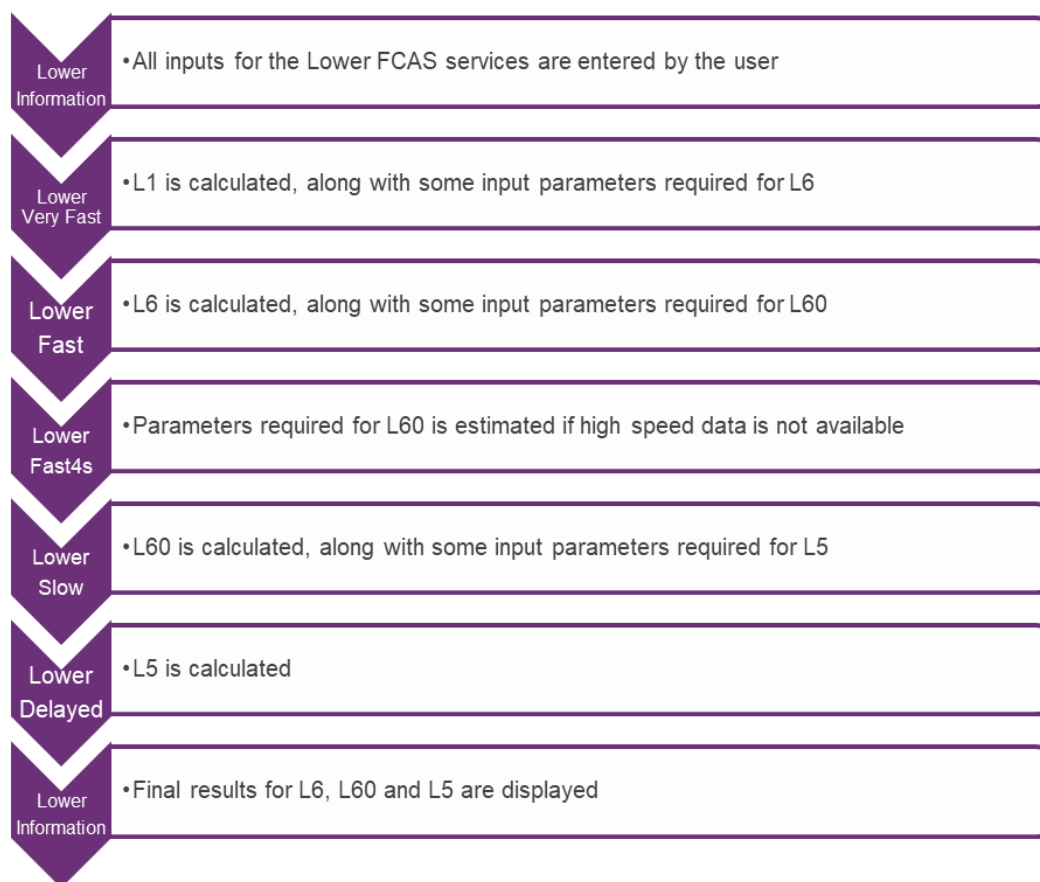
Figure 3 FCAS VT calculation process – Raise



4.3.1. “Lower” tabs

The “Lower” tabs reference each other in the following order to produce the results.

Figure 4 Standard Frequency Ramp for Tasmania – Lower



5. Using the FCASVT

5.1. User interaction

Of the 14 tabs in the FCASVT spreadsheet, not all tabs require interaction from the user if the intention is purely to calculate a result. Some tabs are applicable only to get a better understanding of the calculation, and user interaction with those tabs is optional.

The following diagram specifies which tabs are applicable for obtaining a result, and which tabs are applicable for gaining a better understanding of the calculation.

Figure 5 List of tabs in FCASVT spreadsheet

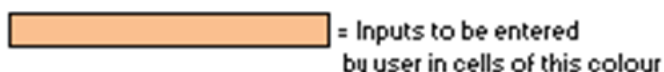
- User interaction mandatory to obtain result**
 - RaiseInformation
 - LowerInformation
- User action optional (only to facilitate better understanding)**
 - RaiseVeryFast
 - RaiseFast
 - RaiseFast4s
 - RaiseSlow
 - RaiseDelayed
 - LowerVeryFast
 - LowerFast
 - LowerFast4s
 - LowerSlow
 - LowerDelayed
 - Disclaimer and Instructions
 - Revision History

This section describes tabs which require user interaction whereas section 6 describes tabs where user interaction is optional.

5.2. Input data

In order to calculate Raise services R1, R6, R60 and R5, the user should navigate to the “RaiseInformation” tab. To calculate Lower services L1, L6, L60 and L5, the user should navigate to the “LowerInformation” tab

Inputs should be entered in the left side of the worksheet labelled “**INPUTS**”. All cells in orange have to be filled in by the user.



The required inputs are divided into two parts:

- Parameter inputs
- High/low speed data inputs

5.2.1. Parameter inputs

The parameter inputs in entered in the left table below.

Figure 6 Parameter inputs

Plant Information	Value	Comment
Plant Name	MgGenUnit1	For information only
Plant Inertia	0.022913179	In MW sec ³ (or kg.m ² /1000) [HELP]
Allocated Frequency Setting		In Hz, corresponding to allocated frequency level - see table 6 or 7 in the MASS V8.0. This is only applicable to Switching controllers (S)
Boost	1	G [HELP]
Sample Rate of Frequency Recorder for high speed data (<= 50ms) for Very Fast and Fast services	0.02	In seconds
Sample Rate of Frequency Recorder for low speed data (<= 4s) for estimation of the FD parameter	4	In seconds [HELP]
Sample Rate of Frequency Recorder for low speed data (<= 4s) for Slow services	4	In seconds
Sample Rate of Frequency Recorder for low speed data (<= 4s) for Delayed services	4	In seconds
Frequency Controller Dead-band Lower Limit	49.85	In Hz, as defined in the MASS
Generator or Load?	GENERATOR	
Incident and Dispatch Information	Value	Comment
High speed data start time	15:10:14	Time only (no date) exact precision not required - This is used for determining the trading interval
Low speed data Start time	15:10:05	Time only (no date) exact precision not required - This is used for determining the trading interval
Very Fast Service Enabled (NEMDE target)	0	MW value of Very Fast Raise service enabled
Fast Service Enabled (NEMDE target)	0	MW value of Fast Raise service enabled
Slow Service Enabled (NEMDE target)	0	MW value of Slow Raise service enabled
Delayed Service Enabled (NEMDE target)	0	MW value of Delayed Raise service enabled
Manual basepoint override		
Basepoint for Very Fast and Fast		in MW
Basepoint for Slow and Delayed		in MW
Frequency trace		
Frequency Ramp or Local Frequency	RAMP	To set whether the assessment is for a frequency injection test (Ramp) or an event (Local)
Initial MV for trading interval:		
15:10	100.0	In MW, initial MW at the start of the trading interval, for scheduled generating units and loads only
15:15	150.0	
15:20	0.0	
15:25	0.0	
Dispatch Targets for trading interval:		
15:10	580.0	In MW, dispatch target for the trading interval, for scheduled generating units and loads only
15:15	600.0	
15:20	620.3	
15:25	630.0	
Region	MAINLAND	
Applicable MASS Parameter	Value	Comment
Raise reference frequency:	49.5	In Hz, as defined in the MASS V8.0
Normal frequency operating band:	49.85	In Hz, as defined in the Frequency Operating Standards
Frequency Recovery	49.9	In Hz, as defined in the Frequency Operating Standards
Frequency Ramp Rate	1	In Hz/second, as defined in the MASS V8.0. If calculating Very Fast FCAS, this must be set to 1Hz/s in Mainland and Tasmania. If not calculating Very Fast FCAS, this must be set to 0.125Hz/s in Mainland or 0.4Hz/s in Tasmania
Controller R1	P	Controller type for this service
Controller R6	P	Controller type for this service
Controller R60	P	Controller type for this service
Controller R5	P	Controller type for this service

A description of the parameter inputs are as follows:

Table 2 Input parameters

Input parameter	Description
Plant Name	DUID of the unit. This is for information only and does not impact the result
Plant Inertia	<p>The inertia of the plant in units of $MW \cdot s^3$ (or $\frac{kg \cdot m^2}{1000}$)</p> <p>In order to calculate the plant inertia, use the following equation:</p> $Plant\ inertia = \frac{H \cdot S}{2 \cdot \pi^2 \cdot f_0^2}$ <p>where,</p> <p>H = Plant inertia constant on machine MVA base (seconds) S = Plant MVA base (MVA) f_0 = 50 Hz</p>
Allocated Frequency Setting	In Hz, corresponding to frequency level allocated by AEMO. The frequency setting would be from Table 6 or 7 of the MASS. This is only applicable to switching controllers.
Boost	This parameter is equal to 1 unless a different value as been agreed to with AEMO. Refer to paragraph 2.1(a)(ix).
Sample Rate of Frequency Recorder for high speed data (<= 50ms) for Fast Services	In seconds, the sample rate for high speed data (Note that the high speed data points are also an input in the bottom section of this tab). The MASS requires data for R1, R6, L1 and L6 services to be sample at least at 0.05s intervals, or 0.2s for aggregated ancillary facilities with no inertial response.
Sample Rate of Frequency Recorder for low speed data (<= 4s) for estimation of the FD parameter	In seconds, the sample rate for low speed data (Note that the low speed data points are also an input in the bottom section of this tab). If a plant is enabled for fast services and high speed data is not available, then R60 and L60 cannot be calculated because the parameter FD which is an input to R60 and L60 calculation has to be calculated from high speed data. However, this spreadsheet will still calculate R60 and L60 using an estimate of FD as long as low speed data is available. This parameter specifies the sampling rate of the low speed data.
Sample Rate of Frequency Recorder for low speed data (<= 4s) for Slow services	In seconds, the sample rate for low speed data (Note that the low speed data points are also an input in the bottom section of this tab). The MASS requires data for R60 and L60 to be sampled at least at 4s intervals.
Sample Rate of Frequency Recorder for low speed data (<= 4s) for Delayed services	In seconds, the sample rate for low speed data (Note that the low speed data points are also an input in the bottom section of this tab). The MASS requires data for R5 and L5 to be sampled at least at 4s intervals.
Frequency Dead-band Lower/Upper Limit	In Hz, the lower limit of the frequency deadband of the governor for Raise, and the upper limit of the frequency deadband of the governor for Lower. For example, if the deadband is ± 0.1 Hz, then the value to be entered is 49.9 Hz (=50-0.1 Hz) for Raise and 50.1Hz for Lower.
Generator or Load?	Choose either "GENERATOR" or "LOAD" from the drop down box
High speed data start time	Enter the start time of the high speed data in 24 hour format. E.g. 20:53:38. Do not enter the date. Exact precision is not required as it is only used to determine the trading interval (DI) that the contingency occurred.
Low speed data Start time	Enter the start time of the low speed data in 24 hour format. E.g. 20:53:38. Do not enter the date. Exact precision is not required as it is only used to determine the trading interval (DI) that the contingency occurred.

Input parameter	Description
Very Fast Service Enabled (NEMDE target)	Very Fast service enabled by NEMDE. This is the cleared Very Fast service for the DI that the contingency occurred. Enter 0 if no Very Fast service was cleared for the plant.
Fast Service Enabled (NEMDE target)	Fast service enabled by NEMDE. This is the cleared Fast service for the DI that the contingency occurred. Enter 0 if no Fast service was cleared for the plant.
Slow Service Enabled (NEMDE target)	Slow service enabled by NEMDE. This is the cleared Slow service for the DI that the contingency occurred. Enter 0 if no Slow service was cleared for the plant.
Delayed Service Enabled (NEMDE target)	Delayed service enabled by NEMDE. This is the cleared Delayed service for the DI that the contingency occurred. Enter 0 if no Delayed service was cleared for the plant.
Manual basepoint override	This is only a label.
Basepoint for Very Fast and Fast	Manual basepoint override for Very Fast and Fast services. this will override 'SA' and 'DA' to allow for a different time averaging period before the frequency disturbance time. Leave blank to use the standard -4 to -2 seconds.
Basepoint for Slow and Delayed	Manual basepoint override for Slow and Delayed services. This will override 'SA' and 'DA' to allow for a different time averaging period before the frequency disturbance time. Leave blank to use the standard -20 to -8 seconds.
Frequency trace	This is only a label.
Frequency Ramp or Local Frequency	Defaults to "LOCAL" – use "RAMP" only where FCAS frequency ramping strategy is applied.
Initial MW for trading interval:	This is only a label
20:50	(The text of the label will depend on the High/Low speed data start time entered above) Enter the initial MW for the DI. This is the measured MW value at the beginning of this DI
20:55	(The text of the label will depend on the High/Low speed data start time entered above) Enter the initial MW for the DI. This is the measured MW value at the beginning of this DI
21:00	(The text of the label will depend on the High/Low speed data start time entered above) Enter the initial MW for the DI. This is the measured MW value at the beginning of this DI
21:05	(The text of the label will depend on the High/Low speed data start time entered above) Enter the initial MW for the DI. This is the measured MW value at the beginning of this DI
Dispatch Targets for trading interval:	This is only a label
20:50	(The text of the label will depend on the High/Low speed data start time entered above) Dispatch target for this DI.
20:55	(The text of the label will depend on the High/Low speed data start time entered above) Dispatch target for this DI.
21:00	(The text of the label will depend on the High/Low speed data start time entered above) Dispatch target for this DI.

Input parameter	Description
21:05	(The text of the label will depend on the High/Low speed data start time entered above) Dispatch target for this DI.
Region	Choose either "MAINLAND" or "TASMANIA" from the drop down box
Applicable MASS Parameters	These are not user inputs. Do not change
Raise reference frequency:	
Normal frequency operating band:	
Frequency Recovery	
Frequency Ramp Rate	Choose 2Hz/s if calculating R1 or L1 service in Tasmania Choose 1Hz/s if calculating R1 or L1 service in Mainland Choose 0.125Hz/s if calculating non-R1 or non-L1 service in Mainland Choose 0.4Hz/s if calculating non-R1 or non-L1 service in Tasmania
Controller R1/L1	Choose either "P" or "S" from the drop down box to indicate if the type of the R1/L1 controller is a Variable controller (aka Proportional controller) or a switched controller. Refer to the MASS for further details.
Controller R6/L6	Choose either "P" or "S" from the drop down box to indicate if the type of the R6/L6 controller is a Variable controller (aka Proportional controller) or a switched controller. Refer to the MASS for further details.
Controller R60/L60	Choose either "P" or "S" from the drop down box to indicate if the type of the R60/L60 controller is a Variable controller (aka Proportional controller) or a switched controller. Refer to the MASS for further details.
Controller R5/L5	Choose either "P" or "S" from the drop down box to indicate if the type of the R5/L5 controller is a Variable controller (aka Proportional controller) or a switched controller. Refer to the MASS for further details.

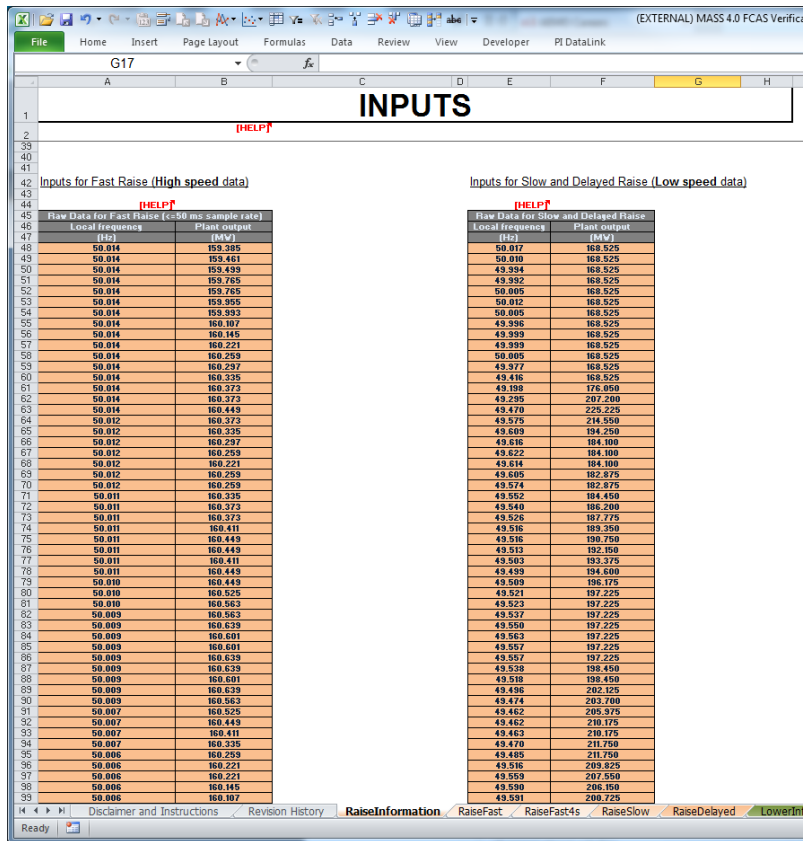
5.2.2. High/low speed data inputs

The MASS requires the following data resolution for calculating Raise and Lower services:

- R1, L1, R6, L6 – High speed data (sampling rate $\leq 0.05s$, or $\leq 0.2s$ for aggregated ancillary facilities with no inertial response)
- R60, L60, R5, L5 – Low speed data (sampling rate $\leq 4s$)

Scroll down to find additional high/low speed data inputs:

Figure 7 High and low speed data inputs



The user should enter high speed data on the left table and low speed data on the right table. A line in each table corresponds to a frequency and power measurement (in Hz and MW). Note that the sampling interval should be the same sampling interval specified as a parameter in the section 5.2.1.

5.3. Results

The results are calculated automatically as the data is input by the user. There is no need do any further actions such as pressing a button to obtain the result.

As shown in Figure 8 below, the results (and some intermediate parameters) are shown in the “RESULTS” section of the RaiseInformation or LowerInformation tabs.

Note that the section greyed out should be ignored. When high speed data is not available, it is used to estimate the parameter FD which is an input for L60 and R60 but requires high speed data for accurate calculation.

Figure 8 FCAS VT Results

J		K		L	M	N	O
RESULTS							
[HELP]							
Very Fast Lower (MW)		9.2		[HELP]			
VA		527.11					
VB		-9.2					
VC		-58.5					
VD		-53.5					
Fast Lower (MW)		49.2		[HELP]			
FA		527.11					
FB		-65.7					
FC		-67.6					
FD		-53.6					
Fast Lower 4s (MW) (NOT a reliable estimate of Fast Lower)		n/a		[HELP]			
FA (estimate)		550.4					
FB (estimate)		#DIV/0!					
FC (estimate)		-77.0					
FD (estimate)		-63.0					
Slow Lower (MW)		53.6		Participant supplied fast data used for calculati			
SA		550.4					
SB		-185.5					
SC		-173.5					
SE		-93.5					
Delayed Lower (MW)		38.1					
DA		550.4					
DB		-53.8					
DC		-38.1					

The user should refer to the MASS to obtain further information on the intermediate parameters such as FA, FB, FC etc.

5.4. Worked example

The downloaded version of the FCASVT comes pre-populated with a fully worked non-trivial example to show the user how data is entered into the RaiseInformation and LowerInformation tabs.

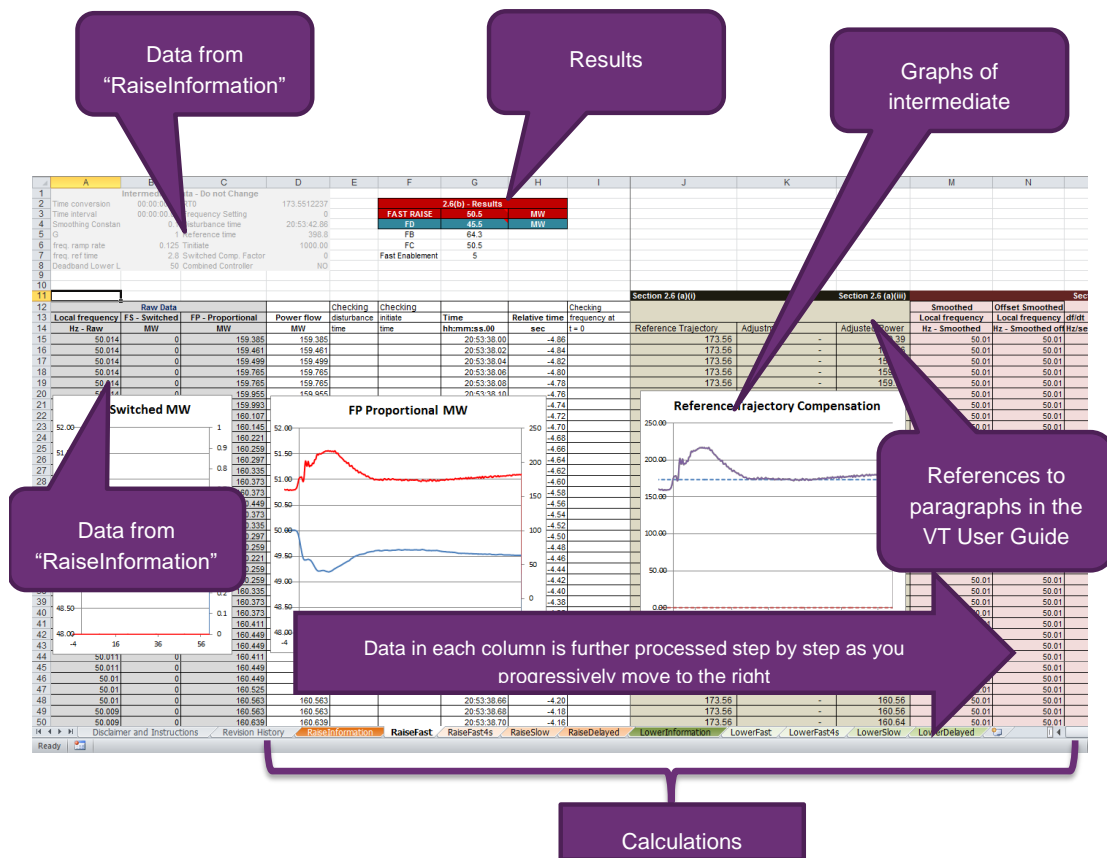
6. Understanding the calculation steps in FCASVT

The theoretical basis for calculations in FCASVT is beyond the scope of this guide, and users should refer to the MASS for further information. A useful way gain an understanding behind the reasoning for a particular clause in the MASS is to refer to the AEMO consultation that established the clause¹⁴.

With sufficient understanding of the MASS, it can be instructive to follow through the calculation steps in the spreadsheet.

In section 4.3 and 4.3.1, the data and control flow of the calculation was briefly shown. For example, in the R6 calculation, the user first inputs the data in the “RaiseInformation” tab. In order to view the intermediate steps in the calculation, the user should navigate to the “RaiseFast” tab.

Figure 9 Calculation layout



¹⁴ 2011: <http://www.aemo.com.au/Consultations/National-Electricity-Market/Closed/Market-Ancillary-Service-Specification-MASS-Amendment-Consultation>

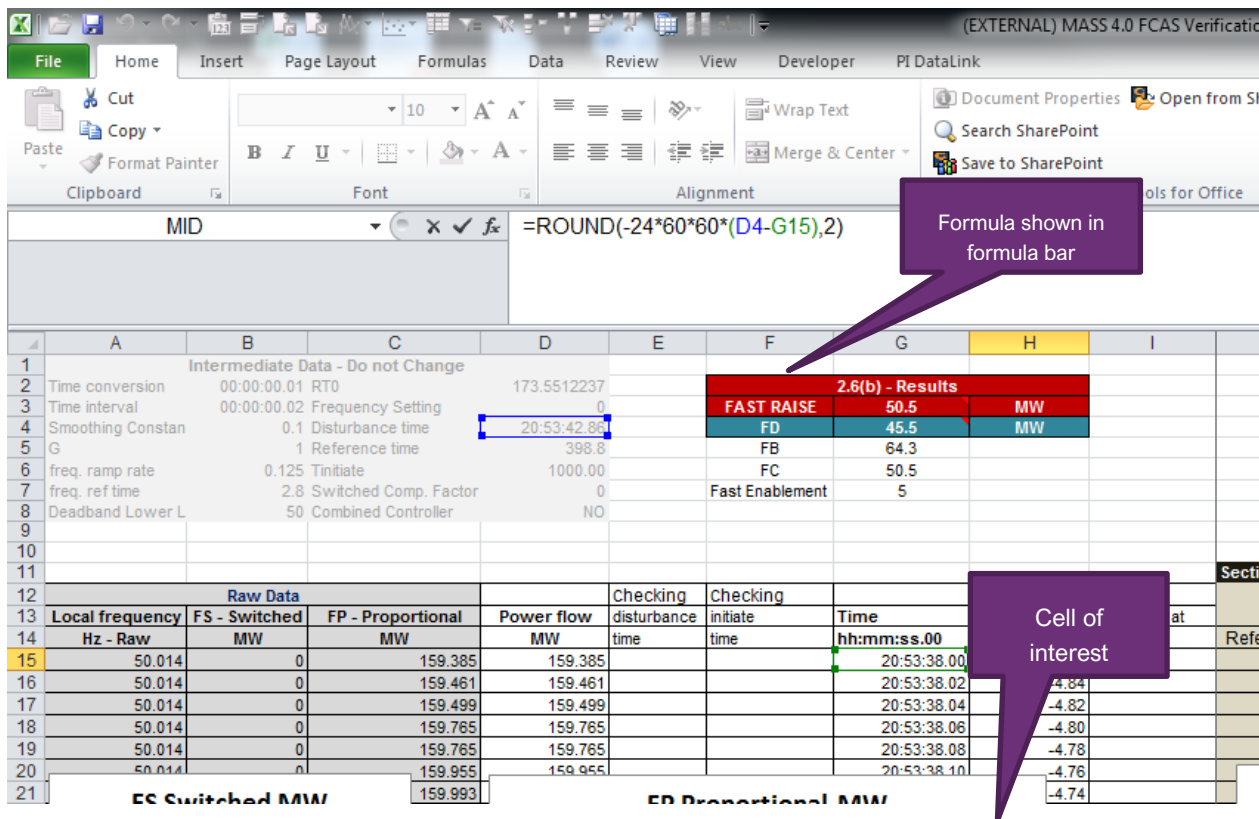
2017: <https://aemo.com.au/consultations/current-and-closed-consultations/amendment-of-the-market-ancillary-service-specification>

2020: <https://aemo.com.au/consultations/current-and-closed-consultations/primary-frequency-response-under-normal-operating-conditions>

2022: <https://aemo.com.au/consultations/current-and-closed-consultations/amendment-of-the-mass-very-fast-fcas>

It can be see that as the user moves progressively to the right, each column is further processed step by step as per the methodology in the MASS. The applicable paragraph numbers in the VT User Guide are also identified to assist the user to locate the calculation step in the MASS. It is also instructive to consider the plots of intermediate results.

Figure 10 Calculation analysis



If the user wishes to inspect the formula behind a particular cell, place the cursor on that cell and click on the formula bar. This will show the underlying calculation as shown below. Variables are colour coded as a visual aid.

The other tabs can similarly be examined to get an understanding of how the magnitude of FCAS services is calculated.

7. Support and information

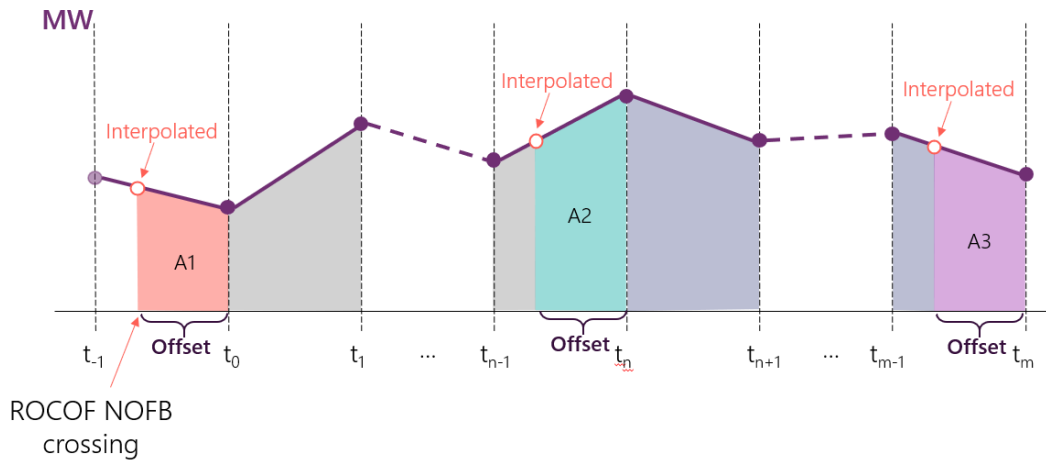
To report any issues or suggest improvements to either the FCASVT or this user guide, please email Freq_Event.Data@aemo.com.au.

Appendix A. Calculation of time average

The trapezoidal rule is used to calculate the *time average* of an FCAS response, defined as the integral of the Raise Response or Lower Response over the time interval divided by the duration of the time interval. This estimate of *time average* is further adjusted to account for the interpolated FDT between time t_{-1} and t_0 by adding and subtracting trapezium areas A1, A2 and A3 as below. Figure 11 demonstrates this calculation, where;

- t_0 is the time of the first FCAS measurement after frequency crosses to outside the NOFB,
- t_n is the time of the last FCAS measurement of the first FCAS integral,
- t_m is the time of the last FCAS measurement of the second FCAS integral.
- *Offset* is the time between the time of frequency crossing the NOFB estimated by interpolation and t_0 .

Figure 11 Visual representation of calculation of FCAS delivery



The following equations represent the calculation of *time average*, where;

- Compensated Basic Response (CBR) refers to the power (MW) response after adjustments and compensation have been applied.
- First and second integral refers to the two FCAS assessment windows represented in each of {VB, VC}, {FB, FC}, {SB, SC} or {DB, DC}.
- $A1 = \frac{1}{2} * Offset * (CBR_{interpolated,1} + CBR_0)$
- $A2 = \frac{1}{2} * Offset * (CBR_{interpolated,2} + CBR_n)$
- $A3 = \frac{1}{2} * Offset * (CBR_{interpolated,3} + CBR_m)$
- T is the sampling resolution

$$time\ average\ first\ integral = \frac{\frac{1}{2} \times T \times (2 \times \sum_{t=0}^n CBR\ values - CBR_0 - CBR_n) + A1 - A2}{T \times (n - 1)}$$

$$time\ average\ second\ integral = \frac{\frac{1}{2} \times T \times (2 \times \sum_{t=n}^m CBR\ values - CBR_n - CBR_m) + A2 - A3}{T \times (m - n - 1)}$$

Version release history

Version	Effective date	Summary of changes
6.1	9 October 2023	<p>1. Version number updated from v5.0 to v6.1 to align with FCASVT v6.1</p> <p>2. FCASVT and guide updated following industry feedback on FCASVT Version 6 and MASS consultation on Fast Frequency ramp rate for Tasmania:</p> <ul style="list-style-type: none"> – Revised calculation of Reference Trajectory based on a linear trajectory between successive dispatch targets instead of initial MW to dispatch target. – Included a manual basepoint override for all services to allow a different time averaging period before the frequency disturbance time. – Revised formula for the Proportionally Compensated Basic Response depending on if the frequency trace is a ramp or uses local frequency measurement. – Revised calculation of raise and lower FCAS delivered to account for frequency recovery before the end of the measurement window for each service <p>Revised Fast Frequency Ramp for Tasmania to 2 Hz/s</p>
5.0 (Draft)	N/A	Update for MASS changes required 9 October 2023 - Very Fast FCAS market start and removal of multiplier effect
4.1	1 February 2022	<p>Update for MASS changes required 1 February 2022 following industry feedback.</p> <p>1. Calculation of Time Average in draft Verification Tool and draft User Guide updated with changes in red below.</p> <ul style="list-style-type: none"> – Included missing 2x multiplier inside brackets in FCAS VT User Guide formulas – Reversed cancellation of T terms as values $A1$, $A2$ and $A3$ are not of duration T – Removed 2x multiplier from formula for Time Average as 2x multiplier is not in definition of Time Average – These formulas for Time Average have been implemented in FCAS Verification Tool $time\ average_{\text{first integral}} = \frac{\frac{1}{2} \times T \times (2 \times \sum_{t=0}^n CBR\ values - CBR_0 - CBR_n) + A1 - A2}{T \times (n - 1)}$ $time\ average_{\text{second integral}} = \frac{\frac{1}{2} \times T \times (2 \times \sum_{t=n}^m CBR\ values - CBR_n - CBR_m) + A2 - A3}{T \times (m - n - 1)}$
3.0	1 July 2020	Updated following review of MASS focusing on interaction with Mandatory Primary Frequency Reponse rule change.
2.0	30 July 2017	Added description of verification tool process
1.0	8 February 2012	Initial release