FCAS VERIFICATION TOOL USER GUIDE

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VERSION RELEASE HISTORY

Version	Effective Date	Summary of Changes
1.0	8 February 2012	Created initial release
2.0	30 July 2017	Added description of verification tool process
3.0	1 July 2020	Updated following review of MASS focusing on interaction with Mandatory Primary Frequency Reponse rule change.
4.0 DRAFT	(TBC)	Updated following review of MASS focusing on DER and General Issues. Other minor guide issues also corrected.
4.1	1 February 2022	Update for MASS changes required 1 February 2022 following industry feedback. 1. Calculation of Time Average in draft Verification Tool and draft User Guide updated with changes in red below. - 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 $$time\ average_{first\ integral} = \frac{\frac{1}{2} \times T \times (2 \times \sum_{t=0}^{n} CBR\ values - CBR_0 - CBR_n) + A1 - A2}{T \times (n-1)}$$ $$time\ average_{second\ integral} = \frac{\frac{1}{2} \times T \times (2 \times \sum_{t=n}^{m} CBR\ values - CBR_n - CBR_m) + A2 - A3}{T \times (m-n-1)}$$

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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 Fast Raise (R6), Slow Raise (R60), Delayed Raise (R5), 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.

Table 1   Definitions

Term	Definition
Aggregated Ancillary Service Facility	The *ancillary service generating units* or *ancillary service loads* 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 *connection points* of an Aggregated Ancillary Service Facility.
Aggregated Load Amount	The aggregate Load Amounts through one or more *connection points* of an Aggregated Ancillary Service Facility.
Ancillary Service Facility	The *ancillary service generating unit* or *ancillary service load* used to deliver FCAS.
Contingency Event Time	The time at which a *contingency event* occurred, which is determined as follows: (a) Where the initial *frequency* change that led to a Frequency Disturbance is clear, there was a single rapid and significant change in *frequency*, the Contingency Event Time is the starting point of that *frequency* change. (b) If there was a series of step changes in *frequency* or a slow ramp in *frequency*, the Contingency Event Time will be at the start of the greatest rate of change of *frequency*, as measured by AEMO. (c) If neither paragraph (a), nor (b), applies, AEMO will take into account the circumstances of the *contingency event* and select a time that, in AEMO's opinion, represents the start time of the *frequency* disturbance, against which the FCAS response to it can reasonably be measured.
Contingency FCAS	A term used to refer to *fast raise service, fast lower service, slow raise service, slow lower service, delayed raise service* and *delayed lower service* collectively.

Term	Definition
Controlled Quantity	A quantity of *generation* or *load* that is: (a) controlled by Raise Signals and Lower Signals*;* (b) measured at the relevant connection point
Frequency Control Ancillary Services (FCAS)	*market ancillary services*, 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.
FOS	The *frequency operating standard*.
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 *region*.
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 *region* 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 *frequency* or a combined level of *frequency* and *frequency* 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 *active power flow* through the *connection point* of an Ancillary Service Facility into the *transmission network* or *distribution network* to which it is *connected*, 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 *inertia*.
Initial Value	The Generation Amount or Load Amount immediately prior to a Contingency Event Time.
Load Amount	The amount of *active power flow* through the *connection point* of an Ancillary Service Facility into the *transmission network* or *distribution network* to which it is *connected*, expressed as a negative value in MW.
Load Event	As defined in the FOS.
Local Frequency	The *frequency* measured by an FCAS Provider at the *connection point* 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.

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[1] The Frequency Disturbance Time is referred to in the equations in the MASS as occurring at t = 0.

Term	Definition
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 *regions* other than Tasmania.
MASS	The *market ancillary service specification*.
NER	National Electricity Rules.
NOFB	The *normal operating frequency band* that applies under normal operating conditions, namely the values in Column 2 of Table A.1 in the FOS.
OFTB	The *operational frequency tolerance band*.
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	means 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 *control system* that delivers a specific amount of FCAS by either switching *generation* or *load* 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 *frequency* of the *power system*, 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 *frequency* range for which an Ancillary Service Facility with one or more switching controllers must record and store data regardings 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 *control system* that is used by an Ancillary Service Facility to deliver FCAS upon the commencement of the Frequency Disturvance in proportion to the size of the frequency excursion.

1.2.2. Interpretation

The following principles of interpretation apply to the MASS 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.

Table 2   Related documents

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 6.4 of the MASS contain the principles that must be followed in verifying the response of *ancillary service generating units* and *ancillary service loads* 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 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 2.1(a)(ii), if the *ancillary service generating unit* or *ancillary service load* is *scheduled* or *semi-scheduled* then determine its reference trajectory as the successive straight line interpolations of the initial metered loading at the beginning of a dispatch interval to the expected *dispatch* target or *dispatch level* at the end of the dispatch interval. The reference trajectory is to start with the initial loading at the beginning of the dispatch interval in which the frequency deviation occurs and is to continue for the succeeding two dispatch intervals[2].

(ii)   determine a set of values RT such that:

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[2] For example if a frequency event occurs at 01:04 hrs then the associated reference trajectory will be the straight line interpolations between the initial loadings measured at the beginning of the 01:05, 01:10, and 01:15 *dispatch intervals* to the dispatch targets corresponding with the 01:05, 01:10, and 01:15 *dispatch intervals*.

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

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 *Contingency Event Time*

(iii)   adjust each power measurement (P_i at time interval i) after the *Contingency Event 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 *Contingency Event Time*

the minimum of RT_i and 0 if *local frequency* was above 50 Hz at the *Contingency Event 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 generating unit* or *ancillary service load* 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

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

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

$f_i^{offset\text{-}smoothed} = f_{i+9}^{smoothed}$, 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 value FA as the *time average* of the adjusted power measurements made during the period between twenty seconds and eight seconds before the *frequency disturbance time*;

(vi)   determine the basic response measurements by subtracting value FA from each adjusted power measurement after the *Contingency Event 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 6.3 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 (RPP) for a *variable controller* by:

$$RPP = \frac{(f_{raise\,DB} - f_{local})}{(f_{raise\,DB} - f_{resp-rate})} \times Fast\ Enablement$$

(ix)   compensate each value of FP after the *Contingency Event Time* for *frequency* change by multiplying the minimum of FP and RPP by the following factor, disregarding any measurement at or after a *frequency recovery* and, in the case where FP is greater than RPP, adding FP minus RRP to the total:

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

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

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

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 * 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} = 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} = 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*:*

MAX (1, (6 - *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 the *Contingency Event Time* 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[3].

(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[4].

(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 *local frequency* was below 50 Hz at the *frequency disturbance time*, the amount of fast *raise response* is within the range of ± 5% of the lesser of value FB and value FC;

(iii) If local *frequency* was above 50 Hz at the *frequency disturbance time*, the amount of *fast lower response* is within the range of ± 5% the negative of the greater of value FB and value FC[5]; and

(iv) For the purposes of paragraph 2.2(b), value FD is:

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

$$FD = FC - MIN(FC, F_{enb}); \text{ and}$$

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

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

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

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[3] See Appendix A for further information.
[4] See Appendix A for further information.
[5] Note that FB and FC are negative values.

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.

(v) If *frequency recovery* occurs prior to the first measurement required for evaluation of FC, FB will be the amount of fast response.

(c) If two or more *ancillary service generating units* or *ancillary service loads* 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 generating units* or *ancillary service loads* use *switching controllers*, the actual *frequency* trajectory compared with the *frequency* setting of each relevant *switching controller*.

(d) If at the time of the *frequency disturbance* the maximum service capability of the *ancillary services generating unit* or *ancillary services load* is less than *enabled price bands*, then the expected service delivery is equal to the maximum service capability.

The maximum *fast raise service* capability is equal to the *ancillary services generating unit* or *ancillary services load's* bid *fast raise service* capability that corresponds to FA.

The maximum *fast lower service* capability is equal to the *ancillary services generating unit* or *ancillary services load's* bid *fast lower service* capability that corresponds to FA.

2.2. 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 2.2(a)(ii), if the *ancillary service generating unit* or *ancillary service load* is *scheduled* or *semi-scheduled* then determine its reference trajectory as the successive straight line interpolations of the initial metered loading at the beginning of a dispatch interval to the expected *dispatch* target or *dispatch level* at the end of the dispatch interval. The reference trajectory is to start with the initial loading at the beginning of the dispatch interval in which the frequency deviation occurs and is to continue for the succeeding two dispatch intervals[6].

(ii) determine a set of values RT such that:

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

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

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[6] For example if a frequency event occurs at 01:04 hrs then the associated reference trajectory will be the straight line interpolations between the initial loadings measured at the beginning of the 01:05, 01:10, and 01:15 *dispatch intervals* to the dispatch targets corresponding with the 01:05, 01:10, and 01:15 *dispatch intervals*.

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

(iii)   adjust each power measurement (P_i at time interval i) after 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 value SA as the *time average* of the adjusted power measurements made during the period between twenty seconds and eight seconds before the *frequency disturbance time*;

(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 discrete combination of *switching controller* and *variable controller* is used (refer clause 6.3 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 (RPP) for a *variable controller* by:

$$RPP = \frac{(f_{raise\ DB} - f_{local})}{(f_{raise\ DB} - f_{resp-rate})} \times Slow\ Enablement$$

(viii)   compensate each value of SP for *frequency* change by multiplying the minimum of SP and RPP by the following factor, disregarding measurements made at or after a *frequency recovery* and, in the case where SP is greater than RPP, adding SP minus RRP to the total:

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

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

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

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

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

if f_{local} is 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 * the appropriate *frequency ramp rate*

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

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

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

$f_{resp-rate}$ = 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[7].

(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

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[7] See Appendix A for further information.

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[8].

(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 *local frequency* was below 50 Hz at the *frequency disturbance time*, determine the amount of *slow raise response* as within the range of ± 5% of the lesser of value SC and:

A if the *ancillary service generating unit* or *ancillary service load* was not *enabled* for a *fast raise service,* value SB; and

B otherwise, the greater of zero and value FD determined under paragraph 2.1(b)(iv);

(iii) If *local frequency* was above 50 Hz at the *frequency disturbance time*, determine the amount of *slow lower response* as within the range of ± 5% of the negative of the greater of value SC and:

A if the *ancillary service generating unit* or *ancillary service load* was not *enabled* for a *fast lower service,* value SB; and

B otherwise, the lesser of zero and value FD determined under paragraph 2.1(b)(iv); and

(iv) For the purposes of paragraph 2.3(b), value SE is:

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

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

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

$$SE = SC - MAX(SC, -S_{enb})$$

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.

(v) If *frequency recovery* occurs prior to the first measurement required for evaluation of SC, SB will be the amount of slow response.

(c) If two or more *ancillary service generating units* or *ancillary service loads* 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 generating units* or *ancillary service loads* have switching controllers, the actual *frequency* trajectory compared with the *frequency setting* of each relevant *switching controller*.

---

[8] See Appendix A for further information.

(d)   If at the time of the frequency disturbance the maximum service capability of the *ancillary services generating unit* or *load* is less than *enabled price bands*, then the expected service delivery is equal to the maximum service capability.

The maximum *slow raise service* capability is equal to the *ancillary services generating unit* or *load's bid fast raise service* capability that corresponds to SA.

The maximum *slow lower service* capability is equal to the *ancillary services generating unit* or *load's bid fast lower service* capability that corresponds to SA.

2.3.   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 2.3(a)(ii), if the *ancillary service generating unit* or *ancillary service load* is *scheduled* or *semi-scheduled* then determine its reference trajectory as the successive straight line interpolations of the initial metered loading at the beginning of a dispatch interval to the expected *dispatch* target or *dispatch level* at the end of the dispatch interval. The reference trajectory is to start with the initial loading at the beginning of the dispatch interval in which the frequency deviation occurs and is to continue for the succeeding two dispatch intervals[9].

   (ii)   determine a set of values RT such that:

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

   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 time of the frequency disturbance

   (iii)   adjust each power measurement (P_i at time interval i) after 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 value DA as the *time average* of the power measurements made during the period between twenty seconds and eight seconds before the *frequency disturbance time*;

   (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

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[9] For example if a frequency event occurs at 01:04 hrs then the associated reference trajectory will be the straight line interpolations between the initial loadings measured at the beginning of the 01:05, 01:10, and 01:15 *dispatch intervals* the dispatch targets corresponding with the 01:05, 01:10, and 01:15 *dispatch intervals*.

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[10].

(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[11].

(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 *local frequency* was below 50 Hz at the *frequency disturbance time*, determine the amount of *delayed raise response* as within the range of ± 5% of the lesser of value DC and:

A if the *ancillary service generating unit* or *ancillary service load* was not *enabled* for a *slow raise service,* value DB; and

B otherwise, the greater of zero and value SE determined under paragraph 2.2(b)(iv);

(iii) If *local frequency* was above 50 Hz at the *frequency disturbance time*, determine the amount of *delayed lower response* as within the range of ± 5% of the negative of the greater of value DC and:

A if the *ancillary service generating unit* or *ancillary service load* was not *enabled* for a *slow lower service,* value DB; and

B otherwise, the lesser of zero and value SE determined under paragraph 2.2(b)(iv).

(iv) If *frequency recovery* occurs prior to the first measurement required for evaluation of DC, DB will be the amount of delayed response.

(c) If two or more *ancillary service generating units* or *ancillary service loads* 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 generating units* or *ancillary service loads* have switching controllers, the actual *frequency* trajectory compared with the *frequency setting* of each relevant *switching controller*.

(d) If at the time of the *frequency disturbance* the *maximum service* capability of the *ancillary services generating unit* or *ancillary services load* is less than *enabled price bands*, then the expected *service delivery* is equal to the maximum service capability.

The maximum *delayed raise service* capability is equal to the *ancillary services generating unit* or *load's bid fast raise service* capability that corresponds to DA.

The maximum *delayed lower service* capability is equal to the *ancillary services generating unit* or *load's bid fast lower service* capability that corresponds to DA.

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[10] See Appendix A for further information.
[11] See Appendix A for further information.

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.
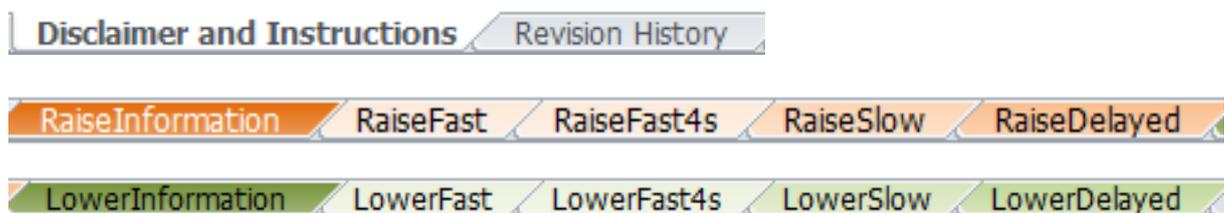
Figure 1   MASS VT icon

4.   STRUCTURE AND FLOW OF THE FCASVT

4.1.   Navigating the FCASVT

The FCASVT consists of 12 worksheet tabs as seen below.

Figure 2   Worksheet tabs

Note that for ease of use, the five "Raise" tabs are in different shades or orange, whereas the "Lower" tabs in different shades of green.

Table 3   Tab descriptions

Worksheet Tab	Description

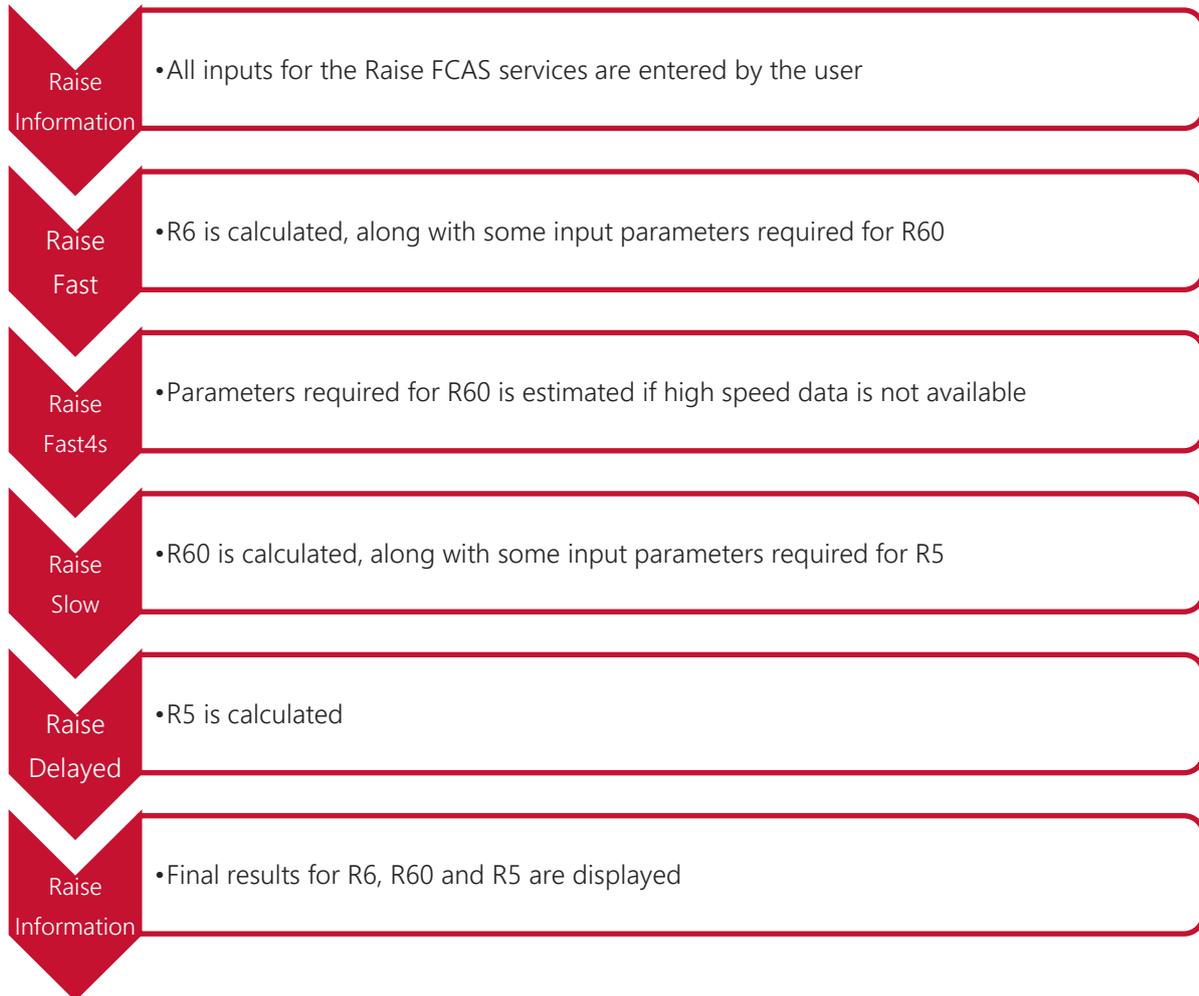| Disclaimer and Instructions	Contains AEMO disclaimer and brief instructions on how to use the FCASVT
Revision History	Contains software updates made for each version
RaiseInformation	For Raise FCAS, the user should enter input data in this tab. Once input data is entered, the calculated R6, R60 and R5 FCAS output is displayed
RaiseFast	*This tab is for information only and no user interaction is required.* This tab contains the detailed steps to process the input data to calculation R6 services.
RaiseFast4s	*This tab is for information only and no user interaction is required.* 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	*This tab is for information only and no user interaction is required.* This tab contains the detailed steps to process the input data to calculation R60 services.
RaiseDelayed	*This tab is for information only and no user interaction is required.* This tab contains the detailed steps to process the input data to calculation R5 services.
LowerInformation	For Lower FCAS, the user should enter input data in this tab. Once input data is entered, the calculated L6, L60 and L5 FCAS output is displayed
LowerFast	*This tab is for information only and no user interaction is required.* This tab contains the detailed steps to process the input data to calculation L6 services.
LowerFast4s	*This tab is for information only and no user interaction is required.* 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	*This tab is for information only and no user interaction is required.* This tab contains the detailed steps to process the input data to calculation L60 services.
LowerDelayed	*This tab is for information only and no user interaction is required.* This tab contains the detailed steps to process the input data to calculation L5 services.

4.2. Data and control flow

The five "Raise" tabs work together, as do the five "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.
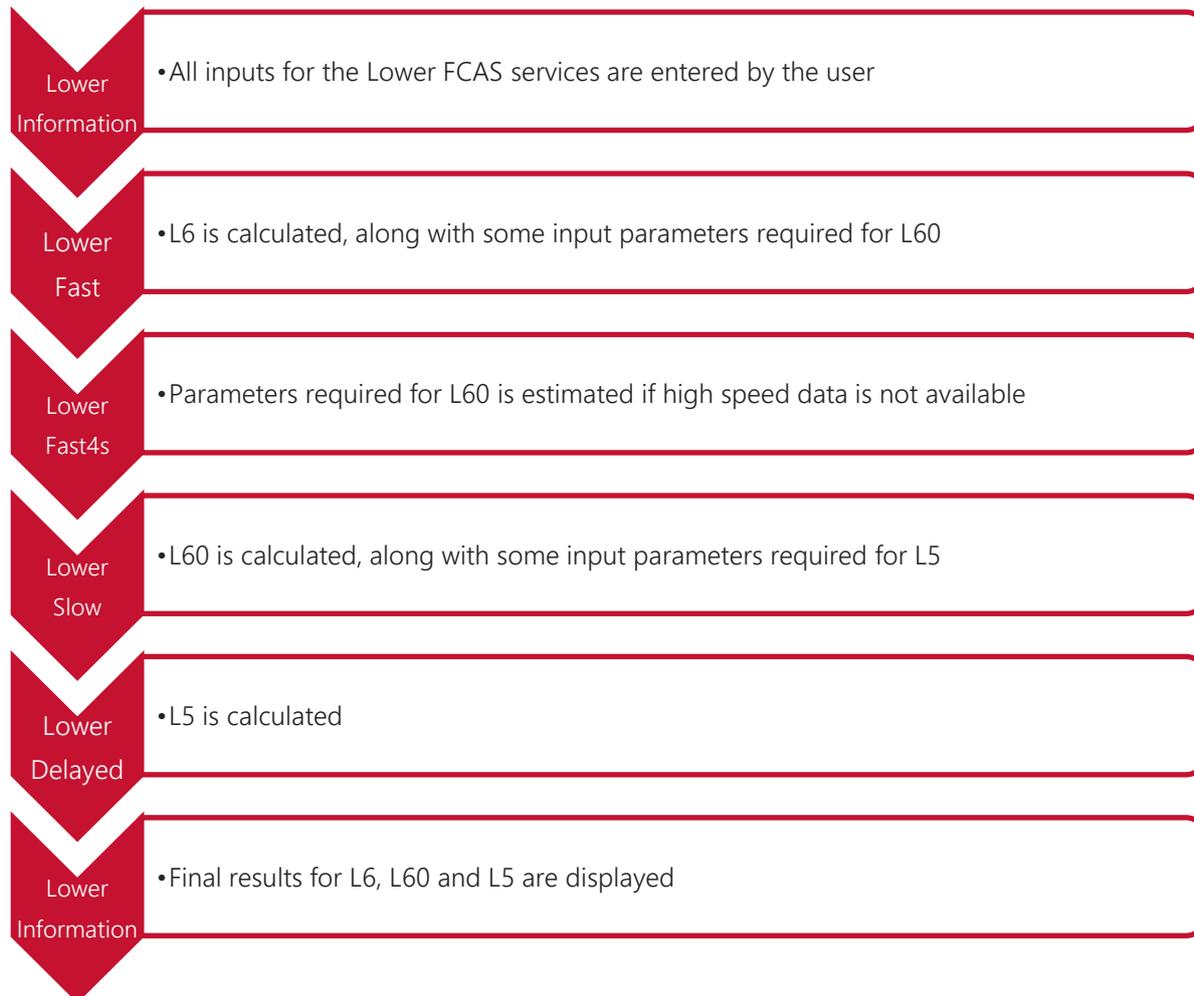
Figure 3   FCAS VT calculation process - Raise

Raise Information	• All inputs for the Raise FCAS services are entered by the user
Raise Fast	• R6 is calculated, along with some input parameters required for R60
Raise Fast4s	• Parameters required for R60 is estimated if high speed data is not available
Raise Slow	• R60 is calculated, along with some input parameters required for R5
Raise Delayed	• R5 is calculated
Raise Information	• Final results for R6, R60 and R5 are displayed

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

Lower Information	• All inputs for the Lower FCAS services are entered by the user
Lower Fast	• L6 is calculated, along with some input parameters required for L60
Lower Fast4s	• Parameters required for L60 is estimated if high speed data is not available
Lower Slow	• L60 is calculated, along with some input parameters required for L5
Lower Delayed	• L5 is calculated
Lower Information	• Final results for L6, L60 and L5 are displayed

5.   USING THE FCASVT

5.1.   User interaction

Of the 12 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.

User interaction mandatory to obtain result
- RaiseInformation
- LowerInformation

User action optional (only to facilitate better understanding)
- RaiseFast
- RaiseFast4s
- RaiseSlow
- RaiseDelayed
- 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 R6, R60 and R5, the user should navigate to the "RaiseInformation" tab. To calculate Lower services 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.

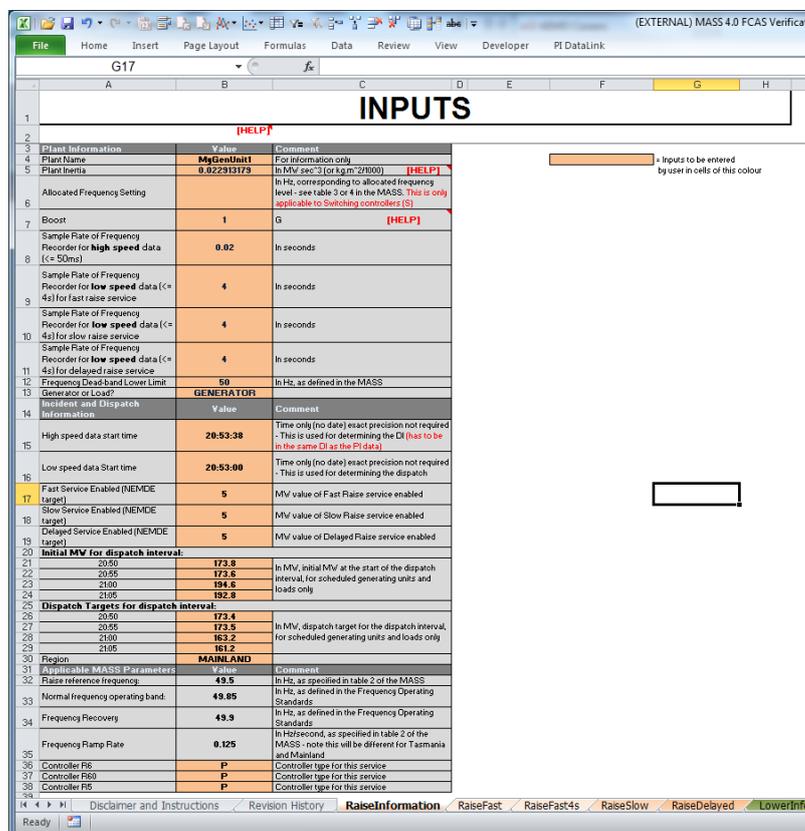= Inputs to be entered
by user in cells of this colour

In 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 5   Parameter inputs

A description of the parameter inputs are as follows:

Table 4   Input parameters

Input parameter	Description
Plant Name	DUID of the unit. This is for information only and does not impact the result
Plant Inertia	The inertia of the plant in units of $MW \cdot s^3$ (or $\frac{kg \cdot m^2}{1000}$) In order to calculate the plant inertia, use the following equation: $$Plant\ inertia = \frac{H \cdot S}{2 \cdot \pi^2 \cdot f_0^2}$$ where, H = Plant inertia constant on machine MVA base (seconds) S = Plant MVA base (MVA) f_0 = 50 Hz
Allocated Frequency Setting	In Hz, corresponding to frequency level allocated by AEMO. The frequency setting would be from Table 5 or 6 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)(viii).
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 R6 and L6 services to be sample at least at 0.05s intervals, or 0.2s for aggregated ancillary facilities with no inertial response. Frequently, sample rates of 0.02s are used.
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 specifices the sampling rate of the low speed data. Refer to paragraph 2.2(b) for further details. |
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 dispatch 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 dispatch interval (DI) that the contingency occurred.
Contingency Event Offset	Time in seconds between Contingency Event Time and Frequency Disturbance Time (NOFB crossing). Determined by AEMO for each FCAS assessment event in accordance with the MASS. Fast Service assessment window begins from Contingency Event Time. Prior to MASS v6.0 (1 July 2020) Fast Service assessment began from NOFB crossing.

FCAS assessments may use supplied CEO value or 0 if FCAS assessment is higher with 0. |

	Switching controlled providers to use 0.
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.
Initial MW for dispatch 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 dispatch 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.
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	
Controller R6	Choose either "P" or "S" from the drop down box to indicate if the type of the R6 controller is a Variable controller (aka Proportional controller) or a switched controller. Refer to the MASS for further details.
Controller R60	Choose either "P" or "S" from the drop down box to indicate if the type of the R60 controller is a Variable controller (aka Proportional controller) or a switched controller. Refer to the MASS for further details.
Controller R5	Choose either "P" or "S" from the drop down box to indicate if the type of the R5 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:

- R6, L6 – High speed data (sampling rate ≤ 0.05s, or ≤ 0.2s for aggregated ancillary facilities with no inertial response)

- R60, L60, R5, L5 – Low speed data (sampling rate ≤ 4s)

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

Figure 6　High and low speed data inputs
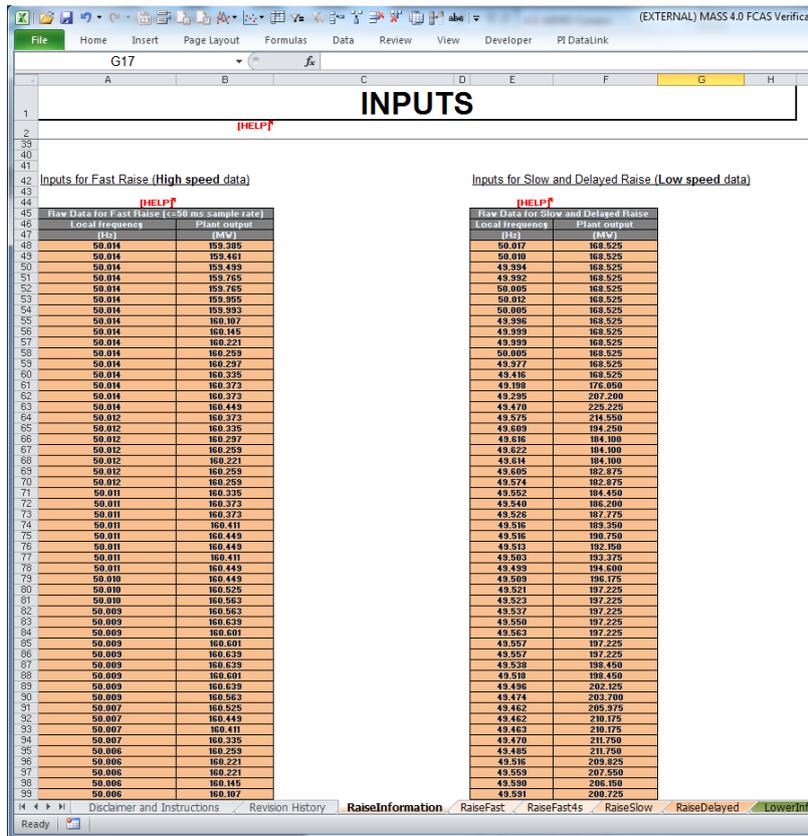
The user should enter high speed data on the left table and low speed data on the right table. A line in each table corresponds to a frequency and power measurement (in Hz and MW). Note that the sampling interval should be the same sampling interval specified as a parameter in the section 5.2.1.

5.3.　Results

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

As shown in the figure 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 7   FCAS VT Results

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 clause[12].

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[12] 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

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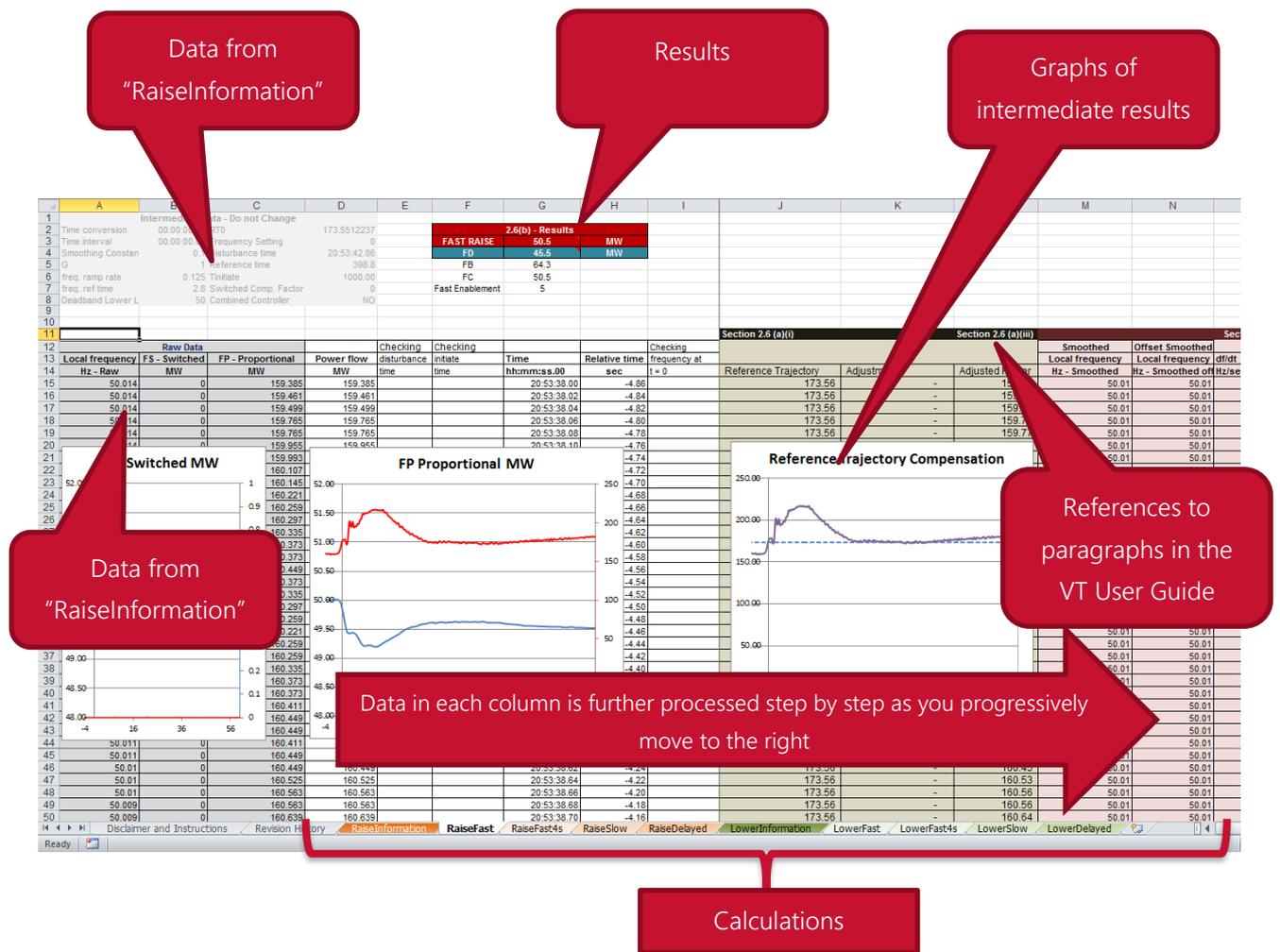
It can be see that as the user moves progressively to the right, each column is further processed step by step as per the methodology in the MASS. The applicable paragraph numbers in the VT User Guide are also identified to assist the user to locate the calculation step in the MASS. It is also instructive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

Figure 9   Calculation analysis
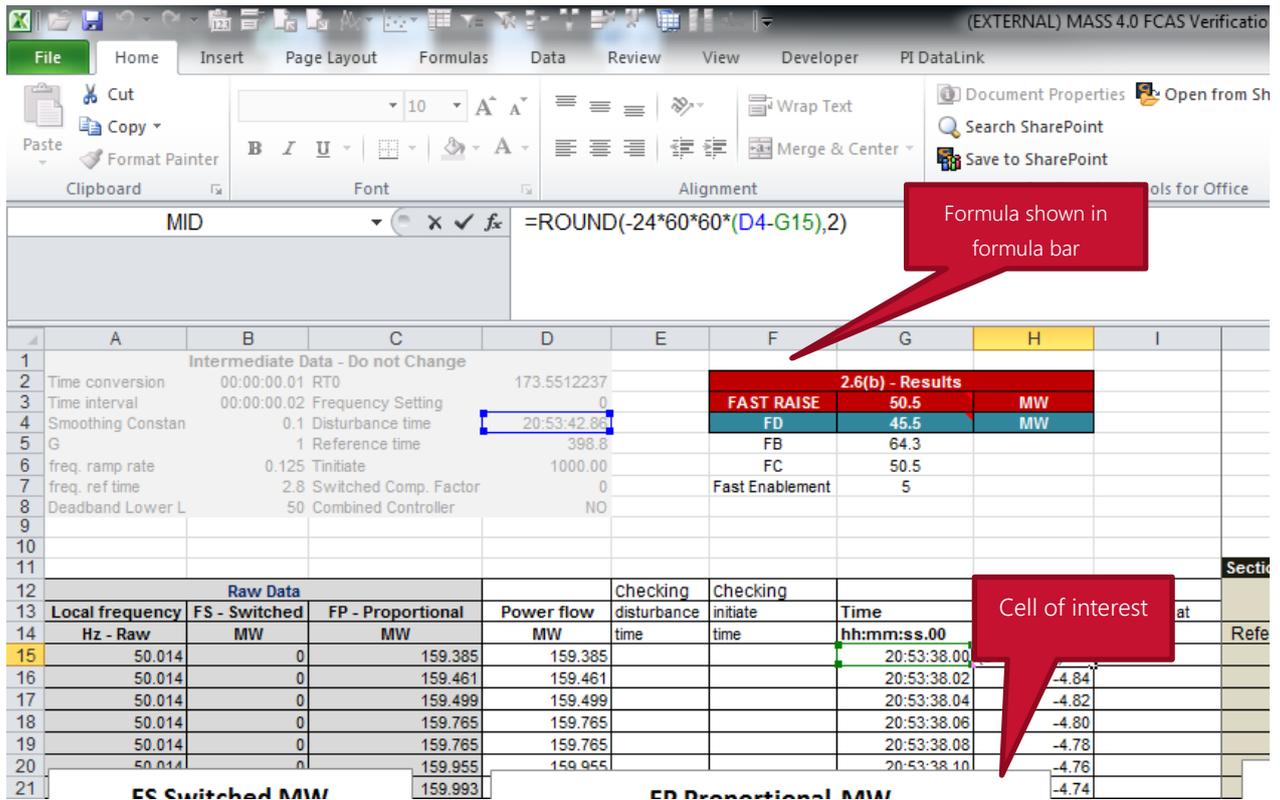
If the user wishes to inspect the formula behind a particular cell, place the cursor on that cell and click on the formula bar. This will show the underlying calculation as shown below. Variables are colour coded as a visual aid.

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.
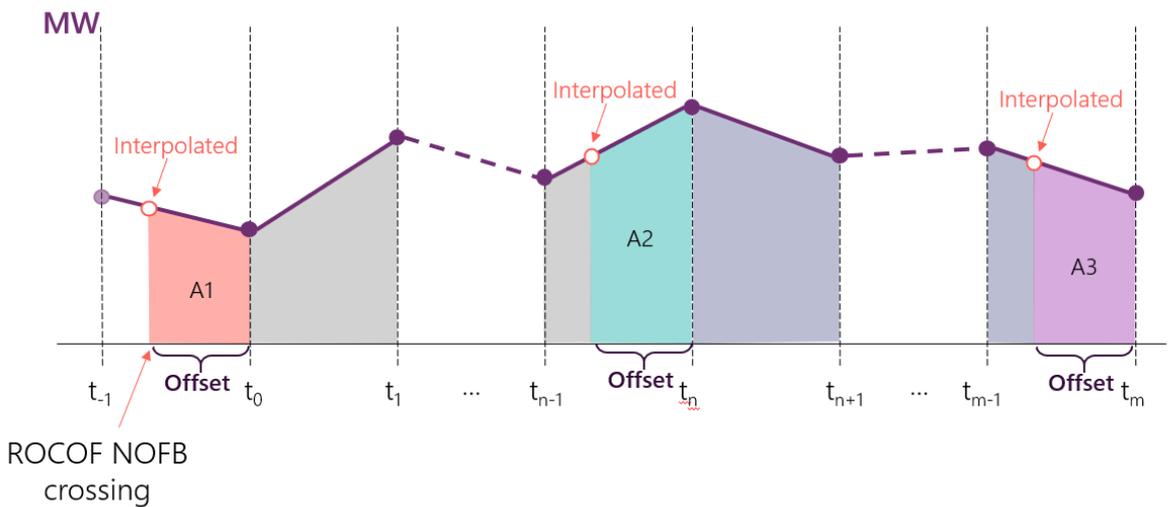
APPENDIX A. CALCULATION OF TIME AVERAGE

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 1 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 1   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 {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

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

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