AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

WEM Procedure: Essential System Service Quantities

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Version Release History

Version	Effective Date	Summary of Changes
1.0	1 October 2023	WEM Procedure developed in accordance with clauses 3.11.7 and 7.2.5 of the WEM Rules.
2.0	30 October 2025	Amendments made in accordance with Schedule 4 of the Wholesale Electricity Market Amendment (Cost Allocation Reform) Rules 2024 (Amending Rules) to update Contingency Reserve Lower requirement setting process to reflect new co-optimisation requirements. Additional changes made as general improvements or to improve clarity: • Update to Minimum RoCoF Control Requirement and Additional RoCoF Control Requirement. • Introduce service limits on Contingency Reserve services from Block Response. • Include maximum service limit for Regulation services. • Clarify how inputs associated with distributed photovoltaic systems are reflected in the Dynamic Frequency Control Model.

IMPORTANT NOTICE – EXPLANATORY NOTES

Disclaimer

Explanatory notes included in this document as shaded in-line text are provided for explanatory purposes only to assist comprehension and readability. The information contained in these explanatory notes does not constitute legal or business advice and should not be relied on as a substitute for obtaining detailed advice about the *Electricity Industry Act 2004* (WA), ESM Rules, or any other applicable laws, procedures or policies. AEMO has made reasonable efforts to ensure the quality of the information, but cannot guarantee its accuracy or completeness.

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1. Introduction

1.1. Purpose and scope

1.1.1. This WEM Procedure: Essential System Service Quantities (Procedure) is made in accordance with AEMO's functions under clause 2.1A.2(h) of the Electricity System and Market Rules (ESM Rules).

1.1.2. The *Electricity Industry Act 2004* (WA), the ESM Regulations and the ESM Rules prevail over this Procedure to the extent of any inconsistency.

1.1.3. In this Procedure, where obligations are conferred on a Rule Participant, that Rule Participant must comply with the relevant obligations in accordance with clause 2.9.7A, 2.9.7D or 2.9.8 of the ESM Rules, as applicable.

1.1.4. The purpose of this Procedure is to document:

(a) the methodologies and processes to be followed by AEMO in determining, for each Pre-Dispatch Interval and Dispatch Interval:

(i) the quantity of Regulation to schedule and dispatch, including:

(A) the identification and measurement of sources of variability **[Clause 3.11.7(a)(i)]**; and

(B) the method by which the quantity of Regulation required is calculated **[Clause 3.11.7(a)(ii)]**;

(ii) the combination of Contingency Reserve and RoCoF Control Service required to maintain the frequency of the SWIS within the Credible Contingency Event Frequency Band, including the use of Facility Speed Factors for a Facility **[Clause 3.11.7(b)]**; and

(iii) the expected quantities of any other Frequency Co-optimised Essential System Services required in each Dispatch Interval or Pre-Dispatch Interval to meet the Essential System Service Standards **[Clause 3.11.7(c)]**;

(b) the Dispatch Algorithm used by AEMO for the purpose of the Central Dispatch Process and setting Market Clearing Prices and the mathematical formulation of the Dispatch Algorithm, including:

(i) the conversion of Facility Speed Factors into Facility Performance Factors **[Clause 7.2.5(a)(i)]**; and

(ii) the calculation of Minimum RoCoF Control Requirement and Additional RoCoF Control Requirement **[Clause 7.2.5(a)(ii)]**,

in a form that:

(iii) AEMO reasonable considers will enable a third party, such as the Market Auditor or Economic Regulation Authority, to replicate the results of the Dispatch Algorithm by using the same inputs **[Clause 7.2.5(a)(vii)]**; and

(c) the methodology AEMO uses to determine:

(i) Contingency Raise Offsets **[Clause 7.2.5(b)(i)]**;

(ii) Contingency Lower Offsets **[Clause 7.2.5(b)(ii)]**;

(iii) Facility Performance Factors **[Clause 7.2.5(b)(iii)]**;

(iv) the Minimum RoCoF Control Requirement **[Clause 7.2.5(b)(iv)]**;

(v) the Additional RoCoF Control Requirement **[Clause 7.2.5(b)(v)]**; and

(vi) the RoCoF Upper Limit **[Clause 7.2.5(b)(vii)].**

E[A] Items from clause 7.2.5

Clause 7.2.5 of the ESM Rules requires AEMO to document a range of detailed aspects in the design and implementation of the Dispatch Algorithm.

The bulk of these requirements are included in the WEM Procedure: Dispatch Algorithm Formulation, which covers the core optimisation problem to be solved by the dispatch engine.

The sub-clauses of 7.2.5 listed above [(a)(i), (a)(ii), (b)(i) to (b)(v) inclusive, and b(vii)] are instead included in this Procedure. These items are not determined as part of the regular dispatch engine solutions, but are instead established in advance of Market Schedules using methodologies as required to be documented in this Procedure under clause 3.11.7.

1.1.5. Appendix A of this Procedure outlines the head of power clauses that this Procedure is made under, as well as other clauses of the ESM Rules requiring an obligation, process or requirement be documented in this Procedure.

1.2. Definitions

1.2.1. Terms defined in the *Electricity Industry Act 2004* (WA), the ESM Regulations and the ESM Rules have the same meanings in this Procedure unless the context requires otherwise.

1.2.2. The following definitions apply in this Procedure unless the context requires otherwise.

Table 1 Definitions

Term	Definition
Block Response	A manner of providing a Contingency Reserve where the response delivers a specific amount of service when one or more specified conditions are met and where each amount of service is a quantity independently capable of responding to Contingency Events.
Contingency Reserve Maximum Provision Percentage	Means a percentage figure, which sets the upper limit of provision of Contingency Reserve Raise or Contingency Reserve Lower by a single Registered Facility.
Dynamic Frequency Control Model (DFCM)	Has the meaning in paragraph 3.1.2.
ESS System Configuration	Has the meaning in paragraph 3.1.1.
High-Resolution Time Synchronised Data Recorder	Measurements of the following types of information: 1. Substation busbar voltage, current, real and reactive power output (MW and MVAr) and frequency; 2. Circuit breaker and protection devices status; and 3. Any other data collected by the High-Resolution Time Synchronised Data Recorder.
Largest Credible Load Contingency Coefficient	A coefficient applied to the variable representing the size of the Largest Credible Load Contingency when determining the Contingency Reserve Lower Requirement against the size of the Largest Credible Load Contingency

Term	Definition
Largest Credible Load Contingency Constant	A constant added to the Largest Credible Load Contingency when determining the Contingency Reserve Lower requirement.
LCLC Inertia Baseline Constant	The constant term for the Largest Credible Load Contingency used to determine the Minimum RoCoF Control Requirement under paragraph 4.1.1.
LCLC Inertia Sensitivity Coefficient	The coefficient term for the Largest Credible Load Contingency used to determine the Minimum RoCoF Control Requirement under paragraph 4.1.1.
LCSC Inertia Baseline Constant	The constant term for the Largest Credible Supply Contingency used to determine the Minimum RoCoF Control Requirement under paragraph 4.1.1.
LCSC Inertia Sensitivity Coefficient	The coefficient term for the Largest Credible Supply Contingency used to determine the Minimum RoCoF Control Requirement under paragraph 4.1.1.
Load Relief Factor	A parameter to be applied to the Underlying System Load within the DFCM, to account for the phenomenon in which electrical load varies proportionally with system frequency.
Margin for Operation	A margin applied by AEMO when determining Frequency Co-optimised Essential System Services quantities to account for uncertainty.
Non-Securable ESS System Configuration	An ESS System Configuration in which the DFCM determines no quantity of Frequency Control Essential System Service would allow a Secure Operating State.
Reference ESS System Configuration	Has the meaning in paragraph 3.2.1.
Regulation Baseline Model	Has the meaning in paragraph 5.1.1.
Residual Inertia	AEMO's estimate of Inertia provided by any Facilities and other equipment connected to the SWIS that are not accredited for RoCoF Control Service.
Regulation Maximum Provision Percentage	Means a percentage figure, which sets the upper limit of provision of Regulation Raise or Regulation Lower by a single Registered Facility.
RoCoF Control Service Requirement	The portion of the RoCoF Control Service quantity that is determined endogenously in the Dispatch Algorithm and must be procured for the Dispatch Interval or Pre-Dispatch Interval.
Total Contingency Reserve Block Size	The maximum provision of Contingency Reserve Raise or Contingency Reserve Lower from all providers using a control scheme to deliver a set quantity (to provide a Block Response), expressed as either an absolute value, or a percentage of the total provision of the relevant Contingency Service.
Underlying System Load	AEMO's estimate of behind-the-meter demand that is responsive to changes in frequency. Underlying System Load may differ from Forecast Operational Demand due to "behind the meter" and other non-registered generation sources.
WEMDE	Wholesale Electricity Market Dispatch Engine.

1.3. Interpretation

1.3.1. The following principles of interpretation apply in this Procedure unless the context requires otherwise.

(a) Clauses 1.3 to 1.5 of the ESM Rules apply in this Procedure.

(b) References to time are references to Australian Western Standard Time.

(c) Terms that are capitalised, but not defined in this Procedure, have the meaning given in the ESM Rules.

(d) A reference to the ESM Rules or WEM Procedures includes any associated forms required or contemplated by the ESM Rules or WEM Procedures.

(e) Words expressed in the singular include the plural and vice versa.

(f) A reference to a paragraph refers to a paragraph of this Procedure.

(g) A reference to an appendix refers to an appendix of this Procedure.

(h) A reference to a clause refers to a clause or section of the ESM Rules.

(i) References to ESM Rules in this Procedure in bold and square brackets **[Clause XXX]** are included for convenience only, and do not form part of this Procedure.

(j) Text located in boxes and headed as **E[X]** in this Procedure is included by way of explanation only and does not form part of this Procedure. The Procedure prevails to the extent of any inconsistency with the explanatory notes contained within it.

(k) The body of this Procedure prevails to the extent of any inconsistency with the figures, diagrams, appendices, schedules, annexures or attachments contained within this document.

(l) Measurements are specified using the International System of Units with the following symbols:

(i) Hz: hertz.

(ii) mHz: millihertz.

(iii) MW: megawatt.

(iv) MWs: Megawatt-second.

(v) MVAr: Megavolt-ampere reactive.

1.3.2. This Procedure must be read in conjunction with the ESM Rules relevant to this WEM Procedure, noting that in many cases the ESM Rules provide descriptive processes, timeframes and other obligations which are not duplicated in AEMO's WEM Procedures.

1.4. Related documents

1.4.1. The documents in Table 2 are associated with this Procedure.

Table 2 Related documents

Reference	Title	Location
WEM Procedure	WEM Procedure: Dispatch Algorithm Formulation	WEM Website
WEM Procedure	WEM Procedure: Frequency Co-optimised Essential System Service Accreditation	WEM Website

2. Frequency Co-optimised Essential System Services principles

E[B] Feedback control systems

The term 'feedback control system' is used here to mean an algorithm or decision-making component that repeatedly measures output performance against a target reference and adjusts input variables to minimise the difference between output performance and the target reference.

2.1.1. AEMO will take the following principles into account in determining Frequency Co-optimised Essential System Service quantities for each Dispatch Interval and each Pre-Dispatch Interval:

(a) in managing risk and uncertainty in real-time operations:

(i) the application of empirical validation and Margin for Operations is essential in applying good system operations engineering practice;

(ii) a simpler approach that covers a wider range of plausible operational circumstances is preferred to a complex approach that performs better under a narrower range of circumstances; and

(iii) any model or practice needs continual monitoring, refinement, and tuning to remain effective in a changing environment;

(b) advanced models and fundamental analysis may inform the selection of input variables, but physical measurements, statistics, and feedback control systems should be used to define, support, or validate determinations, where possible; and

(c) controlled experimentation is necessary to validate model predictions and confirm the secure operating envelope.

2.1.2. Where AEMO is required to make an operational decision or determination that is not explicitly described in this Procedure that may be necessary to ensure Power System Security or Power System Reliability, AEMO must make reasonable endeavours (to the extent that time constraints and other circumstances allow) to follow the principles in paragraph 2.1.1.

3. Contingency Reserve services

E[C] Contingency services

Contingency Reserve services are required to ensure Facilities can rapidly adjust their Injection or Withdrawal after a Contingency Event to maintain frequency stability. To procure Contingency Reserve services, AEMO:

1. analyses the system configuration and historical occurrences to determine the set of Credible Contingency Events to prepare for;
2. models system performance and determines the necessary quantities of Contingency Reserve services to manage the set of Credible Contingency Events to meet the Frequency Operating Standards; and
3. operates the Real-Time Market to purchase the necessary quantities and dispatch reserves among the fleet of Facilities accordingly.

Paragraph 3.1 describes the second step of the process – refer to the below documents for more information on the other steps:

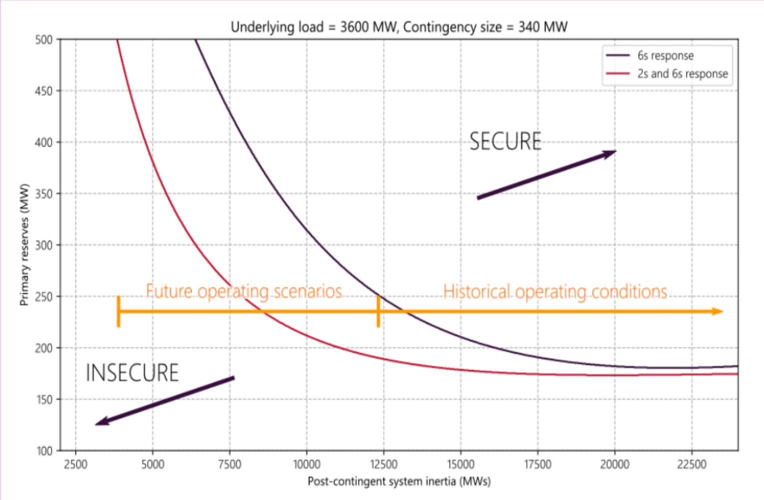
- WEM Procedure: Credible Contingency Events (step 1)
- WEM Procedure: Dispatch Algorithm Formulation (step 3)

3.1. The Dynamic Frequency Control Model

E[D] Dynamic contingency modelling

Figure E[1] shows a conceptual overview of the Contingency Event management framework, as applied in the SWIS.

Figure E[1] Inertia-primary reserve secure zone



The diagram illustrates how, for a given Contingency Event size (in MW) and Underlying System Load, the interplay between System Inertia and Contingency Reserve Raise (both speed and quantity) defines a secure operating region.

It is not practical to run the detailed calculations needed to determine the secure operating region in real time. The relationship between parameters (such as speed of response and Inertia) and contingency services is also non-linear, while WEMDE can only optimise linear Constraint Equations to procure these services.

This paragraph describes the methodology AEMO will use to manage the requirements for Contingency Event management to support secure and optimal market dispatch. At a high level, AEMO uses an 'offline' power systems model to pre-calculate the required contingency services for all plausible operating configurations and stores secure results as a look-up table.

AEMO uses this look-up table as an input to the Dispatch Algorithm, which will interpolate between different system configurations that result in a Secure Operating State to select the optimal configuration of contingency services.

3.1.1. An ESS System Configuration is a scenario for the configuration of the SWIS defined by a combination of parameters representing:

(a) Underlying System Load;

(b) Load Relief Factor;

(c) Facility Speed Factor;

(d) Largest Credible Supply Contingency or Largest Credible Load Contingency;

(e) estimated total generation from distributed photovoltaic systems connected to the SWIS; and

(f) any other factor that AEMO determines necessary to accurately predict frequency performance for system operations.

3.1.2. The DFCM is a computer simulation of the SWIS Frequency that uses an ESS System Configuration as an input and, for a given quantity of System Inertia, calculates as separate outputs, the quantity of:

(a) Contingency Reserve Raise in response to the Largest Credible Supply Contingency; or

(b) Contingency Reserve Lower in response to the Largest Credible Load Contingency, required to maintain the SWIS Frequency within the Credible Contingency Event Frequency Band.

3.1.3. AEMO:

(a) will determine the set of ESS System Configurations needed to cover the range of credible operating conditions for the SWIS; and

(b) may, from time to time, change the set of ESS System Configurations determined in paragraph 3.1.3(a) to more accurately reflect the current operating conditions of the SWIS.

3.1.4. For any set of ESS System Configurations determined by AEMO in accordance with paragraph 3.1.3, AEMO will:

(a) develop and maintain the DFCM, and use it to determine, for each of the relevant ESS System Configurations, the combinations of System Inertia and Contingency Reserve required to maintain SWIS Frequency within the Credible Contingency Event Frequency Band; and

(b) publish on the WEM Website the set of ESS System Configurations and the associated combinations of System Inertia and Contingency Reserve determined in paragraph 3.1.4(a) as outputs of the DFCM.

3.1.5. In developing and maintaining the DFCM in paragraph 3.1.4(a), AEMO:

(a) may determine and use a single estimation of SWIS Frequency to apply at all Network locations;

(b) will use an initial condition of SWIS Frequency at 50 Hz;

(c) may include a Margin for Operation from the Credible Contingency Event Frequency Band to account for the uncontrolled risk of:

(i) an initial condition of SWIS Frequency other than 50 Hz; and

(ii) Facility non-delivery or under-delivery of Contingency Reserve services;

(d) may determine the appropriate form and level of detail of the DFCM components, inputs, approximations, and simulation parameters; and

(e) may, from time to time, change any of the aspects listed in paragraph 3.1.5(d) to improve the accuracy, robustness, or performance of the DFCM.

3.1.6. AEMO will, as soon as practicable, use the DFCM to recalculate and publish the model outputs in accordance with paragraph 3.1.4 where:

(a) AEMO changes the DFCM in accordance with paragraph 3.1.5(e); or

(b) The Frequency Operating Standards change.

3.1.7. If AEMO includes a Margin for Operation in the DFCM in accordance with paragraph 3.1.5(c), AEMO will publish the Margin for Operation on the WEM Website.

3.1.8. Where the DFCM is applied in accordance with paragraph 3.1.4 to determine combinations of System Inertia and Contingency Reserve, and the simulation identifies that SWIS Frequency:

(a) exceeds the RoCoF Safe Limit for the quantity of RoCoF Control Service; or

(b) cannot be maintained within the Credible Contingency Event Frequency Band for a quantity of Contingency Reserve less than or equal to the relevant Largest Credible Supply Contingency or Largest Credible Load Contingency, AEMO will determine that ESS System Configuration is a Non-Securable ESS System Configuration.

3.1.9. For each Dispatch Interval or Pre-Dispatch Interval, AEMO will use measurements, readings, or forecasts of the parameters in paragraph 3.1.1, as applicable, to determine the forecast ESS System Configuration for the relevant Dispatch Interval or Pre-Dispatch Interval.

3.1.10. Following an occurrence of either a Credible Contingency Event which was the Largest Credible Supply Contingency or the Largest Credible Load Contingency, at that time AEMO may:

(a) validate the approximations and predicted outcomes of the DFCM against SWIS Frequency data measured using a High-Resolution Time Synchronised Data Recorder from at least two Network locations;

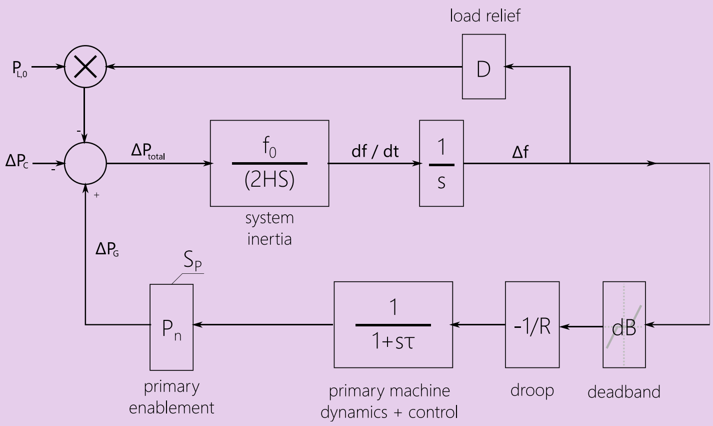
(b) determine and make any necessary changes to the DFCM in accordance with paragraph 3.1.5(e); and

(c) publish the reasons for the changes to the DFCM on the WEM Website.

E[E] The Dynamic Frequency Control Model

Figure E[2] shows the conceptual form of the DFCM setup for a Contingency Event relating to loss of generation, presented as a control system block diagram:

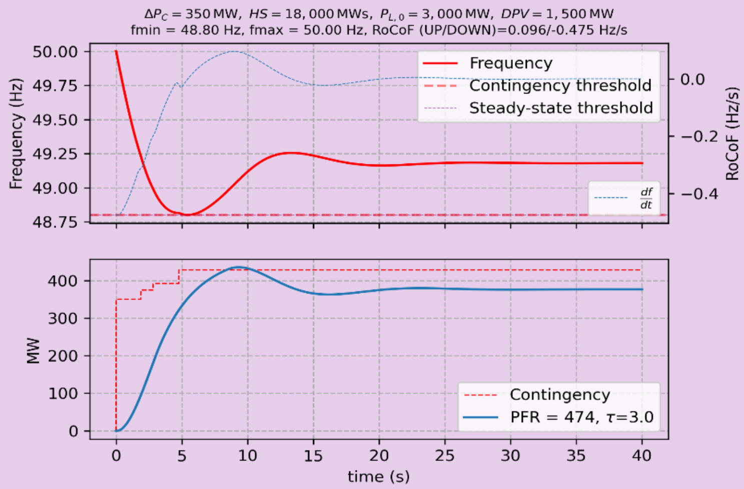
Figure E[2] Illustrative format of the DFCM



For a given set of inputs, Underlying System Load ($P_{L,0}$), System Inertia (HS), and Facility Speed Factor (τ), the required combinations of Contingency Reserve service and RoCoF Control Service are determined by numerically integrating the DFCM. From a starting frequency of 50 Hz and a contingency of ΔP_C, the DFCM is run over different levels of primary enablement (S_p) to ensure that the Frequency Operating Standards (± any Margin for Operation) are exactly met.

In the model, a standard droop response of 4% ($R = 25$) and deadband of 25 mHz are used. Refer to AEMO's WEM Procedure: Frequency Co-optimised Essential System Service Accreditation for how these parameters are calibrated against physical Facility performance.

Figure E[3] Example output from the DFCM



The diagram in Figure E[3] shows example simulation results corresponding to a given ESS System Configuration, as referenced in paragraph 3.1.2(a), determining that 474 MW of Contingency Reserve Raise with a Facility Speed Factor of three seconds is required, in combination with 18,000 MWs of System Inertia, for the given inputs. This example satisfies a minimum frequency of 48.80 Hz, allowing a 0.05 Hz Margin for Operation above the Credible Contingency Event Frequency Band. This example uses AEMO's estimate of loss of distributed photovoltaic generation based on historical performance. Distributed photovoltaic generation loss following a Credible Contingency Event may be modelled as two distinct components: voltage-dependant and frequency-dependent. The voltage-dependent loss occurs rapidly following the Credible Contingency Event and is included in the initial loss of Injection or Withdrawal. The frequency-dependant component is modelled as three discrete 'blocks' of distributed photovoltaic generation loss in the seconds following the Credible Contingency Event, as system frequency declines to specific thresholds. In this example, this results in a total loss of generation of 474 MW, up from the initial loss of 350 MW in the initial Credible Contingency Event.

Historical event analyses have demonstrated comparable SWIS Frequency, which makes a low-order single mass machine model suitable for frequency stability studies. AEMO will monitor this performance across incidents and may identify conditions where this assumption is no longer suitable in accordance with paragraph 3.1.5(d).

Note that the DFCM does not otherwise choose or give preference to any specific Frequency Control Essential System Service combinations for dispatch; this is optimised by the Dispatch Algorithm based on Facilities' Real-Time Market Offers.

3.2. Conversion of DFCM solutions for the Dispatch Algorithm

3.2.1. For a given ESS System Configuration, the Reference ESS System Configuration is an ESS System Configuration with parameters identical to the given ESS System Configuration, except that the Facility Speed Factor is set to 0.2.

E[F] Conversion of DFCM parameters for the Dispatch Algorithm for Contingency Reserve Raise

Outputs of the DFCM need to be converted into the format required by the Dispatch Algorithm.

Consider the example shown in Figure E[3] in explanatory box E[E] above, which has the following set of input parameters:

- Underlying System Load: 3000 MW
- Load Relief Factor: 2%
- Facility Speed Factor: 3 s
- Largest Credible Supply Contingency: 350 MW
- distributed photovoltaic generation: 1500 MW

For a RoCoF Control Service of 18,000 MWs, the example DFCM determines 473 MW of Contingency Reserve Raise is required. The relevant parameters for the Dispatch Algorithm are Contingency Raise Offset: 350 MW – 473 MW = –123 MW

Re-running the same input set with a Facility Speed Factor of 0.2 s determines $CR_{0.2}$ = 321 MW, hence Facility Performance Factor (FPF_3) for a Facility with Facility Speed Factor of 3 would be: FPF_3= 321 MW / 473 MW = 0.67

> Refer to the WEM Procedure: Dispatch Algorithm Formulation for a description of how these parameters are used in the Dispatch Algorithm.

3.2.2. Using the combinations that are outputs of the DFCM calculated in accordance with paragraph 3.1.4(a), for each ESS System Configuration and associated combinations of RoCoF Control Service and Contingency Reserve Raise, AEMO will determine the corresponding:

(a) Contingency Raise Offset as the difference between the Largest Credible Supply Contingency and required Contingency Reserve Raise for the Reference ESS System Configuration;

(b) linear approximation of the relationship between the size of a Credible Contingency Event that would result in a net loss of Injection, in MW, and the minimum quantity of Inertia, in MWs that, in AEMO's reasonable opinion, is necessary to maintain SWIS Frequency within the Credible Contingency Event Frequency Band, were the Credible Contingency Event to occur; and

(c) Facility Performance Factor for Contingency Reserve Raise, for the ESS System Configuration:

(i) as zero, if the relevant ESS System Configuration was determined as a Non-Securable ESS System Configuration in accordance with paragraph 3.1.8;

(ii) otherwise:

$$\mathrm{FPF}_{\tau} = \frac{\mathrm{CRR}_{0.2}}{\mathrm{CRR}_{\tau}}$$

where:

(A) τ is the Facility Speed Factor in the relevant ESS System Configuration;

(B) FPF_{τ} is the Facility Performance Factor corresponding to τ;

(C) CRR_{τ} is the Contingency Reserve Raise quantity for τ; and

(D) $\mathrm{CR}_{0.2}$ is the Contingency Reserve Raise quantity for the Reference ESS System Configuration.

3.2.3. AEMO will determine a representative combination of Facility Speed Factors based on the expected response of Facilities to a Credible Contingency Event resulting in a net loss of Withdrawal, based on typical dispatch patterns within the SWIS.

3.2.4. Using the representative combination of Facility Speed Factors determined in paragraph 3.2.3, and the outputs of the DFCM calculated in accordance with paragraph 3.1.4(a), AEMO will determine the corresponding:

(a) a linear approximation of the relationship between the size of a Credible Contingency Event that would result in a net loss of Withdrawal, in MW, and the minimum quantity of Inertia, in MWs that, in AEMO's reasonable opinion, is necessary to maintain SWIS Frequency within the Credible Contingency Event Frequency Band, were the Credible Contingency Event to occur; and

(a) Largest Credible Load Contingency Coefficient and Largest Credible Load Contingency Constant.

3.2.5. For each Dispatch Interval, AEMO will determine the Contingency Lower Offset as the difference between the Largest Credible Load Contingency and the Contingency Reserve Lower requirement.

3.2.6. In determining quantities under paragraphs 3.2.2 and 3.2.4, AEMO will account for the Network configuration of the SWIS, including circumstances where parts of the SWIS are being operated as an Island.

3.2.7. AEMO will use the Contingency Raise Offset values determined in paragraph 3.2.2(a), and the Facility Performance Factors for Contingency Reserve Raise determined in paragraph 3.2.2(c) as inputs to the Dispatch Algorithm, selecting values that, in AEMO's reasonable opinion, most accurately represent conditions in the SWIS for the relevant Dispatch Interval or Pre-Dispatch Interval, in accordance with the WEM Procedure: Dispatch Algorithm Formulation, and WEM Procedure: Market Schedules.

3.2.8. AEMO will use the Largest Credible Load Contingency Coefficient and Largest Credible Load Contingency Constant in accordance with the WEM Procedure: Dispatch Algorithm Formulation, and WEM Procedure: Market Schedules.

4. RoCoF Control Service

4.1. Minimum and Additional RoCoF Control Requirement

4.1.1. For each Dispatch Interval, AEMO will determine the Minimum RoCoF Control Requirement using the following equation:

$$MAX\begin{bmatrix}\alpha_{LCSC} \times LCSC + \beta_{LCSC} - LoadInertia, \\ \alpha_{LCLC} \times LCLC + \beta_{LCLC} - LoadInertia, \\ 0\end{bmatrix}$$

where:

(a) $LCSC$ is the Largest Credible Supply Contingency;

(b) $LCLC$ is the Largest Credible Load Contingency;

(c) α_{LCSC} is the LCSC Inertia Sensitivity Coefficient;

(d) β_{LCSC} is the LCSC Inertia Baseline Constant;

(e) α_{LCLC} is the LCLC Inertia Sensitivity Coefficient;

(f) β_{LCLC} is the LCLC Inertia Baseline Constant; and

(g) $LoadInertia$ is AEMO's reasonable estimate of the quantity of System Inertia that is contributed by equipment other than Registered Facilities accredited to provide RoCoF Control Service.

4.1.2. In determining parameters defined in paragraphs 4.1.1(c) and 4.1.1(d), AEMO will use a linear approximation of the relationship between Largest Credible Supply Contingency and System Inertia from the outputs of the DFCM calculated in accordance with paragraph 3.1.

4.1.3. In determining parameters defined in paragraphs 4.1.1(e) and 4.1.1(f), AEMO will use a linear approximation of the relationship between Largest Credible Load Contingency and System Inertia from the outputs of the DFCM calculated in accordance with paragraph 3.1.

E[G] Linear representation for System Inertia

This explanatory note provides a general example and additional context of the linearisation of the relationship between System Inertia and the size of the Largest Credible Supply Contingency, outlined in the equations in paragraph 4.1.1.

In the SWIS, the most critical factor in determining the amount of required System Inertia within the RoCoF Safe Limit is the contingency size. AEMO uses the linear equation "$\text{System Inertia} = \frac{\Delta P_C \times f_0}{2 \times df/dt}$" for System Inertia with respect to the contingency size (ΔP_C), "*instant*" Rate of Change of Frequency (RoCoF) (df/dt) and nominal frequency (f_0 equal to 50 Hz). However, the equation needs adjustments to take into account the RoCoF Safe Limit ($RoCoF_{safeLimit}$) which is defined over a 500 millisecond time window. The rest of this explanatory note demonstrates the need for coefficients and constants defined under paragraph 4.1.1 to be able to present the relationship linearly.

For instant RoCoF (df/dt):

$$\text{System Inertia} = \frac{\Delta P_C \times f_0}{2 \times df/dt}$$

Since the RoCoF Safe Limit ($RoCoF_{safeLimit}$) is defined over a 500 millisecond time window, AEMO considers the below linear relationship to determine the required System Inertia to maintain RoCoF within the RoCoF Safe Limit:

$$\text{System Inertia} = \alpha \frac{\Delta P_C \times f_0}{2 \times RoCoF_{safeLimit}} + \beta$$

where α and β are respectively a coefficient and a constant applied to the generic equation for instant RoCoF, i.e. equation "$\text{System Inertia} = \frac{\Delta P_C \times f_0}{2 \times df/dt}$", to represent a linear approximation for Inertia required over a 500 millisecond time window. The equation can be re-written as below with all fixed values coming under a single coefficient and constant.

$$\text{System Inertia} = \alpha_c \times \Delta P_C + \beta_c$$

where:

$\alpha_c = (\alpha \times f_0)/(2 \times RoCoF_{safeLimit})$

$\beta_c = \beta$

α_c and β_c, being described as sensitivity coefficient and baseline constant in paragraph 4.1.1, are derived from a linearisation (as per paragraphs 4.1.2 and 4.1.3.) applied to the non-linear DFCM model described under paragraph 3.1. The parameters are considered separately for the Largest Credible Supply Contingency (as in α_{LCSC} and β_{LCSC}) and Largest Credible Load Contingency (as in α_{LCLC} and β_{LCLC}) and are used in the WEM Procedure: Dispatch Algorithm Formulation.

4.1.4. For each Dispatch Interval, AEMO will determine the Additional RoCoF Control Requirement as the total requirement for RoCoF Control Service determined via the Central Dispatch Process, minus the Minimum RoCoF Control Requirement.

4.2. RoCoF Upper Limit

4.2.1. In determining and publishing the RoCoF Upper Limit in accordance with clause 7.5.14, AEMO will:

(a) determine an ESS System Configuration that includes AEMO's forecast estimate for the next 12 months of the credible scenarios for the:

(i) smallest Underlying System Load;

(ii) smallest applicable Load Relief Factor;

(iii) greatest Largest Credible Supply Contingency; and

(iv) greatest Largest Credible Load Contingency; and

(b) determine the RoCoF Upper Limit as the maximum rate of change of frequency in the DFCM when the DFCM is run with inputs consisting of the ESS System Configuration determined in paragraph 4.2.1(a) and a System Inertia determined as the lesser of:

(i) 3000 MWs; or

E[H] Theoretical Minimum System Inertia

A total System Inertia of 3,000 MWs is assumed to represent a hypothetical low-Inertia operating condition, corresponding to the RoCoF Upper Limit under which the SWIS can still theoretically operate. This level reflects periods when synchronous generation is reduced, yet the system remains stable and capable of maintaining secure operation. It is worth noting that this assumed Inertia threshold and the corresponding RoCoF Upper Limit are determined independently of Network Constraints and the RoCoF Ride-Through Capability of Registered Facilities.

(ii) AEMO's estimate of the forecast equivalent minimum Inertia available over the next 12 months, incorporating AEMO's expectation of addition or retirement of equipment and Facilities to the SWIS in this period.

5. Regulation services

E[I] Regulation services

Regulation of the SWIS Frequency requires the adjustment of Injection or Withdrawal to match relatively small fluctuations in demand that occur during real-time operations.

Unlike contingency management, the longer timescales, uncertainty, and range of phenomena that contribute to demand fluctuations means that analytic power system models are ineffective at predicting Regulation service quantity requirements.

Instead, the core approach described in this paragraph is a feedback process consisting of:

- the selection of forecastable inputs to feed into a statistical prediction (machine learning) model; and
- the ability for AEMO to gradually increase or decrease quantities as required to manage real-time volatility conditions.

The statistical model is continually fed actual (measured) Regulation usage statistics and uses these to improve forecasting performance.

Similarly, both the input selection and detailed parameters of the model may be refined over time to improve both accuracy and operational effectiveness.

5.1. The Regulation Baseline Model

5.1.1. The Regulation Baseline Model is a statistical model that relates forecastable signals to the observed usage of Regulation in real-time system operations.

5.1.2. AEMO will:

(a) develop and maintain the Regulation Baseline Model; and

(b) periodically use the Regulation Baseline Model to set the required quantity of Regulation Lower and Regulation Raise for each Dispatch Interval and Pre-Dispatch Interval, except where this quantity is varied under paragraph 7.

5.1.3. In developing and maintaining the Regulation Baseline Model in accordance with paragraph 5.1.2(a), AEMO:

(a) will use a combination of the following as inputs (as relevant) to the model:

(i) solar irradiation and cloud cover;

(ii) wind speed;

(iii) Forecast Operational Demand;

(iv) other indirect factors that affect approximate quantities in paragraph 5.1.2(b), including but not limited to:

(A) time of day;

(B) day of the week, public holidays, or other scheduled events; and

(C) time of year or season;

(v) approximations of uncertainty and dispatch error, including but not limited to:

(A) output variation and non-conformance of Registered Facilities; and

(B) communications delay and other latency in market dispatch or physical Facility response; and

(vi) any other forecastable source of variation that AEMO deems necessary to consider;

(b) will determine a metric that quantifies the usage of Regulation service through any period of at least five minutes;

(c) will determine a statistical relationship between each of the factors in paragraph 5.1.3(a) and the usage metric determined in accordance with paragraph 5.1.3(b);

(d) may modify the raw statistics determined in paragraph 5.1.3(c) to reduce error and improve operational performance through any combination of the following:

E[J] Inapplicable system conditions

Emergency and other non-standard SWIS Operating States may generate statistics under paragraph 5.1.3(c) that do not reflect effective use of Regulation services for frequency management.

For example, in the period following a major Contingency Event, Regulation resources are generally exhausted, and these statistics will bias the perceived requirement for additional Regulation services. However, by definition, these circumstances should be managed using Contingency Reserve services and, therefore, may be removed from the Regulation statistics.

Similarly, system conditions following a system black event or a Real-Time Market suspension under clause 7.11D may also result in non-standard Regulation metrics and will be removed from forecasts of future requirements.

(i) removal of select time periods from the statistics due to corrupt data or inapplicable system conditions that result in non-standard Regulation metrics;

(ii) application of a smoothing filter;

(iii) determination of a confidence interval and selection of an appropriate confidence level; and

(iv) addition of a Margin for Operation;

(e) will determine the appropriate Regulation quantities for a Dispatch Interval or Pre-Dispatch Interval as the result of applying the statistical relationship in paragraph 5.1.3(c), including any modifications in accordance with paragraph 5.1.3(d), to the quantities of the inputs that are forecast under paragraph 5.1.3(a) for the relevant Dispatch Interval or Pre-Dispatch Interval; and

(f) may, from time to time, change any of the following aspects of the Regulation Baseline Model:

(i) add a new input in accordance with paragraph 5.1.3(a);

(ii) redetermine a metric to apply under paragraph 5.1.3(b); and

(iii) adjust, add, or remove any modifications made in accordance with paragraph 5.1.3(d), to improve accuracy, performance, or robustness of the model overall.

5.1.4. For any input used in the Regulation Baseline Model in accordance with paragraph 5.1.3(a), AEMO:

(a) will determine the appropriate data source and forecasting method; and

(b) may, from time to time, update the data source or forecasting method determined in accordance with paragraph 5.1.4(a).

5.2. Real-time adjustment of Regulation quantities

5.2.1. As new information becomes available to AEMO, if AEMO determines that the scheduled Regulation service quantities are:

(a) insufficient to manage expected system conditions; or

(b) in excess of what is required to manage expected system conditions,

AEMO may increase or decrease Regulation service quantities or forecast quantities for a Dispatch Interval or Pre-Dispatch Interval as AEMO determines necessary to ensure compliance with Frequency Operating Standards.

6. Service limits

E[K] Contingency Reserve Maximum Provision Percentage

In circumstances where market outcomes result in a single provider supplying most of a Contingency Reserve service, the (non-credible) combination of a largest Contingency Event and non-delivery of the Contingency Reserve service by the single provider can result in frequency instability that risks total loss of electricity to the SWIS. The 80% threshold specified under paragraph 6.1.1 enables AEMO to ensure that under frequency load shedding schemes have sufficient time to operate in these extreme circumstances.

6.1.1. AEMO may limit the provision of Contingency Reserve Raise or Contingency Reserve Lower from a single provider to the Contingency Reserve Maximum Provision Percentage, being 80% of the total required quantity of the relevant service for a Dispatch Interval.

6.1.2. AEMO may limit the total provision of Contingency Reserve Raise or Contingency Reserve Lower from providers using a control scheme to deliver a set quantity (to provide a Block Response) to the Total Contingency Reserve Block Size for the relevant Contingency Reserve service.

6.1.3. Where AEMO determines a limit applies under paragraph 6.1.2, AEMO will publish the Total Contingency Reserve Block Size on the WEM Website.

6.1.4. AEMO may limit the provision of Regulation Raise or Regulation Lower from a single provider to the Regulation Maximum Provision Percentage, being 80% of the total required quantity of the relevant service.

7. Requirements during unforeseen circumstances

7.1.1. During any of the following circumstances:

(a) the SWIS is in an Emergency Operating State, or AEMO determines that immediate action is required to avoid an Emergency Operating State;

(b) AEMO has activated the System Restart Plan;

(c) the SWIS is operating under Controlled Circumstances;

(d) AEMO has suspended the Real-Time Market;

(e) an AEMO Intervention Event is in progress;

(f) AEMO has:

 (i) directed the Network Operator to maintain frequency in accordance with an Operating Protocol prepared under clause 3.1A.1; or

 (ii) delegated functions in accordance with clause 2.1A.3;

(g) a Forced Outage has resulted in under-delivery of a Frequency Control Essential System Service;

(h) a Non-Credible Contingency Event has occurred;

(i) a Commissioning Test is in progress; or

(j) any other event has occurred that AEMO determines is a material threat to AEMO's ability to manage Power System Security,

AEMO may override any Frequency Control Essential System Service quantity for a Dispatch Interval or Pre-Dispatch Interval determined in accordance with paragraphs 3.2.7, 4.1.4, or 5.1.2(b), and replace the quantity with a value AEMO determines necessary to manage Power System Security for the duration that the circumstances apply.

7.1.2. There are no methodologies or processes required for other Frequency Control Essential System Services, as no additional Frequency Control Essential System Services, other than Regulation, Contingency Reserve and RoCoF Control Service, are required to meet the Essential System Service Standards.

Appendix A. Relevant clauses of the ESM Rules

Table 3 details:

(a) the head of power clauses in the ESM Rules under which the Procedure has been developed; and

(b) each clause in the ESM Rules requiring an obligation, process or requirement be documented in a WEM Procedure, where the obligation, process or requirement has been documented in this Procedure.

Table 3 Relevant clauses of the ESM Rules

Clause
3.11.7
7.2.5(a)(i)
7.2.5(a)(ii)
7.2.5 (a)(vii)
7.2.5(b)(i)
7.2.5(b)(ii)
7.2.5(b)(iii)
7.2.5(b)(iv)
7.2.5(v)
7.2.5(b)(vii)