WHOLESALE ELECTRICITY MARKET PROCEDURE: CONSTRAINT FORMULATION

PREPARED BY:	AEMO System Management WA
DOCUMENT REF:	XX-XXXX
VERSION:	0.1
EFFECTIVE DATE:	01 OCTOBER 2022
STATUS:	DRAFT

Approved for distribution and use by:

APPROVED BY:	[NAME]
TITLE:	[Title]

DATE: 01 / OCTOBER / 2020

VERSION RELEASE HISTORY

Version	Effective Date	Summary of Changes
0.1	1 October 2022	First draft Transitional Procedure released for consultation at Meeting 5 (2 October 2020) the WEM Reform Implementation Group.

IMPORTANT NOTICE - EXPLANATORY NOTES

Explanatory notes are included in this document as shaded in-line text to assist comprehension and readability only. The Wholesale Electricity Market (WEM) Rules and WEM Procedures prevail over these explanatory sections to the extent of any inconsistency.

The explanatory sections have been prepared by AEMO using information available at 1 October 2020. Information made available after this date may have been included where practical, and the explanatory sections may be subsequently updated or amended.

Disclaimer

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 WEM Rules, or any other applicable laws, procedures or policies. AEMO has made every effort to ensure the quality of the information but cannot guarantee its accuracy or completeness.

Accordingly, to the maximum extent permitted by law, AEMO and its officers, employees and consultants involved in the preparation of this document:

- make no representation or warranty, express or implied, as to the currency, accuracy, reliability or completeness of the explanatory information in this document; and
- are not liable (whether by reason of negligence or otherwise) for any statements or representations in this document, or any omissions from it, or for any use or reliance on the information in it.

Copyright

CONTENTS

1. INTRODUCTION

1.1. Relationship with the Wholesale Electricity Market Rules

1.1.1. This WEM Procedure: Constraint Formulation (Procedure) is made in accordance with AEMO's functions under clause 2.1A.2(h) of the Wholesale Electricity Market Rules (WEM Rules). This Procedure is also made in accordance with clause 2.27A.10 and clause 1.33.1 of the WEM Rules.

1.1.2. This purpose of this WEM Procedure is to document:

(a) the processes to be followed by AEMO and the matters it must consider in formulating and updating Constraint Equations, including:

(i) the approach to be taken by AEMO in applying:

1. an Operating Margin; and

2. the principles described in clause 2.27A.9; and

(ii) the conventions for assigning a unique identifier to Constraint Equations and Constraint Sets [Clause 2.27A.10(b)];

(b) the processes to be followed by AEMO in developing and updating the Constraints Library and notifying Market Participants of updates to the Constraints Library [Clause 2.27A.10(c)];

(c) the processes to be followed and the methodology to be used by AEMO in determining Constraint Equation terms and coefficients for Network Constraints, including the methodology for determining whether the exclusion of a variable from a Fully Co-optimised Network Constraint Equation would have a material effect on Power System Security due to the size of its coefficient [Clause 2.27A.10(cA)];

(d) the processes to be followed and the methodology to be used by AEMO in selecting one or more Constraint Equations to respond to a Network Constraint, including in respect of the location of terms on each side of the Constraint Equation [Clause 2.27A.10(cB)];

(e) the processes and timeframes to be followed by AEMO for creating new Constraint Equations and Constraint Sets in response to a Non-Credible Contingency Event [Clause 2.27A.10(cC)];

(f) the process to be used by AEMO for selecting, applying, invoking and revoking Constraint Equations or Constraint Sets in response to Network Constraints for use in the Dispatch Algorithm [Clause 7.5.4 (a)];

(g) the circumstances in which AEMO will use Fully Co-optimised Network Constraint Equations and Alternative Network Constraint Equations in the Dispatch Algorithm [Clause 7.5.4 (b)]; and

(h) Any other processes or procedures relating to Constraints or Network congestion that AEMO considers are reasonably required to enable it to carry out its functions under the Market Rules [Clause 2.27A.10(d)].

Through the inclusion of explanatory notes, this document also serves as a self-contained introduction to and overall description of the application of Constraint Equations in the WEM.

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 clauses 2.9.7, 2.9.7A, and 2.9.8 of the WEM Rules, as applicable.

1.1.4. References to WEM Rules within this Procedure in bold and square brackets [clause XX] are included for convenience only and are not part of this Procedure.

Explanatory sections are identified the "E" prefix and square brackets, for example E[clause X].

The § symbol is used as a short-hand convention to indicate where further or related detail can be found in this document, for example §E[A]

Explanatory clauses are not part of this WEM Procedure.

1.2. Definitions and interpretation

1.2.1. Terms defined in the WEM Rules have the same meanings in this Procedure unless otherwise specified in this clause. The words, phrases and abbreviations in the table below have the meanings set out opposite them when used in this Procedure.

Table 1 Defined Terms

Term	Definition
Defined Constraint Equation	Has the meaning as defined in clause 2.2.2
Discretionary Constraint Equation	Has the meaning as defined in clause 6.1
Generic Constraint Equation	Has the meaning as defined in clause 2.2.1
Left Hand Side (LHS)	The side of a Constraint Equation that may only include terms to represent adjustable quantities in the Dispatch Algorithm.
Minimum Sensitivity Threshold	The minimum coefficient for a generator term to be included in a Network Constraint Equation as applied in clause 4.1.9 (b)(i).
Non-Thermal Constraint Equation	Means a Constraint Equation that represents a Constraint due to a Non-Thermal Network Limit.
Redistribution Factor (RDF)	Has the meaning as defined in clause 4.1.6 (c).
Thermal Network Constraint Equation	Means a Constraint Equation that represents a Constraint due to a Thermal Network Limit.
Right Hand Side (RHS)	The side of a Constraint Equation that must contain all terms not already included on the LHS.
Sensitivity Factor	Has the meaning as defined in clause 4.1.6 (f).
Special Constraint Equation	Any Constraint Equation not developed following the Standard Methodology
Standard Methodology	Means the process described in clause 2.1.1.
Stop-Gap Constraint Equation	A Constraint Equation developed to manage system security for a temporary period following the instances described in 6.2.1.

1.2.2. The following principles of interpretation apply to this Procedure unless otherwise expressly indicated:

(a) references to time are references to Australian Western Standard Time.

(b) terms that are capitalised, but not defined in this Procedure, have the meaning given in the WEM Rules.

(c) to the extent that this Procedure is inconsistent with the WEM Rules, the WEM Rules prevail to the extent of the inconsistency.

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

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

1.3. Related documents

1.3.1. The following documents in Table 2 provide background information to this Procedure.

Table 2 Background Procedures

Reference	Title	Location
WEM Rules	WEM Rules	Economic Regulation Authority website
Technical Rules	Technical Rules	
TBA	AEMO WEM Procedure: Limit Advice Requirements	AEMO WEM Website
TBA	Western Power WEM Procedure: Limit Advice Development	
TBA	AEMO WEM Procedure: ESS Modelling and Facility Accreditation	
TBA	AEMO WEM Procedure: SCED + WEMDE Formulation	
TBA	AEMO WEM Procedure: PASA	

E[A] PROCESS OVERVIEW

This explanatory note summarises the overall processes described in this WEM Procedure. As with all explanatory sections, it does not create or detail any obligations: refer instead to the relevant content of the Procedure.

E[A1] Summary

A Constraint is the generic term used in the WEM to describe a limitation in the operation of the power system.

Examples of Constraints in the SWIS include the:

(a) Maximum power transfer capacity (rating) of a transmission line.

(b) Minimum stable operating level of a generation unit.

(c) Trade-off between facility operating level and headroom (reserve generation capacity) for frequency control.

Constraint Equations are the tool used by AEMO to represent Constraints that must be satisfied in economic co-optimisation of the Dispatch process. They are an expression by which power system limits are encoded in a specialised and concise mathematical format.

Using Constraint Equations, the Dispatch Algorithm can automatically and efficiently calculate the optimal dispatch solution while considering an arbitrary number of simultaneous Constraints.

In practical terms, a dispatch engine implemented this way can satisfy thousands of interdependent system limits, while simultaneously optimising among thousands of individual facility offers (to supply electricity and/or other Essential System Services). It is this computational capability that enables real time co-optimised operation of the WEM.

This WEM Procedure describes the terminology, conventions, and process by which mathematical expressions of physical limits are converted into the Constraint Equation format required by the dispatch engine.

E[A2] Process flow and Timeline

Constraint Equations are used in directly in Dispatch, and therefore the development process must be sufficiently flexible and robust to meet the requirements of real time operation.

In the most typical case however, the formulation of a Constraint Equation begins in advance (up months in some cases) of real-time deployment. This is the Standard Methodology, and results in the formulation of Fully Co-optimised Constraint Equations (§2).

A power system model is used to determine a mathematical expression of a Constraint. In the case of Network Constraints, these are known as a Limit Equations (§E[C]).

The creation, validation, and usage of models for this purpose depends on the type and source of Constraint to be managed. For example:

(a) Western Power maintains the network model used to create Limit Equations to manage voltage stability (among other Network Limits); whereas

(b) AEMO maintains the Dynamic Frequency Control Model to set mathematical expressions of secure operating limits to meet frequency performance standards.

While an overview and classification scheme are described in this document, the detail of power system modelling is described in other WEM Procedures (§E[C]).

These mathematical expressions are all converted to Constraint Equations according to the constraint formulation principles and processes described in this document. The specific detail of formulation can vary with the type of Constraint, but in all cases includes steps to:

(a) Determine and apply an appropriate Operating Margin to account for uncertainty during real time operation (§3); and

(b) Rearrange the terms of the expression into the format required by the Dispatch Engine (§E[B], §E[E]).

In certain circumstances, AEMO may also apply an Alternative Formulation to create Special Constraint Equations. In general, an Alternative Formulation process is used to manage security requirements when time pressure does not allow for the Standard Methodology (§2).

E[B] Format of Constraint Equations

E[B1] Basic Structure

Power system limits are represented in the dispatch engine as Constraint Equations comprising of 3 basic elements: a Left-Hand Side (LHS), an operator, and a Right-Hand Side (RHS).

Equation (1) shows an example of the basic format, using the less than (<) operator:

$$LHS < RHS \tag{1}$$

The LHS and RHS are made up of mathematical terms, which themselves consist of a variable multiplied by a coefficient.

Variables represent quantities that may change from interval to interval, such as Dispatch Targets or network power flow measurements[1].

Coefficients represent pre-defined, constant parameters that do not change from interval to interval. They express the weighting of a variable in each Constraint Equation, such as the proportion of a generator output that flows through a specific transmission line.

In this document, variables and coefficients are indicated in mathematical script by upper- (G, L, F) and lower-case (a, b, c) letters respectively.

Subscript notation is used to indicate different coefficients or variables that have a conceptual relationship. For example:

(a) Coefficients that have the same function but apply to different terms (b_1, b_2)

(b) Variables representing the same physical quantity at different times ($G_{A,t0}, G_{A,DI}$ to indicate generator G_A output at present t_0 and it's Dispatch Instruction for the next interval DI)

Equation (2) shows an example expression of an LHS consisting of two terms:

$$LHS = a_1 G_A + a_2 G_B \tag{2}$$

Figure E[1] shows a network example contrived to illustrate the evaluation of a Constraint Equation using the expression in Equation (2). Coefficients are determined using a network model (Section 4.1), while the facility output variables (dispatch targets) may vary from interval to interval. Evaluation of Equation (2) as per the figure is as follows:

$$LHS = (0.75 * 50) + (0.50 * 70) = 72.50$$

[1] This usage is not consistent with the mathematical (linear optimisation) definition of variable in the Dispatch Algorithm, however it is a useful distinction in understanding the structure of Constraint Equations.

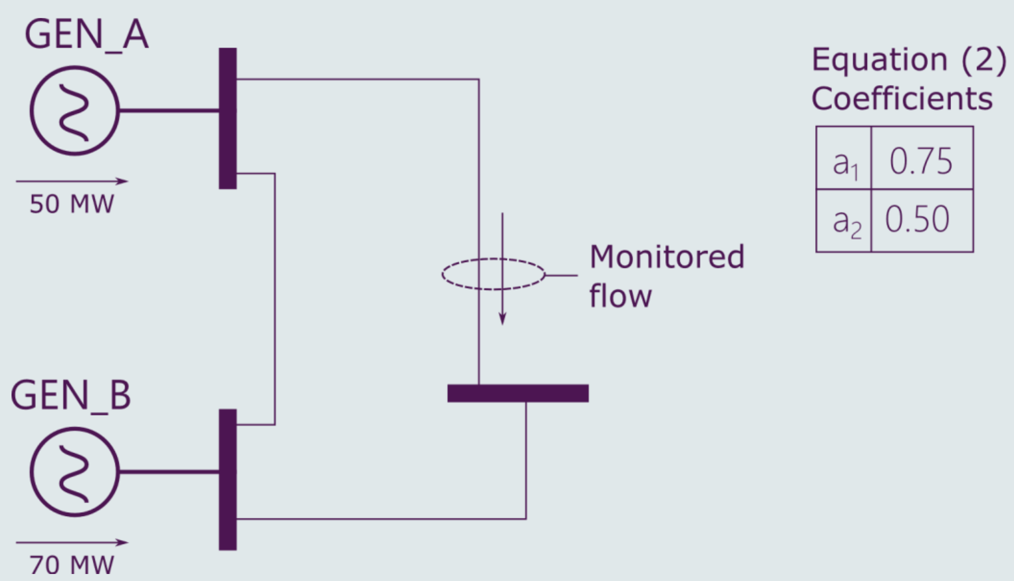


Figure E[1] Network flow example for the evaluation of a Constraint Equation expression.

E[B2] Left-Hand Side (LHS)

The LHS describes the portion of the Constraint Equation that may be controlled and optimised in the Dispatch Algorithm. Terms on the LHS may therefore only include variables that represent physical quantities the dispatch engine can adjust.

Examples of valid LHS variables include:

(a) Dispatch Targets for Scheduled Facilities

(b) The maximum generation Credible Contingency size in a dispatch solution

(c) constraint violation quantities

Uncontrollable quantities, such as Non-Scheduled Facility output, line flows or other measured quantities may not appear on the LHS.

In general, the LHS must be comprised of a mathematical linear combination of terms. For example, $G_A * G_B$ is not a valid term.

E[B3] Right-Hand Side (RHS)

The RHS describes the portion of the Constraint Equation that cannot be adjusted in the dispatch process, i.e. all other quantities necessary to correctly express the power system limit (terms not already included on the LHS).

Examples of valid RHS variables include:

(d) Measurements from the power system, for example:

  (i) Line flow

  (ii) Bus voltage

  (iii) Output from Non-Scheduled Facilities

  (iv) Operational status of generation units or network equipment (circuit breakers, reactive plant, protection schemes)

(e) Ratings of network elements (static or dynamic)

(f) Constants (offsets or margins, §3)

RHS variables may include any mathematical expression or function of values, including conditional logic or non-linear processing. These are pre-calculated before being used in Dispatch Algorithm.

E[B4] Operator

An operator consists of one of the following:

(a) < (less than)

(b) ≤ (less than or equal)

(c) = (equal)

(d) > (greater than)

(e) ≥ (greater than or equal)

Operators describe the relationship between the LHR and RHS according to their usual mathematical definition.

Example use of different operators includes:

(a) The energy balance rule, in which total generation must equal demand (=)

(b) Network Constraints describing the need to limit generation output below an equipment rating (≤)

(c) Essential System Service Constraint Equations restricting facility output within a given range (≤ or ≥)

E[B5] Constraint Sets

Constraint Sets group Constraint Equations that are activated or deactivated concurrently, normally to represent multiple Constraints that apply under the same system configuration and / or operating conditions. They are for logistical and practical purposes in managing dispatch and do not affect the action of any Constraint Equation directly.

A Constraint Set may have one or many Constraint Equations.

A Constraint Equation may only belong to one Constraint Set.

2. STANDARD METHODOLOGY FOR CONSTRAINT EQUATION DEVELOPMENT

2.1. Fully Co-optimised Formulation

2.1.1. The Standard Methodology is a process for the development of Fully Co-optimised Constraint Equations that facilitate secure, economic, and predictable dispatch outcomes. This consists of:

(a) A detailed modelling and understanding of the power system limit to be managed

(b) Mathematical expression of the limit using information available to the dispatch process to create a Limit Equation.

(c) Identification of the specific:

(i) Conditions and circumstances under which the limit applies

(ii) uncertainty and risks associated with the limit, and the selection of an appropriate Operating Margin

(d) Conversion of the mathematical limit expression and Operating Margin into the valid Constraint Equation format

(e) Pre-staging of the Constraint Equation in the Constraint Library, with labelling and grouping into a Constraint Set in preparation for operational use.

(f) Validation and testing of the Constraint Equation under expected power system conditions, using both historical and forecast inputs.

(g) Attaching a “plain-English” description to each Constraint Set and each Constraint Equation to help facilitate comprehension and identification.

2.1.2. To the extent that information availability, operational circumstances and development resources reasonably allow, AEMO must make best endeavours to:

(a) follow the Standard Methodology; and

(b) complete the process as far in advance of live deployment as practical.

This WEM Procedure concerns the process steps described from 2.1.1(c)(ii) onward. The use of models to determine mathematical limit expression is described in other documents, refer to E[C] for further detail.

Figure E[2] shows a diagram linking the terminology and information flow in the Standard Methodology as applied in the formulation of a Network Constraint Equation for Dispatch (§E[C]).

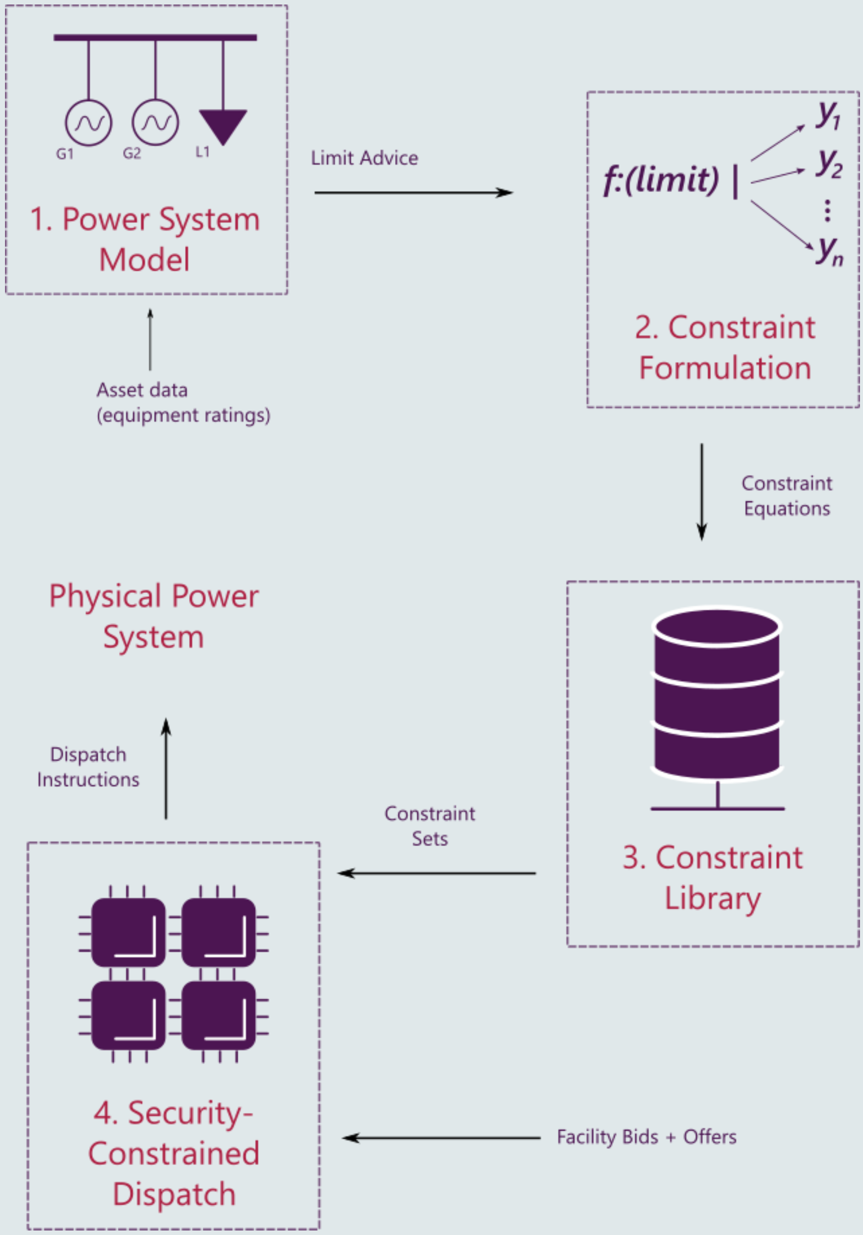


Figure E[2] Overview of terminology and information flow in the Standard Methodology as applied to the formulation of a Network Constraint Equation.

2.1.3. Circumstances where AEMO may not follow the Standard Methodology (and instead apply an Alternative Formulation process) are described in Section 6.

2.2. Generic and Defined Constraint Equations

2.2.1. A Generic Constraint Equation is a Constraint Equation with arbitrary form: any number or selection of terms, and any choice of operator.

2.2.2. A Defined Constraint Equation is a Constraint Equation with predefined form and intended interaction with other Defined Constraints.

In addition to the selection of terms, the predefined form of a Defined Constraint Equation includes positioning of terms on the LHS or RHS.

An example use of Defined Constraint Equations is to manage maximum facility output:

$$G_i < G_{\mathrm{MAX,i}}$$

Where $G_{\mathrm{MAX},i}$ is the maximum output of Facility i as per it's Standing Data. An equation of this form is included in Dispatch for every Market Facility; whenever a new facility Registers in the WEM, a Constraint Equation following this template is automatically included in the Dispatch Algorithm.

The exact form and operation of a Defined Constraint Equation can be understood and predicted from the formulation process. A Generic Constraint Equation is more difficult to interpret but can represent a much larger range of conditions (as is required to accurately model the physical system).

E[C] CONSTRAINT EQUATION CLASSIFICATION

Constraints formulated under the Standard Methodology are grouped according to the type of limit, source of the modelling information, and general complexity.

A diagram summarising the set of constraint classes and the respective information sources is shown in Figure E[3].

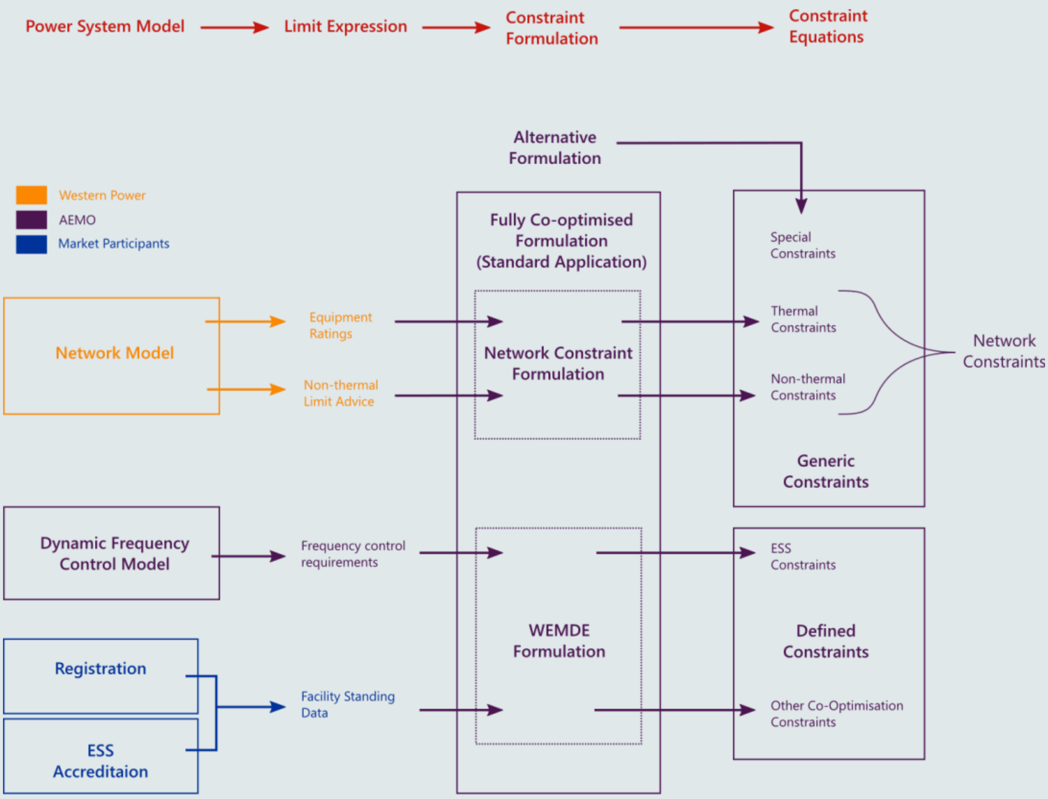


Figure E[3] Constraint equation classes and respective information sources

Thermal Constraints

Thermal Limits are the subset of Network Limits that describe the maximum capacity for electrical throughput of network elements (i.e. beyond which the element typically overheats). These limits are wholly defined by the rating of network equipment as determined by the Network Operator.

The derivation of Thermal Limits (equipment ratings) and application of Limit Margins by the Network Operator is described in WEM Procedure: Limit Advice Development.

Thermal Limits are common, well-understood, and relatively straight-forward to convert and express as Constraint Equations. In the SWIS, these are typically specified by the overall maximum current (Ampere) rating of a circuit. The formulation process used by AEMO to convert these ratings into Constraint Equations is described in Section 4.1.

Non-thermal Constraints

All other Network Limits are classified as Non-thermal Limits, which encompasses a broad range of possible physical phenomena that can influence the secure operating state of the power system. Non-

Thermal Limits may derive from complex network characteristics, have dynamic aspects, and involve interactions between multiple pieces of equipment across wide geographic areas.

Responsibility for identification and development of Limit Equations to manage Non-Thermal Limits is owned by the Network Operators. It requires ongoing modelling and investigation of network capability and comparison against actual system data and performance. In some circumstances, Non-thermal Limits can only be partially controlled by dispatch optimisation and must work in concert with network switching arrangements and other special protection schemes.

The derivation of Non-thermal Limits and application of Limit Margins by the Network Operator is described in WEM Procedure: Limit Advice Development.

AEMO undertakes an iterative review process with the Network Operator to revise Limit Advice, however in preparing Non-Thermal Constraint Equations, AEMO typically makes only minor adjustments to Non-Thermal Limit Equations. This process is described in Section 4.2.

Network Constraints

The Limit Equations and all supporting information for both Thermal and Non-thermal Limits are packaged by the Network Operator for use by AEMO as Limit Advice. AEMO's requirements of the for the communication, format and management of Limit Advice are described in WEM Procedure: Limit Advice Requirements.

The combined set of Thermal Constraints and Non-Thermal Constraints make up the Network Constraints.

All Network Constraints are implemented as Generic Constraint Equations. This allows for the full range of power system conditions and configurations to be securely represented within the commercial Dispatch optimisation.

Essential System Service and Other Co-optimisation Constraints

Essential System Service (ESS) Constraints describe the need to reserve generation capacity on specific machines and adjust output dynamically to maintain a secure operating state (i.e. for purposes other than supplying electrical demand). These constraints are used to implement the co-optimisation of Essential System Services.

AEMO maintains a dynamic frequency control model (DFCM) for the development and validation of frequency control requirements. These requirements are expressed as generic ESS service quantities needed to meet the performance requirements in the Frequency Operating Standards.

An example ESS is the Contingency Raise Service, which maintains system frequency following generation contingencies by ensuring enough headroom (MW raise capacity) is reserved on fast-responding facilities. In this example:

(a) The DFCM output expresses the minimum amount of generic headroom required (e.g. $\text{contingency\_raise\_MW} \geq 200$)

(b) The WEMDE formulation combines this requirement with facility Standing Data to generate a series of Constraint Equations that ensure the co-optimisation process allocates enough headroom across the generation fleet.

The generic ESS quantities are input as parameters to a series of Constraint Equations that govern the full co-optimisation rules, including:

(a) Energy balance between demand and generation

(b) Allocation of capacity between different market services (Facility trapeziums)

(c) Facility operating limits (maximum and minimum capacity, ramp rates, energy storage limitations)

The scope and complexity of these Constraint Equations is such that the detailed formulation is described in other documents:

(a) The Essential System Service Modelling and Facility Accreditation WEM Procedure describes:

(i) The physical model and assumptions used to develop the DFCM and determine the generic ESS quantities for secure operation; and

(ii) The process and testing regime to accreditable capability for a specific Facility to supply an Essential System Service.

(b) The Security-Constrained Economic Dispatch WEM Procedure describes:

(i) The structure and format of Facility offers and trapeziums, and how these are applied as Constraint Equations for market co-optimisation;

(ii) The process by which Facility ESS parameters are converted into Facility Performance Factors for market offers under different system conditions, and then used to satisfy generic ESS requirement constraints; and

(iii) The integration of Generic Constraints (e.g. Network Constraints) into the overall co-optimised dispatch.

All Essential System Service and other co-optimisation Constraint Equations are Defined Constraint Equations.

Special Constraints

All other constraints are classed as Special Constraints. These do not follow the Standard Methodology process and are created using alternative formulation (generally less rigorous) processes (§6).

All Special Constraints are Generic Constraints.

3. OPERATING MARGINS

E[D] OPERATING MARGIN CONCEPTS

Operating Margins are safety factors used in Constraint Equations to account for uncertainty and error in Dispatch. It creates a buffer to absorb unexpected or uncontrollable factors during real time operations and assist in maintaining the security of the power system.

Operating Margins also improve robustness, simplicity, and legibility in Constraint Equation actions, by abstracting complex details that have limited market impact but are otherwise difficult to model and control within the Dispatch Optimisation.

In functional terms, an Operating Margin typically:

(a) appears as a constant Term on the RHS that "offsets" the binding action of a Constraint Equation; and

(b) is expressed as a percentage relevant to the Limit to be managed.

For example, a "5% margin" applied to a Thermal Constraint Equation would bind under a Dispatch Solution that could credibly load a network element to 95% of its rating. It allows for a combined 5% variance from the mathematical optimisation due to real time operational factors, such as facility dispatch variance or measurement errors in physical sensors.

There is no objective value for an Operating Margin; reducing an Operating Margin increases the risk of a power system incident but can improve market efficiency. Depending on the balance of consequences, likelihood, and market impact, the appropriate size of an Operating Margin may vary among specific Constraint Equations.

3.1.1. In following the Standard Methodology process (described in Section 2.1), AEMO must calculate and apply an Operating Margin in the development of any Fully Co-Optimised Constraint Equation.

3.1.2. AEMO must calculate any Operating Margin according to the following process:

(a) Identification of the relevant error sources (i.e. those that may alter the terms of the Constraint Equation);

(b) Statistical estimation of the coincident distribution of the combined error sources to determine risk likelihood;

(c) Identification of the risk consequences associated with exceeding the limit managed by the Constraint Equation; and

(d) selection of an Operating Margin consistent with the appetite for each respective risk.

In developing and following the approach described in 3.1.2, AEMO's principles to support alignment with Market Objectives and good industry practice are a preference for:

(a) The use of measured data and statistical analysis

(b) Linkage with relevant policy or statements of risk appetite

(c) Efficient allocation of engineering analysis and development resources to relieve market congestion

(d) Simplicity, robustness and clarity over mathematical sophistication or purity.

3.2. Application Strategy

3.2.1. In the absence of any other relevant information, AEMO may default to applying conservative Operating Margins.

3.2.2. Under clause 3.2.1, relevant information includes:

(a) Additional market performance data, experience and analysis following live deployment of a Constraint Equation

(b) A change in SWIS risk appetite following an industry consultation session or publication of new government policy

(c) specific Limit Advice from the Network Operator

3.2.3. AEMO may utilise the real time environment for performance monitoring and prioritisation of Constraint Equation optimisation.

While some market pre-validation of Constraints is possible, the scale of possible combinations of operating conditions and Constraint Equations variables is such that extensive offline analysis is not practical and unlikely to be effective.

Instead, AEMO's general strategy is to deploy new Constraint Equations with conservative Operating Margins (err on the secure side of any risk-efficiency trade-off) and gather feedback from real market performance. This is to:

(a) Minimise cognitive burden and risk of security incidents during the initial period following the addition of new elements to the real time operating environment, while

(b) Avoiding allocation of analysis resources to prematurely optimising Constraint Equations that may have limited impact on market outcomes.

The approach and process AEMO follows in utilising the real-time environment in described in Appendix B.3

3.3. Error Sources

Modelling Simplifications and Assumptions

3.3.1. AEMO may consider errors due to modelling assumptions and simplification within an Operating Margin

Physical dispatch includes known processes that are difficult to represent meaningfully within the mathematical limitations of the Dispatch Optimisation.

The prototype example in this category is the handling of MW vs MVA (active and apparent power) differences across the power system:

(a) While the measurement and use of MVA quantities to manage network limits is more physically accurate, the use of MW terms on the LHS is required by dispatch. An additional set of Constraint Equations would be required to account for the MW-MVA relationship in real time.

(b) In practice, most generators operate in a relatively narrow power factor range (e.g. <5% increase in MVA to MW output), such that AEMO instead opts to account for variance through an Operating Margin. This variance is readily measured and quantified from power system data on a per-term basis.

The determining characteristic of managing these errors through the Operating Margin is a poor trade-off in adding significant complexity to the dispatch process for limited gains in market efficiency.

Other examples in this category include:

(a) Finite study cases: the theoretical set of power system configurations (e.g. load distribution, generation profiles, network switching) is infinite. AEMO can satisfy the practical requirements of operational security though:

(i) explicit modelling of only a select set of realistic circumstances to generate Constraint Equations and coefficients, while

(ii) managing edge cases through the Operating Margin.

(b) Constraint Equation linearity requirement: most physical phenomena are nonlinear. In some instances, the market impact of nonlinearity may warrant significant complexity (e.g. management of system inertia), but the more common case is very high complexity relative to the potential improvements in market efficiency.

(c) Facility model detail: the true performance of generation facilities can be highly complex and dependent on variable local conditions, such as ambient temperature or the state of auxiliary equipment (pumps, fans, valves etc.). The state and influence of these variables may be known to AEMO for real time security purposes but is deliberately excluded from complicating market optimisation where reasonable to do so.

Real Time Error

3.3.2. AEMO may consider real time error sources within an Operating Margin

The real time environment also includes variance that fundamentally cannot be controlled by the Dispatch Process, due to restrictions that arise from both physical limitations and the base market design.

The prototype example in this category is the dynamic and non-exact nature of intra-interval dispatch:

(a) Physical equipment has fundamental limits to accuracy, precision, and reliability. For example:

(i) A generator assigned a dispatch target will vary within a given tolerance

(ii) Communications and control systems will suffer communications and response delays

(iii) From the system operations perspective, any device is liable to simply fail in service with a statistical probability

(b) System conditions vary and change continuously, while the market optimisation process can only measure and readjust at each Dispatch Interval.

Other examples in this category include:

(a) Measurement error from physical sensors

(b) Forecast error for load or intermittent generation

Generic Error

3.3.3. In the case of Generic Constraint Equations, AEMO may consider alternative sources in selecting an Operating Margin on a case by case basis in order to manage error and uncertainty that may accumulate in unforeseen ways during dispatch.

Non-operational Error

In the Fully Co-optimised Formulation process, AEMO does not consider error or uncertainty associated with ratings of network equipment or parameters in the Standing Data, as a margin for these sources is assumed to have already been included by the Network Operator or relevant Market Participant respectively.

In the case of the network equipment ratings and Network Limits, the process applied by the Network Operator in determining Limit Margins is described in the Western Power WEM Procedure: Development of Limit Advice.

3.3.4. Changes to market and operating conditions can alter the appropriate balance of Dispatch complexity, such that AEMO may adjust Operating Margins following occurrences such as:

(a) additional operating experience;

(b) technological or policy developments; or

(c) increased sophistication of Participant bidding strategy.

The process by which AEMO monitors and responds to the changes is described in Section B.3.

3.4. Statistical Likelihood Estimation

3.4.1. For each error source AEMO chooses to manage through an Operating Margin, AEMO must determine a mapping that relates the size of the Operating Margin to the likelihood categories listed in Figure 1.

LIKELIHOOD	ANNUAL PROBABILITY	QUALITATIVE DESCRIPTION
Almost Certain	>90%	Will occur in most circumstances; statistical record of several occurrences
Likely	51% - 90%	Can be expected to occur in most circumstances; statistical record of multiple occurrences
Possible	11% - 50%	May occur, but not expected in most circumstances; statistical record of a few occurrence
Unlikely	1% - 10%	Conceivable but unlikely to occur in any given year; statistical record of at least one occurrence
Rare	<1%	Will only occur in exceptional circumstances; no history of occurrence

Figure 1 Likelihood categorisation for risk assessment

3.4.2. Where relevant and sufficient measurement data are available, AEMO may determine the likelihood mapping through statistical fitting of an estimated probability distribution of the error source.

3.4.3. Where data is not available or appropriate for an error source, AEMO may estimate the error distribution according to the qualitative descriptions in Figure 1.

Where there is ambiguity in subjective reading of the descriptions, AEMO will bias initially toward maintaining security as per AEMO's core obligation to operate securely and reliably.

These estimations may be refined following operational experience via an efficiency review (Appendix B.3).

3.4.4. In performing the estimation in 3.4.2 and 3.4.3, AEMO may select any distribution that it believes reasonably approximates the observed error (i.e. without any formal analysis or understanding of the underlying processes).

In general, the likelihood of a risk does *not* reflect (is statistically independent to) the probability of the Constraint Equation binding in the first place. A large margin is indicative of a high degree of uncertainty associated with the limit (or perhaps severe consequences, see Section 3.6), but contains no direct information about the frequency of conditions that may restrict the market.

3.4.5. In combining likelihood estimations for multiple error sources applicable to a single Constraint Equation, AEMO may apply any reasonable statistical method to estimate error correlation, based on its own best judgement.

3.4.6. Where AEMO identifies a recurring class of error source applicable to multiple Constraint Equations, it may develop a heuristic to efficiently adapt existing likelihood estimations (rather than repeat calculations for each applicable Constraint Equation).

E[D1] Example Operating Margin Calculation

TODO: Example here stepping through the build-up of a margin from multiple facility SCADA (4s) traces

Error in MVA assignment + dispatch variance is measured from known data

Error in SCADA accuracy is given qualitative treatment.

Combine the non-correlated error source due to SCADA measurements

E[D2] Risk Consequence Framework

This explanatory note contains procedural clauses that are anticipated to be included as part of a more general security and risk framework.

It has been included here as an explanatory note to show how a consequence framework would be applied to the specific case of Operating Margins.

3.5. Consequence assessment

3.5.1. Table 1 shows an example matrix AEMO may use to assess the consequences associated with setting or changing the Operating Margin for a given Constraint Equation.

3.5.2. In Table 1:

(a) The primary assessment category is secure operation, which AEMO must apply to all Constraint Equations. It describes AEMO's timeliness and capacity to restore a Secure Operating State following a Credible Contingency.

(b) The secondary categories apply only to certain equation categories. AEMO may use secondary categories to further refine consequence assessment as appropriate.

Table 1 Example risk consequence matrix

	Primary	Secondary		
Consequence	Secure Operation	Load Shedding / reliability	System Damage	Example
Extreme	AEMO cannot restore Satisfactory operation	Cascading, uncontrolled system loss	Widespread irreversible damage to multiple assets	Breach of ROCOF safe limit leads to cascading generator loss
Major	AEMO can restore a Satisfactory state only through multiple directions and not within 15 minutes.	>100 MW load shed or multi-stage UFLS	Irreversible damage to performance capability of up to 10 primary assets	System separation event with large (>30 MW) self-sustaining islands
Moderate	AEMO can restore a Satisfactory state through single intervention or direction within 15 minutes	Up to 100 MW load shed or first-stage UFLS	Single asset: Irreversible damage to performance capability	Market Generator islanded with distribution load
Minor	Satisfactory state restored within next Dispatch Interval by Market Dispatch (<10 minutes)	Up to 30 MW load shed	Single asset: increased wear and tear within acceptable operating parameters	Temporary overload of transformer
Immaterial	Satisfactory state restored automatically within 1 Dispatch Interval (<5 minutes)	Up to 1 MW load shed	Single asset: Temporary breach of continuous operating parameters without permanent damage	Overload of transmission line within dynamic rating

The consequence descriptions apply to the operating conditions immediately following a Credible Contingency.

For example, consider a typical Thermal Network Constraint Equation. Deployment with a 0% Operating Margin creates a risk that random factors could drive the system into a non-Secure state, wherein a Credible Contingency during binding conditions would overload another network asset:

(a) If market dispatch could resolve the overload in the next Dispatch Interval (<10 minutes), the consequence notionally has a Minor rating; however, if

(b) the overload during this time would result in irreversible damage and performance degradation to the asset (e.g. a transformer), the consequence would be increased to Moderate.

(c) If instead the overload would result in temporary breach of continuous rating without permanent damage (e.g. to a transmission line), the consequence could be downgraded to Immaterial.

3.5.3. In cases where none of the secondary categories in Table 1 apply to a specific Constraint Equation, AEMO may develop and apply an alternative category to refine a consequence assessment.

3.5.4. In the absence of specific information required for AEMO to determine secondary risk consequences (e.g. detailed network asset overloading capability), AEMO may default to a conservative (higher) consequence judgement.

3.6. Risk rating

3.6.1. Figure 2 shows the risk classification scheme AEMO must use to assess the overall risk level of a given likelihood and consequence combination.

		CONSEQUENCE				
		Immaterial	Minor	Moderate	Major	Extreme
LIKELIHOOD	Almost Certain	Medium	Medium	High	Critical	Critical
	Likely	Low	Medium	High	Critical	Critical
	Possible	Low	Medium	High	High	Critical
	Unlikely	Low	Low	Medium	Medium	High
	Rare	Low	Low	Medium	Medium	High

Figure 2 Weighting for risk assessment

3.6.2. The size of the Operating Margin corresponds to adjusting the likelihood dimension of the overall risk.

3.6.3. In the absence of any explicit obligation, formal policy or written advice on risk appetite, AEMO may default to set an Operating Margin to achieve a "Low" risk rating.

In typical cases, this approach results in setting Operating Margins that allow "Unlikely" occurrence of "Minor" consequences due to error (1-10%).

4. NETWORK CONSTRAINT FORMULATION

4.1. Thermal Network Constraints

Equation Selection

4.1.1. The network combinatorial strategy is a methodology for the selection of Constraint Equations to ensure appropriate coverage of Network Constraints. It consists of a single Constraint Equation per combination of:

(a) network configuration;

(b) Thermal Network Limit; and

(c) Credible Contingency.

E[E] NETWORK MODELLING

E[E1] Network Coverage

Constraint Equations can be mathematically expressed in different ways to achieve secure outcomes in the dispatch process and physical system.

Under the network combinatorial strategy:

(a) Each network element requires multiple Constraint Equations to protect against different contingencies; and

(b) a network outage (change in configuration) requires reconsideration of all contingency and monitored element combinations.

In a large and complex system, this keeps physical interpretation and confirmation of the correct behaviour of each individual Constraint Equation relatively simple. It facilitates confidence that Constraint Equations will influence dispatch as designed and in accordance with the Market Objectives.

A disadvantage of this approach is the large volume of resulting constraints, many of which may never plausibly alter economic dispatch. A large volume of constraints is undesirable primarily because it creates noise and limits comprehensibility of dispatch outcomes and congestion market signals. This creates risks both to system security and efficient economic operation.

4.1.2. In the application of Constraint Equations to manage Thermal Network Constraint, AEMO must make use the network combinatorial strategy to manage network coverage wherever practical.

4.1.3. In situations where the network combinatorial strategy is ineffective or impractical to apply, AEMO may apply any formulation methodology it deems necessary to ensure satisfaction of:

(a) Limit Equations pertaining to Thermal Network Limits; and

(b) AEMO's obligation for Secure Operation of the SWIS overall.

For Thermal Constraints Equations, the Limit Equations are defined by the equipment ratings of the various network elements.

4.1.4. Where AEMO determines that a Constraint Equation predicted by the network combinatorial strategy would have negligible market impact, AEMO may opt not to formulate the Constraint Equation.

4.1.5. Any decision AEMO makes to bypass a Network Constraint Equation under 4.1.4 must only be done:

(a) for the purpose of reducing complexity in the dispatch system;

(b) where AEMO determines the impact to Power System Security and Reliability is negligible; and

(c) in accordance with the Market Objectives.

The primary intent of 4.1.4 is to exclude Constraint Equations where all Facility coefficients fall under a Minimum Sensitivity Threshold (§4.1.9).

Coefficient Determination

4.1.6. For each Thermal Network Constraint Equation predicted under the network combinatorial strategy, the conceptual methodology for determining linear coefficients in the SWIS from a load flow simulation is as follows:

(a) One or more simulation base cases are established with appropriate system configuration:

(i) The relevant network configuration; and

(ii) realistic distributions of load and generation for the Thermal Network Limit under consideration.

The initial power flows through the contingent P_{C0} and monitored elements P_{M0} are recorded.

(b) The swing bus is set to an appropriate location to recreate any power redistribution following the Credible Contingency under consideration.

The swing bus is a component of load flow analysis that absorbs or supplies power as required by the simulation mathematics. Its placement is a matter of engineering judgement to ensure that the simulation produces realistic results.

(c) The system is reconfigured and re-simulated to represent steady state following the contingency. The new power flow on the monitored element P_{M1} is recorded and used to determine the Redistribution Factor (RDF):

$$RDF = \frac{P_{M1} - P_{M0}}{P_{C0}} = \Delta P_M / P_{C0}$$

(d) In the case of Credible losses of multiple network elements, and the RDF is calculated according to (c) for each contingent element separately, where the pre-contingent configuration includes all other contingent elements initially out of service.

(e) The swing bus is shifted to the Regional Reference Node

Switching the swing bus prior to the calculation of sensitivity factors is referred to as "orienting" a constraint to that bus.

(f) From this network model state, the linear Sensitivity Factor S at a given bus i is determined as

$$S_i = \Delta P_M / \Delta P_i$$

Where:

- ΔP_i is an injection of MW at bus i
- ΔP_M is the change in power flow through the monitored element following ΔP_i

4.1.7. In following the Standard Methodology to develop a Thermal Network Constraint Equation, AEMO must:

(a) utilise load flow simulations of a suitable SWIS power system model;

(b) follow the process described in 4.1.6 as close as reasonably possible in determining Redistribution Factors and Sensitivity Factors;

(c) derive Thermal Constraint Equation coefficients from:

(i) Redistribution Factors; and

(ii) the Sensitivity Factors (at the connection point) of Market Facilities.

4.1.8. AEMO may adjust, make detailed technical judgements on a case by case basis, or deviate from the process in 4.1.6 where it determines that:

(a) The resulting Constraint Equation would otherwise not maintain Power System Security under reasonably expected power system conditions; or

(b) Still ensuring AEMO core objectives of maintaining Power System Security and Reliability, the Market Objectives can be better served by doing so.

Term Selection and Placement

4.1.9. In formulating a Thermal Network Constraint Equation, AEMO must:

(a) determine an appropriate Minimum Sensitivity Threshold;

(b) include:

(i) a term for each Market Facility, where the Sensitivity Factor of that Facility is greater than the Minimum Sensitivity Threshold determined in (a);

(ii) all other terms necessary to represent the relevant Network Limit;

(c) position:

(i) each term representing a controllable Facility on the LHS;

(ii) all other terms on the RHS.

4.1.10. The Minimum Sensitivity Threshold for any Constraint Equation must be ≤ 0.01.

> The Minimum Sensitivity Threshold ensures that Facilities only appear in Constraint Equations where the Dispatch Algorithm would plausibly constrain their output (and therefore would materially change security outcomes). This declutters Constraint Equations (and the Constraint Library overall), improving the accessibility and quality of market information from constrained dispatch.
>
> By default, a value of 0.01 is used (i.e. for a Facility to appear in a Constraint Equation, at least 1% of power from a Facility must flow through the monitored element), based on experience and operating practice in the NEM.
>
> In select cases it may be appropriate to use a different threshold, such as in areas of very high network congestion. These cases will generally be identified through real time performance monitoring (Section B.3).

4.2. Non-thermal Network Constraints

4.2.1. AEMO must formulate Non-Thermal Constraint Equations according to the Limit Advice provided by the Network Operator for Non-Thermal Limits. This includes:

(a) Ensuring satisfaction of all relevant Limit Equations; and

(b) Consideration of all supporting information

4.2.2. In formulating equations under 4.2.1, AEMO may:

(a) Add an appropriate Operating Margin

(b) Rearrange terms between the LHS and RHS

(c) Re-orient a Limit Equation to the Regional Reference Node

(d) Re-express a Limit Equation as multiple Constraint Equations.

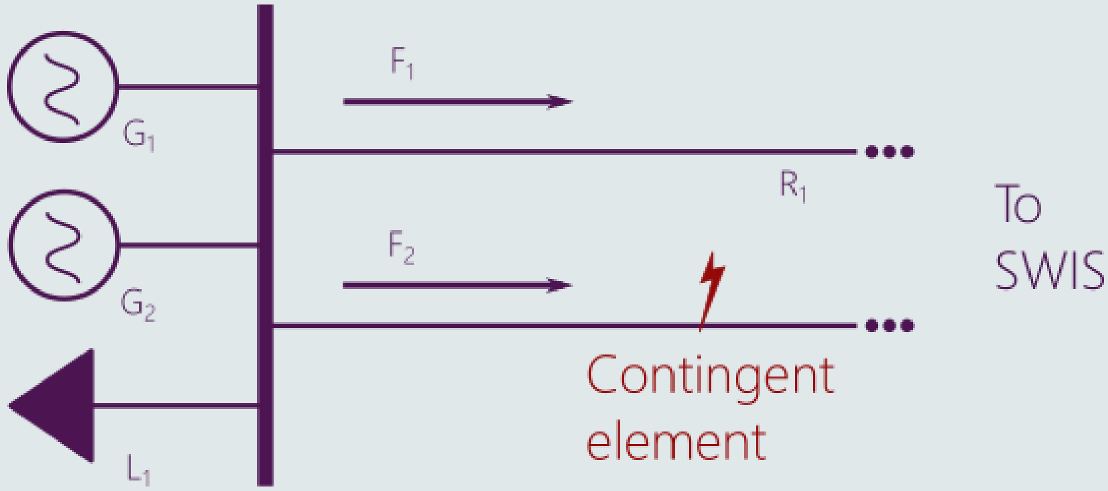
E[E2] Open Loop Constraint Equations

The figure below shows a relatively simple network schematic of a radial portion of network connected by two transmission lines to the remainder of the system. It depicts a scenario under the network combinatorial strategy (Section 4.1.1) for the formulation of a Constraint Equation to cover the:

(a) configuration with all network elements in service

(b) Network Limit of the maximum thermal capacity of one of the lines

(c) Credible loss of the other transmission line.



The diagram uses the following variables for MW quantities:

(i) G: dispatchable generation output

(ii) L: local load

(iii) F: transmission line flow

(iv) R: transmission line rated capacity

The Network Limit in this scenario is to ensure the flow through line 1 is less than its rated capacity. The relevant Limit Equation is:

$$F_1 < R_1 \qquad \text{E[E2](1)}$$

By inspection, an appropriate expression to manage E[E2](1) under post-contingent conditions is:

$$\text{RDF} \times F_2 + a_1 G_1 + a_2 G_2 - b_1 L_1 < R_1 \qquad \text{E[E2](2)}$$

where RDF and (a_1, a_2, b_1) are the Redistribution Factor and Sensitivity Factor coefficients respectively.

The (constant) values for the linear RDF and Sensitivity Factors are determined through the load flow process described in 4.1.6. In this simple example, it can be seen that:

(i) the generators and load are connected to the same bus, and thus have the same Sensitivity Factor; and

(ii) both the RDF and bus Sensitivity Factor are 1.

As per the requirements listed in 4.1.9, only the dispatchable generators may appear on the LHS. Further, assume that an analysis according to §3.1.2 finds an Operating Margin of 8% is appropriate to manage uncertainty due to the combined effect of:

(a) the real time variation of the generators and loads

(b) measurement accuracy of the field devices and SCADA system.

The form of the resulting Constraint Equation is:

$$1G_1 + 1G_2 < 1(1 - 0.08)R_1 - F_2 + 1L_1 \qquad \text{E[E2](3)}$$

In equation E[E2](3):

(a) The LHS is a linear combination of terms representing dispatchable Facilities, while all variables on the RHS are available in real time from the SCADA system (including the line rating, which may be a constant or dynamic value).

(b) There is no explicit occurrence of the flow value F_1 being controlled. For this reason, this is described as an open loop formulation.

E[E3] Feedback Constraint Equations

An open loop Constraint Equation is fully valid and appropriate to use in the dispatch; however, it requires a detailed modelling and understanding of the Network Limit to be managed.

When applied to realistic power systems (characterised by many buses, elements and meshed interconnections), open loop formulations rapidly become complex and error prone, and are generally not robust over a large range of operating conditions:

(a) The translation of detailed models into the linear form required by the dispatch engine can only approximate physical phenomena, which becomes increasingly inaccurate as conditions drift from the specific configuration and assumptions used in the load flow analysis;

(b) The detailed representation requires consideration of many physical measurement points, each of which adds an additional point of failure and error to the calculation;

(c) If the flow direction reverses over certain elements, the Constraint Equation can become invalid (no longer ensures secure dispatch).

Equation E[E2](4) shows the generalised form of a feedback formulation for a Thermal Network Limit:

$$\mathrm{a}_1\Delta G_1 + a_2\Delta G_2 + \cdots a_n\Delta G_n < (1 - \epsilon)R_m - F_m - \mathrm{RDF} \times F_c \qquad \text{E[E2](4)}$$

Where

(i) n: number of generators in the system

(ii) $\Delta G_i = G_{i,DI} - G_{i,t0}$: difference between the dispatch instruction and current output of generator G_i

(iii) ϵ: Operating Margin

(iv) R_m: capacity rating of the monitored element.

(v) F_m, F_c: measured flow through the monitored and contingent elements respectively

The Feedback Formulation expresses the expected relative increase in flow through an element for a given dispatch profile. The RHS expresses the remaining capacity on the monitored element (for which it is sometimes described as a headroom equation).

A Feedback Constraint Equation is resistant to all the limitations of Open Loop equations and can also be generalised to apply to Non-Thermal Network Constraints (by replacing the thermal rating and flow terms with appropriate limit and measurement quantities).

In formulating Feedback Constraint Equations for the Dispatch Engine, the Facility measurements must be moved to the RHS, such that the normal form is:

$$a_1 G_{1,\mathrm{DI}} + a_2 G_{2,\mathrm{DI}} + \cdots a_n G_{n,DI} < (1-\epsilon) R_m - F_m - \mathrm{RDF} \times F_c + a_1 G_{1,\mathrm{t0}} + a_2 G_{2,\mathrm{t0}} + \cdots a_n G_{n,t0} \qquad \text{(F5)}$$

AEMO's preference is to use a feedback formulation for Generic Constraints where possible.

E[E4] System Normal

Most network equipment has a default configuration in which it is expected to operate for most of the time. This is the normal operating state for that equipment

For example:

(a) most transmission lines are designed and expected to remain in-service (connected and transmitting electricity) whenever possible; while

(b) some network switching points (circuit breakers) are deliberately left "normally open" (blocking power flow) and only reconnected under outage or emergency circumstances.

System normal refers to the configuration in which all network equipment is in its normal operating state.

In the ideal case, the SWIS is operated as closely to system normal and as often as possible. The Constraint Equations that apply under system normal therefore typically see the most frequent utilisation.

In practice, the system regularly varies from the strict normal configuration to remove network equipment form service and facilitate planned maintenance. Generally, however, network outages create a more restrictive operating range (reduce the technical envelope). In these instances, Constraint Equations for outage configurations may be securely invoked in parallel (simultaneously) with the system normal Constraint Set.

Network faults and other Forced Outages also result in a deviation from system normal.

E[E5] Distribution System Constraints

AEMO overall obligation to ensure secure operation covers the entire SWIS, which includes both the transmission and distribution system. As a general statement:

(c) the system and approach described in this procedure is designed to manage transmission system constraints; while

(d) it is assumed that equivalent downstream limits in the distribution system are:

  (i) not impacted by flows within the transmission system; and

  (ii) otherwise managed by the Network Operator.

In select circumstances, these assumptions do not hold and AEMO requires some information of Network Limits in the distribution system. Generally, this occurs at the transmission-distribution boundary where the classification of equipment is ambiguous (the "sub-transmission" elements). Examples include:

(a) Generation systems (or other Market Facilities) connected at medium voltages which would normally be considered part of the distribution system.

(b) Any situation or configuration where a distribution circuit might be connected in parallel with the transmission system.

In these instances, AEMO requires Limit Advice (e.g. equipment ratings and network model) to cover all possible connection paths from the Facility through to the transmission system.

4.3. Moving Terms to the LHS

4.3.1. Normalising a Constraint Equation is the process dividing all its terms by the largest coefficient on the LHS.

Following normalisation:

(a) all LHS terms in a Constraint Equation have a coefficient ≤ 1

(b) the Constraint Equation can no longer be interpreted as having physical units (e.g. ratings as MVA quantities or generator coefficients as % of MW output); the size of terms is converted to a relative % weighting.

4.3.2. AEMO may move any term from the LHS to the RHS of a Constraint Equation where the normalised coefficient of that term is <0.07

Moving a term to the RHS is a practical means of managing the situation where the Dispatch Algorithm will opt to violate a Constraint Equation in preference to dispatching highly priced offers for facilities with relatively small coefficients.

This approach (i.e. tuning) ensures that the system is operated in a secure state, while ensuring that the Dispatch Algorithm may still violate Constraint Equations in the manner intended by the hierarchy of Constraint Violation Penalties.

There is no objective value for threshold when a term should be shifted from the LHS to the RHS under these circumstances, only that the Dispatch Algorithm produces secure, reasonable and predictable outcomes under realistic operating and market conditions.

The threshold of 0.07 is chosen following experience and consultation in the NEM. It may be adjusted in future versions of this WEM Procedure following market testing and/or operational experience.

E[F] Non-Dispatch Constraints

E[F1] Projected Assessment of System Adequacy (PASA)

Following completion of the changes to the regulatory framework for operational planning, a future section may be added to this procedure to describe the relevant process for the formulation of Constraint Equations in Pre-Dispatch and PASA

E[F2] Network Access Quantities (NAQs)

Following completion of the changes to the regulatory framework for reserve capacity, a future section may be added to this procedure to describe the relevant process for the formulation of Constraint Equations for use in the determination of NAQs.

5. THE CONSTRAINT LIBRARY

E[G] Constraint Library Overview

The Constraint Library is a database that contains the repository of all Constraint Equations. It is a single convenient resource by which a user can determine the status and detailed form (i.e. specific terms and LHS/RHS arrangement) of one or more constraints at any given point in time.

The Constraint Library interfaces directly with the dispatch engine and is therefore the authoritative source of the information it contains.

The Constraint Library does not store offer / bidding history or dispatch outcomes. Sources of information and analysis of network congestion is described in the AEMO WEM Procedure: Congestion Information Resource

5.1. Constraint Lifecycle

The Constraint Equation staged but not necessarily immediately included in any future dispatch cycle. For example, a Constraint Equation used to manage a network outage will not be included in Dispatch until a relevant outage commences.

To invoke a Constraint Equation is to flag it for inclusion by the Dispatch Engine for use in a Dispatch Optimisation. To revoke a Constraint Equation is to remove it from Dispatch.

5.1.1. AEMO must include all formulated Network Constraint Equations in the Constraint Library.

5.1.2. Throughout the lifecycle of a Constraint Equation in the Constraint Library, AEMO may subject it to one or more instances of:

(a) Being invoked for set time periods before being subsequently revoked

(b) Having its form modified (coefficients adjusted; addition, removal, or repositioning of terms)

(c) Being re-assigned to a new Constraint Set

5.1.3. If a Constraint Equation in the Constraint Library is found to be no longer accurate or relevant to Dispatch, AEMO may retire it permanently.

A retired Constraint Equation may no longer be Invoked, but it remains archived in the Constraint Library with its status updated accordingly.

5.1.4. At all such instances described in 5.1.1, 5.1.2 and 5.1.3, AEMO must:

(a) record the timestamp and action in the Constraint Library; and

(b) notify participants as detailed in the WEM Procedure: Market Systems.

The detail of the notification mechanism will be expanded following further development of AEMO's constraint systems architecture.

This explanatory note contains procedural clauses that outline anticipated requirements of future Energy Transformation rule packages.

AEMO has not yet determined which WEM Procedure is most appropriate to include these descriptions.

6. SPECIAL CONSTRAINTS

6.1. Discretionary Constraint Equations

6.1.1. Discretionary Constraint Equations are a class of Constraint Equations developed in real time to manage unexpected or extreme operating conditions.

6.1.2. AEMO may apply Discretionary Constraint Equations with any form it determines appropriate to represent the physical status of the power system, in response to the following triggering conditions:

(a) Non-Conformance: where a facility fails to follow a Dispatch Instruction

(b) Post-Contingency: following a Contingency Event (Credible or Non-Credible)

(c) Direction: where AEMO has previously issued a direction

(d) Emergency: following declaration of an Emergency Operating State

(e) Constraint Deficiency: during a normal operation, where AEMO either

(i) finds existing Constraint Equation does not securely manage the intended Limit; or

(ii) identifies a situation where it believes a Constraint Equation should have otherwise been developed under the Standard Methodology (i.e. a Constraint Equation is missing from the Constraint Library)

6.1.3. AEMO may apply a Discretionary Constraint Equation until it is aware:

(a) the triggering condition has been resolved; and

(b) the system will remain in a Secure Operating State following release of the Equation.

6.1.4. AEMO must publish the outcomes of all Discretionary Constraints in the Congestion Information Resource

Discretionary Constraint Equations communicate unexpected operating circumstances back the Dispatch Optimisation process. This application of Discretionary Constraint Equations is preferred in preference to direct request for non-market action from participants as it ensures:

(a) the Dispatch Engine does not issue unachievable or non-physical Dispatch Instructions to facilities impacted by the real time circumstances; while also

(b) optimising the remaining portion of the fleet as best possible.

A common example of Discretionary Constraint Equations application is during the Non-Conformance condition, triggered when a Facility is temporarily unable to reach an operating point due to unforeseen plant issues in real time. In these circumstances, the form of the equation is:

(a) LHS: the Dispatch Target or ESS allocation of the non-conforming Facility with a unity coefficient

(b) RHS: the last telemetered value or temporary capability advised from the Facility

(c) Operator: any ($\geq, \leq, =$), as advised by the plant operator.

This form can lock the facility to its current position or constrain further Dispatch Instructions to within the facility's reduced physical operation range.

Generally, onsite operations personnel will advise AEMO when they believe any plant issues have been resolved. To confirm this advice and/or ensure a Secure Operating state, AEMO may opt to gradually relax the constraint (e.g. by increasing the RHS term) prior to fully revoking the Constraint Equation.

6.2. Stop-Gap Constraint Equations

6.2.1. Following either the:

(d) deployment of a Discretionary Constraint Equation under 6.1.2 (b) in response to a Non-credible Contingency Event;

(e) reclassification of Non-credible Contingency Event as a Credible Contingency Event; or

(f) identification new Credible Contingency Event

AEMO may create one or more a Stop-Gap Constraint Equations in any form it determines appropriate to manage the associated Contingency Event.

6.2.2. AEMO may modify, invoke, or revoke Stop-Gap Constraint Equations at any time up until 20 business days after the time a Constraint Set was first invoked to manage the associated Contingency Event. During this period, AEMO must:

(a) Determine, with the assistance of the Network Operator if:

(i) the Contingency Event should be reclassified; and

(ii) additional Limit Advice is required to manage the Contingency Event;

(b) Publish a report to the Congestion Information Resource that summarises:

(i) The form and intended function of the Stop-Gap Constraint Equations;

(ii) Any market impact to date; and

(iii) The outlook for likelihood and future management of the triggering Contingency Event.

6.2.3. AEMO may extend the application period described in 6.2.2 by up to 20 further business days any number of times, provided AEMO publishes an interim report following the requirements of 6.2.2 (b) at each instance.

6.2.4. The Network Operator must make all reasonable efforts to assist and respond to requests by AEMO in fulfilling 6.2.2 (a).

6.2.5. AEMO must publish the outcomes of all Stop-Gap Constraints in the Congestion Information Resource

E[H] Non Co-optimised Network Constraints

Following the development of a regulatory framework to manage the development of contracted network support arrangements, a new section may be added here to describe the formulation of Special Constraints for these purposes.

7. CONSTRAINT NAMING

7.1.1. AEMO must assign a unique identifier for every Constraint Equation in the Constraint Library

E[I] Defined Constraint Naming Conventions

The conventions for describing ESS and other Defined Constraint Equations are described in Market Procedure: WEMDE Formulation

7.2. Generic Constraint Conventions

7.2.1. In determining an appropriate identifier for Generic Constraint Equations under 7.1.1, AEMO may compose the identifier as an ordered series of any of the following components:

(a) prefix

(b) cause ID

(c) configuration

(d) contingency

(e) monitored element

(f) postfix

Figure 3 shows an example of a Network Constraint that conforms with the Generic Constraint naming conventions.

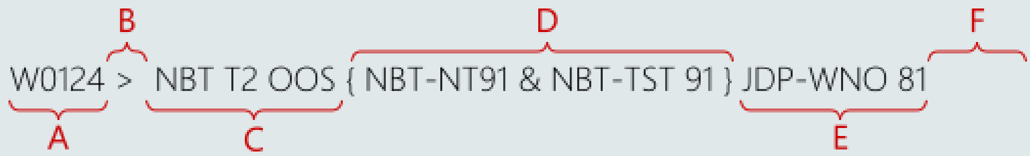


Figure 3 Example constraint identifier with labelled components

7.2.2. Where AEMO elects to include one of the components in a constraint identifier under 7.2.1:

(a) The prefix must include a code to indicate the class Constraint Equation:

(i) "W" for Network Constraint Equations, or

(ii) For Discretionary Constraints, one of (NC, CONT, DIRECT, EMER, DEFI); or

(iii) For all other Special Constraints, a similarly indicative word.

and a short set of characters to assist human identification.

(b) The cause ID must indicate the type of limit managed by the constraint, as per Table 2

Table 2 Cause ID codes

Code	Cause ID Description
>	Thermal overload
:	Transient or oscillatory stability
^	Voltage stability
+	Frequency control
*	Any other limit that does not fit into the above categories

(c) The configuration component must indicate any changes to the network configuration or power system conditions under which the constraint applies.

> A NIL configuration component indicates system normal configuration.
>
> This component is typically used to distinguish Constraint Equations that apply under network outage or non-standard configurations.

(d) The contingency component must:

(i) describes the system event the constraint secures the system against; and

(ii) be indicated by enclosing curly braces

(e) The monitored component must describe the equipment or operating condition to be protected from the contingency.

> Physical equipment is identified following the conventions described in Appendix A.

(f) The postfix may include any characters.

> The postfix is used to indicate slight variations or relationships between Constraint Equations not otherwise described by other components.

APPENDIX A. NETWORK EQUIPMENT NAMING CONVENTIONS

A.1.1 All network equipment identifiers are associated with a primary substation, as determined by the connection point busbar.

A.1.2 Two-terminal elements use a secondary busbar.

A.1.3 Substations in the Western Power network are designated by unique codes of 1 to 3 letters.

A.1.4 Western Power distinguishes between distribution zone substations and (primarily) bulk-transmission terminal substations. Terminal substations have multiple entries for different voltage levels, as per the following examples:

- W: Wellington Street zone substations
- MR: Margaret River zone substation
- MU 132: 132 kV section of Muja terminal substation
- MU 330: 330 kV section of Muja terminal substation
- TST 330: Three Springs 330 kV terminal substation

A.1.5 A shorthand code is used to indicate the nominal voltage of network assets:

- 9: 330 kV
- 8: 132 kV
- 7: 66 kV
- 6: 33 kV
- 5: <33 kV
- X: 220 kV

A.1.6 The sections below describe the conventions for each of the following asset classes:

- Transmission lines
- Transformers
- Other equipment (auxiliary equipment and reactive plant)

A.2 Transmission lines

A.2.1 Transmission lines use the format S1-S2VC, where:

- S1, S2 are the codes for the primary and secondary busbar connected;
- V is a voltage code:
- C is the circuit ID (typically 1, 2 or 3)

A.2.2 Examples include:

- KW-ST 92: second circuit of the 330 kV line connecting Kwinana and Southern Terminal
- KDN-MRT X1: first circuit of the 220 kV line connecting Kondinin and Merredin Terminal

A.3 Transformers

A.3.1 Transformers use the format SUB TX SIDE, where:

- SUB: substation code
- TX: transformer identifier (typically T1, T2 etc.)
- SIDE: optional designation to indicate high- or low-voltage side and/or winding (if relevant)

A.3.2 Generator step-up transformers omit the SIDE designation.

A.3.3 Examples include:

- MU BTT3 L: Muja bus-tie transformer 3, as seen from the 220 kV side;
- MU BTT3 H: Muja bus-tie transformer 3, as seen from the 330 kV side;
- MU SUT8: step up transformer 8 at Muja; and
- PJR SUT1 L2: 2nd low-voltage winding for the three-winding step up transformer 1 at Pinjar.

A.4 Other equipment

A.4.1 Follows the form SUB T VN, where:

- SUB is the substation code;
- T: type code that varies with asset type;
- V is a voltage code;
- N is the asset number (typically 1, 2. A. B etc.).

A.4.2 Common type codes are summarised in the following table:

Code	Asset	Example
CP	Capacitor	GLT CP 82: Guilford Terminal 132 kV capacitor 2.
RX	Reactor	MU RX 62A: Muja 33 kV shunt reactor A (connects to the 2nd auxiliary winding of a bus-tie transformer). ST RX 8846: Southern Terminal 132 kV reactor in series with the 846 bus-coupler.
VC	Static VAR compensator	WKT SVC 61: West Kalgoorlie Terminal 30.5 kV SVC 1.

APPENDIX B. QUALITY CONTROL

B.1 Playback Analysis

B.1.1 As time and/or criticality permits, a Constraint Equation may be tested via a "playback" of historical data to directly input or forecast Variables where applicable. This allows for a Constraint Equation to be rapidly tested and statistically analysed over a large range of operating conditions.

B.1.2 Some Terms may not be directly recoverable from historical data, such as the flow over new transmission line, or a newly connecting facility. In these instances, terms in the Constraint Equation may be back-cast / interpolated to estimate if feasible.

B.1.3 Where the constraint binds in playback, the result is confirmed by recreating the dispatch conditions and re-simulating using the power system model originally used to develop the Limit Equation. Similarly, playback may also identify circumstances where a Constraint fails to bind but is expected to do so.

B.1.4 Where the playback finds unexpected or inappropriate constraining action, the formulation process is reviewed for error and the Operating Margin adjusted accordingly.

B.2 Simulation Environment

B.2.1 Prior to live operation, a Constraint Equation is first deployed in a simulation environment.

B.2.2 The environment has equivalent systems to real time dispatch but uses historical or simulated data feeds.

B.2.3 Simulation testing confirms the constraint is correctly formulated from a system interfacing standpoint, and further confirms the expected impact to dispatch.

B.3 Monitoring and Optimisation

B.3.1 The primary means and tool for Constraint Equation monitoring is the real time environment.

Constraint Deficiencies

B.3.2 Where the Standard Methodology process has either incorrectly formulated a Constraint Equation or failed to identify a security limit outright (no Constraint Equation exists to manage a limit), the deficiency will be identified in real time by the security management tools available to the control room.

B.3.3 In this instance, the AEMO controller may create and/or invoke Discretionary Constraints or take direct intervention as required to resecure the power system.

B.3.4 This action will trigger immediate priority for modification or development of a new Constraint Equations as required, and an investigation of the incident and Standard Methodology process to determine the root cause of the deficiency.

B.3.5 Irrespective of any real time incidents, AEMO may also modify or create new Constraint Equations or review the Standard Methodology process to correct deficiencies as they are identified.

Constraint Efficiency

B.3.6 From time to time, AEMO may undertake an internal efficiency review of a Constraint Equation, to confirm that its impact to the Co-Optimised Dispatch process is consistent with the Market Objectives.

B.3.7 The efficiency review consists of:

(a) a general investigation of system conditions during binding action, to confirm the Constraint Equation correctly prevented risk to secure operation and minimised the overall dispatch cost; and

(b) a review of the assumptions and development of the Constraint Equation Operating Margin, with consideration as to whether the margin may be reduced through further analysis or risk assessment.

B.3.8 Following an efficiency review, a Constraint Equation may:

(a) be modified, reformulated (e.g. with an adjusted Operating Margin), retired and/or replaced by one or more new Constraint Equations as per Section 5.1; and

(b) deemed either efficient or needing further observation under real time operation.

B.3.9 Where a Constraint Equation may be formulated with a conservative Operating Margin but has negligible impact on Co-optimised Dispatch, it is considered appropriately formulated and is not routinely considered for an efficiency review.

B.3.10 The impact of a Constraint Equation is considered non-negligible if it has either:

(a) bound for at least 6 consecutive intervals; or

(b) resulted in more than:

(i) $0.05 change in the Market Clearing Price for all bound Dispatch Intervals; or

(ii) $10 in total Uplift Payments.

B.3.11 Where a Constraint Equation has non-negligible impact and has not been deemed efficient in the preceding 6 months, AEMO will conduct an efficiency review.

B.4 Power system model review

B.4.1 The quality control processes (playback and preproduction testing or following online monitoring and optimisation) may also identify a need for further analysis or refinement of power system models.

B.4.2 In the case of Network Constraint Equations, AEMO will request additional Limit Advice from the Network Operator in accordance with Western Power WEM Procedure: Limit Advice Development.