AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

WEM Procedure: Constraint Formulation

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Version	Effective Date	Summary of Changes
0.1		First version for public consultation
0.2		Draft for consultation. Developed in accordance with draft changes to the Wholesale Electricity Market Rules

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), WEM 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: 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).

1.1.2. The *Electricity Industry Act 2004* (WA), the WEM Regulations and the WEM 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 WEM Rules, as applicable.

1.1.4. The purpose of this Procedure is to document (with respect to Constraint Equations that are not Preliminary RCM Constraint Equations or RCM Constraint Equations):

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

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

(A) an Operating Margin; and

(B) 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 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)]**;

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

(d) 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)]**; and

(e) 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 WEM Rules **[clause 2.27A.10(d)]**.

1.1.5. Appendix A of this Procedure outlines the head of power clauses that this Procedure is made under, as well as other obligations in the WEM Rules covered by this Procedure.

1.2. Definitions

1.2.1. Terms defined in the Electricity Industry Act 2004 (WA), the WEM Regulations and the WEM 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
Constraint Violation Penalty	Has the meaning given in the WEM Procedure: Dispatch Algorithm Formulation.
Formulation Constraint Equation	is a Constraint Equation with predefined form and intended interaction with other Formulation Constraints.
Dispatchable Facility	A Facility that is either a Scheduled Facility or a Semi-Scheduled Facility, where its generation output is dispatchable by the Central Dispatch Process.
Dispatch Constraint Equation	Is a Fully Co-optimised Network Constraint Equation formulated for use in the Dispatch Market Schedule.
Primary Dispatch Interval	The first Dispatch Interval for a given Dispatch Market Schedule, in which the Central Dispatch Process takes place. That is, the real time Dispatch Interval in which Dispatch Instructions are issued to Registered Facilities, as opposed to forecast dispatch outcomes and prices in future intervals.
Dynamic Frequency Control Model (DFCM)	The Dynamic Frequency Control Model (DFCM) developed under the WEM Procedure: Essential System Service Quantities for use within the Dispatch Algorithm
Flow Equation	An equation that describes the power flow on a Network equipment or a set of Network equipment.
Forward-Looking Constraint Equation	Refers to a Constraint Equation that is not a Dispatch Constraint Equation.
Generic Constraint Equation	Is a Constraint Equation with arbitrary form, any number or selection of terms, and any choice of operator.
Left Hand Side (LHS)	Means the left hand side of a Constraint Equation.
Minimum Sensitivity Threshold	The minimum coefficient for a Facility term to be included in a Fully Co-optimised Network Constraint Equation.
Network Reinforcement Scheme	A scheme developed, designed and maintained by a Network Operator, which includes runback of supply or inter-tripping, for the purpose of ensuring the Network Limits are not violated.
Non-Thermal Constraint	Is a Network Constraint relating to a Non-Thermal Network Limit.
Non-Thermal Constraint Equation	Means a Fully Co-optimised Network Constraint Equation that represents a Constraint due to a Non-Thermal Network Limit.
Pre-Dispatch Constraint Equation	Is a Fully Co-optimised Network Constraint Equation formulated for use in Dispatch Intervals other than Dispatch Run in the Dispatch Schedule Horizon or in Pre-Dispatch Intervals in Pre-Dispatch Schedule Horizon.
Redistribution Factor (RDF)	The ratio that measures the amount of power flow on the contingent element that gets transferred to the monitored element.
Thermal Constraint	Is a Network Constraint relating to a Thermal Network Limit
Thermal Constraint Equation	Means a Fully Co-optimised Network Constraint Equation that represents a Constraint due to a Thermal Network Limit.
Right Hand Side (RHS)	Means the right hand side of a Constraint Equation.
Sensitivity Factor	Means the relative impact of an increase in a term in a Constraint Equation on the power transfer through the monitored element that is managed by the Constraint Equation.
Standard Methodology	Means the process described in paragraph 2.1.1.
Swing Bus	Means a component of load flow analysis that absorbs or supplies power as required by the simulation, to balance supply and demand.

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 WEM 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 WEM Rules.

(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.

(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 WEM Rules.

(i) References to WEM 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.

1.4. Related documents

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

Table 2 Related documents

Reference	Title	Location
Technical Rules	Technical Rules	Western Power Website
WEM Procedure	WEM Procedure: Congestion Information Resource	WEM Website
WEM Procedure	WEM Procedure: Dispatch Algorithm Formulation	WEM Website
WEM Procedure	WEM Procedure: Essential System Services Quantities	WEM Website
WEM Procedure	WEM Procedure: Facility Dispatch Process	WEM Website
WEM Procedure	WEM Procedure: Frequency Co-Optimised Essential System Services Accreditation	WEM Website
WEM Procedure	WEM Procedure: Limit Advice Development	Western Power Website
WEM Procedure	WEM Procedure: Limit Advice Requirements	WEM Website
WEM Procedure	WEM Procedure: MT PASA	WEM Website
WEM Procedure	WEM Procedure: ST PASA	WEM Website

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 Network Constraint Equations that facilitate secure, economic, and predictable dispatch outcomes. This process consists of:

(a) Using a power system model deemed appropriate by AEMO for describing the Network Limits to be managed.

(b) Identifying the specific conditions and circumstances under which the Network Limit applies.

(c) Expressing the Network Constraints arising as a result of the Network Limits mathematically, in accordance with paragraph 0.

(d) Identifying uncertainty and risks associated with the Network Constraints and determine an appropriate Operating Margin, in accordance with paragraph 5.

(e) Assigning a unique identifier to Constraint Equations and Constraint Sets, in accordance with paragraph 6.

(f) Publishing the Constraint Sets and Constraint Equations in the Constraints Library, in accordance with paragraph 7.

(g) Validating and testing of the Constraint Equation under expected power system conditions, in accordance with paragraph 8.

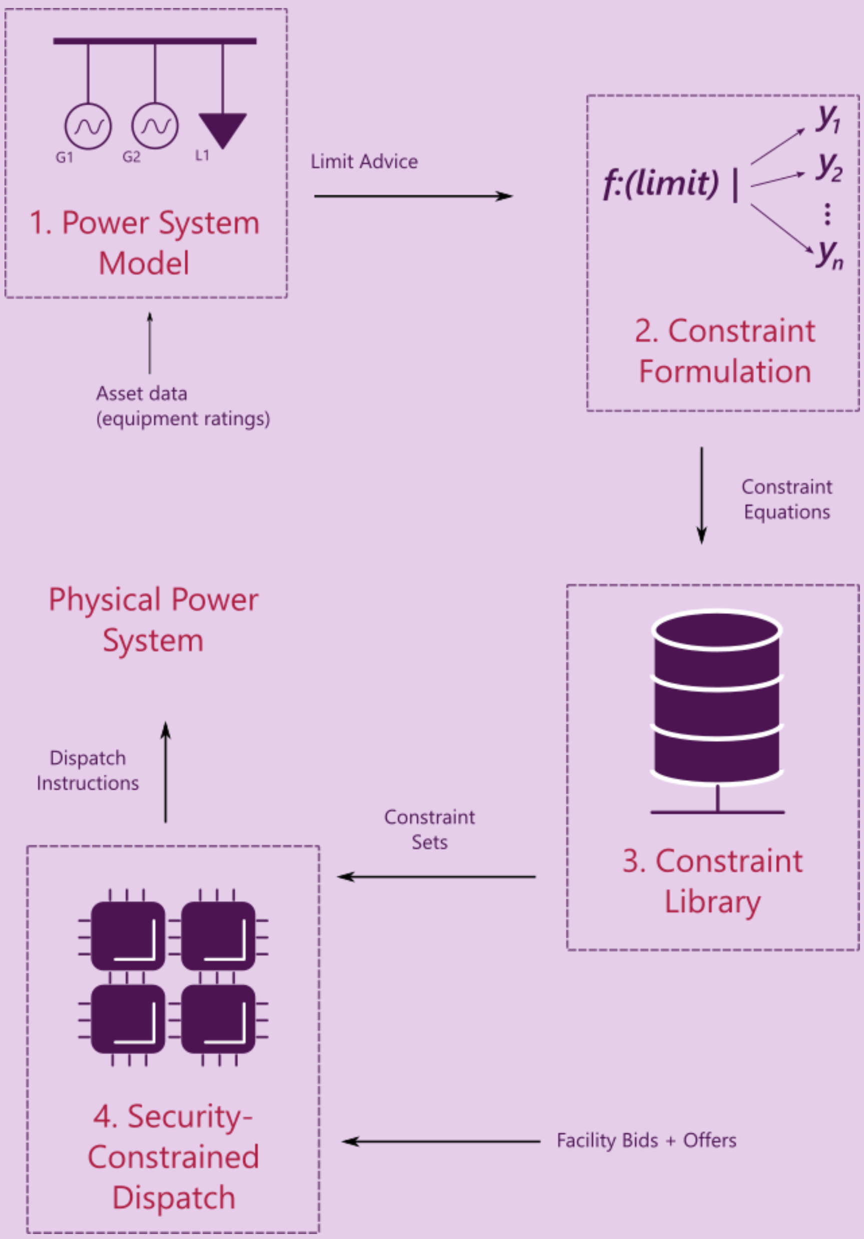
2.1.2. To the extent that information availability, operational circumstances and development resources reasonably allow, AEMO must make best endeavours to follow the Standard Methodology.

2.1.3. Where AEMO is unable formulate the Constraint Equations in accordance with the Standard Methodology, AEMO must formulate Alternative Network Constraint Equations in accordance with paragraph 4.

E[A] Standard Methodology

Figure E1 shows a diagram demonstrating the terminology and information flow in the Standard Methodology in paragraph 2.1.1, as applied in the formulation of a Fully Co-optimised Network Constraint Equation for dispatch process (E[B]).

Figure E1 Overview of terminology and information flow in the Standard Methodology as applied to the formulation of a Fully Co-optimised Network Constraint Equation.

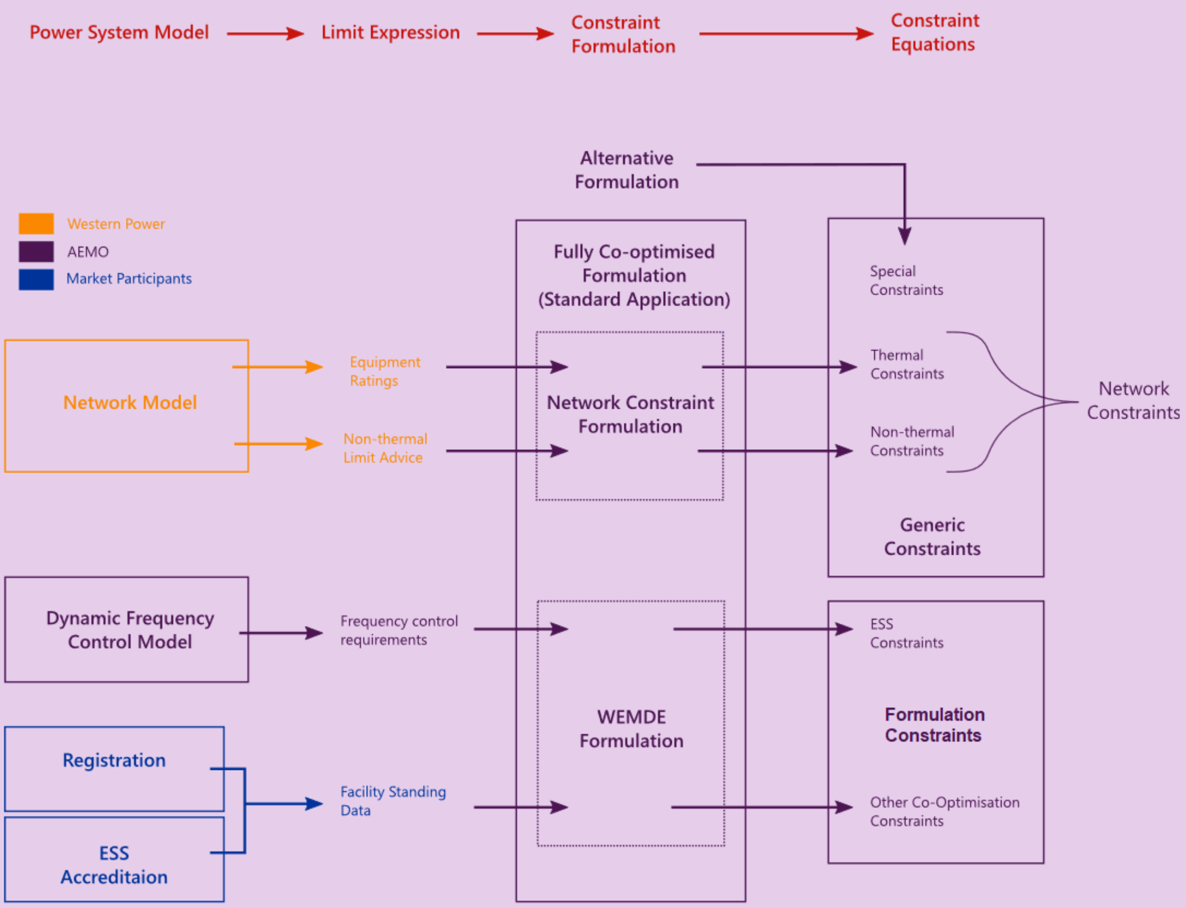


E[B] Constraint Equation Classification

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

Figure E2 summarises the set of Constraint classes and their respective information sources.

Figure E2 Constraint equation classes and respective information sources



E[B1] Classes of Constraint Equations

From Dispatch Algorithm's perspective, there are two classes of Constraint Equations:

- Formulation Constraint Equations; and
- Generic Constraint Equations.

The exact form and operation of a Formulation Constraint Equation can be understood and predicted from the formulation process.

An example use of Formulation Constraint Equations is Essential System Services (ESS) equations (refer to E[B7]).

E[B2] Generic Constraint Equations

The operation of a Generic Constraint Equation is more difficult to interpret. It can however represent a much larger range of conditions (as are required to accurately model the physical power system).

An example use of Generic Constraint Equations is Fully Co-optimised Network Constraint Equation, which may be a:

- Thermal Constraint Equation (E[B3]);
- Non-Thermal Constraint Equation (E[B4]); or
- Alternative Network Constraint Equation (E[B6]).

E[B3] Thermal Constraints

Thermal Network Limits are the subset of Network Limits that describe the maximum capacity for electrical throughput of Network elements due to temperature or related effects (i.e. beyond which the element typically overheats). These limits are defined by the rating of Network equipment as provided by the Network Operator under clause 2.27A.1 of the WEM Rules, and in accordance with the process specified in WEM Procedure: Limit Advice Requirements.

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

Thermal Network 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 Thermal Constraint Equations is described in paragraph 3.2.

E[B4] Non-Thermal Constraints

All other Network Limits are classified as Non-Thermal Network Limits, which encompass a broad range of possible physical phenomena that can have an impact on the power system operating in a Secure Operating State. Non-Thermal Network 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 Network Limits is held by the Network Operators under Clause 2.27A.1 of the WEM Rules. It requires ongoing modelling and investigation of Network capability and comparison against actual system data and performance. In some circumstances, Non-Thermal Network Limits can only be partially controlled by Dispatch optimisation and must work in concert with Network switching arrangements and other Network Reinforcement Schemes.

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

AEMO may undertake an iterative review process with the Network Operator to revise Limit Advice in accordance with WEM Procedure: Limit Advice Requirements. AEMO follows the process described in paragraph 3.3 in preparing the Non-Thermal Constraint Equations.

E[B5] Network Constraints

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

E[B6] Alternative formulation

Alternative Network Constraint Equations do not follow the Standard Methodology process. They are created using alternative formulation processes described in paragraph 4.

E[B7] Essential System Service and Other Co-optimisation Constraints

ESS Constraint Equations 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 ESS.

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 of the Frequency Operating Standards.

An example of ESS is Contingency Raise, a service which maintains system frequency following Contingency Events that result in loss of generation, by ensuring enough headroom is reserved on the fast-responding Facilities to provide additional capacity. In this example:

- The DFCM output expresses the minimum amount of headroom required.
- The Dispatch Algorithm combines this requirement with the Standing Data of the Facilities to generate a series of Constraint Equations that ensure the co-optimisation process allocates enough headroom across the Facilities.

The generic ESS quantities are input as parameters to a series of Constraint Equations that govern the fully co-optimised dispatch process, including:

- Energy balance between demand and generation.
- Allocation of capacity between different Market Services for a Facility.
- Facility operating limits (e.g. maximum and minimum capacity, ramp rates and energy storage limitations of a Facility).

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

- WEM Procedure: Essential System Service Quantities:
  - The physical model and assumptions used to develop the DFCM and determine the generic ESS quantities for secure operation.
  - The process and testing regime to accreditable capability for a specific Facility to supply an ESS.
  - The process by which Facility ESS parameters are converted into Facility Performance Factors for market offers under different power system conditions, and then used to satisfy generic ESS requirement constraints.
- WEM Procedure: Dispatch Algorithm Formulation:
  - The structure and format of Facility offers and trapeziums, and how these are applied as Constraint Equations for market co-optimisation.
  - The integration of Generic Constraint Equations (e.g. Network Constraints) into the overall co-optimised dispatch.

3. Network Constraint Formulation

E[C] Variations of Constraint Equations

For each Fully Co-optimised Network Constraint Equation that is not an Alternative Network Constraint Equation, the equation could be formulated up to a number of variations.

Each variation of equation is either used in the real-time dispatch process or to provide forward-looking information to the market. The four equations are typically known as

- 'dispatch', which are formulated for use in the Primary Dispatch Interval;
- 'pre-dispatch', which are formulated for use in Dispatch Intervals other than the Primary Dispatch Interval in the Dispatch Schedule Horizon and in the Pre-Dispatch Intervals in the Pre-Dispatch Schedule Horizon;
- 'st-pasa', which are formulated for use in the Week Ahead Schedule Horizon and Short-Term PASA period;
- 'mt-pasa', which are formulated for Medium-Term PASA period.

Figure E3 summarises the resolution, the frequency at which the information is updated, and the horizon to which it looks out of each variation of equation.

RCM Constraint Equations formulated for the purpose of Network Access Quantities, and Constraint Equations developed for the purpose of assessing reliability under Long Term PASA can be found in the WEM Procedure: RCM Constraint Formulation.

The 'dispatch' Constraint Equations are also known as Dispatch Constraint Equations. They typically utilise real-time (from the end of the last Dispatch Interval) measurements in the Right Hand Side (RHS) of the Constraint Equations. These measurements include but are not limited to:

- power flow on the monitored Network element;
- power flow on the contingent Network element;
- actual output of the relevant Facilities; and
- status of a Network element.

The 'dispatch' Constraint Equations provide reasonably accurate information for the current Dispatch Interval because the changes in the Network are generally gradual. Should there be any major changes in the Network after the measurements were sourced, the changes will be accounted for in subsequent Dispatch Intervals.

The 'pre-dispatch', 'st-pasa' and 'mt-pasa' equations are generally known as Forward-Looking Constraint Equations. They are not used in the 5-minute Dispatch process but are used to provide forward-looking information to the WEM.

The Forward-Looking Constraint Equations do not typically use measurements from the last Dispatch Interval because the information becomes less accurate in predicting the state of the Network a few hours or a few days later.

The flow and the status of the Network elements are typically estimated or assumed in the Forward-Looking Constraint Equations.

As such, Dispatch Constraint Equations are typically formulated as a feedback type and Forward-Looking Constraint Equations are typically formulated as an open-loop type (refer to E[E] for the formulation types).

Figure E3 The resolution, horizon, and the frequency of updates of each Constraint Equation variation

Variation	Resolution	Horizon	Update
'dispatch'	5 min	2 hours	5 min
'pre-dispatch'	30 min	2 days	30 min
'st-pasa'	30 min	7 days	Daily
'mt-pasa'	30 min	3 years	Daily

E[D] Coverage of Network Constraints

A Constraint Equation formulated by AEMO typically consisting of the following:

- Network configuration, including any applicable prior Outages;
- monitored element(s);
- Network Limit; and
- the next contingent element(s) if describing a post-contingent condition.

That is, in order to ensure the Network Constraints are comprehensively accounted for in the Central Dispatch Process, a Constraint Equation is required for each,

- Network element to protect against each Contingency Event; and
- Network configuration.

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 the Constraint Equations will enable dispatch of Facilities as designed, and in accordance with the WEM Objectives.

A disadvantage of this approach is the large volume of resulting Constraint Equations, many of which may never plausibly change the economic outcome of the dispatch process. A large volume of Constraint Equations is undesirable primarily because it limits comprehensibility of the dispatch outcomes. This creates risks both to Power System Security and efficient market operation.

In order to strike a balance between the advantage and disadvantage of this approach, AEMO follows the processes specified paragraph 3.1 in selecting one or more Constraint Equation to represent a Network Constraint.

E[D1] Distribution System Constraints

AEMO is required to ensure the SWIS operates in a secure and reliable manner in accordance with clause 2.1A.1A and formulate Constraint Equations in accordance with clause 2.27A.9. These obligations cover the entire SWIS, which includes both the transmission and distribution systems. However,

- the system and approach described in this Procedure is designed to manage transmission system Constraint Equations; while
- it is assumed that equivalent downstream limits in the distribution system are:
  - Not impacted by flows within the transmission system; and
  - Otherwise managed by the Network Operator.

In select circumstances, these assumptions may not hold and AEMO may require 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:

- Generation systems (or other Facilities) connected at medium voltages which would normally be considered part of the distribution system.
- Any situation or configuration where a distribution circuit might be connected in parallel with the transmission system.

In these instances, AEMO may request additional Limit Advice (e.g. equipment ratings and Network model) under clause 2.27A.4 and in accordance with WEMP: Limit Advice Requirements, to cover all possible connection paths from the Facility through to the transmission system.

E[E] Open-loop Versus Feedback

E[E1] Background

A Constraint Equation is commonly formulated as one of two types: open-loop or feedback.

An open-loop type Constraint Equation has the advantage of not having to use real-time information to inform the allowable power flow through a Network element. However, it is generally formulated based on a specific set of assumptions about the operating conditions, and the equation becomes less accurate as the real-time operating conditions drift further from this specific set of assumptions. The open-loop type Constraint Equations are therefore not typically used for formulating Dispatch Constraint Equations where the accuracy is critical. It is more generally used in Forward-Looking Constraint Equations (paragraphs 3.4.1 to 3.4.3).

On the other hand, the feedback type Constraint Equation uses real-time information to inform the allowable changes in the power flow through an element for a given dispatch condition. It does not depend on the assumptions about the power system conditions during formulation process and is very robust over a wide range of operating conditions. It is therefore generally preferred for formulating Dispatch Constraint Equations (paragraph 3.4.1).

E[E2] demonstrates the concept of an open-loop type Constraint Equation associated with a Thermal Network Limit post-contingency. The concept is also applicable to Non-Thermal Network Limit and pre-contingent conditions.

The example in E[E2] is extended to demonstrate the concept of a feedback type Constraint Equation.

E[E2] Open-loop type

Figure E4 is an example Network connected by two transmission lines to the remainder of the SWIS. The variables in the diagram are MW quantities for:

- G: dispatchable generation output;
- L: local load;
- F: transmission line power flow; and
- R: transmission line rated capacity appropriate for post-contingent condition.

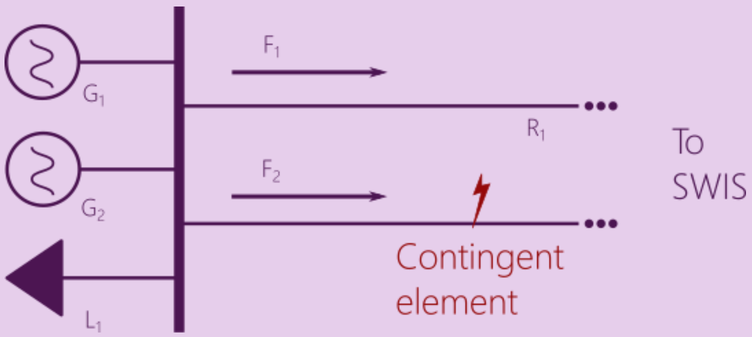


Figure E4 Simplified Network diagram

In this example, in order to protect Line 1 from thermal overloading following a Contingency Event of Line 2, the post-contingent power flow through Line 1, F_1 must be less than less than its Thermal Network Limit, which is the rated capacity.

The relevant Limit Equation for post-contingent condition is therefore:

Equation E1

$$F_1 \leq R_1$$

The post-contingent F_1 in Equation E1 may be approximated by the combined effect of the generation and the load demand, as shown in Equation E2. The accuracy of such approximation is dependent on the assumptions made about the operating conditions. While additional constant value may be introduced to make it more accurate for a limited range of operating conditions (paragraph 3.2.4(j)), it is not capable of covering all required operating conditions that can be expected in real-time operation.

Equation E2

$$a_1G_1 + a_2G_2 - b_1L_1 \approx F_1$$

where (a_1, a_2, b_1) are the Sensitivity Factor coefficients determined following the process in paragraph 3.2.4.

Replacing F_1 in Equation E1 with Equation E2, Equation E1 under post-contingent conditions is re-expressed as Equation E3:

Equation E3

$$a_1G_1 + a_2G_2 - b_1L_1 \leq R_1$$

In this example:

- The Facilities and the load are connected to the same bus, and thus have the same Sensitivity Factor.
- 1 MW of generation or load demand results in 1 MW of change in Line 1, as measured at the bus end of Line 1, the bus Sensitivity Factor is therefore 1.

The LHS of a Constraint Equation must consist only of terms that represent Dispatchable Facilities (paragraph 3.4.6).

Assuming:

- both G1 and G2 are Dispatchable Facilities; and
- an Operating Margin of 8% (Operating Margin is determined under paragraph 5);

and after moving the load demand term to RHS, the resulting open-loop Constraint Equation is shown in Equation E4:

Equation E4

$$1G_1 + 1G_2 \leq 1(1 - 0.08)R_1 + 1L_1$$

This concept is also applicable to:

- pre-contingent condition, where the Network Limit arises without any next Contingency Event;
- Non-Thermal Network Limit.

In the case of pre-contingent condition, the same equations from Equation E1 to Equation E4 apply. However,

- The Network Limit R1 is a rating appropriate for the pre-contingent condition.
- a_1, a_2, b_1 are the Sensitivity Factor coefficients calculated under pre-contingent conditions under paragraph 3.2.4.

In the case of Non-Thermal Network Limit, the Network Limit R_1 is replaced by the Non-Thermal Network Limit, which is typically a linear equation. As in the case of Thermal Network Limits, the Non-Thermal Network Limit and the coefficients are uniquely determined for pre-contingent and post-contingent conditions.

E[E3] Feedback type

The feedback type Constraint Equations differ from the open-loop type in the following aspects:

- The feedback type Constraint Equations are based on the concept of 'headroom'. The headroom in the example in E[E2] refers specifically to the available margin before the post-contingent power flow reaches the Network Limit.
- The post-contingent power flow, F_1 is not approximated. The pre-contingent power flow values measured in real-time are used directly in the feedback type constraint Equations to calculate the post-contingent flow (Equation E5).
- As the post-contingent power flow is not approximated as in Equation E2, all terms within Equation E2 except for Dispatchable Facilities, are no longer relevant.
- The Dispatchable Facilities in Equation E2 instead are re-expressed as the difference between the Dispatch Instruction and the current generation output.

Equation E6 is the resulting feedback type Constraint Equation for the example described in E[E2]. This type of Constraint Equation is named feedback type because it uses real-time information (the flow and generation current output) as feedback, to inform the required changes to the power flow by changing the generation output.

Equation E5

$$F_1 = F_{1\_pre} + (\text{RDF} \times F_{2\_pre})$$

where RDF is the Redistribution Factor determined under paragraph 3.2.4.

Equation E6

$$a_1 \Delta G_1 + a_2 \Delta G_2 \le R_1 - (F_{1\_pre} + \text{RDF} \times F_{2\_pre})$$

Equation E6 is generalised to yield Equation E7 :

Equation E7

$$a_1 \Delta G_1 + a_2 \Delta G_2 + \cdots a_n \Delta G_n \le (1 - \epsilon) R_m - F_m - \text{RDF} \times F_c$$

where:

- n: number of Facilities that are relevant to a Network Constraint
- $\Delta G_i = G_{i,DI} - G_{i,t0}$: difference between the Dispatch Instruction and the current generation output of Facility G_i
- ϵ: Operating Margin
- R_m: rated capacity rating of the monitored element.
- F_m, F_c: measured power flow through the monitored and contingent elements respectively

Or equivalently, Equation E8.

Equation E8

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

As in the case in the open-loop type Constraint Equations, the concept here is also applicable to pre-contingent conditions and Non-Thermal Network Limits.

E[E4] Sign Convention

The sign convention for a power flow direction is generally as such:

- positive if the power flows away from the point of measurement; and
- negative if the power flows towards the point of measurement.

A Constraint Equation can be formulated using power flows measured at either end of a Network element. Where a Constraint equation is formulated using the negative power flow measurement, care must be taken to ensure the signs in the rest of the equation correctly reflect such power flow direction.

In Figure E4 for example, assuming the power flows are now measured at SWIS end of lines (the power still flows towards SWIS), the open-loop Equation E3 retains the same form as shown in Equation E9.

Equation E9

$$a_1 G_1 + a_2 G_2 - b_1 L_1 \le R_1$$

However, the feedback type Equation E7 must be adjusted as shown in Equation E10 to account for the sign change of the measured power flows.

Equation E10

$$a_1 \Delta G_1 + a_2 \Delta G_2 + \cdots a_n \Delta G_n \le (1 - \epsilon) R_m + F_m + RDF \times F_c$$

In practice, the quality or reliability of physical measuring devices out on the field can also dictate which measurements are more appropriate to use. For example, remote areas may suffer from communication delays or outages of measuring equipment, low data bandwidth, or sensors with lower accuracy or sample rates. The measurement at one end of the line may be more reliable than the other in this case. It is therefore more appropriate for a Constraint Equation to use the measurement that has higher quality data.

E[E5] Reverse Flow

In areas of the Network where dispatch and load demand conditions can result in reverse power flow, the Limit Equation is to consider the absolute flow through a monitored element as follows:

Equation E11

$$|F_m| < R_m$$

Or equivalently:

Equation E12

$$-R_m \leq F_m \leq R_m$$

This is implemented as a Constraint Equation with all terms negated except for the rating term, for example the format of a feedback type Constraint Equation protecting against a reverse flow is as follows:

Equation E13

$$-(\mathrm{a}_1 \Delta G_1 + a_2 \Delta G_2 + \cdots a_n \Delta G_n) \leq (1-\epsilon) R_m + +RDF \times F_C$$

3.1. Selecting Constraint Equations

3.1.1. AEMO must select one or more Constraint Equations to represent a Network Constraint by following the processes specified in paragraphs 3.1.2 to 3.1.4.

3.1.2. AEMO must formulate a Fully Co-optimised Network Constraint Equation if for a Network configuration, a Network element has been identified at risk of exceeding its Network limits, unless the circumstances described in paragraphs 3.1.3 and 3.1.4 apply.

3.1.3. AEMO may choose not to formulate a Constraint Equation if it determines that the Constraint Equation would have negligible impact on Power System Security, including:

(a) all Facility coefficients in the Constraint Equation fall under a Minimum Sensitivity Threshold as defined in paragraph 3.4.4;

(b) the risks of the Network element exceeding its Network Limits may be mitigated by another Constraint Equation or other Constraint Equations under all operating conditions; or

(c) AEMO forms the view that the Network conditions under which the Network Limits arise are highly improbable.

3.1.4. AEMO may choose not to formulate a Forward-Looking Constraint Equation for a Constraint Equation if it forms the view that the Network conditions under which the Network Limits arise are highly improbable.

3.2. Thermal Network Constraints

E[F] Thermal Ratings of Network Equipment

E[F1] Static versus Dynamic

Thermal Network Limits typically refer to the thermal equipment ratings of the Network elements. In providing the Limit Advice associated with Thermal Network Limits, a Network Operator must provide the Normal Ratings and any relevant Revised Ratings, and where applicable, the Short-Time Ratings and Emergency Ratings (refer to WEM Procedure: Power System Security).

The Normal Rating of a Network element can be described as a static value (may be adjusted according to seasons) or a dynamic one that changes regularly in accordance with the ambient weather conditions. The dynamic ratings reflect the capability or the limits of a Network element at any one time more accurately and are typically less restrictive than the static ones. The static ratings however are easier and less costly to implement operationally.

As such, a Network Operator typically provides the Normal Ratings as static ratings to AEMO. It may choose to provide dynamic ratings for selected Network elements, to be used under all or very specific operating conditions only.

The Network Operator follows largely the same process (refer to WEM Procedure: Limit Advice Requirements) and mechanism (refer to WEM Procedure: Network Modelling Data) regardless of the type of Normal Ratings that they provide to AEMO. One of the few exceptions is that, when providing the dynamic ratings, the Network Operator must provide additional information described in WEM Procedure: Limit Advice Requirements. The additional information is to assist AEMO in applying the dynamic ratings as intended by the Network Operator. This additional information includes but is not limited to the timeframe for which a dynamic rating must be applied, and the ratings to use beyond that time or the ratings to use if the dynamic rating is unavailable.

E[F2] Application of thermal ratings

In a Constraint Equation formulated for the Primary Dispatch Interval in a Dispatch Schedule Horizon, paragraph 3.2.2 specifies that AEMO must use the real-time thermal ratings that have been applied in AEMO's Energy Market System (EMS) where possible. Such approach applies regardless of if the thermal ratings are dynamic or static, and it negates the need for AEMO to create multiple Constraint Equations or to constantly update the Constraint Equation to reflect the rating applied at any one time.

For the 'pre-dispatch' variation of the equation (Pre-Dispatch Constraint Equation),

- where the dynamic ratings have not been provided, AEMO uses the static values (paragraph 3.2.2(b));
- where the Network Operator has provided different static values for different seasons, AEMO may use only the most restrictive one (paragraph 3.2.3).
- where the dynamic ratings have been provided, AEMO will apply the dynamic ratings for the specified period of time, by using the real-time thermal ratings applied in EMS, and change over to the static values (paragraph 3.2.2(c)) .

For all other Forward-Looking Constraint Equations, AEMO uses the static ratings under all circumstances. Where the Network Operator has provided different static values (e.g. for different seasons), AEMO may use only the most restrictive one.

3.2.1. In formulating each Thermal Constraint Equation, AEMO must follow the Standard Methodology:

(a) Use a power system model deemed suitable by AEMO for describing the Thermal Network Limits.

(b) Express the Thermal Network Limit mathematically by following the process described in paragraph 3.2.4, in determining:

(i) Redistribution Factors;

(ii) Sensitivity Factor for each relevant Facility;

(iii) Sensitivity Factor for the relevant load demand if the determination is required; or

(iv) the flow constant value if the determination is required.

(c) Apply the Thermal Network Limits in accordance with paragraphs 3.2.2 and 3.2.3.

(d) Use the appropriate type of Constraint Equation in accordance with paragraphs 3.4.1 and 3.4.2.

(e) Exclude a variable from the Constraint Equation in accordance with paragraphs 3.4.4 and 3.4.5.

(f) Follow paragraph 3.4.6 in determining the location of terms on each side of the Constraint Equation.

(g) Include an Operating Margin in accordance with paragraph 5.

3.2.2. Where possible, AEMO must:

(a) use the Thermal Network Limits applied in real-time operation in Dispatch Constraint Equations, irrespective if they have been provided as dynamic or static limits by a Network Operator;

(b) apply the Thermal Network Limits as static limits in Forward-Looking Constraint Equations unless paragraph 3.2.2(c) applies; and

(c) where the Thermal Network Limits have been provided by a Network Operator as dynamic limits, apply them in Pre-Dispatch Constraint Equations in accordance with the Limit Advice.

3.2.3. Where multiple limits have been provided for a Thermal Network Limit by the Network Operator in paragraph 3.2.2(b), AEMO may use only the most restrictive limit in Forward-Looking Constraint Equations.

3.2.4. AEMO must follow the process below in determining the variables under paragraph 3.2.1(b):

(a) Establish one or more simulation cases in the power system model with an appropriate system configuration, which include:

(i) the relevant Network configuration.

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

(b) Record the initial power flows through the contingent element P_{C0} and the monitored element P_{M0}.

(c) Set the Swing Bus to an appropriate location to recreate any power redistribution following the Credible Contingency under consideration.

(d) Where a Constraint Equation is to describe a post-contingent condition, reconfigure and re-simulate the system to represent the state of the Network following the relevant Contingency Event. The new power flow on the monitored element P_{M1} is recorded.

(e) Determine the Redistribution Factor (RDF) using Equation 1:

Equation 1

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

(f) In the case of a Credible Contingency Event consisting of losses of multiple Network elements, the RDF is calculated according to paragraph 3.2.4(e) for each contingent element separately, where the pre-contingent configuration includes all other contingent elements initially out of service.

(g) Shift the Swing Bus to the Reference Node.

E[G] Orienting a Constraint Equation

Switch the Swing Bus prior to the calculation of sensitivity factors in accordance with paragraph 3.2.2(g) is referred to as "orienting" a Constraint Equation to that bus.

(h) From this state of the Network, determine the linear Sensitivity Factor a Facility, S at a given bus using Equation 2:

Equation 2

$$\boldsymbol{S_i = \Delta P_M / \Delta P_i}$$

Where:

ΔP_i is an injection of MW at bus i

ΔP_M is the change in power flow in MW through the monitored element following ΔP_i

(i) If required, determine the Sensitivity Factor of the load demand by scaling the loads that are relevant to the Thermal Network Limits using Equation 3:

Equation 3

$$\boldsymbol{S_d = (P_{M0}{}' - P_{M0}) \,/\, (D_0{}' - D_0)}$$

Where:

- $P_{M0}{}'$ is the power flow on the monitored element after increasing the relevant load demand;
- P_{M0} is the power flow on the monitored element prior to increasing the relevant load demand;
- $D_0{}'$ is the load demand after increasing the relevant load demand;
- D_0 is the initial load demand; and
- $\boldsymbol{S_d}$ is the Sensitivity Factor for the load demand.

(j) If required, calculate the flow constant value using Equation 4:

Equation 4

$$constant = P_{M0} - \sum_{i=1}^{n} (S_i * P_i) + S_d * D_0$$

where:

S_i is the Sensitivity Factor for Facility i

P_i is the output (MW) for Facility i.

S_d is the Sensitivity Factor for the load demand.

D_0 is the load demand.

E[H] Power flow on the monitored element

The Forward-Looking Constraint Equations do not typically use the SCADA measurements from the last Dispatch Interval directly in their equations because the information becomes less accurate in predicting the state of the Network a few Dispatch Intervals or a few days later. The flow and the status of the Network elements in the Forward-Looking Constraint Equations are normally estimated or assumed using other means.

To estimate the power flow on the monitored element or a group of monitored elements, the open-loop equation in Equation E14 is generally used. Note Equation E14 is Equation E2 in a general form.

Equation E14

$$\sum_{i=1}^{n}(S_i * P_i) + S_d * D + \ constant \approx flow$$

The equation is also commonly known as the Flow Equation. The Sensitivity Factor of a relevant Facility in the Flow Equation is determined using Equation 2 while the Sensitivity Factor of the load demand is determined using Equation 3.

As the flow may vary in accordance with the power system conditions, e.g. voltage levels, the accuracy of the Flow Equation approximation may also vary. A constant value may be introduced so that the Flow Equation will at least approximate the flow to an acceptable accuracy range under various power system conditions where the flow is most likely to reach very close to the relevant Network Limit. The constant value is calculated using Equation 4 under paragraph 3.2.4, which is derived from Equation E14.

3.2.5. AEMO may make or adjust detailed technical judgements on a case by case basis or deviate from the process in paragraph 3.2.4 where it determines that:

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

(b) AEMO's core functions of maintaining Power System Security or the WEM Objectives can be better served by doing so.

3.3. Non-Thermal Network Constraints

E[I] Overview of Non-Thermal Network Constraints

E[I1] Power transfer limit

While the Thermal Network Limits are typically the thermal ratings of the Network equipment, Non-Thermal Network Limits are more abstract and often approximated by Limit Equations (refer to WEM Procedure: Development of Limit Advice, which is developed and maintained by the Network Operator).

The most common type of Limit Equations is an equation that describes the power transfer limit that must be imposed on the power flow through a piece of Network equipment or a set of Network equipment ('cutset'), so that non-thermal system stability (e.g. voltage stability and transient stability) is maintained. The Network equipment is typically a transmission line. The power transfer limit is typically described in the following form:

Equation E15

$$Cutset\ MW\ Import\ (or\ Export) \leq constant\ +\ A1.X1\ +\ A2.X2\ +\ A3.X3\ +\ ...\ +\ An.Xn$$

Where:

- Xn is the variable necessary to describe the Non-Thermal Network Limit and An is the associated coefficient (both as determined by the Network Operator);
- Cutset refers to a Network element (e.g. a line) or a set of Network elements.

The power flow of the cutset is formulated the same way as described in E[H], using the process described in paragraph 3.2.4. It may be formulated by AEMO or the Network Operator. Where a cutset consists of a set of M x Network elements, the power flow is approximated as follows:

Equation E16

$$F_{custet} = \sum_{m=1}^{M} F_m$$

where:

- F_m is the power flow on one of the lines of the cutset
- F_{cutset} is the power flow across the cutset

3.3.1. In formulating each Non-Thermal Constraint Equation, AEMO must follow the Standard Methodology:

(a) Use a power system model deemed suitable by AEMO for describing the specific Non-Thermal Network Limit to be managed.

(b) Express the Non-Thermal Network Limit mathematically by:

(i) re-expressing a Limit Equation as multiple Constraint Equations if required.

(ii) formulating the Flow Equation in accordance with paragraph 3.2.4 if required.

(c) Use the appropriate type of Constraint Equation in accordance with paragraphs 3.4.1 and 3.4.2.

(d) Exclude a variable from the Constraint Equation in accordance with paragraphs 3.4.4 and 3.4.5.

(e) Follow the paragraph 3.4.6 in determining the location of terms on each side of the Constraint Equation.

(f) Include an Operating Margin in accordance with paragraph 5.

3.3.2. In formulating a Non-Thermal Constraint Equations as a Forward-Looking Constraint Equation, where it is impractical to use the real-time SCADA values, AEMO may assume any reasonable value that it deems appropriate.

E[J] Non-Thermal Constraint Equations and required assumptions

The Non-Thermal Network Limits may only arise under very specific system conditions. A Network Operator must specify such system conditions in the Limit Advice, in accordance with WEM Procedure: Limit Advice Requirements. These system conditions include :

- the power transfer flow (e.g. LHS of Equation E15) must be greater than or less than a threshold; or
- one or more Network equipment must be out-of-service.

In addition, a Limit Equation in the form of Equation E15 generally consists of many terms that could vary significantly in real-time operation, for example, the MVAr flow on a Network element.

While Dispatch Constraint Equations can source the above information using the near real-time values, it is not appropriate to use the near real-time values to predict the future states of the Network in the Forward-Looking Constraint Equations.

Under such instances, AEMO has to make assumptions and replaces these terms with fixed values (paragraph 3.3.2). Examples of some of these assumptions include:

- A Network element may be assumed in-service if it is typically switched in under power system conditions when the equation is most likely to bind.
- A Network element may be assumed out of service if it is only switched in by the Network Operator as last-resort mechanism under emergency conditions.
- A term may be assumed zero if its impact on the Network Limit, as indicated by its coefficient, is comparatively small or insignificant to other terms in the Limit Equation.

Due to increasingly low accuracy of the Forward-Looking Constraint Equation in representing the Network Constraints as the horizon of a Forward-Looking Constraint Equation increases, this approach is considered reasonable. The assumptions may be verified over time using the dispatch outcome (refer to process described in paragraph 8.1.8).

3.4. Common

E[K] Common requirements

Paragraph 3.4 specifies the requirements that are common to formulating both Thermal Constraint Equations and Non-Thermal Constraint Equations.

3.4.1. AEMO must formulate a Dispatch Constraint Equation, where possible, as a feedback type Constraint Equation.

3.4.2. AEMO may formulate a Forward-Looking Constraint Equation as either a feedback type or an open-loop type Constraint Equation.

3.4.3. In addition, where applicable, AEMO must formulate a Forward-Looking Constraint Equation for the:

(a) Short Term PASA period, in accordance with WEM Procedure: Short Term PASA; or

(b) Medium Term PASA period, in accordance with WEM Procedure: Medium Term PASA.

E[L] Minimum Sensitivity Threshold

The Minimum Sensitivity Threshold ensures that Facilities only appear in Constraint Equations if constraining the Facility's output would materially change Power System Security outcomes. This declutters the Constraint Equations (and the Constraints Library overall), improving the accessibility and quality of market information from constrained Dispatch.

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 and refined through data, analysis and evidence from the outcome of the Dispatch Algorithm.

3.4.4. For each Constraint Equation, AEMO may exclude a variable from a Constraint Equation by applying a Minimum Sensitivity Threshold such that:

(a) excluding the variable does not result in AEMO failing to maintain Power System Security; and

(b) AEMO forms the view that the Market Clearing Price or the overall cost to the market may be improved with the application of the Minimum Sensitivity Threshold, while maintaining Power System Security.

3.4.5. Where a Minimum Sensitivity Threshold is determined for a Constraint Equation under paragraph 3.4.4, AEMO must exclude only a term for which its Sensitivity Factor is greater than the Minimum Sensitivity Threshold.

3.4.6. For each Constraint Equation, AEMO must:

(a) include each term representing a Dispatchable Facility on the LHS of the Constraint Equation; and

(b) include all other terms on the RHS of the Constraint Equation.

3.4.7. For each Constraint Equation, AEMO may, at its discretion,

(a) normalise a Constraint Equation;

(b) move any terms from the LHS to the RHS of a Constraint Equation where the normalised coefficient of that term is below a threshold; and

(c) exclude terms for which the normalised coefficients are less than the Minimum Sensitivity Threshold determined for the Constraint Equation.

E[M] Normalisation and moving terms to RHS

Normalising a Constraint Equation is the process of dividing all its terms by the largest coefficient on its LHS. Following normalisation:

- All LHS terms in a Constraint Equation have a coefficient ≤ 1.
- The Constraint Equation can no longer be interpreted as having physical units (e.g. ratings as MVA quantities or Facility coefficients as % of MW output); the size of terms is converted to a relative % weighting.

Moving a term to the RHS of the Constraint Equation 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 Power System Security is maintained, while ensuring that the Dispatch Algorithm will still violate Constraint Equations in the manner intended by the hierarchy of Constraint Violation Penalties.

There is no objective value for the threshold when a term should be shifted from the LHS to the RHS of the Constraint Equation 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 used in the Constraint Equations in National Electricity Market.

AEMO in WEM may choose not to adopt such approach on and after New WEM Commencement Day until sufficient data, analysis and evidence from the dispatch outcomes support such approach.

4. Alternative Network Constraint Formulation

E[N] Alternative Network Constraint Equations

Alternative Network Constraint Equations are also commonly known as discretionary Constraint Equations. They are typically formulated during real-time operation of the power system. The circumstances under which AEMO may formulate the Alternative Network Constraint Equations are described in paragraph 4.1.3. The naming conventions that AEMO may adopt for the Alternative Network Constraint Equations and their associated Constraint Set are described in paragraphs 6.1.4 and 6.1.5, respectively.

Alternative Network Constraint Equations are generally required within a short period of time to maintain Power System Security in real-time operation. They therefore must be formulated quickly and do not typically follow the processes specified under paragraph 0.

Alternative Network Constraint Equations may be formulated in any form (paragraph 4.1.2) required to maintain Power System Security and Power System Stability. One of the most common forms is:

- LHS: the Dispatch Target or ESS allocation of the non-conforming Facility with a unity coefficient.
- RHS: the last telemetered value or temporary capability advised from the Facility.
- Operator: any (≥, ≤, =), as advised by the operator of the Facility.

This form either affixes the generation output to its current level, increases or reduces it to a required level to maintain Power System Security.

Note that where an Alternative Network Constraint Equation has been formulated to direct a Facility to increase its generation output during an AEMO Intervention Event, it is also known as an Intervention Constraint.

4.1.1. In response to a Non-credible Contingency Event, AEMO must create Alternative Network Constraint Equation in accordance with paragraph 4.1.2 as soon as practicable.

4.1.2. AEMO may formulate the Alternative Network Constraint Equations in any form that it deems appropriate to maintain Power System Security for the circumstances they are used.

4.1.3. AEMO may also create Alternative Network Constraint Equations in the Dispatch Algorithm in other circumstances described in WEM Procedure: Facility Dispatch Process.

4.1.4. AEMO must publish information related to an Alternative Network Constraint Equation in accordance with WEM Procedure: Congestion Information Resource.

5. Operating margins

5.1. Application Strategy

E[O] 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 assists in maintaining Power System Security.

Operating Margins also improve robustness, simplicity, and legibility of Constraint Equations by abstracting complex details that have limited market impact but are otherwise difficult to model and control within the Central Dispatch Process.

In functional terms, an Operating Margin typically:

- Appears as a constant on the RHS that "offsets" the binding action of a Constraint Equation.
- Is expressed as a percentage relevant to the Network Limit to be managed.

For example, in a Constraint Equation, a "5% margin" applied to the thermal rating of the Network element that it monitors, means that the Network element could credibly be loaded up to 95% of its thermal rating. It allows for a combined 5% variance from the mathematical optimisation due to real-time operational factors, such as a Facility not generating in accordance with a Dispatch Target 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 a balance assessment of the consequences, likelihood, and market impact, the appropriate size of an Operating Margin may vary among specific Constraint Equations.

5.1.1. AEMO must follow the principles specified in paragraph 5.1 when developing the approach for applying an Operating Margin in a Constraint Equation (not including an Alternative Network Constraint Equation):

(a) Support the determination of an Operating Margin by using statistical analysis and quantitative data, including those from SCADA and state estimator, where possible.

(b) Prioritise simplicity, robustness and clarity over mathematical sophistication or purity in its statistical analysis in paragraph 5.1.1(a).

(c) Prioritise maintaining Power System Security, while using its best endeavours to maintain market efficiency, by considering the likelihood and consequence of a Network Limit being violated.

(d) Undertake review and update of the Operating Margins as required to maintain Power System Security.

5.1.2. AEMO must take the approach specified in this Paragraph 5.1.1(b) in applying an Operating Margin in a Constraint Equation (not including an Alternative Network Constraint Equation):

(a) if it forms the view that relevant information is sufficient, both in terms of quality and quantity, follow the process specified under paragraph 5.1.3; or

(b) if it forms the view that relevant information is insufficient in terms of quality or quantity, follow the process specified under paragraph 5.1.4.

5.1.3. Consistent with the principle specified in paragraph 5.1.1(a), under paragraph 5.1.2(a), AEMO must follow the process specified in this paragraph 5.1.3:

(a) identifying the sources of error that could have a material impact on Power System Security, in accordance with paragraph 5.2;

(b) performing statistical analysis on the error sources identified under paragraph 5.1.3(a), in accordance with paragraph 5.3;

(c) determining the risk level based on the likelihood and consequence of a Network Limit being violated, in accordance with the paragraph 5.4;

(d) determining the appropriate probability of exceedance based on the risk level in paragraph 5.1.3(c), in accordance with paragraph 5.4.5;

(e) calculate the Operating Margin in accordance with paragraph 5.3.3.

5.1.4. Under paragraph 5.1.1(b), AEMO may apply any Operating Margin that it deems appropriate and in is consistent with the principle specified in paragraph 5.1.1(c), including based on any of the following:

(a) those applied in any other relevant Constraint Equations, including those formulated by other network operators or market operators outside the SWIS; or

(b) common practices within the electricity industry.

5.1.5. The circumstances under which AEMO may form its view under paragraph 5.1.2(b), including:

(a) insufficient good quality data, which covers sufficiently large number of variations, for any of the processes specified in paragraph 5.1.3;

(b) insufficient operating data, market data or analysis for a Constraint Equation, including:

(i) insufficient deployment time following the New WEM Commencement Day; or

(ii) the Constraint Equation is formulated for a new Network Limit or a new Network element that has no sufficient prior data for analysis.

E[P] Insufficient relevant information

While validation of Constraint Equations is possible in the absence of sufficient relevant information (such as those described in paragraph 5.1.5), 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, consistent with the principles specified in paragraph 5.1.1(c), AEMO's strategy in paragraph 5.1.4 is to assign new Constraint Equations with Operating Margins that prioritise Power System Security and, review and update the Operating Margins as sufficient quantitative data become available. This is to:

- minimise the risks of Power System Security, especially when new Constraint Equations for new Network element or new Network Limits are first introduced to the real-time operating environment; or
- avoid prematurely optimising Constraint Equations that may have limited impact on market outcomes.

5.1.6. AEMO may apply the same Operating Margin across multiple Constraint Equations where AEMO forms the view that:

(a) they are for the same type of Network Limits or have similar size of errors or likelihood of occurrence and acceptable risk levels; or

(b) further refinement of the Operating Margin for a Constraint Equation would result in very limited improvement in the operating and market outcome.

5.1.7. AEMO may apply the same Operating Margin that it applies in a Dispatch Constraint Equation in the corresponding Forward-Looking Constraint Equations.

5.1.8. AMEO may apply another more appropriate Operating Margin in paragraph 5.1.6 when it forms the view that a different Operating Margin may result in a more appropriate Dispatch outcome for each Pre-Dispatch Interval in Pre-Dispatch Schedule Horizon or Week-Ahead Schedule Horizon.

5.1.9. AEMO may apply any Operating Margin that it deems appropriate for an Alternative Network Constraint Equation.

5.2. Error Sources

E[Q] Sources of errors

E[Q1] Modelling

The modelling may refer to computer representation of any part of SWIS. The examples of errors that may arise from representing the SWIS accurately include the following factors:

- Finite study cases: there are infinite sets of power system configurations in reality (e.g., load demand distribution, generation profiles, Network switching). It is sufficient for AEMO to explicitly model a selected set of realistic circumstances to generate Constraint Equations and coefficients that can sufficiently maintain Power System Security for most circumstances. Additional margin may be applied to account for limited or unknown circumstances where the Power System Security may have been impacted.
- Facility model detail: the true performance of generating Facilities can be highly complex and are dependent on a range of variables arising from the 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 but may not be included in Constraint Equations to avoid complicating the Constraint Equations or the optimisation within the Central Dispatch Process. It may be more appropriate to account for such variation in the Operating Margin.
- Accuracy of computer models: computer models used to represent the power system are often representative of the real Network to a certain accuracy level, depending on the availability of the relevant data. In a computer model, different parts of the Network may also have different levels of accuracy. A margin therefore may be required in a Constraint Equation to account for the discrepancy between the computer model and SWIS in reality.
- Constraint Equation linearity requirement: mathematically, most power system stability phenomena are non-linear. Constraint Equations on the other hand, are usually expressed in linear form to approximate the Constraints. The linearity aims to provide simplicity and clarity to the Constraint Equations, as well as to simplify the optimisation within the Central Dispatch Process. In some instances, the market impact of such nonlinearity may warrant significant complexity within the Constraint Equation (e.g., management of system inertia), but in most cases, including nonlinearity results in very high complexity within the Constraint Equations but may not result in material improvements in market efficiency.

E[Q2] Dispatch

The examples of errors relating to the dispatch processes either by the Dispatch Algorithm or a Facility, include :

- MW vs. MVA: The measurement and use of MVA quantities to manage the Network Limits are more physically accurate. The design of the Dispatch Algorithm however is such that the terms on the LHS of the Constraint Equations and the Dispatch Target set by the Central Dispatch Process for a Facility are in MW, aiming to manage the MW flow on a Network element from violating its limit.
- Discrete Dispatch Interval: the power system conditions vary and change continuously, while the Central Dispatch Process can only measure and determine the Dispatch Target discretely for each Dispatch Interval. The outcome of the Central Dispatch Process may not reflect the required Dispatch Targets to prevent the violation of a Network Limit if there have been material changes during a Dispatch Interval.
- For a Dispatch Instruction, a Facility may operate within its Tolerance Range or Facility Tolerance Range, without being non-compliant. This results in deviation from the intended outcome of the Central Dispatch Process and potentially, a Network Limit being violated.

E[Q3] Measurement

Each Constraint Equation is formulated to manage the power flow on a Network element (or a set of Network elements) such that it remains within the relevant Network Limit. The Network Limit however may be violated, if the measured power flow used in the Central Dispatch Process always under or over represent the power flow in reality by a large margin.

Typically, this kind of errors arise from:

- physical limitation of the measuring equipment, including their limits in accuracy, precision and reliability; or
- communications and response delays between different communication systems or infrastructure.

E[Q4] Others

Forecasting for load, especially block loads, or intermittent generation may involve assumptions that result in the outcome in Pre-Dispatch Intervals in Pre-Dispatch Schedule Horizon or Week-Ahead Schedule Horizon, that is significantly different from those in the Dispatch Target for a Dispatch Interval.

5.2.1. The error sources specified under paragraph 5.1.3(a), may include:

(a) Network modelling;

(b) Facility Modelling;

(c) the nature of finite system studies in Constraints Formulation;

(d) nonlinearity nature of the power system;

(e) use of MW quantities in all SCED relevant processes;

(f) constantly changing nature of the power system condition;

(g) discrepancy between the Dispatch Target and actual output of the generating units;

(h) measurement errors, or delay in communicating the measurement to Central Dispatch Process; or

(i) any other sources that result in errors that may accumulate in unforeseen ways.

5.2.2. In its determination of an Operating Margin, AEMO may include only errors or uncertainties that in its reasonable opinion, have a material impact on Power System Security. The circumstances under which AEMO may include an error or an uncertainty include:

(a) the errors are known to have a material impact on Power System Security historically in SWIS or in other power systems;

(b) if modelling of a Network or a Facility consistently results in a more optimistic view of the power system than that in reality, and until such time the errors in the modelling are rectified by a Rule Participant; or

(c) if forecasting consistently results in a more optimistic view of the power system than that in reality, and until such time the errors in forecasting are rectified by AEMO.

5.2.3. Notwithstanding paragraph 5.2.2, the error sources specified under paragraph 5.1.3(a) do not typically include errors or uncertainties associated with:

(a) information submitted by a Market Participant, including in its:

(i) Real-time Market Submissions;

(ii) Standing Data; or

(iii) and any data that may affect the Dispatch outcome; or

(b) Limit Advice provided by a Network Operator under clause 2.27A.2 of the WEM Rules.

5.2.4. AEMO may include the error sources specified in paragraph 5.2.3 in its determination of an Operating Margin if it forms the view that the information submitted by a Rule Participant could result or have resulted in a negative impact on Power System Security, or market outcome, until more appropriate information is provided by the relevant Rule Participant to AEMO.

5.3. Statistical analysis

E[R] Data for statistical analysis

E[R1] Modelling

The data required for quantifying the possible modelling errors may include:

- measurement data or state estimator for relevant Network element; or
- modelling data.

E[R2] Dispatch

The data required for quantifying the possible errors related to the dispatch processes may include:

- binding or violation periods of a Constraint Equation;
- measurement data for relevant Network elements during binding or violation periods; or
- generation output of relevant Facilities during binding periods.

E[R3] Measurement

The data required for quantifying the possible measurement errors may include:

- state estimator data for flow on relevant Network elements; or
- measurement data for relevant Network elements.

E[R4] Forecasting

The data required for quantifying the possible forecasting errors may include:

- measurement data or state estimator data;
- forecasting data; or
- for a load demand, load demand for a part of the Network, a generating Facility or the SWIS.

5.3.1. AEMO must undertake statistical analysis that is consistent with the principle specified in paragraph 5.1.1(b), which may include:

(a) excluding incorrect data, anomalies, or data recorded during extreme power system events that may skew the outcome of the statistical analysis;

(b) determining the possible size of each identified error source in MW using any appropriate statistical estimation; and

(c) combining the total possible size of the errors by combining the identified error sources, using any appropriate statistical method.

5.3.2. AEMO may quantify the possible size of each identified error source in paragraph 5.3.1(a) by calculating its average and standard deviation.

5.3.3. AEMO may determine the Operating Margin, which is the total possible size of all identified errors in paragraph 5.3.1(c) by:

(a) applying the probability of exceedance determined under paragraph 5.4.5, to the combined standard deviation of all identified errors; and

(b) summing all average values and the adjusted standard deviation in paragraph 5.3.3(a).

5.3.4. AEMO may round the Operating Margin to the nearest 5 MW, if appropriate, to simplify the process of applying the Operating Margin, including where AEMO applies it in accordance with paragraph 5.1.6.

5.4. Risk assessment

5.4.1. Consistent with the principle specified in paragraph 5.1.1(c), for each Constraint Equation, AEMO must determine the risk level, based on the likelihood and the consequences of a Network Limit being violated, if the Operating Margin is inappropriately sized.

5.4.2. AEMO may determine the risk level in paragraph 5.4.1 in accordance with:

(a) where applicable, any relevant requirements in WEM Rules, WEM Procedures, internal policies or advice; or

(b) paragraphs 5.4.3 and 5.4.4; or

(c) any other methods deemed appropriate by AEMO.

5.4.3. AEMO may determine the likelihood specified in paragraph 5.4.1 using any method deemed appropriate by AEMO, considering one or more of the following factors:

(a) for the power system configuration necessary for a Network Limit to be violated, likelihood of the system configuration to transpire;

(b) for the operating condition necessary to give rise to the Network Limit, likelihood of the operating condition to transpire;

(c) likelihood of the Constraint Equation being violated by the Central Dispatch Process, including due to any relaxation of Constraints applied by AEMO under clause 7.2.6 of the WEM Rules.

5.4.4. AEMO may determine the consequence rating specified in paragraph 5.4.1 using any method deemed appropriate by AEMO, considering its ability to restore the power system to a Secure Operating State.

5.4.5. AEMO may determine an appropriate probability of exceedance, in relation to the risk level determined in paragraph 5.4.1, using any method deemed appropriate by AEMO.

E[S] Example: Risk assessment

The following figures and tables provide example methods to determine the

- risk level under paragraph 5.4.2;
- likelihood of occurrence under paragraph 5.4.3;
- consequence ratings under paragraph 5.4.4; and
- Probability of Exceedance under paragraph 5.4.5.

Table 3 Example risk level

Likelihood	Consequence				
	Immaterial	Minor	Moderate	Major	Extreme
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

Table 4 Example likelihood of occurrence

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 occurrences
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

Table 5 Example Consequence ratings vs Secure Operating State

Consequence	Descriptions
Extreme	AEMO cannot restore a Secure Operating State
Major	AEMO can restore a Secure Operating State through multiple directions and not within 15 minutes.
Moderate	AEMO can restore a Secure Operating State through a single intervention or direction within 15 minutes
Minor	Secure Operating State can be restored during next Dispatch Interval by Central Dispatch Process or within time period equivalent to two Dispatch Intervals.
Immaterial	Secure Operating State is restored automatically within one Dispatch Interval or the time period equivalent to one Dispatch Interval.

Table 6 Example of consequences

Consequence	Load Shedding / reliability	System Damage	Example
Extreme	Cascading, uncontrolled system loss	Widespread irreversible damage to multiple assets	Breach of ROCOF Safe Limit leads to cascading loss of generation
Major	>100 MW load shed or multi-stage under frequency load shedding (UFLS)	Irreversible damage to performance capability of up to 10 primary assets (as determined by AEMO)	System separation event with large (>30 MW) self-sustaining islands
Moderate	Up to 100 MW load shed or first-stage UFLS	Single asset: Irreversible damage to performance capability	A Facility islanded with distribution load
Minor	Up to 30 MW load shed	Single asset: increased wear and tear within acceptable operating parameters	Temporary overload of transformer

	Immaterial	Up to 1 MW load shed	Single asset: Temporary breach of continuous operating parameters without permanent damage	Overload of transmission line within dynamic rating

Note: these consequence descriptions apply to the operating conditions immediately following a Credible Contingency.

Table 7 Example risk level vs probability of exceedance

Risk level	Probability of Exceedance
Critical	0% to 1%
High to Critical	1% to 5%
Medium to High	5% to 10%
Low to Medium	10%

E[T] Example: Operating Margin Calculation

Consider a Constraint Equation that has been formulated under E[E] and has the form of Equation E8. The possible errors that could result in the Network Limit being violated in real-time operating conditions are:

- those related to the dispatch processes (paragraphs 5.2.1(e) to 5.2.1(g)); and
- power flow measurement of the monitored line, F_m (paragraph 5.2.1(h)).

E[T1] Quantify errors using quantitative data

Where sufficient qualitative data is available for that particular Constraint Equation, the process to determine the Operating Margin is:

1. Determine the dispatch error by:
   a. calculating the target flow for the monitored line during binding period;
   b. calculating the error during binding periods whereby the measured flow exceeds the target flow; and
   c. calculating the average, Ave_{DE} and standard deviation, $SD_{DE,}$ of the error.
   d. Determine the measurement error by:
   e. calculating the total possible flow on the monitored line $F_t = F_m + \text{RDF} \times F_c$ using
      i. state estimator data; and
      ii. measurement data;
   f. calculating the error by subtracting the measured total possible flow from state estimated total possible flow;
   g. calculating the average, Ave_{ME} and standard deviation of the error, $SD_{ME.}$
2. Determine the probability of exceedance by:
   a. the likelihood of the Network Limit being violated is determined to range from 'Likely' to 'Almost Certain' (paragraph 5.4.3);
   b. the consequence of the Network Limit being violated is determined to be 'Minor' (paragraph 5.4.4);
   c. the risk level is assessed to be 'Medium' (paragraph 5.4.2); and
   d. the probability of exceedance is determined to be 5% and the corresponding x value is 1.65 (paragraph 5.4.5).
3. Determine the total possible size of the errors, or the Operating Margin by summing the average and standard deviation values, that is, $Ave_{DE} + Ave_{ME} + x * SQRT(SD_{DE}^2 + SD_{ME}^2)$.

E[T2] Quantify errors without quantitative data

Until AEMO has sufficient binding information following,

- New WEM Commencement Day; or
- implementation of new Constraint Equations for new Network Limits or new Network elements;

a margin of 5% of the thermal rating of the monitored line may be assumed to account for all errors that may arise from the relevant dispatch processes. As such the Operating Margin is calculated using $(0.95 \times Rating_m) + Ave_{ME} + x * SQRT(SD_{ME}^2)$.

5.5. Review and update

5.5.1. Consistent with the principle specified in paragraph 5.1.1(d), AEMO may review any Operating Margin, at any time, which include circumstances where:

(a) sufficient data from dispatch outcome have become available; or

(b) it undertakes a review of the Constraint Equations under paragraph 8.1.1.

5.5.2. AEMO may determine the appropriateness of any Operating Margin based on the following criteria:

(a) if the Network Limit could be violated in a range of scenarios, including following the occurrence of the next Credible Contingency Event;

(b) if the violation of a Constraint Equation would not lead to the violation of the relevant Network Limit; or

(c) if the Operating Margin could be reduced to improve market efficiency, while Power System Security could still be maintained.

5.5.3. AEMO may increase the size of an Operating Margin if circumstances if the Network Limit could be violated as described in paragraph 5.5.2(a).

5.5.4. AEMO may reduce the size of an Operating Margin if the circumstances described in paragraphs 5.5.2(b) and 5.5.2(c) apply.

6. Naming of Constraint Equations and Constraint Sets

6.1.1. AEMO must include the following components in assigning the unique identifier for a Fully Co-optimised Network Constraint Equation:

(a) power system configuration or power system conditions under which the Constraint Equation applies where:

(i) 'NIL' indicates normal power system condition;

(ii) Network element(s) indicates prior Outage(s) of that Network element(s).

(b) cause ID that indicates the type of Limit managed by the Constraint Equation, in accordance with Table 8;

(c) Contingency Event that the Constraint Equation is securing the power system against; and

(d) Network element(s) or areas in the Network to be protected from the Contingency Event.

E[U] Fully Co-optimised Network Constraint Equation Naming Convention

Figure E5 shows an example of a Fully Co-optimised Network Constraint Equation that conforms with the naming conventions specified in paragraph 6.1.1.

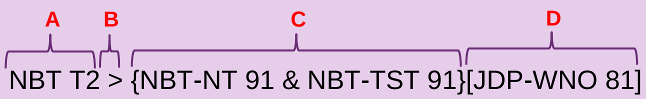


Figure E5 Example of a Fully Co-optimised Network Constraint Equation

where:

- A represents the power system configuration under paragraph 6.1.1(a);
- B represents the cause ID under paragraph 6.1.1(b);
- C represents the Contingency Event under paragraph 6.1.1(c); and
- D represents the Network element to be protected under paragraph 6.1.1(d).

AEMO may include additional components to the example in Figure E5 in accordance with paragraph 6.1.2.

Table 8 Cause ID

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

6.1.2. AEMO may include the following additional components in assigning the unique identifier for a Fully Co-optimised Network Constraint Equation:

(a) Prefix to indicate that it is a Fully Co-optimised Network Constraint Equation; or

(b) Prefix or postfix which may include any characters to assist with identifying the purpose of the Constraint Equation quickly.

6.1.3. AEMO must include information about the system configuration in assigning a unique identifier for a Constraint Set associating with Fully Co-optimised Network Constraint Equations.

E[V] Constraint Set Naming Convention

Under paragraph 6.1.3, the Constraint Set is typically named in accordance with paragraph 6.1.1(a). Using the example in Figure E5, the Constraint Set is NBT T2, which indicates prior Outage of NBT T2.

6.1.4. In assigning the unique identifier for an Alternative Network Constraint Equation, AEMO may include

(a) a prefix to indicate that it is an Alternative Network Constraint Equation; or

(b) a prefix that indicates the purpose of the Alternative Network Constraint Equation.

E[W] Alternative Network Constraint Equation Naming Convention

Under paragraph 6.1.4(b), AEMO may choose to use any prefixes to indicate the need for an Alternative Network Constraint Equation. Example prefixes include:

- NC to indicate non-conformance of a Facility; or
- CONT to indicate a Contingency Event.

6.1.5. AEMO may include any unique identifier for a Constraint Set associating with Alternative Network Constraint Equations that it deems appropriate.

E[X] Physical equipment identifier

AEMO may also identify the physical equipment following the conventions described in this paragraph:

- All Network equipment identifiers are associated with a primary substation, as determined by the connection point busbar.
- Two-terminal elements also use a secondary busbar.
- Substations in the Western Power Network are designated by unique codes of one to three letters.
- The Network Operator 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 substation
  - 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 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: <=22 kV
  - X: 220 kV

  (Note that a Network Operator may further distinguish the distribution voltages by assigning 5: 22 kV, 3: 11 kV, 2: 6.6 kV).

- The following paragraphs describe the conventions for each of the following asset classes:
  - Transmission lines
  - Transformers
  - Other equipment (auxiliary equipment and reactive plant)

E[Y] Transmission lines

Transmission lines use the format S1-S2 VC, 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)

Examples include:

- KW-ST 92: second 330 kV line connecting Kwinana and Southern terminal substations
- KDN-MRT X1: first 220 kV line connecting Kondinin and Merredin terminal substations

E[Z] Transformers

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 Facility's generator step-up transformers omit the SIDE designation.

Examples include:

- MU BTT3 LV: Muja bus-tie transformer 3, as seen from the 220 kV side.
- MU BTT3 HV : Muja bus-tie transformer 3, as seen from the 330 kV side.
- MU SUT8 : Generator step up transformer 8 at Muja.

E[AA] Other equipment

Other equipment 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.).

Common type codes are summarised in the following table:

Table 9 Type Codes

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.

7. Publishing Constraint Equations

E[BB] Constraints Library Overview

The Constraints Library is a database that contains the repository of all Constraint Equations (as well as Limit Advice and Constraint Sets) as described in Chapter 11 of the WEM Rules. 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 Constraint Equations at any given point in time.

The Constraints Library does not store offer or bid history or dispatch outcomes. Sources of information and analysis of Network congestion is described in WEM Procedure: Congestion Information Resource.

E[BB1] Constraint Lifecycle

After a Constraint Equation is formulated, it is scheduled within the Constraints Library to indicate the time from which it is available to be used in the Dispatch Algorithm. The Constraint Equation must be scheduled for a time in the future, that is, either in the next immediate cycle of the dispatch process, or for a specified time in the future. For example, a Constraint Equation used to manage a Network Outage may be scheduled to be available only when the relevant Outage commences sometime in the future.

A Constraint Equation's availability is not an indicator that it has been or will be included in the Dispatch Algorithm. In addition to being available, a Constraint Equation is only included in the Dispatch Algorithm if it has been invoked. Likewise, it is excluded from the Dispatch Algorithm if it has been revoked.

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

- Being invoked for set time periods before being subsequently revoked.
- Having its form modified (coefficients adjusted; addition, removal, or repositioning of terms).
- Being re-assigned to a new Constraint Set.
- Being retired permanently when it is found to be no longer accurate or relevant.

7.1.1. AEMO must publish the Constraint Equations in the Constraints Library, in accordance with WEM Procedure: Congestion Information Resource.

8. Verifying Constraint Equations

E[CC] Constraint Equation Monitoring and Verification

E[CC1] Real-time

In practice, the impact of the Constraint Equations on the dispatch outcome is primarily monitored and verified in real-time. Where a Constraint Equation is incorrectly formulated or no Constraint Equation has been formulated for a Network Limit, the deficiency will be identified in real-time by the security management tools available to the AEMO control room.

In this instance, AEMO may take any of the actions described in paragraph 8.1.2 in real-time.

E[CC2] Ex-ante

AEMO may also verify a Constraint Equation before being deployed to Central Dispatch Process if time permits, or if it forms the view that it is critical to do so.

One of the aspects that AEMO may want to verify is its formulation in accordance with the requirements of Central Dispatch Process (paragraph 8.1.4(a)). It refers to the requirements established by other parts of the dispatch process that the Constraint Equation is required to follow, or it will not be implemented successfully. For example, the Constraint Equation may have to follow the nomenclatures and scripting requirements defined by the system that performs the dispatch algorithm, or it will not be processed as intended. Such verification is most appropriate to be performed in the simulation environment if it is available. In the absence of a simulation environment, it is possible for AEMO to incorporate some of the key verifications in their formulation process.

Paragraph 8.1.4(b) refers to the common process to verify if a Constraint Equation can successfully maintain Power System Security as intended, by performing analysis using historical data from a large range of operating conditions. These historical operating conditions may be adjusted to produce other possible variations of the operating conditions. The verification process is described in paragraph 8.1.6.

Paragraph 8.1.4(c) refers to if a Constraint Equation results in unintended impact on the market outcome. This can only be verified if a simulation environment is available. Alternatively, it may be verified ex-post under paragraph 8.1.8.

E[CC3] Ex-post

From time to time, AEMO may undertake a review of a Constraint Equation after the fact, to confirm that its impact on the Dispatch process is consistent with the WEM Objectives.

The ex-post process is described in paragraphs 8.1.8 to 8.1.10.

8.1.1. To satisfy its requirements under clause 2.27A.10(b)(i)(2), AEMO may assess a Constraint Equation,

(a) in real-time operation, using any real-time monitoring and assessment tools available to AEMO, to identify if a Constraint Equation, or a lack thereof, has failed to maintain Power System Security;

(b) prior to deploying it to Central Dispatch Process, in accordance with paragraph 8.1.4, or

(c) after the fact, in accordance with paragraph 8.1.8.

8.1.2. In real-time operation, where AEMO identifies that a Constraint Equation, or a lack thereof, has failed to maintain Power System Security, AEMO may:

(a) invoke Alternative Network Constraint Equations;

(b) create and invoke Alternative Network Constraint Equations; or

(c) take any other necessary actions to return the power system to Secure Operating State.

8.1.3. If required following the circumstances described in paragraph 8.1.2, AEMO may,

(a) review the relevant Constraint Equation;

(b) modify the relevant Constraint Equation, including the Operating Margin;

(c) create the required Constraint Equation; and

(d) review the Standard Methodology process.

8.1.4. AEMO may verify any of the following aspects of a Constraint Equation prior to deploying it to Central Dispatch Process:

(a) its formulation with respect to the requirements of the Central Dispatch Process;

(b) its impact on the dispatch outcome, with regards to maintaining Power System Security; and

(c) its impact on the Market Clearing Price.

E[DD] Simulation Environment

The real-time dispatch process is performed by an integrated system consisting of multiple systems, including but not limited to those developed for the purpose of performing dispatch algorithm, Real-time Market Submissions and, managing Constraint Sets and Constraint Equations.

A simulation environment is an equivalent integrated system to those required to perform dispatch process in real-time but uses historical or simulated data. In addition to verifying its impact on the dispatch outcome, testing a Constraint Equation in the simulation environment has the advantages of confirming that the Constraint Equation is correctly formulated from system interfacing standpoint, as well as Market Clearing Price standpoint.

8.1.5. AEMO may verify the formulation of a Constraints Equation with respect to the requirements of the Central Dispatch Process under paragraph 8.1.1(a) by:

(a) incorporating the required validation in the formulation process; or

(b) testing it in a simulation environment if it is available.

8.1.6. AEMO may verify the impact of a Constraint Equation in maintaining Power System Security under paragraph 8.1.1(b) by following the process:

(a) prepare a large range of operating conditions in power system model, which may be historical operating conditions, or any valid variations of those historical operating conditions.

(b) where historical data is not available, assume a reasonable value or where appropriate, use the forecast values.

(c) for each prepared operating condition, identify,

(i) if a Constraint Equation binds when it is expected to do so, and if Power System Security is maintained following binding of the Constraint Equation;

(ii) circumstances where a Constraint Equation binds, but it is not expected to do so; or

(iii) circumstances where a Constraint Equation fails to bind, but is expected to do so.

(d) Where the any circumstances in paragraph 8.1.5(c) identify a requirement to modify the Constraint Equation:

(i) review the formulation process for error; or

(ii) adjust the Operating Margin.

8.1.7. AEMO may verify the impact of the Constraint Equation on Market Clearing Price under paragraph 8.1.1(c) in the simulation environment if it is available.

8.1.8. AEMO may undertake a review of a Constraint Equation after the fact, and the review may consist of:

(a) a general investigation of power system conditions during binding action of Constraint Equation, to confirm the Constraint Equation correctly prevented risk to maintain Power System Security and minimised the overall cost to the market.

(b) a review of the Operating Margin, in accordance with the criteria described in paragraph 5.5.2, which may result an Operating Margin being updated as described in paragraphs 5.5.3 and 5.5.4.

8.1.9. Following a review of a Constraint Equation, AEMO may identify that

(a) the Constraint Equation may be:

(i) modified, reformulated (e.g. with an adjusted Operating Margin), retired and/or replaced by one or more new Constraint Equations;

(ii) deemed needing further observation under real-time operation; or

(iii) deemed efficient;

(b) the power system models used to formulate the Constraint Equations require refinement; or

(c) the Limit Advice is inappropriate or require updates.

8.1.10. AEMO must notify the relevant network Operator in accordance with the process specified in WEM Procedure: Limit Advice Requirements if paragraph 8.1.9(c) is identified.

Appendix A. Relevant clauses of the WEM Rules

Table 10 details:

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

(b) each clause in the WEM 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 10 Relevant clauses of the WEM Rules

Clause
2.27A.10(b)
2.27A.10(cA)
2.27A.10(cB)
2.27A.10(cC)
2.27A.10(d)