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28 January 2010

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Dear Shantha,

Consultation on Constraint Formulation Guidelines

The national Generators Forum (NGF) appreciates the opportunity to comment on these draft guidelines.

We will make several substantive comments here, and will also include in an appendix a number of drafting suggestions designed to make the draft guidelines clearer and more accurate.

For ease of reference, the comments below will include the heading of the relevant section, as used in the consultation paper.

4.1 Components of Constraint Equations

In the list of RHS variables, there is a reference to “loads”. From the context, this appears to be a reference to scheduled loads. We suggest that the nature of the loads referenced should be clarified.

We further suggest that the list should include “sub-regional demand”, since such variables are frequently included in RHS calculations.

4.4 How factors are determined

This section includes the following statement –

“In cases where the network service provider has determined the generating unit(s) at the RRN impact on the actual limit then the terms for these generating units will appear on the LHS of the constraint equation.”

We believe that the process described is neither necessary nor desirable. It appears that this process would lead to pricing errors when the relevant constraints were binding, and that such pricing errors could be easily avoided.

Our understanding of the situation where generating units at the RRN impact on a network limit is as follows –

- Any constraint equation including units at the RRN can be re-oriented to the regional reference node and that these units will then not explicitly appear in the constraint equation;
- That the combination of such a properly oriented constraint equation with the supply/demand balance will result in the contribution of these units to the constraint being properly managed; and
- The determination of price at the RRN will be accurate when the constraint is binding if and only if the constraint is properly oriented to the RRN.

On the basis of this understanding, we contend that the process described in the quotation above should not be used in the future, and that any such constraints should be re-oriented to ensure accurate market pricing.

The concept of constraint orientation and the effect of different orientations on the validity of market pricing are illustrated in appendix 2.

4.5.1 LHS Coefficients

The section describes the need for a limitation to avoid very small coefficients applying to LHS variables. A value of 0.07 is given as the smallest allowable coefficient that will remain in a constraint equation, after certain processing to avoid small coefficients.

However the basis on which this value was derived is not given. We submit that it would add to the value of the guidelines if they included a description of this derivation, and the logic for it.

We also seek clarification on whether any other materiality thresholds are applied in constraint formulation, and if there are any, an explanation of the basis on which the threshold value was determined.

4.7 Alternative Formulation

This section describes the use of an alternative formulation of a constraint where a fully optimised formulation “does not provide appropriate control of the power system”.

But the example that has been given there is in conflict with this statement. In the example, it is explicitly stated that an alternative formulation was used “which leads to the same dispatch outcomes”. In other words, the control over the power system with the alternative formulation was precisely the same as with the fully optimised formulation.

The actual reason for this alternative formulation is revealed in the further description, stating that this alternative formulation gave “alternative regional prices.”. In other words, the alternative, by introducing a pricing error, had purported benefits other than providing “appropriate control of the power system”.

It is therefore clear that the example given does not relate to a situation where an alternative formulation of a constraint is allowable on the basis that has been stated.

We contend that the guidelines should not include an example where an alternative formulation was used in circumstances that do not meet the stated criterion for using an alternative formulation.

4.8 Process to Address Concerns with Constraint Equations with Small Differences in the Values of LHS Coefficients

This section describes a process to address concerns in relation to nearly identical coefficients in constraint equations, but does not address the reasons why such a concern may arise.

Our understanding is that this concern will arise from the likelihood of so-called “dis-orderly bidding” in the event that the constraint binds. With “disorderly bidding”, small differences in coefficients in a constraint equation can lead to major differences in dispatch outcomes between the relevant units.

We suggest that an explanation of the reason why concern may arise in relation to small differences in coefficients would enhance the value of this guideline.

5.2 How AEMO Receives Information

This section describes the process by which AEMO receives information in relation to network limits. It does not include any discussion in relation to oversight of the quality of the information provided, except that AEMO may request updated information if it believes that existing advice is no longer effective.

The NGF proposes that AEMO should take a more active role in ensuring that the information that may affect the market dispatch process for which AEMO is responsible, is fit for this purpose.

We propose that AEMO should routinely evaluate all network limit information received in order to be assured that it is accurate, current and defined in a way appropriate to the purpose.

In this context we note the comment, in section 4.4 of the consultation paper, that a network service provider may define limit information in a way that is incompatible with the price calculation process in the NEM. In our comment on that section we put the case that AEMO has the opportunity, capability and the responsibility to correct such errors before using the data. In this context, this possibility forms one of the issues on which AEMO should satisfy itself of the validity and relevance of information provided before using it.

Further to this proposal for “quality control” over inputs to dispatch, we also suggest that given the comment in section 4.4 referred to above; there would be value in the AEMO constructing guidelines to assist network service providers in meeting the need for appropriately structured input into the market dispatch process

7.7 Units Disconnected Due To Loss of a Transmission Element

This section includes a statement that, in relation to excluding service provision on the critical contingency defining the requirement –

“This is not done for loss of the largest unit as it is impractical to do this in NEMDE.”

We agree with the statement that it is not done, but do not agree that it is impractical.

We believe that, currently the requirement for any contingency raise service is set on the basis of the largest contingency among the actual generation values at the start of the dispatch interval, and not on the basis of the largest contingency among the dispatch target values.

In this context, the largest contingency to be considered in the enablement process has been identified at the start of the dispatch interval and there is no inherent reason why this known unit could not be excluded from the provision of those services needed in the case of its own contingent loss.

We propose that the practicality of such exclusion should be reviewed, and that the guidelines should then be amended to reflect the outcome of that review.

If you have any questions in relation to this submission, please call Ken Secomb on 03 9617 8321.

Yours sincerely



Malcolm Roberts
Executive Director

Appendix 1: Consultation paper with drafting suggestions marked



CONSTRAINT FORMULATION GUIDELINES

PREPARED BY: MOP and ESOPP (with drafting suggestions by NGF added)

DOCUMENT REF: 170-0040

VERSION: 9

DATE: 30 November 2009

FINAL

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Version Release History

VERSION	DATE	REVISION DESCRIPTION
9	30 November 2009	Complete revision to align with the Congestion Management Review NER changes



1 Definitions

Table 1 – Definitions

ABBREVIATION	DEFINITION
Constraint Equation	These are the mathematical representation that AEMO uses to model power system limitations and FCAS requirements in NEMDE.
CVP	Constraint Violation Penalty Factor
DNSP	Distribution Network Service Provider
FCAS	Frequency Control Ancillary Service
LHS	Left Hand Side of a constraint equation. This consists of the variables that can be optimised by NEMDE. These terms include scheduled or semi-scheduled generators, scheduled loads, regulated Interconnectors, MNSPs or regional FCAS requirements.
Limit Equation	A mathematical expression describing a limitation on a part of the transmission or distribution network. These are provided to AEMO by both TNSPs and DNSPs.
Mainland	The NEM regions: Queensland, New South Wales, Victoria and South Australia
MNSP	Market Network Service Provider
MPC	Market Price Cap (previously called VOLL)
NEM	National Electricity Market
NEMDE	National Electricity Market Dispatch Engine
PASA	Projected Assessment of System Adequacy
RHS	Right Hand Side of a constraint equation. The RHS is calculated and presented to the solver as a constant; these terms cannot be optimised by NEMDE.
SCADA	Supervisory Control And Data Acquisition. Information such as line flows and generator outputs are delivered via SCADA.
System Normal	The configuration of the power system where the status of all major transmission elements is normal (this usually means all major transmission elements are in service).
TNSP	Transmission Network Service Provider

2 References

1. SO_OP3709 – Generic Constraints due to Network Limitations
2. SO_OP3705 – Dispatch: <http://www.aemo.com.au/electricityops/3705.html>
3. Constraint Naming Guidelines: <http://www.aemo.com.au/electricityops/200-0141.html>
4. Constraint Violation Penalty Factors: <http://www.aemo.com.au/electricityops/140-0011.html>
5. Confidence Levels, Offsets & Operating Margins: <http://www.aemo.com.au/electricityops/170-0051.html>
6. Reliability Panel Frequency Operating Standards: <http://www.aemc.gov.au/Market-Reviews/Completed/Review-of-Mainland-Frequency-Operating-Standards-during-Periods-of-Supply-Scarcity.html>
7. MMS Data Model: <http://www.aemo.com.au/data/320-0024.pdf>

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3 Introduction

This document, the Constraint Formulation Guidelines (CFG), has been written to satisfy the requirement in NER 3.8.10(c).

AEMO determines generation schedules and regional prices in the National Electricity Market using a solver which finds the optimal solution to maximise the value of trade. The solution must satisfy linear constraint equations which are crafted to represent the physical restrictions necessary for secure and sustainable operation. This document sets out principles for translating these restrictions into (i.e. formulating) constraint equations, grouped by type or purpose. It also covers the life cycle of constraint equations from business requirement identification through to notification of application in the operation of the NEM, and the process for applying and removing constraint equations from the dispatch process.

Constraint equation formulation is important to scheduled entities such as generators and dispatchable loads because the formulation determines the influence or variation in output from that which might be expected from a consideration of offer prices alone. When a generator is bound by a constraint equation to provide an output at a higher level, it is said to be constrained on and may be forced to generate energy at a power level which is more costly than the market return it receives for that energy. Conversely, when a generator is bound to reduce its output through the action of a constraint equation, it is said to be constrained off, and it may be unable to obtain a potentially high market return by increasing its energy production. In some situations generators and interconnectors can be in direct competition with each other to provide relatively cheap energy through a network constraint. The constraint equation decides the most efficient balance of supply from the various contributors, while providing a high degree of confidence that the network limit is not violated. This formulation guideline provides transparency on AEMO's objective and impartial process of constraint equation development.

3.1 CFG update process

The Constraint Formulation Guidelines are amended where necessary by AEMO in accordance with the Rules consultation procedures. Amendments may be required to address:

1. The circumstances in which AEMO will use alternative network constraint formulations in dispatch (section 4.7);
2. The process by which AEMO will identify or be advised of a requirement to create or modify a constraint equation, including the methodology to be used in determining network constraint equation terms and coefficients and the means by which AEMO will obtain and disseminate information to scheduled generators, semi-scheduled generators and market participants
3. The methodology for selecting the form of a network constraint equation, including the location of terms on each side of the equation
4. The process for implementing, invoking and revoking network constraint equations, including the circumstances in which AEMO will use alternative network constraint formulations and fully co-optimised network constraint formulations and the dissemination of information to scheduled generators, semi-scheduled generators and market participants (section 10); and
5. AEMO's policy in respect of the management of settlement residues by intervening in the central dispatch process and the process of that intervention.

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AEMO will act on all reasonable requests to initiate a change to the CFG so that the amendment may be resolved by a final determination in accordance with those consultation procedures. If the proposed amendment is found to have merit through the consultation process then an amended version of these guidelines will be issued as part of that final determination.

4 General Principles of Constraint Equations

4.1 Components of Constraint Equations

Constraint equations that are input into the market solver, NEM Dispatch Engine are formulated such that they can be separated into the following:

1. Left Hand Side
2. Operator
3. Right Hand Side

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The LHS of constraint equations consist of controllable variables and their respective multiplying factors (or coefficients). Only linear combinations of the controllable variables are allowed since NEMDE is based on linear programming optimisation. The controllable variables can contain a mixture of interconnector flow, MNSPs, scheduled/semi-scheduled generator output, scheduled loads and regional FCAS. The multiplying factors may be either positive or negative values. These controllable variables are optimised by NEMDE.

The operator of constraint equations can be either “equal to” (=), “less than equal to” (\leq) or “greater than equal to” (\geq). It simply equates the LHS and RHS components. Typically network type constraint equations will have the “less than equal to” operator while FCAS type constraint equations will have the “greater than equal to” operator.

The RHS of a constraint equation can be either a single value (static RHS) or a calculation based on multiple variables (dynamic RHS). The dynamic RHS can be made up of various inputs with either linear or non-linear calculations. The RHS can include any of the following variables:

1. SCADA values
2. Current MWs of scheduled, semi-scheduled generators or loads
3. Region demand
 - Sub-regional demand
4. Interconnector flow
5. Transmission Equipment rating
6. Generator or equipment status
7. Constant

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Comment [k1]: Is this scheduled loads?

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Before solving the dispatch run NEMDE will calculate the RHS based on the current values of each of the terms.

4.2 Constraint Sets

Constraint equations that apply under the same set of power system conditions, either for system normal or plant outage conditions are grouped into constraint sets. Constraint sets contain one or more constraint equations and also includes a description about the constraint set. AEMO uses constraint sets to efficiently activate / deactivate constraint equations as described in 10.1.

4.3 Types of Power System Limitations

Each constraint equation represents a particular type of power system limitation or requirement. Constraint equations can also exist for specific configurations of the power system such as system normal or plant outages. These power system limitations may include:

1. Network

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- 1-o Thermal – for managing the power flow on a transmission element so that it does not exceed ~~the continuous or short term~~ rating (~~either continuous or short-term~~) under normal conditions or following a credible contingency
- 1-o Voltage Stability – for managing network flows so that transmission voltages ~~so that they~~ remain at acceptable levels after a credible contingency
- 2-o Transient Stability – for managing network flows to ensure maintaining the continued synchronism of all generators on the power system following a credible contingency
- 3-o Oscillatory Stability – for managing network flows to ensure the damping of power system oscillations is adequate following a credible contingency
- 4-o Network Control Schemes – the modelling of generator control schemes or reactive control devices on generator output
- 2-e Frequency Standards – maintain the frequency within the Reliability Panel standards by dispatching Frequency Control Ancillary Services
- 3-e Other (For more details see section 8)
 - 1-o Managing Negative Residues
 - 2-o Rate of Change (Interconnector(s), Generator(s))
 - 3-o Non-Conformance
 - 4-o Network Support Agreement
 - 5-o Unit Zero
 - 6-o Discretionary limit on generator(s) and/or interconnector(s)

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4.4 How factors are determined

The coefficients for a constraint equation can be determined by several methods. For constraint equations representing a flow across a network element (whether a single element or a group) the coefficients are determined by running a load flow application. When coefficients are calculated for scheduled, semi-scheduled generators, loads and interconnectors this is done relative to a single bus (known as a swing bus). This process is known as orienting a constraint equation. In the NEM the swing bus is set to the regional reference node (RRN) where the network limitation exists or for lines crossing regional boundaries it is the region on the sending end. Since the calculation is relative to the RRN any generators on that bus will have a coefficient of zero.

Interconnector coefficients are used to represent the overall contribution from the neighbouring region’s generators. Where the neighbouring region’s generators or interconnectors with remote regions have a larger contribution than the neighbouring region’s interconnector their coefficient reflects their contribution above the interconnector contribution. This most often occurs when neighbouring region generators and remote interconnectors are located electrically close to the boundary with the neighbouring region (e.g. Murraylink and Southern Hydro generators can appear in constraint equations for limitations in southern NSW).

Coefficients can also be determined by running multiple studies for various power system conditions and then performing regression analysis. This is typically done by the TNSPs. In cases where the network service provider has determined the generating unit(s) at the RRN impact on the actual limit then the terms for these generating units will appear on the LHS of the constraint equation.

Usage of each approach is covered in section 6.1.

4.5 LHS & RHS Materiality Considerations

4.5.1 LHS Coefficients

There is a practical limitation to size of the coefficients used on the LHS of a constraint equation. When the coefficient is small there is a risk that NEMDE may choose to violate the constraint equation in preference to dispatching high priced offers. To avoid this no LHS terms (whether scheduled generator(s), load(s) or interconnectors) will have a coefficient less than 0.07.

The following procedure is applied to ensure no coefficients less than 0.07 are on the LHS:

1. All constraint equations with LHS coefficients less than 0.07 are normalised (i.e. by multiplying both the LHS and RHS so the absolute value of the largest LHS coefficient is 1)
2. Moving any remaining LHS terms with coefficients less than 0.07 onto the RHS

For FCAS constraint equations all Region LHS coefficients are 1. Additionally where there is a region FCAS LHS term for either Lower 5 minute or Raise 5 minute services there will also be a Lower Regulation or Raise Regulation term with a matching factor (see 7.4)

4.5.2 Restrictions on moving terms to the LHS

Normally if a scheduled generating unit appears in a limit equation it would be moved to the LHS of the constraint equation. However, this can only occur if the scheduled entity has been defined as a dispatchable MW quantity with no other mathematical operations upon it (such as a square of the generation, a maximum of a group of generators or the online status of a generating unit).

Only in cases where AEMO has determined there is a power system security or market benefit would AEMO use various methods to move these generation terms to the LHS (as long as the coefficient on the generation term satisfies the size rule in 4.5.1). These methods include linearising the squared terms of the limit equation and moving each generator in a maximum calculation into a separate constraint equation.

Generating units are also not moved to the LHS of FCAS constraint equations, see section 7.10 for more information.

4.5.3 RHS Scaling Factor Thresholds

As described in section 4.7 constraint equations are scaled. AEMO has determined that the maximum allowable scaling factor to be applied is 30. Additionally the actual scaling on an individual LHS term (i.e. the scaling factor divided by the term's co-efficient) is to be limited to a maximum value of 200. This will avoid issues of a large ramping of LHS terms (up or down) to only relieve the limit by a small amount.

4.6 Fully Co-optimised Formulation

As per NER clause 3.8.10 (b) AEMO uses the fully co-optimised constraint formulation to represent network constraint equations. This allows AEMO to control all the variables that can be determined through the central dispatch process.

Having more control variables on the LHS will allow NEMDE more flexibility, or degrees of freedom, to find the optimal solution. For a given constraint equation, increasing the number of LHS terms will increase the number of possible feasible solutions, which satisfy the constraint equation. Therefore NEMDE has more options to find the optimal solution by comparing the economic impact of these feasible solutions.

However some variables, due to the small size of their coefficients, may be excepted where control of these variables would not be practical or enhance the security of the power system. These thresholds are discussed in section 4.5.

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Comment [k2]: This issue does not
appear to be discussed in section 4.7.

4.7 Alternative Formulation

An alternative formulation is used, in some specific situations, where the fully co-optimised constraint formulation does not provide appropriate control of the power system. FCAS constraint equations are discussed in section 7 and other types are listed in section 8 of this document, in accordance with AEMO's disclosure requirement under NER clause 3.8.10 (c) (1).

AEMO will determine, as part of the process of assessing the need for an alternative formulation, which terms and factors go onto the LHS and RHS. This may be, but not limited to, re-orienting the constraint equation towards any transmission node in the network.

For example reorientation gives equivalent dispatch outcomes, but produces alternative regional pricing outcomes. It also has merit in situations where loop flows involving 3 or more regions exist. For example, when the Snowy region existed, there was an inter-regional loop flow path around Murray – Tumut – Wagga – Jindera – Wodonga - Dederang - Murray. When a binding constraint exists on one of the links in such a loop, counter-price flows can appear in the efficient dispatch solution. These counter price flows can be eliminated by replacing the binding constraint with a re-oriented version, which leads to the same dispatch outcomes but alternative regional prices. Any counter-pricing of inter-regional flows can be reversed by selecting a suitable form of re-orientation.

Since the abolition of the Snowy region in 2008, there are currently no locations or circumstances where reorientated constraint equations are implemented or invoked in the NEM.

Generally AEMO does not implement constraint equations in the distribution network unless requested by a DNSP. Where DNSPs supply AEMO with limit equations these are implemented as specified by the DNSP. The resulting constraint equations may or may not conform to a fully co-optimised formulation.

4.8 Process to Address Concerns with Constraint Equations with Small Differences in the Values of LHS Coefficients

Any NEM Participant can raise concerns with AEMO about any constraint equations where it is felt that differences in the value of coefficients for left hand side terms are so small that these differences are due more to measurement or other uncertainties in the development of these constraint equations than to actual differences in the network.

In such an application the NEM Participant would have to:

1. identify the constraint equations of concern;
2. identify the coefficients within those constraint equations which are of concern ; and
3. provide prima -facie evidence as to why it believed that the difference in these coefficients was not justified by the accuracy of their determination and that a benefit would arise from the removal of this difference.

AEMO in response to such a request would publish a report to the NEM that covers the following issues:

1. Details of the request received;
2. AEMO's assessment of the measurement errors of the coefficients of concern;
3. A comparison between these assessed measurement errors and the current differences in the constraint equation values;
4. A decision by AEMO as to whether or not the difference in these coefficients was justified by the accuracy of their determination and if so whether action is to be taken;
5. If action is to be taken an outline of the proposed changes to the constraint equations in question and
6. A request for comments within two weeks of date of publication

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AEMO would assess the comments received and then publish a final decision setting out the following:

- 1. Whether or not a change will be made; and
- 2. If a change is to be made:
 - 1. Confirm details for the change
 - 1. Set out a timetable for the change to ensure at least 15 business days notice

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4.9 Constraint Priority

4.9.1 Constraint Violation Penalty Factors

The central dispatch algorithm uses a linear programming model to find the optimal dispatch solution, subject to a number of constraints. This optimal dispatch solution attempts to maximise the value of spot market trading, by minimising the total cost to the market price of the dispatched resources whilst maintaining a secure operating system.

Comment [k3]: The original wording implies that the total cost in settlement is minimised, which is untrue.

~~NEMDE can only find a feasible dispatch solution when~~ A dispatch solution will be feasible and secure only if all constraint equations are satisfied. It may happen that a solution can only be obtained by violating a constraint equation(s). The solver decides which constraint equation(s) to violate based on the CVP factor that is assigned to every type or class of constraint equation. The CVP factor multiplied by the MPC price represents the incremental cost (in \$/MWh) incurred imposed if the constraint equation is violated. Since NEMDE attempts to find the lowest cost secure solution, it will break the constraint equation with the lowest CVP factor first and add the cost of doing so to the overall cost of the solution.

Comment [k4]: The CVP is not a cost actually incurred, but rather an artificial cost imposed to guide the solution.

Examples of constraint equation types include ramp rate, interconnector capacities, Unit availabilities FCAS requirements, secure network limits, etc.

Comment [k5]: The solutions under discussion here are, by definition, not secure.

CVP prices are assigned to each constraint equation type based on the following criteria:

Comment [k6]: Are interconnector capacities defined other than as secure network limits – suggest deletion.

- 1. The higher the CVP price, the greater importance the solver associates with complying with the constraint equation.
- 1. CVPs effectively assign an order of priority to violating constraint equations, with lower CVP constraint equations violated first to resolve dispatch conflicts.
- 2. Ensure sufficient grading between CVP prices of different constraint equation types (i.e. step changes in CVPs should be sufficiently large) to ensure that the pre-defined priority order is maintained when determining the optimal dispatch solution.

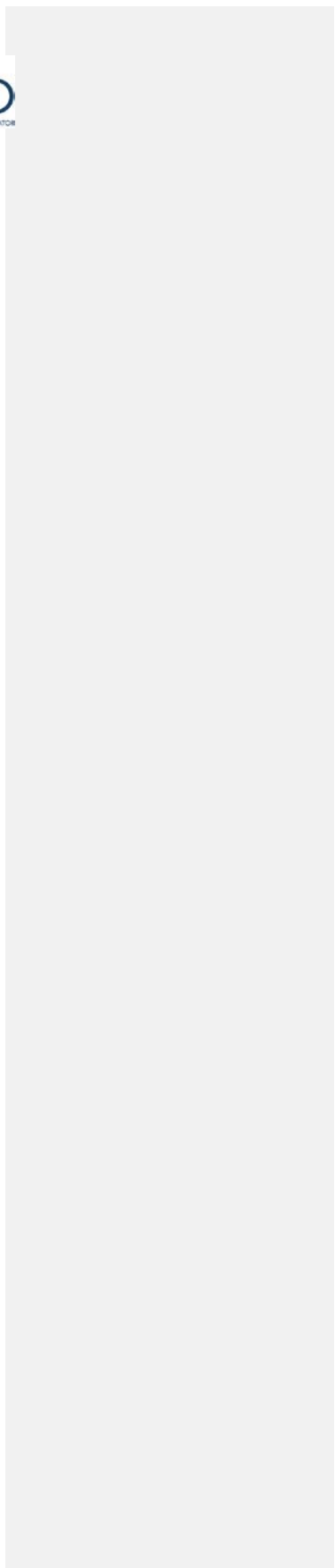
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For further information on constraint violation penalty factors, refer to the document 'Dispatch Constraint Violation Penalty Factors', available on AEMO's website.

4.9.2 Over-Constrained Dispatch (OCD) Re-run Process

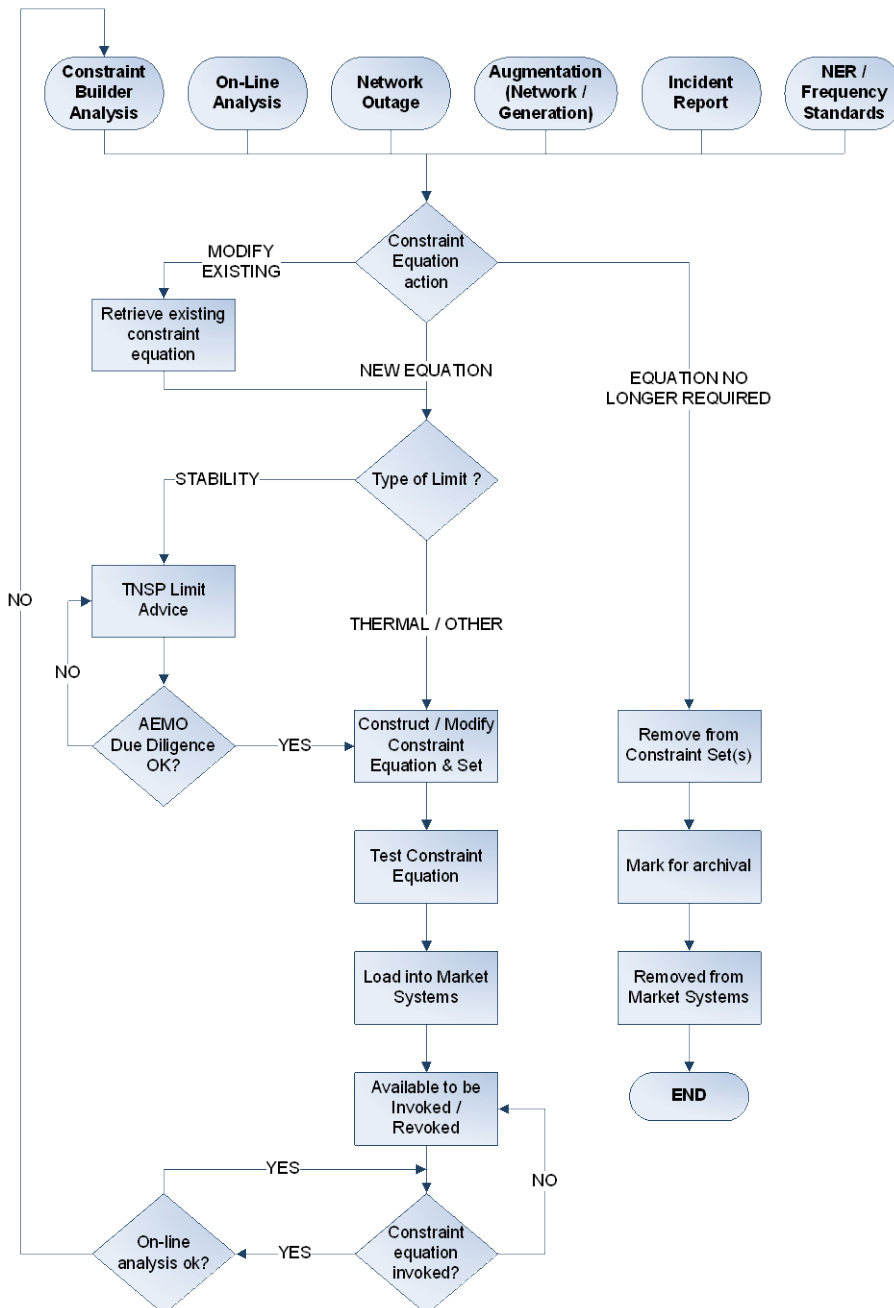
As mentioned in the previous section, the overall cost of the solution increases when a constraint equation is violated in order to obtain a feasible dispatch solution. This increase is calculated as the product of the associated CVP, the MPC and amount the constraint equation is violated by. Due to the constraint equation violation the regional price calculated by NEMDE may be higher than the MPC. NEMDE will attempt to resolve the issue through a process known as the Automated Over-Constrained Dispatch re-run.

NEMDE will automatically relax the RHS of the violated constraint equation by the over-constrained amount plus 0.01 MW and re-run the solution. If the constraint equation is still violated in order to find a feasible solution, the RHS of the constraint equation is manually relaxed in increments of 0.01MW until no violation occurs. The resulting dispatch prices are published to the market.



5 Constraint Equation Lifecycle

5.1 Lifecycle from Limits to Constraint Equations



5.2 How AEMO Receives Information

TNSPs are responsible for supplying AEMO with information on the limitations of their part of the transmission network. Similarly DNSPs are responsible for the distribution network limitations. This information, or limit advice, can take the form of equations (known as limit equations), a transmission element rating or a maximum flow on a group (or cut-set) of transmission elements. Limit advice is supplied for both system normal and outage of one or more transmission elements.

Limit advice is most often supplied when there are changes to the capability of the power system such as new / retired generation, new / retired transmission or the addition of control schemes. AEMO may also request updated limit advice from the TNSP if it believes an existing limit advice is no longer effective.

TNSPs and DNSPs supply both limit equations and rating information to common mailboxes at AEMO.

AEMO receives information about scheduled generators via the registration process (NER 2.2.1) and the generator performance standards (NER Schedule 5.2).

5.3 Publication of Constraint Information to Participants

5.3.1 Constraint Library

The Constraint Library is published through AEMO’s market systems via participant data feeds and the public AEMO website. The data is consistent with the AEMO supported “MMS Data Model”.

The MMS Data Model is a logical data model provided and supported by AEMO for participants operating in the wholesale electricity market.

The constraint library contains information about all the constraint equations that are maintained by AEMO office staff. The key MMS data model tables that contain information about the library are listed below.

Table 2 - Constraint Library in MMS Data Model

MMS DATA MODEL TABLE NAME	CONTENT
SPDCONNECTIONPOINTCONSTRAINT	LHS terms for dispatchable units and loads (Connection Points)
SPDINTERCONNECTORCONSTRAINT	LHS terms for interconnectors and market network service providers
SPDREGIONCONSTRAINT	LHS terms for aggregated regional FCAS
GENCONDATA	Description of a constraint equation, Static RHS, mathematical operator
GENERICCONSTRAINTRHS	Constraint equation RHS terms
GENERIC EQUATIONDESC	Description of a Generic Equation
GENERIC EQUATIONRHS	Generic Equation RHS terms
GENCONSETTRK	Description of a Constraint Set
GENCONSET	Links Constraint Equations to Constraint Sets
EMSMAS TER	Links the ID used on the constraint equation RHS with a value in AEMO’s EMS. Also includes a description of the ID.

5.3.2 Information on Constraint Equation Results

Dispatch information on constraint equations is also available from AEMO's market systems. The key MMS data model tables that provide constraint results are listed below.

Table 3 - Dispatch Information in MMS Data Model

MMS DATA MODEL TABLE NAME	CONTENT
DISPATCHCONSTRAINT	RHS value, marginal cost and violation degree
DISPATCH_CONSTRAINT_FCAS_OCD	Revised FCAS constraint marginal cost for OCD intervals
DISPATCHBLOCKEDCONSTRAINT	List of constraint equations blocked in a dispatch run
DISPATCHINTERCONNECTORRES	Import and Export limits for constraint equations
GENCONSETINVOKE	Period(s) when a constraint set is invoked

AEMO can remove, or block, constraint equation(s) that are part of a currently invoked constraint set, without removing the constraint equation(s) from the constraint set. For further information on blocking constraint equation(s) refer to the Dispatch Operating Procedure (SO_OP3705) on AEMO's website.

5.3.3 Congestion Information Resource

AEMO is required to publish the Congestion Information Resource (CIR) as per NER 11.30.2 (Interim CIR) and 3.7A (First and subsequent CIRs). The CIR is available on the AEMO website and it includes the Constraint Formulation Guidelines. Other constraint related information that is included in the CIR includes reporting of interconnector quarterly performance and mis-pricing information of connection points in the NEM.

6 Network Constraints

6.1 General Formulation Principles

Network constraint equations are used by AEMO to manage flows across one or more transmission elements (either transformers or transmission lines) by dispatching generation, loads or interconnectors in the energy market.

As described in section 5.2 network service providers provide AEMO with limit equations and/or transmission element ratings.

Where only thermal ratings have been supplied AEMO will formulate a feedback constraint equation (see 6.2).

For limit equations defined in terms of existing market quantities (such as Interconnectors) AEMO will rearrange the LHS and RHS of these to comply with both the fully co-optimised formulation (4.6) and LHS co-efficient (4.5) rules. Only those limit equation terms which are specified as dispatchable MW quantities can be moved onto the LHS (see section 4.5.2 on restrictions for moving terms to the LHS).

For limit equations defined for a cut-set which is not a market interconnector AEMO will determine a translation into market quantities (one such method is using a flow equation – see 6.2) and then rearrange LHS and RHS quantities similarly to limit equations defined in terms of market quantities.

Constraint Equations generally have an operating margin applied as per the Confidence Levels, Offsets & Operating Margins policy.

Comment [k7]: It appears that this should read "feedback". All network limits involve flow.

6.2 Feedback Constraint Equations

Feedback constraint equations allow the dispatchable units and interconnector(s) on the LHS to move by the MW available (or headroom) between the limit and the flow across the line or cut-set.

These constraint equations rely on the use of actual measurements of the LHS variables and the line flow(s).

a x Generator 1

- b x Generator 2

+ c x Interconnector ≤

[Limit

– Flow across line(s)

] x Scaling

+ a x Generator 1 (current value)

- b x Generator 2 (current value)

+ c x Interconnector (current value)

The limit can be either a transmission element rating or the calculation of a stability limit.

7 FCAS constraints

The control of frequency on the power system is managed through the dispatch of FCAS. AEMO uses constraint equations to procure FCAS to ensure that when an event occurs on the power system (e.g. loss of the largest generator or loss of an interconnector and subsequent islanding of a region) frequency is maintained within the frequency standards specified by the Reliability Panel.

Constraint equations specify each FCAS service on a regional basis requirement for one region or a group of regions. In this way constraint equations can be formulated for requirements for the whole NEM (global requirements) or for local requirements for one or more regions.

7.1 Types of FCAS

AEMO procures FCAS for each of the 2 regulation and 6 contingency FCAS markets:

- 1. Raise and Lower Regulation
- 2. Raise and Lower 5 minute
- 3. Raise and Lower 60 second
- 4. Raise and Lower 6 second

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7.2 Load Relief

When there is an increase or decrease in frequency there is a corresponding change in demand, this effect is called load relief and is an integral part of the contingency FCAS constraint equations. The change in demand is always in a direction that tends to alleviate the frequency deviation, i.e. for a reduction in frequency, the load relief is negative (decrease in demand), which tends to alleviate the falling frequency

For the Mainland regions for every 1% change in frequency (0.5 Hz) it is assumed there will be a corresponding 1.5% change in demand. In Tasmania the load relief is equivalent to a 1.0 % change in demand for every 1% change in frequency.

7.3 General Formulation

FCAS Requirement Region 1 (Service xx) + ... +

FCAS Requirement Region n (Service xx) ≥ RHS

Where the Service is the same for all regions and is one of the 8 raise or lower services

7.4 5min Services Co-Optimised With Regulation

The 5 min and regulation services are both delivered in the 5 minute timeframe so the amount of regulation enabled is subtracted from the 5 min service that would otherwise be required. This is implemented in the constraint equations by including the regulation on the LHS.

FCAS Requirement Region(s) (Lower or Raise 5 min Service)

+ FCAS Requirement Region(s) (Lower or Raise Regulation Service) ≥ RHS

A number of the standards can be satisfied in 10 minutes instead of 5. In these cases 2x the regulation is subtracted. However, since NEMDE requires that the LHS factors in FCAS constraint equations are 1 these are implemented so that the first 5 minutes of dispatched regulation is on the LHS and the second 5 mins is on the RHS as a constant term:

FCAS Requirement Region(s) (Lower or Raise 5 min Service)

+ FCAS Requirement Region(s) (Lower or Raise Regulation Service) ≥

*RHS – Regulation **Dispatch Requirement** in the 2nd 5 mins (Constant)*

Where the constant term is the current minimum regulation requirement for the region(s) on the LHS e.g. Mainland = 130 MW, Tasmania = 50 MW

Comment [k8]: The dispatch in the second DI may exceed the requirement (if used as a substitute for delayed service).

7.5 Risk of Region(s) Separating

Where there is a credible risk of separation of 2 regions (either from a prior plant outage or a reclassification of multiple line failure as a credible contingency) the interconnector flow that is at risk is co-optimised with the FCAS requirements.

Raise FCAS Requirement for Region(s) on one side of the interconnector at risk

- Interconnector at risk flow into those regions ≥

+ Load added to the regions on separation

- Load removed from the regions on separation

- Load relief from these regions

Lower FCAS Requirement for Region(s) on one side of the interconnector at risk

- Interconnector at risk flow out of those regions ≥

- Load added to the regions on separation

+ Load removed from the regions on separation

- Load relief from these regions

There are 2 constraint equations for each service. One constraint equation is for the region(s) on one side of the interconnector, the other for the regions on the other side. The load relief excludes the load that becomes physically disconnected, and includes load that becomes physically connected, post-separation.

7.6 Separation Not Aligned With a Regional Boundary

For separation points that do not align with the market defined regional boundary these can leave generating units disconnected from their parent region. Since FCAS is dispatched on a regional basis and there is no way to tell NEMDE these units are or will be electrically connected to a different region the FCAS services for the generating unit(s) are set to zero.

$$FCAS \text{ Requirement Generator (Service)} \leq 0$$

7.7 Units Disconnected Due To Loss of a Transmission Element

Similarly to 7.6 if multiple generating units will be disconnected from the power system on a single contingent event and their capacity exceeds the capacity of the single largest generating unit in the region or group of regions then all the contingency FCAS services for those generating units will be set to zero.

This is not done for loss of the largest unit as it is impractical to do this in NEMDE.

7.8 Tasmanian local requirements

The Tasmanian FCAS requirements for contingency events are calculated incorporating the effect of inertia. Due to the complexity of these calculations they are performed in AEMO's EMS and are provided to the constraint equation via a single data value.

7.9 Basslink

Unlike other interconnectors that are generally capable of transferring FCAS under all conditions, Basslink is not permitted to prevented by its control system from transfer of FCAS services if this would take its flow beyond its upper and lower transfer limits (594 MW and -478 MW respectively). This requires the headroom between Basslink flow and Basslink limit to be considered when formulating FCAS constraint equations. Additionally Basslink has a No-Go zone between approximately -50 MW and +50 MW and is deemed to be unable to transfer FCAS services while flow is within this range, and is limited in FCAS transfer by the headroom from the relevant no-go boundary.

Therefore Basslink is considered to be insensitive to frequency if any of the following are met:

- 1. The Basslink dispatch target from the previous dispatch run is at the boundary or within the No-Go zone
- 2. The Basslink frequency controller is not operational
- 3. The Basslink measured flow at the start of the dispatch interval is within the range ± 50 MW
- 4. The Basslink measured flow is equal to or greater than the bid availability

To allow for cases when Basslink is unable or restricted in the amount of FCAS it can transfer for NEM regulation and global contingent events 5 groups of constraint equations exist:

- 1. Global requirements – when Basslink is unconstrained for FCAS
- 2. Local requirements for the Mainland regions when Basslink is in the No-Go zone

$$Raise \text{ FCAS Requirement for Mainland Regions} \geq$$

$$Size \text{ of Generator Event on Mainland regions}$$

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- Load Relief from Mainland regions

3. Local requirements for Tasmania - when Basslink is in the No-Go zone

Lower FCAS Requirement in Tasmania ≥

EMS Calc for Tasmanian Load Event

4. Basslink flow co-optimised with Mainland local requirements – when Basslink is able to transfer FCAS but is limited by its transfer limits or the no-go zone

Raise FCAS Requirement for Mainland Regions

- Basslink flow ≥

Size of Generator Event on Mainland regions

- Load Relief from Mainland regions

+ 50 (if Basslink < -50)

- Basslink Max Bid Availability (Tasmania to Victoria) (if Basslink > 50)

5. Basslink flow co-optimised with Tasmanian local requirements – when Basslink is able to transfer FCAS but is limited by its transfer limits or the no-go zone

Lower FCAS Requirement in Tasmania

- Basslink flow ≥

EMS Calc for Tasmanian Load Event

+ 50 (if Basslink < -50)

- Basslink Max Bid Availability (Tasmania to Victoria) (if Basslink > 50)

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Similarly for local contingent events there are 3 groups of constraint equations:

1. Global requirements

4. Local requirements - when Basslink is in the No-Go zone

2. Basslink flow co-optimised with local requirements - when Basslink is able to transfer FCAS but is limited by its transfer limits or the no-go zone.

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7.10 Moving generating units at risk to the LHS

Normally the critical generating unit at risk will not be ~~moved to~~included in the LHS of FCAS constraint equations. In the case of the largest unit at risk it is impractical (or impossible in Tasmania with the three Gordon units aggregated) to do this and there is little market benefit. Hence the output of the critical unit is generally not co-optimised with the cost of the resulting FCAS.

However, where there is a large amount of generation at risk (> 1.5x largest regional-relevant generating unit) AEMO will determine, on a case by case basis, whether moving-including generating units at risk to the LHS is appropriate, taking into account considerations such as the risk of power system security violations due to the FCAS requirement exceeding the FCAS availability. For example, consider the case of a 400MW power station of 3 units with one double-circuit connection to the transmission system, in a region where the FCAS raise requirement is

typically 130MW, and the maximum FCAS raise service available in the region is 250MW. When the double circuit connection is reclassified as a credible contingency, or one circuit is out of service on a prior outage, system security requires that the generation from the power station must be limited to no more than 250MW (ignoring load relief, inertia and demand effects for simplicity). If the station were dispatched above 250MW, there would be insufficient raise FCAS to cover the generation lost through the credible contingency. This situation is best managed dynamically by moving the generation risk to the LHS of the constraint equation, and as this avoids introducing and continually updating discretionary constraints to limit the generation.

8 Other Types of Constraint Equations

8.1 Negative Residue Management

As per NER 3.8.1 (b)(12) AEMO manages the accumulation of negative residues across interconnectors. Negative residues accumulate when counter price flows occur, i.e. energy flows from a higher priced region to a lower priced region.

Negative Residues are monitored across all regulated interconnectors, in both directions. Constraint equations to reduce flow across a specific interconnector are applied when the accumulated negative residues across this interconnector exceed a pre-determined level. Constraint equations are removed when counter-price flows are halted or when further constraining would violate power system security. Refer to Dispatch Operating Procedure (SO_OP3705) on AEMO's website for more information on the process of dealing with accumulation of negative residues.

Negative residue constraint equations operate to control network flows at the boundaries between adjacent regions of the NEM. The general form is:

Interconnector 1 target + ... +

Interconnector n target ≤ constant

There is no co-optimisation and these equations are classed as an alternative formulation.

8.2 Non-Conformance

Non-conformance occurs where a market participant (a scheduled generating unit, scheduled network service or scheduled load) fails to follow a Dispatch target. AEMO applies a non-conformance constraint equation when a defined threshold is exceeded (refer to Dispatch Operating Procedure (SO_OP3705) on AEMO's website for more information). The RHS of the constraint equation is set to the last telemetered value of generation, consumption or transfer, i.e. the initial value for the new dispatch interval. The non-conformance constraint equation will remain in place until the participant advises AEMO that they are capable of following dispatch instructions.

Non-conformance constraint equations operate to ensure that market dispatch is consistent with the operation of scheduled and semi-scheduled generators that are temporarily unable to follow dispatch instructions. The general form is:

Generator target = last telemetered value

These are not network constraint equations and are classed as an alternative formulation.

8.3 Network Support Agreements

Transmission Network Service Providers (TNSP) and Distribution Network Service Providers (DNSP) may hold agreements with generating units to assist with system security and to help manage contingencies and binding constraint equations, as an alternative to network augmentation.

The Network Service Provider registers the generating unit with AEMO and specifies that the generating unit may be periodically used to provide a network support function and will not be eligible to set spot prices when constrained on. Where applicable, AEMO will apply constraint equations to reflect the network support agreement between the TNSP and the generators.

Network support constraint equations operate to control network flows of the transmission elements using the generating units identified in the respective agreements. The general form is:

$$\text{Generator target} \geq \text{Generator initial value} + \text{network flow} - \text{network limit}$$

There is no co-optimisation of these network equations as they apply only to the generators subject to the agreement. Accordingly the resulting equations are classed as an alternative formulation.

8.4 Unit Zero Constraints

Unit Zero constraint equations are applied when a generating unit is unable to generate, but is not bid in as unavailable. This may be the case when a generating unit is connected to a transmission element or group of transmission elements that are removed from service. For performance reasons, the market participants may choose not to bid the unit as unavailable for dispatch, since it is technically able to generate. AEMO enters a constraint equation into NEMDE to constrain this generator to zero for dispatch purposes.

Unit zero constraint equations are also applied when a generating unit has tripped and the offers are not updated. The general form is:

$$\text{Generator output} \leq 0$$

These are not network constraint equations and are classed as an alternative formulation.

9 Process for Developing Alternative Formulations

If AEMO determines that an alternative formulation is required then AEMO will publish a report that details the following:

- 1. Problem and reasons why the fully co-optimised formulation cannot be used; and
- 2. Details of the new constraint equation(s).

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Once the above is completed and the constraint equation(s) implemented, AEMO will consult upon the addition to the Constraint Formulation Guidelines as outlined in section 3.1.

10 Application of Constraints

10.1 Process of Invoking and Revoking Constraints

The process of invoking (or activating) and revoking (or deactivating) is not done on individual constraint equations but is instead done via constraint sets.

Constraint Sets are invoked to represent the current or future configuration of the power system in NEMDE. This can include no outages (or system normal), one or multiple transmission elements out of service, reclassification of loss of multiple transmission elements as a credible contingency and separation of two regions.

System normal constraint sets are, in general, invoked all the time unless a transmission element outage increases a power system limits.



10.2 Ramping of Network Constraints

AEMO applies ramping constraint equations to avoid large shifts in power flows and potential price spikes. Two constraint equations for each limit are created, a hard and a soft ramping constraint equation.

The soft and hard constraint equations will have the same LHS formulation and ramp to the same final RHS value. As such, if the original constraint equation is of an alternative formulation then the ramping constraint equations will also be an alternative formulation. The final RHS value is derived from the pre-dispatch RHS value. The soft constraint equation will ramp faster than the hard constraint equation so it can achieve the final RHS value in fewer dispatch intervals. Consequently, the soft constraint equation has a small CVP which is determined by the marginal value of its outage constraint equation in pre-dispatch. The CVP for hard constraint equation will be set as the same for a normal network constraint equation.

Comment [k9]: Does the hard constraint include a slow ramp to ensure this outcome?

10.3 Use of Discretionary and Quick Constraints

It is not practical for AEMO to maintain a library of constraint sets and constraint equations for every possible permutation of power system configurations (though it endeavours where possible to create them for planned outages). Instead, AEMO has created a library of simple constraint equations and sets for limiting groups of generating units and/or interconnectors to predefined values (known as discretionary constraints). Additionally there is an application available to AEMO's control room staff to quickly create and invoke custom constraint equations (Quick constraints).

These discretionary and quick constraint equations can be used to maintaining power system security for cases where there are no existing constraint equations, where AEMO's Constraint Automation cannot create the required constraint equations or the existing ones are not working correctly.

Appendix 1: Rule Reference to CFG section

Table 4 - Rule Reference to CFG Section

RULE REF	DESCRIPTION	CFG SECTION #
3.8.10(b)	Obligation to use fully co-optimised network constraint formulation	4.64-6
3.8.10(c)(1)	Circumstances in which alternative network constraint formulations will be used in dispatch	4.74-7
3.8.10(c)(2)	Process to identify requirement to create or modify a network constraint equation	5.1, 5.2
3.8.10(c)(2)(i)	Methodology for determining terms and coefficients	4.44-4, 4.54-5, 5.2
3.8.10(c)(2)(ii)	Means of obtaining from and disseminating to Participants information	5.2, 5.3
3.8.10(c)(3)	Methodology in selecting the form of equation (including location of terms on each side of equation)	4.54-5, 4.64-6
3.8.10(c)(4)	Process for implementing, invoking and revoking equations including choice of alternative vs fully co-optimised formulations and dissemination of information in respect of this process	99, 10.140-4
3.8.10(c)(5)	Policy in respect of negative settlement residue constraint management	System Operation Operating Procedure 3705
3.8.10(e)(1)	Identification of types of network constraints for which AEMO may use an alternative formulation	4.74-7

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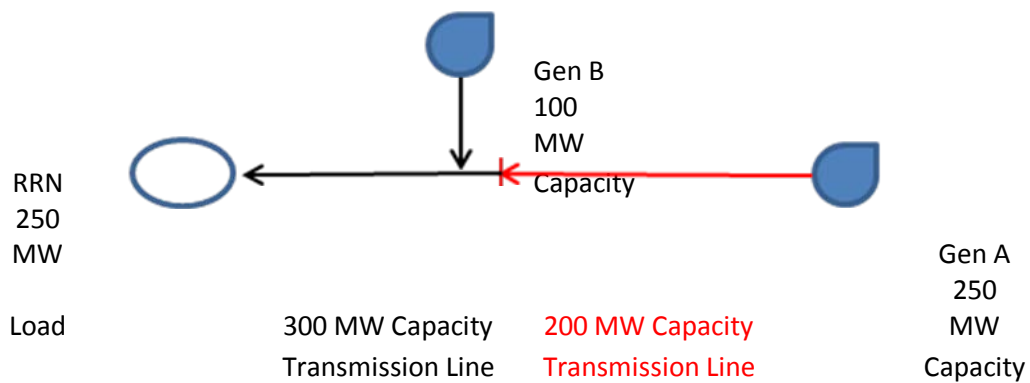
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RULE REF	DESCRIPTION	CFG SECTION #
3.8.10(f)	Represent constraints in a form that can be reviewed after the trading interval	5.3

Appendix 2: Examples of of alternative constraint orientation and the effect on market pricing



Options to control flow on 200 MW capacity transmission line

Option A – Constrain off Gen A

Constrains Gen A to 200 MW and allows Gen B to dispatch to 50 MW and accurately set price at RRN

Option B – Constrain on Gen B

Constrains Gen B to 50 MW then use energy balance equation to only dispatch Gen A to dispatch to 200 MW. In this option Gen B is prevented from accurately setting price at RRN

Option C – Constrain off Gen A and constrain on Gen B

Constrains Gen B to 50 MW and constrain on Gen A to 200 MW. In this option both Gen A and Gen B are prevented from accurately setting price at RRN