CONSTRAINT RELAXATION PROCEDURE

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Approved for distribution and use by:

APPROVED BY:	Paul Austin
TITLE:	Group Manager, Electricity Market Monitoring

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Version	Effective Date	Summary of Changes
1.0	29/07/2011	First published version
2.0	21/08/2013	Added footnote 2 "the MPC changed on 1 July 2012 to become annually indexed"
3.0	15/11/2017	Transferred to new template. Added Section 6 – Modification of CVP factors during real-time operational issues. Updated Figure 1 and ensure that generator offer is visible. Minor changes throughout the document.

CONTENTS

1. PURPOSE AND SCOPE 4
1.1. Glossary 4
2. INTRODUCTION 5
3. CONSTRAINT VIOLATION PENALTY FACTORS 6
3.1. Design 6
3.2. Application of the Constraint Violation Penalty Factors – Worked Example 7
4. OVER-CONSTRAINED DISPATCH RERUN PROCESS 9
4.1. Design 9
4.2. Constraint RHS Relaxation Logic 9
4.3. Operation of the OCD Rerun Process – Worked Example 10
5. REPORTING 11
6. MODIFICATION OF CVP FACTORS DURING REAL-TIME OPERATION 12

1. PURPOSE AND SCOPE

This procedure has been made under 3.8.1(c) of the National Electricity Rules **(NER)** to allow relaxation of power system constraints (**Procedure**).

This procedure has effect only for the purposes set out in the NER. The NER and the National Electricity Law prevail over these Procedures to the extent of any inconsistency.

1.1. Glossary

The words, phrases and abbreviations in the table below have the meanings set out opposite them when used in this Procedure.

Terms defined in the National Electricity Law and the NER have the same meanings in these Procedures unless otherwise specified in this clause.

Terms defined in the NER are intended to be identified in these Procedures by italicising them, but failure to italicise a defined term does not affect its meaning.

Term	Definition
Central Dispatch Process	process that uses the NEM dispatch engine to find the optimal market solution for every 5 minute dispatch interval
CVP factor	constraint violation penalty factor
CVP price	constraint violation penalty price, the marginal cost of violating a constraint; equal to [CVP factor x MPC]
EMMS	Electricity Market Management Systems
FCAS	frequency control ancillary services L6/L60/L5/LREG refers to lower 6 second, 60 second, 5 minute and regulation FCAS R6/R60/R5/RREG refers to raise 6 second, 60 second, 5 minute and regulation FCAS
LHS	left hand side of a constraint equation containing market solution variables
MFP	Market Floor Price
MPC	Market Price Cap (formerly VoLL - value of lost load)
MW	mega watt
MWh	mega watt hour
NEM	National Electricity Market
NEMDE	NEM dispatch engine software, the central dispatch algorithm
NER	National Electricity Rules
OCD	over-constrained dispatch
RHS	Right hand side of a constraint equation
Violation Degree	the amount (in MW) by which the constraint LHS violates the constraint RHS

2. INTRODUCTION

The NEM dispatch engine (NEMDE) is the software developed and used by AEMO to ensure the central dispatch process is optimal[1]. Under some circumstances, it may not be possible to satisfy all constraints that need to be considered in a given dispatch interval (DI). Under these circumstances, the solution is infeasible and would, if not catered for, cause NEMDE to fail to solve. Such a failure is not acceptable, so AEMO has procedures in place to ensure dispatch and pricing continue. The two processes are:

- For dispatch, constraint violation penalty (CVP) prices are applied to all constraint equations to establish a dispatch priority order and allow a feasible next-best solution to be found where constraints would otherwise conflict. The CVP price for each type of constraint is represented as a CVP factor, a multiplier of the Market Price Cap (MPC). CVP factors are selected to control which constraints are violated without distorting central dispatch outcomes when the solution is feasible.
- For pricing, an over-constrained dispatch (OCD) rerun process relaxes any violated constraints by the amount by which they are violated and a small offset. NEMDE will then produce a price that is consistent with the next-best dispatch solution.

These two processes, together with reports produced by AEMO comprise this constraint relaxation procedure.

The relevant National Electricity Rules (NER) clause is 3.8.1(c). This clause provides the following.

> *AEMO* must establish procedures to allow relaxation of *power system constraints* listed in clause 3.8.1(b) in order to resolve infeasible *dispatch* solutions, subject to the following principles:
>
> (1) the procedures are developed in consultation with *Registered Participants* to achieve a reasonable *dispatch* outcome while maintaining consistency with *AEMO's* obligations to maintain *power system security* and the pricing principles listed in clause 3.9.1; and
>
> (2) *AEMO* must report to *Registered Participants* any events requiring the relaxation of these *constraints*.

In this document, section 3 describes the application of CVP factors in constraint equations. Section 4 describes the OCD rerun process. Section 5 describes the reports produced by AEMO under this procedure.

A separate schedule of CVP factors is published by AEMO and used for prioritising which constraints are to be relaxed to find a next-best optimal solution. The detailed steps of OCD rerun process is covered in a separate OCD rerun process document.

[1] That is, it maximises value of trade subject to the various constraints.

3. CONSTRAINT VIOLATION PENALTY FACTORS

3.1. Design

AEMO assigns CVP factors to each type of constraint to ensure that a physically feasible dispatch solution can always be achieved by allowing conflicting constraints to be violated in a pre-defined priority order based on relative CVP factors.

The CVP factors are converted into a per unit constraint violation penalty price (CVP price) for each type of constraint before being passed as input to NEMDE. The CVP price is calculated by multiplying the CVP factor by MPC as shown below.

CVP price = CVP factor x MPC

where:

MPC: Market Price Cap (in $ per MWh)

Although NEMDE uses the CVP prices, CVP factors are more commonly discussed and stored in the database. This is because the MPC is updated annually and that change affects the CVP prices but not the underlying CVP factors.

Section 3.2 provides a worked example of how this dispatch conflict resolution process operates.

CVP prices are set at values above the MPC to ensure that all available energy and frequency control ancillary service (FCAS) offers are used prior to violating constraints. If the CVP price were set below the MPC, the relevant constraint could incorrectly violate in preference to dispatching available capacity offered at a price above that CVP price.

NEMDE solves to find the optimal security-constrained dispatch outcome based on overall cost minimisation of dispatched energy and FCAS offers and constraint violations.

NEMDE calculates the cost of violating a constraint (in $ per hour) as follows:

Violation Cost = CVP price x Violation Degree

where:

Violation Degree: the amount (in MW) by which the constraint left-hand-side (LHS) violates the constraint right-hand-side (RHS)

NOTE:

A separate schedule of CVP factors is published by AEMO on its website and may be updated from time to time. This schedule lists each constraint type and its associated CVP factor.

3.2. Application of the Constraint Violation Penalty Factors – Worked Example

Figure 1 A simple market model

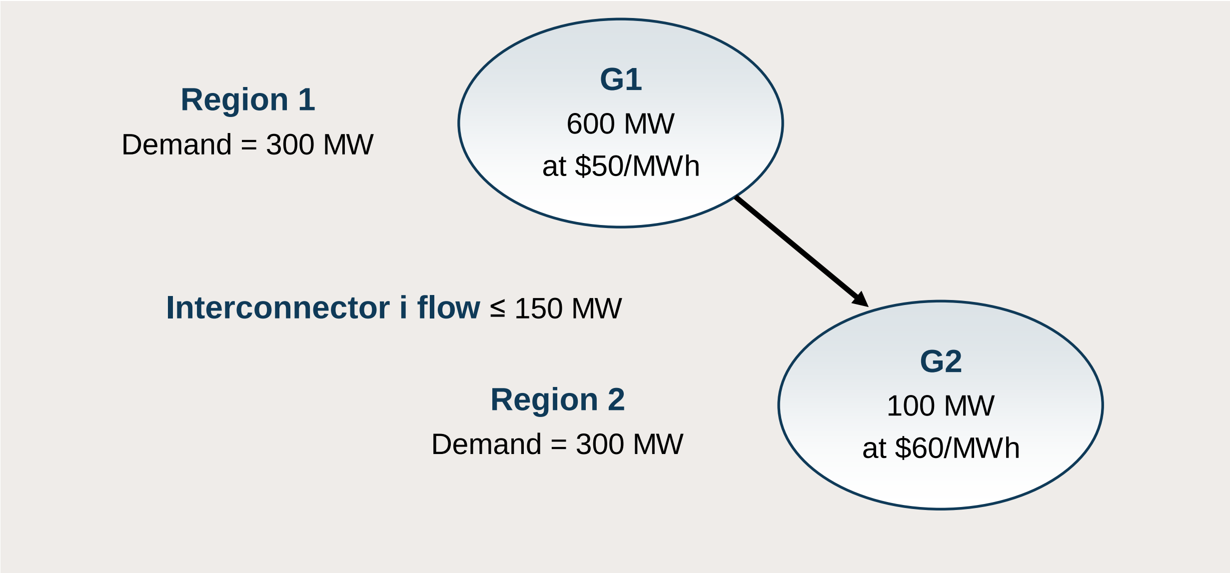

Figure 1 illustrates a simple market model comprising two regions connected by an interconnector. The details are as follows:

- Generation G1 in Region 1 offers 600 MW at $50 per MWh
- Generation G2 in Region 2 offers 100 MW at $60 per MWh
- Interconnector i can transfer up to 150 MW from Region 1 to Region 2
- Demand D1 in Region 1 is 300 MW
- Demand D2 in Region 2 is 300 MW
- MPC is $14,200 per MWh[2]

The above conditions are described using constraints[3] in NEMDE as follows:

- Constraint 1: $X_{G1} - SS_{G1} \leq 600$ — Unit Maximum Availability constraint on G1 dispatch target X_{G1}, with surplus violation variable SS_{G1} and CVP factor = 370
- Constraint 2: $X_{G2} - SS_{G2} \leq 100$ — Unit Maximum Availability constraint on G2 dispatch target X_{G2}, with surplus violation variable SS_{G2} and CVP factor = 370
- Constraint 3: $X_i - SS_i \leq 150$ — Secure Thermal Network Limit constraint on interconnector target flow X_i, with surplus violation variable SS_i and CVP factor = 30
- Constraint 4: $X_{G1} - X_i - SS_{D1} + SD_{D1} = 300$ — Region 1 energy demand supply balance constraint with surplus and deficit violation variables SS_{D1} and SD_{D1}, and CVP factor = 150
- Constraint 5: $X_{G2} + X_i - SS_{D2} + SD_{D2} = 300$ — Region 2 energy demand supply balance constraint with surplus and deficit violation variables SS_{D2} and SD_{D2}, and CVP factor = 150

[2] From 1 July 2012 the MPC changed to become annually indexed
[3] In this example, CVP factors and MPC are as at 1 July 2017.

Note that the above mentioned constraints are simplified version of the constraints that NEMDE would use. Only the constraints that need to be mentioned to demonstrate the concept are discussed in this section.

The dispatch conflict resolution process introduces violation variables SS_{G1}, SS_{G2}, SS_{i}, SS_{D1}, SD_{D1}, SS_{D2} and SD_{D2} (called "slack variables") to constraints 1, 2, 3, 4, and 5 to represent the violation amount (also known as violation degree) of the constraint's RHS.

The market objective is to maximise the value of spot market trade. NEMDE uses linear programming to obtain an optimal solution that minimises the total dispatch cost to the market based on cleared offers and bids, equivalent to maximising the value of spot market trade. This total dispatch cost is represented by an objective function value with two components: total cost for cleared offers and bids[4]; and total constraint violation cost. The optimal solution is the solution with the minimum objective function value. Given that CVP prices are much higher than the MPC, NEMDE typically attempts to find the optimal solution by firstly minimising the total constraint violation cost if possible, as indicated below.

As mentioned in Section 3.1, the cost (in $) of violating a constraint is calculated as follows:

Violation Cost = CVP factor x MPC x Violation Degree

The total cost of violating constraints, therefore, becomes:

∑*Violation Cost =* ∑ *for all constraints of (CVP factor x MPC x Violation Degree)*

The total cost of cleared offers from all dispatchable units can be written as below:

∑*Cleared Offer Cost =* ∑ *for all units of (Offer Price x Dispatch target)*

The objective function can now be written as follows:

Objective Function = ∑Cleared Offer Cost + ∑Violation Cost

= (\$50 x X_{G1}) + (\$60 x X_{G2}) + (370 x MPC x SS_{G1}) + (370 x MPC x SS_{G2}) +

(30 x MPC x SS_{i}) + (150 x MPC x SS_{D1}) + (150 x MPC x SD_{D1}) + (150 x MPC x SS_{D2}) + (150 x MPC x SD_{D2})

In this example, constraints 2, 3 and 5 cannot be satisfied simultaneously. In order to find a feasible solution, one or more of these constraints must be violated. NEMDE would consider the following options:

- **Constraint 2 violation**: violate the unit maximum availability constraint by 50 MW at a total cost of (370 x \$14,200 per MWh x 50 MW) = \$262,700,000 per hour; or
- **Constraint 3 violation**: violate the interconnector flow constraint by 50 MW at a total cost of (30 x \$14,200 per MWh x 50 MW) = \$21,300,000 per hour; or
- **Constraint 5 violation**: violate the Region 2 energy demand supply balance constraint by 50MW at a total cost of (150 x \$14,200 per MWh x 50 MW) = \$106,500,000 per hour.

Due to its lower CVP factor and hence lower violation cost, NEMDE would choose to violate constraint 3 ahead of constraints 2 and 5. The dispatch outcome is as follows:

X_{G1} = 500 MW, X_{G2} = 100 MW, and X_{i} = 200 MW.

The interconnector target flow from Region 1 to Region 2 is 200 MW to meet the demand of 300 MW in Region 2. This target flow violates the interconnector limit of 150 MW by 50 MW.

In general, short term violation of a secure thermal network limit constraint is not as critical to power system security as violating the region's energy demand supply balance (that is, customer load shedding) or violating a generating unit's physical maximum availability. Accordingly, secure thermal limit constraints have lower CVP factors than generating unit maximum availability constraints and region energy demand supply balance constraints.

[4] For simplicity and the sake of the worked example the remainder of the document only refers to offers.

4. OVER-CONSTRAINED DISPATCH RERUN PROCESS

4.1. Design

Energy and FCAS prices for each region represent the marginal value of supply (also known as the marginal price) at the regional reference node (RRN) for a marginal increase of energy demand or FCAS requirement respectively - that is, prices must only be set by offers and bids in the market.

The purpose of the OCD rerun process is to remove from energy and FCAS prices the artificial violation cost components that arise as a consequence of the dispatch conflict resolution process. The OCD rerun does this by sufficiently relaxing violated constraints so that the relevant prices are only set by offers and bids in the market. The OCD rerun process only applies to the 5-minute dispatch process, as it is this process that ultimately determines the spot price used in wholesale market settlements.

An OCD rerun is automatically triggered when the marginal price of one or more regions is suspected to contain an added cost due to violated constraints from the OCD rerun trigger process[5]. The added costs that are reflected on the price indicate that the regional energy demand and FCAS requirement can only be met by a short-term violation of network or FCAS requirement constraints.

The OCD rerun process then removes the violation cost components from the energy and FCAS prices by sufficiently relaxing violated constraints, so that prices are only set by offers and bids in the market.

The principles of the OCD rerun process are summarised as follows:

(a) The process detects the original run solution as over-constrained dispatch if any regional energy or FCAS price contains the cost of any violated network or regional FCAS requirement constraint. During such intervals, the Dispatch price is either greater than Market price cap or lesser than Market Floor price.

(b) If the above condition exists then all violated network and regional FCAS requirement constraints are relaxed before NEMDE is rerun - this rerun is called an OCD rerun. Violated constraints are relaxed by adjusting their constraint RHS by an amount just exceeding the violation degree reported for that constraint in the original run solution. Section 4.2 provides further details of the constraint relaxation logic.

(c) Revised energy and FCAS prices for all regions are determined from the final OCD rerun solution that eliminates the OCD condition. These revised prices are published to the market. All energy and FCAS targets and fast start unit commitments are published from the original run only, rather than from any OCD rerun. If the inline automated OCD rerun process fails to remove all network or regional FCAS requirement constraint violations then AEMO will issue a market notice advising that prices for that dispatch interval will be reviewed off-line and, if necessary, revised before the end of the next business day. AEMO then undertakes an automatic offline and/or manual OCD rerun, with the results advised through a second market notice.

NOTE:

A separate process document to this procedure provides the detailed steps of the OCD rerun process.

4.2. Constraint RHS Relaxation Logic

The constraint RHS relaxation logic is as follows:

IF Deficit < 0 …. (for constraints with an inequality operator of ”≥” or “=”)

THEN

Adjusted RHS = Original RHS + Deficit - Relaxation Offset

ELSE IF Deficit > 0 …. (for constraints with an inequality operator of “≤” or “=”)

THEN

[5] The process to identify the over-constrained dispatch interval is detailed in a separate OCD process document. AEMO may perform checks on the prices to conditionally trigger the OCD rerun only for cases where prices reach certain threshold values in order to reduce the number of OCD reruns required.

Adjusted RHS = Original RHS + Deficit + Relaxation Offset

Where:

Constraint Inequality Operator	"=", "≤" or "≥"
Deficit	Constraint violation amount (aka violation degree) reported in the NEMDE output file. Deficit = dispatched LHS amount minus RHS
Relaxation Offset	A small offset amount (aka constraint over-relaxation constant) (in MW)

4.3. Operation of the OCD Rerun Process – Worked Example

<u>Original Run</u>

Using the worked-example of Section 3.2, NEMDE calculates the energy prices in the original run as follows:

- **Price in Region 1:** Marginally increase Region 1 demand by delta MW[6]. This increase is met by increasing the G1 dispatch by delta MW at its total offer cost of ($50 per MWh x delta MW). If delta MW = 1 MW, then the energy price is ($50 per MWh x 1 MW) / 1 MW = $50 per MWh.
- **Price in Region 2:** Marginally increase Region 2 demand by delta MW. This increase is met by increasing the G1 dispatch by delta MW at its total offer cost of ($50 per MWh x delta MW), which also increases interconnector flow to Region 2 by delta MW and hence increases the violation of the interconnector flow constraint (Constraint 3) by delta MW at its violation cost of (30 x $14,200 per MWh x delta MW). If delta MW = 1 MW, the energy price is [($50 per MWh x 1 MW) + (30 x $14,200 per MWh x 1 MW)] / 1 MW = $426,050 per MWh.

<u>OCD Rerun</u>

The OCD rerun process relaxes Constraint 3 using the relaxation logic discussed in Section 4.2 as follows:

- Original RHS = 150 MW
- Adjusted RHS = Original RHS + Deficit + Relaxation Offset = 150 + 50 + 0.01 = 200.01 MW

  (where Relaxation Offset of 0.01 is used in this example)

The OCD rerun results in the following solution:

- Interconnector constraint (modified Constraint 3) is binding, with a target flow of 200.01 MW from Region 1 to Region 2
- G1 is dispatched to 500.01 MW at $50 per MWh
- G2 is dispatched to 99.99 MW at $60 per MWh

NEMDE calculates the energy prices in the OCD rerun as follows:

- **Price in Region 1:** $50 per MWh (same as in the original run).
- **Price in Region 2:** Marginally increase Region 2 demand by delta MW. This increase is met by increasing the G2 dispatch by delta MW at its total offer cost of ($60 per MWh x delta MW). If delta MW = 1 MW, the energy price is ($60 per MWh x 1 MW) / 1 MW = $60 per MWh.

The OCD rerun process has successfully relaxed the violated constraint and removed the violation component from the Region 2 energy price.

[6] Regional price is the change in objective function for a marginal increase (delta MW) in that region's demand.

5. REPORTING

AEMO reports the incident of constraint violations to the market via the EMMS Data Model. AEMO also sends market notices for the OCD intervals which require further reruns. The right-hand-side value that the constraint is relaxed to is also reported via EMMS Data Model.

Note that AEMO only reports generic constraint violations, not the violations of all constraint types used by NEMDE. Modification of CVP factors during real-time operation

6. MODIFICATION OF CVP FACTORS DURING REAL-TIME OPERATION

AEMO may apply CVP factors that have been modified from those in the published schedule if AEMO considers it necessary to resolve unreasonable dispatch outcomes in real-time operation. AEMO will issue a market notice when it becomes aware of circumstances that may require modification of CVP factors, or as soon as reasonably practicable after applying modified CVP factors, identifying the modifications that may be, or have been, made.