Congestion management Technical Working Group

Working paper – Winner takes all dispatch in the NEM

1. Purpose of paper

The purpose of this paper is to describe how congestion is managed under the current dispatch arrangements, in order to provide background for a working group discussion on the implications for various alternate models under consideration.

In particular, we would like the working group to discuss:

1. Should we consider amending the dispatch arrangements to shift away from the winner-takes-all outcomes, to a model where the costs of congestion are shared more evenly between curtailed generators? This would affect both the congestion relief market and the congestion management model.
2. Should we explore alternative options for reflecting transmission queue numbers in operational timeframes?

2. Introduction

The NEM is based on security constrained, optimised dispatch based on bids and offers through the dispatch engine (NEMDE) every 5 minutes.

A 'snapshot' of the conditions ahead of the five-minute dispatch period provides the starting point. The demand forecasting system provides a forecast for the demand at the end of the 5 minutes dispatch period and then optimises the dispatch of plant to meet that demand while ensuring the power system remains secure and the ramp rate advised for each relevant generating unit is not exceeded. In a single run, NEMDE dispatches all scheduled and semi-scheduled plant across the NEM, either operating or available to operate in the period. There are specific conditions under which two dispatch runs are required to determine optimal dispatch, such as when dispatch is over-constrained and prices breach limits.

Essential system services are also dispatched, with NEMDE co-optimising across energy and market ancillary services to deliver customers' needs at the lowest cost. It is currently being modified to provide for a new fast frequency response service which will also be co-optimised with other services and energy.

3. Background

Power system security

The security of the power system must be maintained through the dispatch process. In a free-flowing AC system, the power flow on each line is a function of the topology of the network, the transfer capacities of each element of the network and the location of load and of generation. Flows across the network are then managed within secure limits by controlling the dispatch of generation and any scheduled load through a series of constraints.

In the NEM TNSPs advise AEMO of the secure operating limits on each element within its network. Secure network limits are those within which the system should operate satisfactorily, and which could withstand any 'credible contingency' and quickly return to a satisfactory state. The Rules, standards set by the Reliability Panel, and AEMO's procedures and guidelines detail the actual requirements and associated standards for secure operation. The maximum secure power transfer across parts of the network will always be limited by its thermal capacity but may also be limited by voltage, transient or oscillatory stability. In recent years limitations based on inertia and system strength have also become important.

Formulation of constraints

To ensure the dispatch delivers a secure power system, AEMO uses 'Constraint Equations' within NEMDE. Taken together, the many constraint equations used creates a mathematical model that reflects the underlying capability (or technical operating envelope) of the physical power system. There are over 10,000 constraints in the total library of constraint equations that AEMO uses, with up to 1,000 invoked at any time. TNSPs continue to provide updated limits and AEMO continues to create more constraint equations as new plant enters the system and as more is learnt through operating experience.

Appendix 1 briefly outlines an example of a network constraint taken from AEMO's "Constraint implementation guidelines".[1] The example is of a system normal constraint that is designed to limit the dispatch of generators in the NEM to ensure that flows on the Marulan to Dapto line remain within secure operating limits if the Marulan to Avon 330 kV line tripped. This is typical of the construction of network constraints in the NEM in that it only seeks to manage one particular potential form of failure on one network element. Other constraints would cover any other potential security risks on that particular element and risks on other network elements.

While thermal limits are usually easier to formulate and more straightforward than other limits such as transient stability, they still build to be quite complex in a meshed network. The resulting equations include a large number of specific generators or interconnectors, each of which has different contribution factors within the equation. The generators contribution factor in a constraint equation reflects its relative impact on the limitation. In the example in Appendix 1, Taralga windfarm has the highest contribution factor in the constraint equation which aims to avoid contingent overloading of the Marulan to Dapto 330 kV line. That is because Taralga is connected directly to Marulan substation so its output will have the most direct impact Marulan to Dapto flows. The contribution factor of a generator in a constraint is key to dispatch outcomes when those constraints bind (discussed below).

The example constraint is one intra-regional constraint in the NSW area and the generators in this network constraint will also be in many other intra-regional constraints. They will all be in inter-regional constraints. The constraint equation or equations which are the most critical will vary as the pattern of load and dispatch change.

Many network constraints would have similar characteristics to the example where they include a number of different generators, all with different contribution factors, on the left-hand side. However, there are some security constraints seeking to manage inertia or system strength which may group generators of a particular type or in a particular sub-regional area, all of which have the same contribution factor. There are also constraints related to market ancillary services which take different forms.

Constraint violation penalties

As outlined, there are many constraint equations invoked at any one time and any one generator will be in a number of those with different contribution factors. It is then possible in dispatch that

[1] https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/congestion-information/2016/constraint-implementation-guidelines.pdf

the overlapping constraints cannot all simultaneously solve – leading to what we refer to as over-constrained dispatch.

To manage that and prevent the situation where NEMDE cannot solve and dispatch plant, each constraint equation has a constraint violation penalty (CVP) factor applied to give a priority order for NEMDE. For example, thermal overload constraint equations have a CVP of 30 while transient stability constraints have a CVP of 35. If NEMDE is over-constrained, it will violate constraints in the order of lowest CVP to highest CVP. For example, based on the above, NEMDE will violate a thermal constraint in preference to transient stability. This seeks to reflect that the risks arising from a short-term breach of thermal limits are less than those from breaching transient stability limits.

Energy constraint equations use an order higher CVP of 360 as these prevent overloads and breaching limits for ongoing satisfactory limits without any contingency. AEMO's publishes a "Schedule of Constraint Violation Penalty Factors" which provides a table with 47 different classes of constraint equation and the CVP applied to each class.[2]

Bidding and security constrained, economic dispatch

All electricity markets seek to dispatch the lowest cost mix of plant to meet customer need subject to ensuring the system remains secure. Security constrained, economic dispatch in the NEM is given effect by the optimisation in NEMDE which has inputs of:

- The 'power balance constraint' or that supply must equal the forecast customer demand in each region at the end of the dispatch interval;
- The constraint equations invoked at the time which define the secure operating envelope; and
- The bids and offers of generators and scheduled loads.

Bids and offers are scaled by their marginal loss factors in the constraints which ensure supply matches demand to represent their supply to the regional reference node. The maximum allowed bid is $15,100 at the RRN and the minimum allowed bid is -$1,000 at the RRN.

Dispatch then is also dependent upon the bids and offers it receives from market participants and will be efficient where those bids and offers reflect costs. The cost of generation, supply from storage or reduction in demand from dispatchable load within a five-minute dispatch interval is not simple to determine. NEMDE is a linear optimiser and does not take into account limitations on generators and loads which may have block limits such as a minimum operating level or a step in load relief. The market participant needs to take account of those issues and reflect that in their bids and offers.

As well as costs associated with the physical operation of a generator, there can be costs or foregone opportunities arising from power purchase agreements or financial contracts to which the participant is a party or through the loss of RECs for renewable generators. These costs also need to be factored into bids and offers.

Importantly NEMDE only optimises dispatch within the five minutes. Market participants are provided with information over the short to medium term through MTPASA, STPASA and pre-dispatch to assist them to optimise their operations over more than that five minutes. They will need to schedule when the plant is available to the market and its operating profile. The NEM is

[2] https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/congestion-information/2016/schedule-of-constraint-violation-penalty-factors.pdf

based on self-commitment and for slow start plant that means they need to determine when they should synchronise to the system and when they should decommit. Storage would need to decide when they are going to charge and when they are going to discharge and supply the market, noting that storage or hydro generating in this five minute period has the opportunity cost that it cannot dispatch that energy later. Again, these costs and operating requirements need to be factored into participant's bids and offers.

In a mathematical sense, NEMDE undertakes the real time optimisation while participants are responsible for the cross-temporal optimisation.

Bids with a common price

The regional design of the NEM leads to a special case where bids have no relation to costs. When a generator is behind a binding intra-regional constraint, they cannot set the price at the regional reference node. They then can bid any number without a risk that they have to supply to that number. This then provides the incentive for generators in such a position to bid the price floor to maximise their dispatch volume. Noting that the price floor is bid at the regional reference node, this can mean that a number of bids in the stack are at exactly the same level of -$1,000.

There can also be an issue when there is little spare capacity online and a number of generators, especially those with some uncontracted capacity, may bid the market price cap. Again, the maximum bid allowed is fixed at the regional reference node such that these bids would all be identical.

4. Role of tie-breaking

The NEM dispatch engine (NEMDE) is a linear programming (LP) solver which seeks to optimise the dispatch of all scheduled and semi-scheduled plant such that the overall cost is minimised and:

- the total generation dispatched matches customer demand
- all necessary market ancillary services are procured
- the system remains within the secure operating envelope defined by the constraint equations invoked at the time

It is possible that two or more separate bids at same price are the marginal supply to the market. NEMDE deems two bids or offers in the same region are price-tied if their prices (adjusted by their MLFs) are within 10^{-6} of one another. In NEMDE tie-breaking is only enforced for energy bids and offers, not for the FCAS offers. Tied bids for blocks of energy are then dispatched in proportion to the MW sizes of the respective bands.

Under normal bidding, it would be unlikely that two blocks on the margin of being dispatched are bid by different parties at exactly the same price. However, this is not the case where parties are bidding to the price floor or the market price cap. In those cases, they would both be bidding the same price at the regional reference node. In recent years there have been large volumes of energy in a region bid in this way such that those could constitute tied blocks which were marginal to dispatch. Tie-breaking is, therefore, more likely than expected when the market was designed.

Its actual prevalence is, however, unclear. Where there are network constraints binding, bids of the same price will not be tied where they have different contribution factors in the constraint equation. The dispatch algorithm will try to dispatch the lowest cost generation to meet customer demand subject to the security constraints. When a network constraint is binding it is restricting access to lower cost supply. The dispatch algorithm will try to maximise access and so will preferentially dispatch those generators which have a lower contribution factor; i.e. lower impact on the constraint.

Winner takes all outcome

Where blocks of energy bid by different generators have the same price, that preferential dispatch will apply even if the contribution factors of two generators only vary by a very small amount. There are constraints where the difference in contribution factors might only differ in the 4th decimal place but, when binding, the party with the lower contribution factor will be preferred. This is what is sometimes referred to as the 'winner takes all' artifact of the current market arrangements.

Network congestion within a region (or intra-regional congestion) is the most likely driver of bidding to the price floor and in such cases that would not be likely to lead to a need for tie-breaking other than for parties located close to each other, on the same radial line and having similar technical characteristics.

Constraint violation penalties

Where there several overlapping constraint equations, NEMDE will violate that with the lowest CVP and the contribution factors in the higher priority constraint will apply. Tie-breaking will be required when blocks are bid the same price, in same region, are marginal to dispatch and where their contribution factors to any binding constraints are identical. This could happen when there are no binding network constraints so only the supply – demand constraint is binding and the regional price clears at the market price floor. It may also happen where some security constraints related to inertia or system strength are binding.

5. ESB view of implications for access reform models

Congestion relief market

Under the congestion relief market, a preliminary run using the status quo arrangements establishes the starting point for buying and selling of congestion relief. If the generators are disorderly bidding and hence bidding to the price floor, their coefficients will play a key role in determining who gets dispatched in the preliminary run.

Generators with a lower coefficient will have the opportunity to sell congestion relief to neighbouring generators with a higher coefficient. Effectively, the lower coefficient generators are agreeing to raise the price of some (or all) of their output, in return for a congestion relief payment. This would change the lower coefficient generators' position in the bid stack, with the result that some of their neighbour's output is now able to be dispatched (but they have had to pay to be able to so).

Generators will have an incentive to sell congestion relief to neighbouring generators if they have higher costs than their neighbours, which creates an arbitrage opportunity. In the short term, it seems likely that much of the trade in congestion relief would be between two generators rather than between a generator and a battery (or load).

Hence, the congestion relief market does not fix the problem of generators "cannibalising" each other's output. Instead, it creates an opportunity to trade to the efficient outcome at the expense of the losers in the "winner takes all" arrangements.

The ESB would like to explore whether stakeholders support the retention of winner takes all, or whether there is support for arrangements that share the costs of congestion in a way that is more transparent and predictable. Alternative arrangements could retain the use of coefficients to deliver efficient dispatch outcomes and locational signals, but spread the financial impact on constrained generators more evenly and/or predictably.

Transmission queue model

The role of coefficients in the dispatch process means that it is not clear that the queue order would come into play very often, as the dispatch algorithm will prioritise based on coefficients before the tie-breaking rules come into effect.

We are interested in the working group's views on an option that combines the congestion relief market and the transmission queue model. Conceptually, the congestion relief market can be thought of as a three-stage process[3]:

1. A preliminary dispatch round that is consistent with the status quo, that establishes who is going to be curtailed and who isn't – at present this is based on winner takes all
2. A congestion relief trading round
3. A final round to co-optimise the outcomes of the congestion relief market within dispatch.

A combined model could work by linking a generator's queue number with the CRM first round outcomes. This would impact which generators can sell and which generators need to buy congestion relief. This model has the potential to enable the market to trade to an efficient dispatch outcome while giving generators with low queue numbers confidence that they will either be dispatched or be paid to not be dispatched.

Congestion management model

The impact of winner-takes-all on the congestion management model depends on how we specify the rebate allocation metric. The ESB is yet to take a position on this critical design choice. For instance:

- If our objective is to preserve financial outcomes associated with the status quo, we could retain a "winner takes all" methodology for allocating rebates. This is where the allocation of rebates is equal to the congestion charge, multiplied by the dispatch quantity that would otherwise have arisen had the congestion charge not been introduced.
- If our objective is to help generators manage access risk, we could adopt some form of "pro rata" scaling methodology. This is where the allocation of rebates is equal to the congestion charge multiplied by the dispatch quantity that would otherwise have arisen with the had the constraint not bound. This approach would more evenly shares the risk of congestion among generators compared to the status quo arrangements.
- A third possible option, if we were to attempt to mix-and-match the congestion management model with the transmission queue approach, would be to scale a generator's rebate entitlement in accordance with their queue number.

[3] Note that the description in terms of a 3 stage process is a helpful concept to aid understanding of the model, but in practice it seems likely that we would need to collapse this process into a single round as we do with other ancillary services markets – bids and offers for both the CRM and the energy market would need to be submitted in advance.

Appendix 1

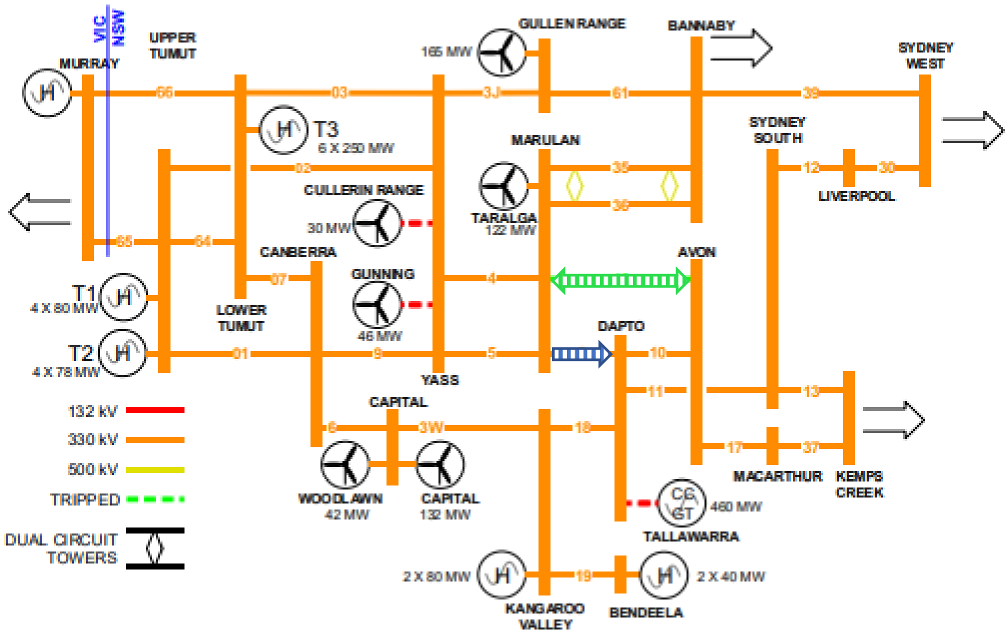
Example from AEMO's CONSTRAINT IMPLEMENTATION GUIDELINES - 2015

1. Introduction

This example is of a constraint equation in NSW which is designed to limit the dispatch of generators to ensure that flows on the Marulan to Dapto line remain within secure limits. In particular, it is designed to for avoid overloading the Marulan to Dapto 330 kV line (shown as on figure 2) the trip of the Marulan to Avon 330 kV line (Shown as on figure 2) under system normal conditions.

Figure 2 shows the topology of the relevant section of the transmission network in southern NSW as it was in 2015. The equation has become more complex since with the addition of more renewable generation but serves to demonstrate how the constraint equation is built up.

Figure 2 Single line diagram of southern NSW electricity network



2. Determining factors

To calculate the generator or load factors (in the example above), AEMO first switches the contingent transmission element out of service in the power flow software and then runs the power flow on the new configuration. This is then used to calculate the factor for generators and interconnectors. The factor is the contribution, relative to a single bus (known as the swing bus), to the monitored line flow that the generator/load makes for a 1 MW increase in the generator output. In the NEM, the swing bus is set to the regional reference node (RRN) of the region where the limitation is located. In this case, the Marulan to Dapto line is located in NSW so the swing bus is set to Sydney West.

The contribution of various generators and dispatchable load are calculated in several steps, first considering the generators in the same region and which would be expected to have the highest contribution factors. Contribution factors are then added to take account of inter-connector flows and finally some additional, more specific a contribution factors are added for some generators in adjacent regions to reflect their impact over and above that of other generators in that region.

2.1 Parent Region Generators

The factors are first determined for the generators in the same region as the swing bus. The factors for all the relevant NSW plant (this includes several large non-scheduled wind farms) are listed in Table 4 from smallest to largest.

Table 4 Raw generator factors for thermal overload example

Generator	Raw factor
Taralga	0.2772
Gullen Range	0.2172
Cullerin Range & Gunning	0.1852
Blowering	0.1786
Uranquinty	0.1722
Hume NSW	0.1708
Lower Tumut	0.1693
Upper Tumut	0.1687
Guthega	0.1465
Boco Rock	0.1465
Nyngan Solar	0.0827
Mt Piper	0.0756
Bayswater 3 & 4	0.0626
Capital & Woodlawn	0.0477
Bayswater 1 & 2	0.0399
Liddell & Hunter GT	0.0377
Eraring 1 & 2	–0.0095
Vales Pt	–0.0092
Colongra	–0.0094
Eraring 3 & 4	–0.0345
Shoalhaven	–0.1662
Tallawarra	–0.2362

2.2 Interconnectors

Interconnectors are used to represent the contribution of the adjacent region generators. The factor for an AC interconnector is the factor at the adjacent region's RRN, using the same swing bus as for the parent region generators. DC interconnector factors are calculated by placing a dummy generator at the parent region end of the link and using the factor of the dummy generator relative to the swing bus. In both cases, the sign used on the interconnector factor is adjusted to represent the NEM convention for interconnector direction (see 2.2). Table 5 details the factors for the three interconnectors between NSW and Qld and Victorian regions.

Table 5 Raw interconnector factors for thermal overload example

Generator	Raw factor
NSW1-QLD1	–0.035
N-Q-MNSP1	–0.0333
VIC1-NSW1	0.1698

2.3 Remote region generators / interconnectors

Normally, generators in the region adjacent to the swing bus region have the same factor as the interconnector to that region. Where generators or interconnectors are located electrically close to the regional boundary, these can have a different contribution than the region as a whole. As the adjacent region contribution is modelled by the interconnector factor, the extra contribution is modelled by taking the raw factor for the remote generator/interconnector and subtracting the interconnector factor. From Table 6 both Murray and Murraylink have different factors than the VIC1-NSW1 interconnector (as they are close to the NSW/Victoria boundary). The corrected factors remain small. For Loy Yang and Millmerran they have the same factors as the VIC1-NSW1 and NSW1-QLD1 interconnectors respectively – their corrected factors are zero.

Table 6 Remote region generators and interconnector factors

Generator / interconnector	Raw factor	Relative factor
Murray	–0.1692	0.0006
V-S-MNSP1	–0.1693	–0.0005
Loy Yang	–0.1698	0
Millmerran	–0.035	0

3 Scaling and normalising

The factors on the left-hand side of constraint equations are normalised (see section 7.2 in the Constraint formulation guideline) so that the absolute value of the largest factor is 1 and the contribution factors for interconnectors and remote region generators/interconnectors are consolidated with the raw generator factors.

The generators on the left-hand side of the constraint equation are being optimally dispatched in NEMDE and are part of the price setting. It is not necessary to optimise all generators in every constraint equation nor practical to do so. AEMO has determined that the absolute value of the factors on the left-hand side of constraint equations must be greater than or equal to 0.07 (see section 5.5.1 in the CFG). Generators with factors which are lower than 0.07, are moved onto the right-hand side (RHS) by subtracting the term from both sides (hence the term appears with the opposite sign). These generators and any relevant non-scheduled generators are then taken into account in the network loading but their impact is not optimised through dispatch.

Final factors for the left-hand side are shown in the following table. Note that 22 generators or windfarms contribute to the constraint equation and only Boco Rock windfarm and Guthega hydro have exactly the same contribution fact other than those which are units of the same generator.

	Generator / interconnector	**Raw factor**		**Scaled factor**
1	Taralga	0.2772		1
2	Gullen Range	0.2172		0.7835
3	Cullerin Range & Gunning	0.1852		0.6681
4	Blowering	0.1786		0.6443
5	Uranquinty	0.1722		0.6212
6	Hume NSW	0.1708		0.6162
7	Lower Tumut	0.1693		0.6108
8	Upper Tumut	0.1687		0.6086
9	Guthega	0.1465		0.5285
10	Boco Rock	0.1465		0.5285
11	Nyngan Solar	0.0827		0.2983
12	Mt Piper	0.0756		0.2727
13	Bayswater 3 & 4	0.0626		0.2258
14	Capital & Woodlawn	0.0477		0.1721
15	Bayswater 1 & 2	0.0399		0.1439
16	Liddell & Hunter GT	0.0377		0.136
	~~Eraring 1 & 2~~	~~–0.0095~~		~~–0.0343~~
	~~Vales Pt~~	~~–0.0092~~		~~–0.0332~~
	~~Colongra~~	~~–0.0094~~		~~–0.0339~~
17	Eraring 3 & 4	–0.0345		–0.1245
18	Shoalhaven	–0.1662		–0.5996
19	Tallawarra	–0.2362		–0.8521
20	NSW1-QLD1	–0.035		–0.1263
21	N-Q-MNSP1	–0.0333		–0.1201
22	VIC1-NSW1	0.11698	**Relative factor**	0.6126
	~~Murray~~	~~–0.1692~~	~~0.0006~~	~~0.0022~~
	~~V-S-MNSP1~~	~~–0.1693~~	~~–0.0005~~	~~–0.0018~~