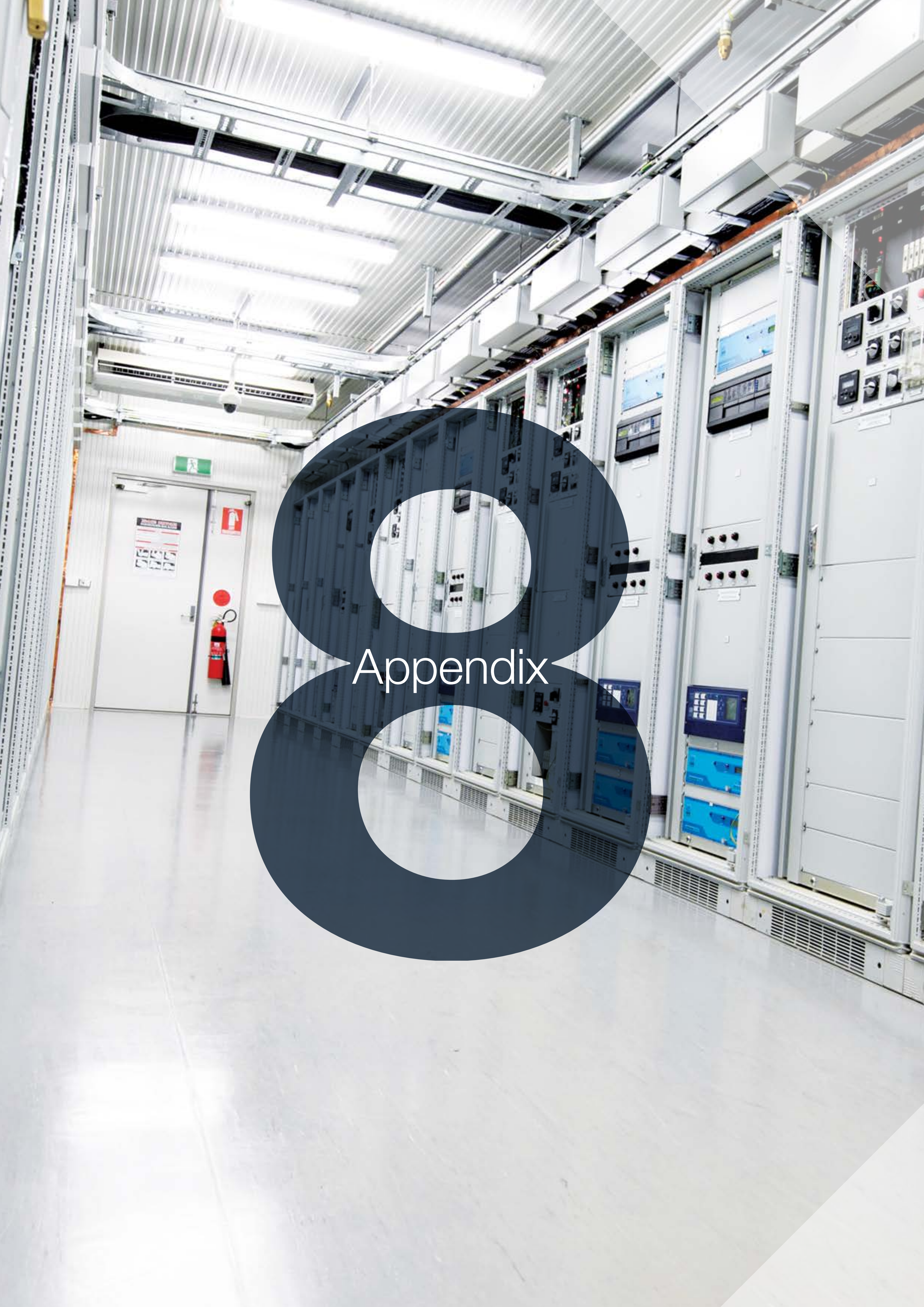


8 Appendix

Transmission constraints

This report provides an analysis of the power flows in our network that have reached or come close to the network limits, and the assets affected.

1 Introduction

This report describes an analysis of how close the flows in TransGrid's network are to its capacity limits. It identifies the transmission elements where flows have been at, or close to, the limits.

Capacity could be limited due to the power flows reaching:

> The maximum rating of a single transmission element such as a transmission line or a transformer

> The combined capacity of a group of transmission elements such as several parallel transmission lines constituting inter regional links

> The limits set by system wide considerations such as voltage, transient or oscillatory stability limits.

TransGrid provides the capability of its transmission network to AEMO. AEMO manages the power flows in the transmission network to be within the capability of the declared limits of the individual assets or the capability of the transmission system. AEMO does so by automatically adjusting the quantity of generation dispatched, so that the transmission flows will be maintained under the prevailing operating conditions, including the flows to be expected under credible unplanned outages. The optimal generation dispatch, the dispatch which minimises total cost while ensuring the capability limits of the transmission system are not violated, is determined using the National Electricity Market Dispatch Engine (NEMDE) analytical tool. The capability limits are included within NEMDE as mathematical equations, which are known as the 'Constraint Equations' (refer to Sections 4 and 5 below). Each constraint equation has a unique identifier, and contains information including the capability limit and the factors which describe or determine the limiting power flows, such as power flow in a transmission line or generator power outputs, which contribute to the limiting power flow.

The constraints reported here cover the transmission system capability limitation experienced during the period from 1 March 2015 to 29 February 2016. The same information is also used to predict potential future constraints.

2 Historical transmission system performance

Table 1 below summarises the constraints where higher cost generation may have been dispatched because some transmission elements or parts of the transmission network have reached their maximum capability. The table shows the constraint identifier, its description, type of limitation addressed by the constraint equation, and length of the time period where the transmission element, or the part of the transmission system, was operated at its maximum capability for the current 12 month period (March 2015 to March 2016), and the previous four 12 month periods.

TABLE 1 – Constraints operating at the capability limit

	Total Duration (dd:hh:mm) for each Time Period (Period Constraint Ranking)					Constraint description		
Constraint ID	**201103-201203**	**201203-201303**	**201303-201403**	**201403-201503**	**201503-201603**	**Limit type**	**Impact**	**Reason**
V::N_NIL_V4		00:00:00 (17)	00:00:00 (22)	18:21:15 (2)	*26:05:15 (1)*	Transient Stability	Victorian Generation + Interconnectors	Avoid transient instability for fault and trip of a Hazelwood – South Morang 500 kV line in VIC
N^^Q_NIL_B1	03:14:45 (3)	10:13:40 (1)	16:12:20 (1)	03:04:35 (5)	*14:14:10 (2)*	Voltage Stability	Qld Generation + Interconnectors	Avoid voltage collapse for loss of Kogan Creek generator
Q:N_NIL_AR_2L-G			00:00:00 (22)	36:10:35 (1)	*13:01:40 (3)*	Transient Stability	NSW - Qld (QNI) Interconnector	Avoid transient instability for fault at Armidale and trip of 330 kV line 8C or 8E from Dumaresq to Armidale
N^^V_NIL_1	04:16:40 (1)	04:18:35 (3)	05:21:10 (2)	06:16:05 (3)	*08:03:15 (4)*	Voltage Stability	Vic Interconnectors + NSW & VIC Generation	Avoid voltage collapse for loss of the largest VIC generating unit or Basslink
V::N_NIL_V3		00:00:00 (17)	00:00:30 (14)	03:13:35 (4)	*06:01:35 (5)*	Transient Stability	Victorian Generation + Interconnectors	Avoid transient instability for fault and trip of a Hazelwood – South Morang 500 kV line in VIC
V::N_NIL_V2		00:00:05 (14)	00:01:35 (10)	00:00:25 (16)	*03:01:40 (6)*	Transient Stability	Victorian Generation + Interconnectors	Avoid transient instability for fault and trip of a Hazelwood – South Morang 500 kV line in VIC
N>>N-NIL__3_OPENED			00:00:10 (19)	00:17:30 (7)	*02:17:25 (7)*	Thermal	NSW Generation + Interconnectors	Avoid overload Liddell to Muswellbrook (83) line on trip of Liddell to Tamworth (84) 330 kV line
V>>N-NIL_HA	01:01:00 (7)	00:09:15 (7)	00:03:05 (7)	00:05:45 (9)	*01:22:05 (8)*	Thermal	NSW Generation + Interconnectors	Avoid overloading Murray to Upper Tumut (65) line on trip of Murray-Lower Tumut (66) 330 kV line
N^Q_NIL_A	00:00:10 (13)	00:00:55 (10)	01:07:50 (3)	00:04:45 (10)	*01:09:20 (9)*	Voltage Stability	NSW - Qld (QNI) Interconnector + Directlink	Avoid voltage collapse for trip of Liddell to Muswellbrook (83) line
V::N_NIL_Q4		00:00:00 (17)	00:00:00 (22)	01:14:05 (6)	*01:01:25 (10)*	Transient Stability	Victorian Generation + Interconnectors	Avoid transient instability for fault and trip of a Hazelwood – South Morang 500 kV line in VIC
V::N_NIL_V1		00:00:00 (17)	00:09:25 (5)	00:06:15 (8)	*00:15:10 (11)*	Transient Stability	Victorian Generation + Interconnectors	Avoid transient instability for fault and trip of a Hazelwood – South Morang 500 kV line in VIC
N>>N-NIL__3_CLOSED			00:00:00 (22)	00:00:00 (18)	*00:12:40 (12)*	Thermal	NSW Generation + Interconnectors	Avoid overloading Liddell to Muswellbrook (83) line on trip of Liddell to Tamworth (84) line

	Total Duration (dd:hh:mm) for each Time Period (Period Constraint Ranking)					Constraint description		
Constraint ID	**201103-201203**	**201203-201303**	**201303-201403**	**201403-201503**	**201503-201603**	**Limit type**	**Impact**	**Reason**
V::N_NIL_Q3		00:00:00 (17)	00:00:00 (22)	00:03:15 (13)	*00:05:15 (13)*	Transient Stability	Victorian Generation + Interconnectors	Avoid transient instability for fault and trip of a Hazelwood – South Morang 500 kV line in VIC
N>N-NIL_LSDU	02:21:10 (4)	07:05:40 (2)	00:14:00 (4)	00:02:30 (14)	*00:05:05 (14)*	Thermal	Terranora Interconnector	Avoid overloading Lismore to Dunoon line (9U6 or 9U7) on trip of the other Lismore to Dunoon line (9U7 or 9U6)
V::N_NIL_S4		00:00:00 (17)	00:00:00 (22)	00:04:15 (11)	*00:04:20 (15)*	Transient Stability	Victorian Generation + Interconnectors	Avoid transient instability for fault and trip of a Hazelwood – South Morang 500 kV line in VIC
V::N_NIL_S3		00:00:00 (17)	00:00:00 (22)	00:00:40 (15)	*00:02:00 (16)*	Transient Stability	Victorian Generation + Interconnectors	Avoid transient instability for fault and trip of a Hazelwood – South Morang 500 kV line in VIC
N>N-NIL_TE_E2	00:00:00 (15)	00:00:00 (17)	00:00:10 (19)	00:00:00 (18)	*00:01:40 (17)*	Thermal	Terranora Interconnector	Avoid overloading Koolkhan to Lismore (967) line on trip of Coffs Harbour - Lismore (87) line
N>>N-NIL__S					*00:01:35 (18)*	Thermal	NSW Generation + Interconnectors	Avoid overloading Mt Piper to Wallerawang (70 or 71) line on trip of the other Mt Piper to Wallerawang (71 or 70) line
N^^N_NIL_1	00:00:00 (15)	00:00:00 (17)	00:00:00 (22)	00:00:00 (18)	*00:01:25 (19)*	Voltage Stability	Vic - NSW Interconnector + Generators	Avoid voltage collapse for trip of Lower Tumut to Canberra (07) line
N>>N-NIL_64					*00:01:00 (20)*	Thermal	NSW Generation + Interconnectors	Avoid overloading Bannaby to Sydney West (39) line on trip of Dapto to Sydney South (11) line
V::N_NIL_Q2		00:00:00 (17)	00:00:00 (22)	00:00:00 (18)	*00:00:45 (21)*	Transient Stability	Victorian Generation + Interconnectors	Avoid transient instability for fault and trip of a Hazelwood – South Morang 500 kV line in VIC
V>>N-NIL_HG	00:00:00 (15)	00:01:15 (9)	00:00:00 (22)	00:00:00 (18)	*00:00:30 (22)*	Thermal	NSW Generation + Interconnectors	Avoid overloading Murray to Upper Tumut (65) line on Nil trip
N>N-NIL_MBDU	02:12:05 (5)	00:10:35 (6)	00:00:00 (22)	00:00:00 (18)	*00:00:20 (23)*	Thermal	Terranora Interconnector	Avoid overloading Mullumbimby to Dunoon line (9U6 or 9U7) on trip of the other Mullumbimby to Dunoon line (9U7 or 9U6)
N>>N-NIL__2_OPENED			00:00:30 (14)	00:00:00 (18)	*00:00:20 (23)*	Thermal	NSW Generation + Interconnectors	Avoid overloading Liddell to Tamworth (84) line on trip of Liddell to Muswellbrook (83) line
N>>N-NIL__B_15M					*00:00:10 (25)*	Thermal	Vic - NSW Interconnector + Generators	Avoid overloading Upper Tumut to Canberra (01) line on trip of Lower Tumut to Canberra (07) line

The constraints listed in the tables above are being reviewed by TransGrid to fully understand their nature, and to provide possible solutions to reduce the market impact of the transmission constraints.

3 Possible future transmission system performance

Based on the performance of the transmission system over the period 1 March 2015 to 29 February 2016, it is expected that the following transmission elements or parts of the transmission system may be operated approaching their maximum limits as described in Table 2.

TransGrid intends to continue with its analysis of network constraints. It is expected that this will involve:

> Analysing additional data as it becomes available

> Investigation of the distribution(s) of marginality values and, if possible, refinement of likelihood estimates

> Identification and analysis of trends (which may be a leading indicator of the onset of constraints).

Table 2 below shows constraints that did not bind but were close to binding in the period March 2015 to March 2016. The ranking is shown in brackets and determined using a closeness test which is the maximum Marginality (LHS-RHS) divided by the Standard Deviation. The Closeness value and ranking is shown for each of these constraints for the 12 month periods starting March 2011 to March 2015. It is noted that if the Closeness Value is 0.00 in earlier years it may indicate that the constraint bound in that time period. Constraints in the most recent period March 2015 to March 2016 are all non-binding constraints.

TABLE 2 – Constraints that were close to binding

	Total Duration (dd:hh:mm) for each Time Period (Period Constraint Ranking)					**Constraint description**		
	201103-201203	**201203-201303**	**201303-201403**	**201403-201503**	**201503-201603**	**Limit type**	**Impact**	**Reason**
V::N_NIL_Q1		-0.05 (15)	-0.03 (16)	0.00 (2)	*0.00 (1)*	Transient Stability	Victorian Generation + Interconnectors	Avoid transient instability for fault and trip of a Hazelwood – South Morang 500 kV line
V::N_NIL_S2		0.00 (9)	-0.01 (13)	-0.01 (4)	*-0.01 (2)*	Transient Stability	Victorian Generation + Interconnectors	Avoid transient instability for fault and trip of a Hazelwood – South Morang 500 kV line
V::N_NIL_S1		-0.01 (10)	0.00 (12)	-0.01 (3)	*-0.01 (3)*	Transient Stability	Victorian Generation + Interconnectors	Avoid transient instability for fault and trip of a Hazelwood – South Morang 500 kV line
V>>N-NIL_HB	-0.01 (10)	-0.01 (11)	0.00 (11)	-0.03 (5)	*-0.01 (4)*	Thermal	NSW Generation + Interconnectors	Avoid overloading Murray to Lower Tumut (66) line on Murray to Upper Tumut (65) line trip
Q:N_NIL_BI_POT	0.00 (3)	0.00 (3)	-0.21 (23)	0.00 (1)	*-0.02 (5)*	Transient Stability	NSW - Qld (QNI) Interconnector	Avoid transient instability on trip of a Boyne Island potline
N>>N-NIL__H_15M					*-0.03 (6)*	Thermal	Vic - NSW Interconnector + Generators	Avoid overloading Lower Tumut to Canberra (07) line on trip of Lower Tumut to Yass (3) line
N>N-NIL_TE_E1	-0.09 (13)	-0.05 (16)	-0.07 (20)	-0.10 (8)	*-0.03 (7)*	Thermal	Terranora Interconnector	Avoid overloading Armidale to Coffs Harbour (96C) line on Armidale-Coffs Harbour (87) line trip;

	Total Duration (dd:hh:mm) for each Time Period (Period Constraint Ranking)					Constraint description		
	201103-201203	**201203-201303**	**201303-201403**	**201403-201503**	**201503-201603**	**Limit type**	**Impact**	**Reason**
N>>N-NIL_996_IN	0.00 (3)	0.00 (3)	-0.03 (17)	-0.27 (18)	*-0.05 (8)*	Thermal	NSW Generation + Interconnectors	Avoid overloading Wagga to ANM (996) line on Wagga to Jindera (62) line trip
N^^Q_NIL_B6	-0.12 (14)	-0.11 (19)	-0.26 (26)	-0.13 (10)	*-0.07 (9)*	Voltage Stability	Qld Generation + Interconnectors	Avoid Voltage Collapse on loss of Callide C4 generator in QLD
N>N-NIL_DC	0.00 (1)	-0.09 (18)	-1.06 (51)	-0.18 (13)	*-0.07 (10)*	Thermal	NSW - Qld (QNI) Interconnector + Terranora Interconnector + NSW generation	Avoid overloading Armidale to Tamworth (86) line on trip of Armidale to Tamworth (85) line
N^^Q_NIL_B5	-0.13 (15)	-0.12 (20)	0.00 (3)	-0.14 (12)	*-0.08 (11)*	Voltage Stability	Qld Generation + Interconnectors	Avoid Voltage Collapse on loss of Callide C3 generator in QLD
N>>V-NIL_O	-0.06 (12)	0.00 (2)	0.00 (3)	-0.11 (9)	*-0.08 (12)*	Thermal	Vic - NSW Interconnector + Generators	Avoid overloading Upper Tumut to Murray (65) line on trip of Lower Tumut to Wagga (051) + 970,990,99M (out of Yass) lines
N>>N-NIL_1A					*-0.09 (13)*	Thermal	NSW Generation + Interconnectors	Avoid overloading Bayswater to Liddell (33 or 34) line on trip of other Bayswater to Liddell (34 or 33) line
N>>N-NIL_01N					*-0.11 (14)*	Thermal	Vic - NSW Interconnector + Generators	Avoid overloading Canberra Yass (9) line on trip of Kangaroo Valley to Dapto (18) line
N::Q_NIL_KC	-0.21 (19)	-0.19 (21)	-0.09 (21)	-0.20 (15)	*-0.12 (15)*	Transient Stability	NSW - Qld (QNI) Interconnector + Terranora Interconnector	Avoid transient instability for trip of Kogan Creek generator

4 Background to constraint equations

APPENDIX 8

TransGrid provides the capability of its transmission network to AEMO, which AEMO then translates into constraint equations. AEMO use the constraint equations in the NEMDE, to control the transmission network to be within its physical capability.

The NEMDE uses linear programming (LP) methods to dispatch the NEM, and the constraint equations use the jargon of LP, which gives special meaning to the left and right hand sides of the equations.

The left hand side (LHS) of the equations contain variables that are controllable by the NEMDE, and contains terms like the MW generated at a power station. The right hand side (RHS) of the equation generally contains the variables that are not controlled by dispatch such as line ratings and the size of loads at various locations. A simple example of a constraint equation follows:

LHS	≤	RHS
a^1 x Generation at power station 1		$+b^1$ x Network Limit1
$+a^2$ x Generation at power station 2	≤	$+b^2$ x Network Limit2
$+a^3$ x generation at power station 3		$+b^3$ x Load1

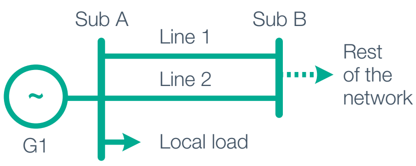
Subtracting the RHS from the LHS (LHS – RHS) of the equation gives an indication of 'how close' the constraint is to binding. If both sides of the equation are equal, then (LHS – RHS) equals zero, the constraint is binding, and the transmission network is operating at its limit.

The (LHS – RHS) value is referred to as the marginality of the constraint.

5 Indicative example of a constraint equation

Figure 1 illustrates a network which consists of a generator (G1) and a 'local load' connected to 'Sub A'. Two transmission lines ('Line 1' and 'Line 2') are connected from 'Sub A' to 'Sub B', which in turn is connected to the rest of the network. The limit of generation from G1 will be the local load plus the power that can be securely transferred from 'Sub A' to 'Sub B' to the rest of the network via 'Line 1' and 'Line 2'. In this example, that will be the minimum Contingency Rating of the two lines. For example, if 'Line 1' has a Contingency Rating of 100 MVA and 'Line 2' has a Contingency Rating of 90 MVA, then the maximum power that can be transferred securely will be 90 MVA. We assume the generation cannot be reduced sufficiently quickly on the loss of one of the lines. If 'Line 1' trips, then 'Line 2' will be at its limit, if 90 MVA is being transferred.

FIGURE 1 – A Two Transmission Line example of a Transfer Limit



The constraint equation for the network illustrated in Figure 1 would be:

LHS	≤	RHS
Generation at power station (G1)	≤	Local load + Rating of 'Line 2'

If the local load is 10 MVA, and the lowest rating of the lines is 90 MVA, then:

> If the generation output is 100 MVA then the marginality of the equation is zero, the constraint is binding, that is, the system is operating at its very limit of power transfer. The constraint equation would be:

LHS	≤	RHS
100	≤	10 + 90

> If we consider the same load and rating, but reduce the generation to 90 MVA, then the marginality is -10, hence, the maximum additional power transfer capacity is 10 MVA. The constraint equation would be:

LHS	≤	RHS
90	≤	10 + 90

> If the generation is increased to 110 MVA, the marginality would be +10. In addition, in the event of a contingency trip of 'Line 1', 'Line 2' would be overloaded. The constraint equation would be:

LHS	≤	RHS
110	≤	10 + 90

If the marginality is greater than zero the network is operating in an insecure state, and the constraint has been violated.

The following Figure 2 shows an example of how close one constraint has come to binding.

FIGURE 2 – Generator behaviour to prevent constraint from binding