THE NEM CONSTRAINT REPORT 2012

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Approved for distribution and use

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Version Release History

VERSION	DATE	AUTHOR	PEER REVIEW	APPROVED	COMMENTS
2	7 June 2013	Ben Blake	Mahsa Ahmadi	Mark Stedwell	Fixed error in IDs for V-SA and QNI histograms, minor formatting changes
1	20 March 2013	Ben Blake & Mahsa Ahmadi	Michael Lyons	Michael Lyons	First version

This document has been created by the Systems Capability Division and will be reviewed from time to time.

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GLOSSARY

(a) In this document, a word or phrase *in this style* has the same meaning as given to that term in the NER.

(b) In this document, capitalised words or phrases or acronyms have the meaning set out opposite those words, phrases, or acronyms in the table below.

(c) Unless the context otherwise requires, this document will be interpreted in accordance with Schedule 2 of the *National Electricity Law*.

TERM	MEANING
CFG	Constraint formulation guidelines
Constraint equation	These are the mathematical representations that AEMO uses to model power system limitations and FCAS requirements in NEMDE.
Constraint function	A group of RHS terms that can be referenced by one or more constraint equation RHSs. These are used where a common calculation is required multiple times (such as a complex stability limit or a calculation for a sub-regional demand). These have been referred to as generic equations, base equations or shared expressions in the past.
Constraint set	A grouping of constraint equations that apply under the same set of power system conditions, either for system normal or plant outage(s). AEMO uses constraint sets to efficiently activate / deactivate constraint equations.
CVP	Constraint violation penalty factor
DFS	Demand Forecasting System
DNSP	Distribution network service provider
EMS	Energy management system
FCAS	Frequency control ancillary service
FCSPS	Frequency control system protection scheme
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.
RTCA	Real time contingency analysis. This is an application in AEMO's EMS that continually monitors the pre and post contingent element flows and alerts if element ratings are exceeded. The RTCA has a list of elements (approximately 2000 are normally active) of which each is tripped in turn and a power flow run. RTCA reports any elements that exceed their NORM, EMER or LDSH element rating pre-contingent, and any elements that exceed their EMER or LDSH rating post-contingent. The list can also include multiple element trips for cases where these are classified as credible contingencies.

TERM	MEANING
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: • All transmission elements are in service, or • The network is operating in its normal network configuration
TNSP	Transmission network service provider

1 References

- Congestion information resource: http://www.aemo.com.au/Electricity/Market-Operations/Congestion-Information-Resource
- Previous annual constraint reports: http://www.aemo.com.au/Electricity/Market-Operations/Dispatch/Annual-NEM-Constraint-Report
- Monthly constraint reports: http://www.aemo.com.au/Electricity/Market-Operations/Dispatch/Monthly-Constraint-Report
- Constraint naming guidelines: http://www.aemo.com.au/Electricity/Market-Operations/Congestion-Information-Resource/Policies-and-Processes/Constraint-Naming-Guidelines
- Constraint formulation guidelines (CFG): http://www.aemo.com.au/Electricity/Market-Operations/Congestion-Information-Resource/Constraint-Formulation-Guidelines
- Constraint violation penalty factors: http://www.aemo.com.au/electricityops/140-0011.html
- 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
- MMS data model: http://www.aemo.com.au/Electricity/Resources/Information-Systems/Market-Management-System-Data-Model

2 Introduction

Constraint equations are used by AEMO to model the power system limitations in NEMDE and PASA. This report details constraint equation performance and transmission congestion related issues for the calendar year 2012. It includes the drivers on constraint equation changes in 2012, analysis of binding and violating constraint equations, market impact of constraint equations, the constraint equations that set interconnector limits, duration of outages and information on other constraint related issues.

This annual report has been developed for both internal AEMO requirements and as a part of the congestion information resource (CIR). AEMO welcomes comments and suggestions on the content of this report from both internal AEMO staff and participants.

The 2012 report includes a number of additions compared to the 2011 report. These include:

- Appendix with tables for the top 10 binding and market impact constraint equations for each region
- Graphs on market impact include network support and negative residue constraint equations

3 Current statistics

This section details the current totals of the constraint sets, equations and functions.

As of 31st December 2012 there were:

- 3597 constraint sets. This is a decrease over 2011's total of 3657 and the first decrease in the past 5 years (2010's total was 3559 and 2009's total was 3431).
- 9745 constraint equations which is a small increase (of 222) over 2011's total of 9523. This compares to the yearly increases from 2009-2011 of approximately 600 each year - 2010's total was 8902 with 8275 in 2009 and 2008's total was 7697.
- 401 constraint functions which is a minor increase over 390 in 2011 and 2010's 382.

Excluded from these totals are any constraint sets, equations or functions that were archived and any that are for outage ramping. The outage ramping constraint sets and constraint equations are not built by the constraint builders but are for single use and generated by an application used by AEMO's control room staff.

The following graphs exclude outage ramping (which would swamp the results), constraint automation built constraint equations as well as any constraint equations which are not in a constraint set (and therefore cannot be active in NEMDE). These graphs show the breakup of constraint equation by regions, FCAS and a few other types (Figure 1) and by limit type (Figure 2).

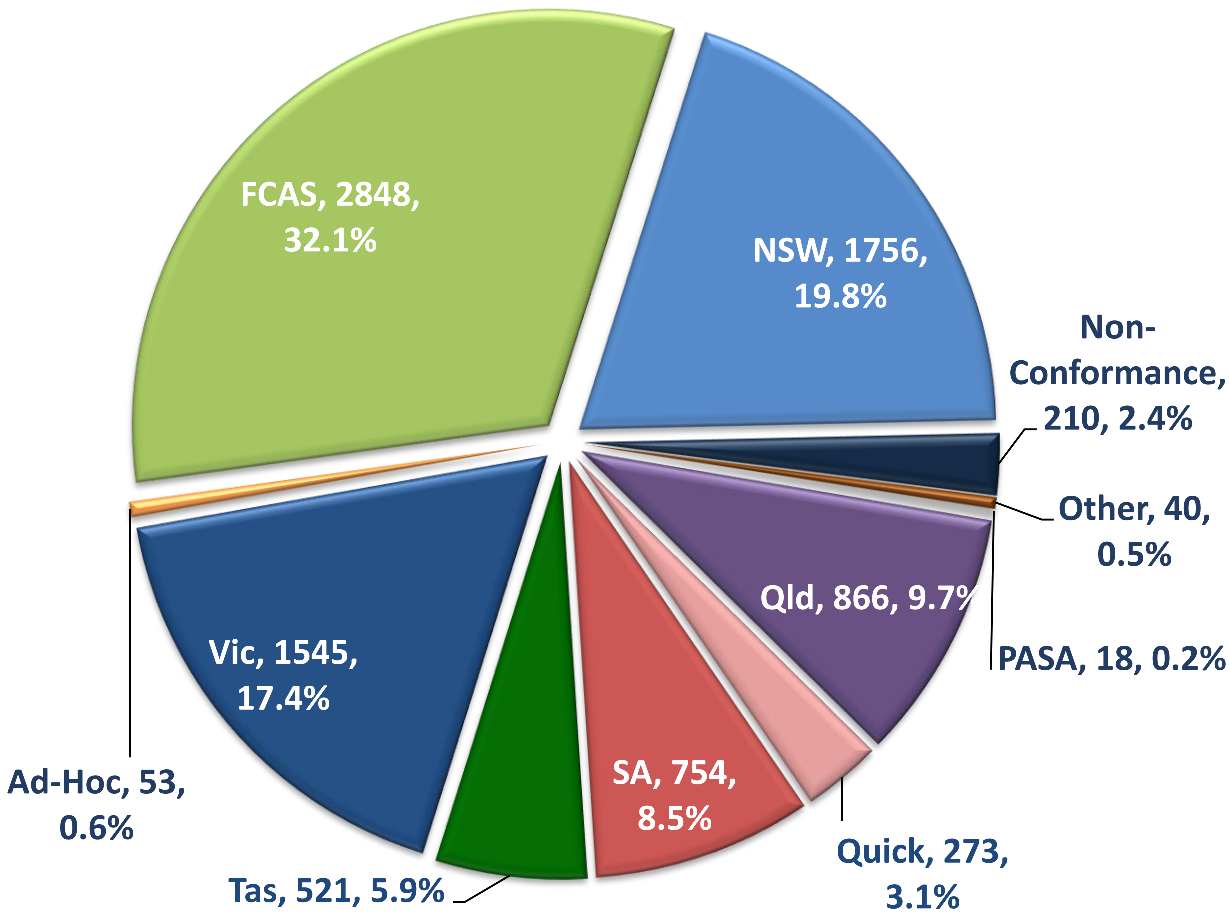

Figure 1: Constraint equations by region/FCAS

As can be seen in Figure 1 the majority of the constraint equations are for frequency control ancillary services (FCAS), NSW and then Victoria. The main types of constraint equations are for thermal overloads (28.3 %) and FCAS (22.3 %) which can be viewed in Figure 2 below.

Quick constraint equations (in Figure 1) are produced by AEMO's electricity control room staff for a selected number of LHS terms and a constant RHS value. IDs for quick constraints are prefixed with "#". Ad-Hoc constraint equations are also created by AEMO's electricity control room staff. However, these were mainly for a large number of LHS terms and software that creates quick constraints now handles more complex LHSs and ad-hoc constraint equations are rarely built. Ad-Hoc constraint equations have an ID prefixed with "@".

The limit type of "DEFAULT" (see Figure 2 below) is only used on very old constraint equations which pre-date the addition of the limit type field. All constraint equations on implementation of the new field were set to "DEFAULT".

Compared to 2011 there were only a few changes to the percentage breakup of the constraint equations in 2011. These differences include:

- Tasmania decreased from 857 to 521
- SA increased from 588 to 754
- Very few changes in the limit types except the number of FCAS constraint equations has increased from 1867 to 1954.

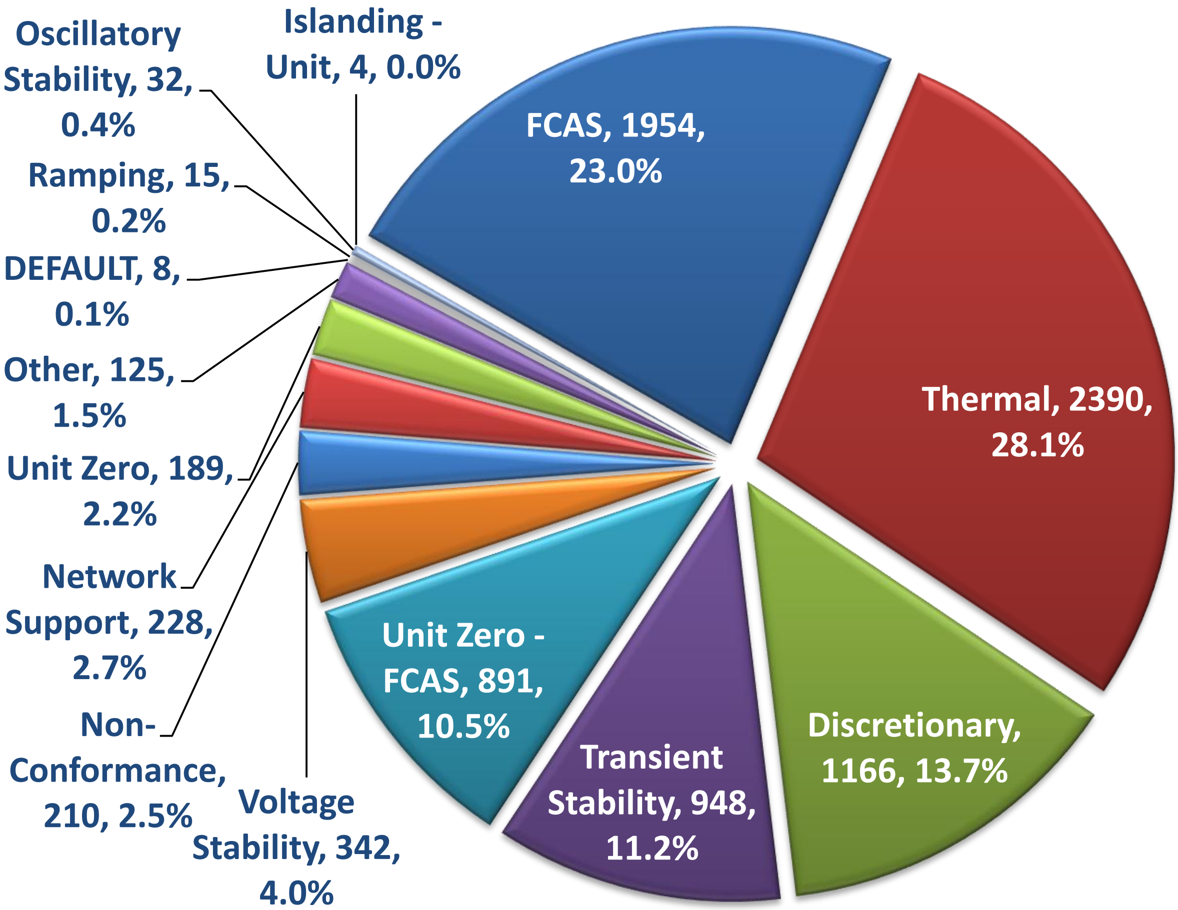

Figure 2: Constraint equations by limit type

4 Constraint equation changes

One of the main drivers for changes to constraint equations is from power system change, whether this is the addition or removal of plant (either generation or transmission). The addition of a new generator, to either the left hand side (LHS) or right hand side (RHS) of a constraint equation, can cause multiple constraint equation changes. Prior to September 2011 AEMO's constraint builders were only able to include generator(s) in constraint equations once the generator(s) were registered in AEMO's market systems. As transmission network modifications (where the new generator's substation is cut into existing lines) and the generator registration usually occur at different times this would generate multiple constraint equation changes.

Following a software change in September 2011 AEMO's constraint builders are now able to include a generator in a constraint equation before it is registered. However, with only a few generator changes since late 2011 this did not really effect the number of constraint changes in 2012.

The tables in this section list the substation work and generator registration separately. Only changes on the main transmission system, normally those that directly cause changes to the constraint equations, are listed.

2 new generators were commissioned in 2013 which is the lowest in the past 4 years (13 in 2009, 4 in 2010 and 5 in 2011).

The number of transmission element changes in the past 4 years has been similar: 19 in 2012, 21 in 2011, 17 in 2010 and 21 in 2009. The most significant change impacting constraint equations in 2012 was the rearrangement of the lines into Gladstone to the new substation at Calliope River.

2012's number of constraint changes (4130) was the lowest since 2004 (which had 4159) - see Figure 3. The greatest number of constraint equation changes was 8592 in 2009. The number of changes in 2011 and 2012 were below the 10 year average of 5200 changes.

4.1 Generators

The following list includes all scheduled and semi-scheduled generators that were added or removed in 2012. Additionally where non-scheduled wind-farms were of a significant size and caused constraint changes these are listed also.

Two new generators were registered in 2012 along with several existing generators de-registering in Queensland.

Table 1: Generator changes in 2012

GENERATOR	REGISTRATION DATE	REGION	NOTES
Macarthur wind farm	21 August 2012	Victoria	
Morton's Lane wind farm	9 November 2012	Victoria	Non-scheduled
Collinsville	1 January 2013	Queensland	De-registered

4.2 Transmission

In 2012 there were a slightly smaller number of transmission changes compared to 2011 (19 versus 21). The most significant change was the rearrangement of the lines from Gladstone to the new Calliope River substation. Similar to previous years the majority of projects were in Queensland.

Table 2: Transmission changes in 2012

PROJECT	DATE	REGION	NOTES
Cranbourne (CBTS) to Wonthaggi (WDP) 220 kV cable	8 March 2012	Victoria	Last section of 220 kV cable to Wonthaggi desalination plant commissioned
Goonyella Rivers 132 kV substation	20 April 2012	Queensland	132 kV substation cut into the existing Moranbah to Stony Creek (7122) 132 kV line
Glen Innes to Inverell (9U4) 132 kV line	1 May 2012	NSW	
Bouldercombe to Calliope River (812) and Calliope River to Gladstone (8876)	16 May 2012	Queensland	Bouldercombe to Gladstone (812) 275 kV line cut into new Calliope River substation

PROJECT	DATE	REGION	NOTES
275 kV lines			
Kempsey - Port Macquarie (96G) 132 kV line recommissioned	17 May 2012	NSW	96G 132 kV line restrung on the new towers of double circuit 9W9 132 kV line (commissioned in November 2011)
Calliope River to Larcom Creek (8859) and Calliope River to Gladstone (8836) 275 kV lines	7 June 2012	Queensland	Gladstone to Larcom Creek (8859) 275 kV line cut into Calliope River
Calliope River to Gin Gin (813) and Calliope River to Gladstone (8877) 275 kV lines	28 June 2012	Queensland	Gin Gin to Gladstone (813) 275 kV line cut into Calliope River
Calliope River to Gin Gin (814) and Calliope River to Gladstone (8878) 275 kV lines	12 July 2012	Queensland	Gin Gin to Gladstone (814) 275 kV line cut into Calliope River
Boyne Island to Calliope River (7145) and Calliope River to Gladstone (7375) 132 kV lines	20 August 2012	Queensland	Boyne Island to Gladstone (7145) 275 kV line cut into Calliope River
Kincraig 132kV Capacitor Bank	28 August 2012	South Australia	15 MVar capacitor
Boyne Island to Calliope River (7146) 132 kV line	3 September 2012	Queensland	Boyne Island to Gladstone (7146) 275 kV line cut into Calliope River
Tarrone terminal station	5 September 2012	Victoria	New connection point for Macarthur wind farm
Suffolk Park 66 kV substation	19 October 2012	NSW	Ewingsdale to Lennox Head (8508) 66 kV line cut into new Suffolk Park substation to form Lennox Head to Suffolk Park (9G3) 66 kV line and Ewingsdale to Suffolk Park (954) 66 kV line
Calliope River to Gladstone (7376) 132 kV line	25 October 2012	Queensland	Connection to Gladstone unit 4
Dystart to Eagle Downs (7383) 132 kV line	9 November 2012	Queensland	Changes the definition of the Central to North Qld cut-set
Eagle Downs to Moranbah (7382) 132 kV line	14 November 2012	Queensland	Changes the definition of the Central to North Qld cut-set
Calliope River to Gladstone North (7195) 132 kV line	29 November 2012	Queensland	7195 cut into Calliope River
Halys to Western Downs (8866 and 8867) 275 kV lines	5 December 2012	Queensland	Lines connected to new Halys substation - part of south west Qld augmentation
Tungkillo 275kV 100Mvar Capacitor Bank	December 2012	South Australia	100 MVar capacitor

4.3 Comparison of constraint equation changes

The following 2 graphs compare the yearly and monthly constraint equation changes. Figure 3 includes a comparison with the total number of constraint equations at the end of each calendar year and Figure 4 includes the total number of changes in 2012 per month. Both Figure 3 and Figure 4 are cumulative area graphs so the NEM yearly / monthly totals are indicated by NSW.

The graphs do not include changes to the constraint sets or constraint functions or any archiving. The number of times a constraint equation changes is not an accurate reflection of the amount of work involved in changing it (some changes are to fix a description; some changes are more complex and can require many days of work). These results measure when the changes occurred and not when they became active, so the FCAS change that was made active on 1st Jan 2009 but was loaded into the database in late 2008 is included in the 2008 results and not the 2009 results.

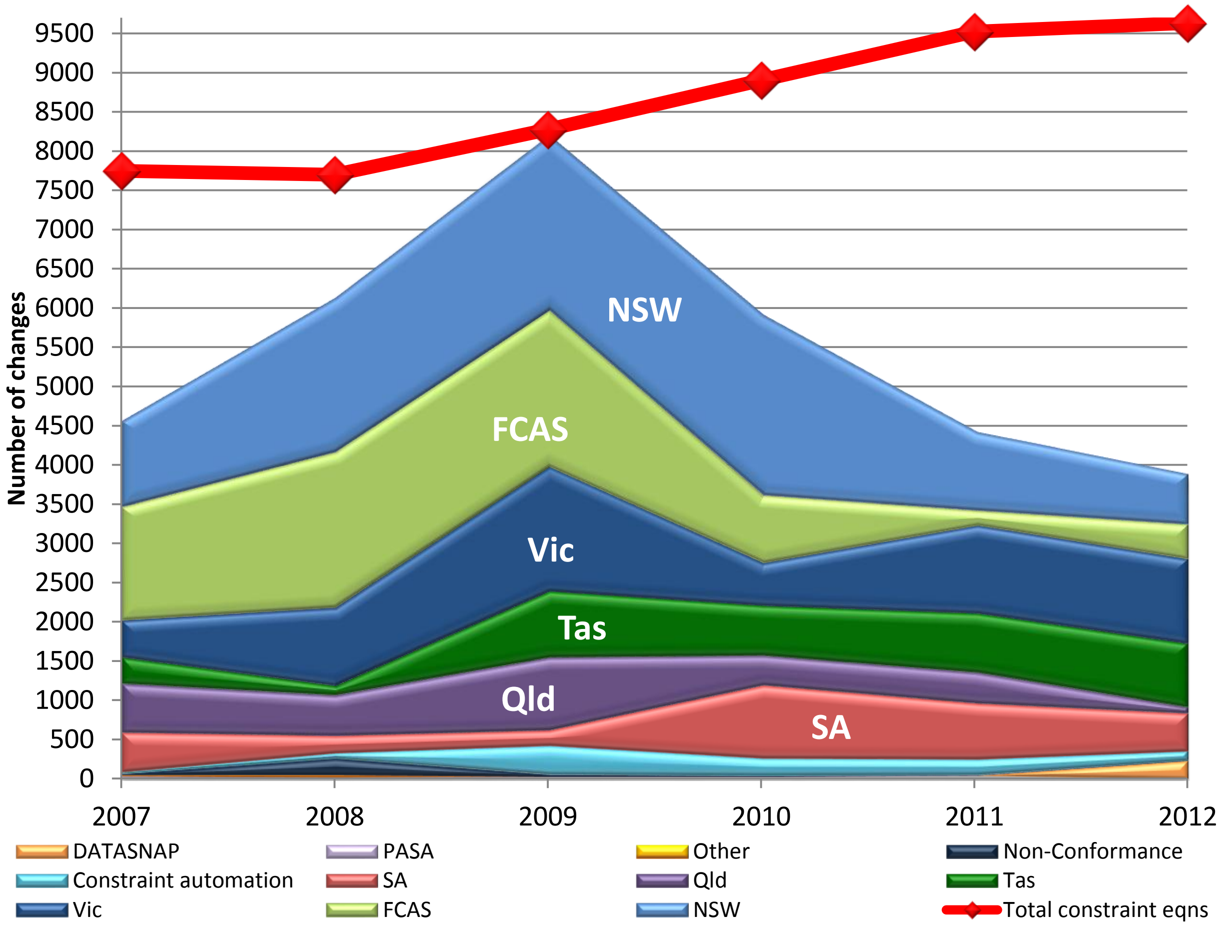

Figure 3: Constraint equation changes per calendar year

As can be seen from Figure 3 the number of constraint changes increased steadily between 2007 and 2009 but fell from 2010 to 2012. 2012 had the lowest number of constraint equation changes (4130) since 2004 (which had 4158 changes). The years with a large number of constraint equation changes are due to:

- the program to convert constraint equations to “fully co-optimised” in 2006
- the Snowy region abolition in 2008
- the multiple stages of the NSW western 500 kV project in 2009 and partly into 2010

The reduction in FCAS constraint equation changes is due to no power system or market changes impacting on FCAS. In previous years the large number of changes was due to co-optimisation of regulation and 5 minute services (2008), Snowy abolition (2008) and Tasmanian frequency operating standards changing (2009).

The 10 year average of constraint equation changes is approximately 5200. It is expected that 2013 will have a smaller number of changes than this average and the number of changes will be similar to 2011 (which had 4776 changes).

Figure 4 shows the constraint equation changes per month in 2011 versus the total changes in 2010 and 2009. Much like the previous 2 years each region had bursts of activity in constraint equation changes. The major groups of constraint equation changes were due to transmission and generation changes (see Table 1 & Table 2):

- Victoria in February – updating the Pre-dispatch RHSs for improved sub-regional demand forecasts
- Tasmania in February – review of constraint equations associated with the network control system protection scheme (NCSPS)
- Tasmania in April – constraint equations were developed to enable the NCSPS to be used for a number of prior outages
- Vic in August – commissioning of Tarrone terminal station and Macarthur wind farm
- Victoria in December – revised transient stability constraint equations
- Queensland in December – De-registration of Collinsville power station (this change did not become active until 1 Jan 2013)

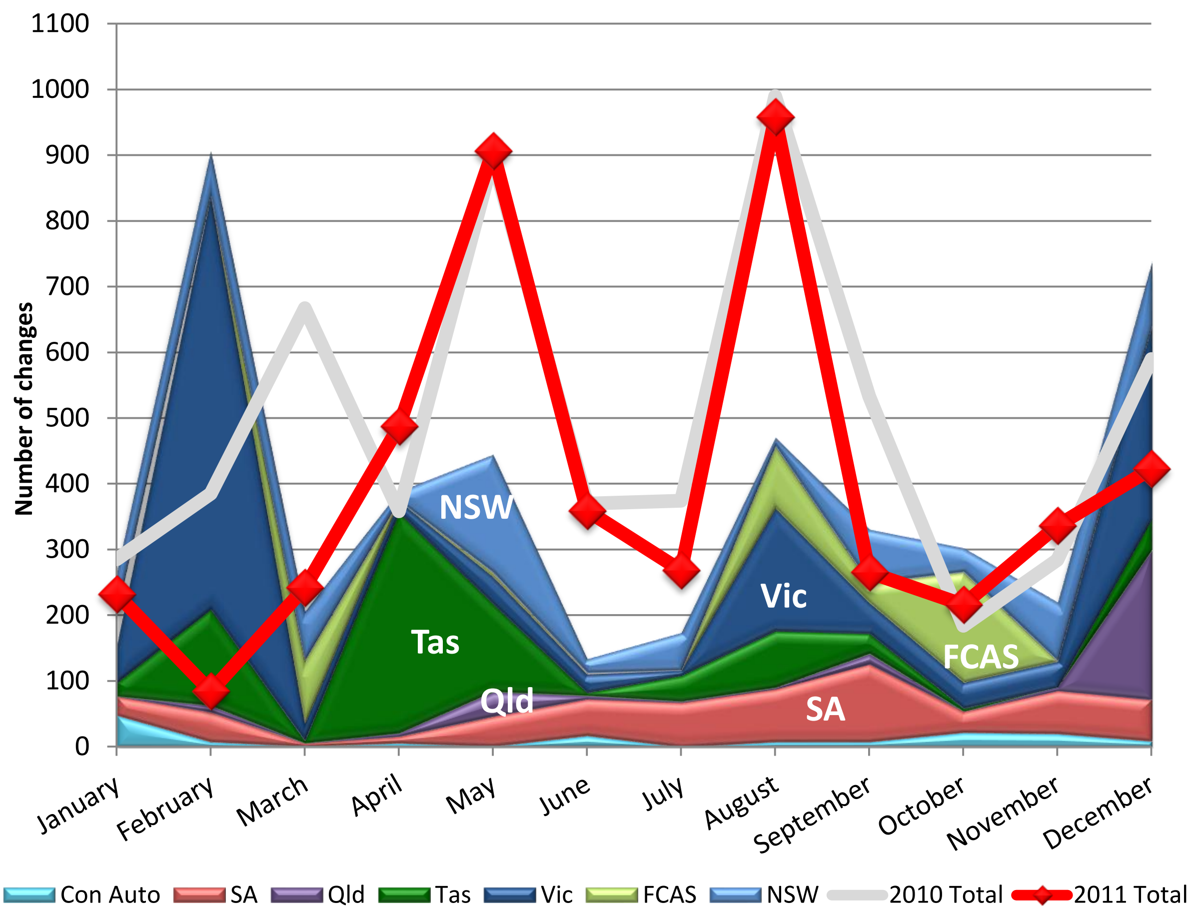

Figure 4: Constraint equation changes per month in 2012

5 Binding and violating

In this section of the report the top 20 binding and violating constraint equations are examined. System normal constraint equations are in bold and the number of hours for 2011 (if any) is indicated in brackets below the 2012 hours. In the tables a brief description of the constraint equation is given (in *italics*) along with any comments. If the full description, LHS or RHS of the constraint equation is required then this can be obtained from either the plain English converter[1] on the MMS web portal or via the MMS data model[2].

5.1 Binding constraint equations

When a constraint equation is binding either flows have reached the thermal or stability limit or the FCAS constraint equation is setting an FCAS requirement. As there is at least one constraint equation setting the FCAS requirement for each of the 8 services at any time this leads to many more hours of binding for FCAS constraint equations. These would dominate the top 20. Due to this the FCAS and network binding results have been separated into two tables (see Table 3 and Table 4 below).

Some constraint equations only bind at certain times of the year (such as winter or summer) and Figure 5 shows a monthly breakup for the top 10 binding network constraint equations. In 2011 the top 10 binding constraint equations were more likely to bind in the second half of the year with sharp peaks in June, July and November.

In some cases the binding results for several constraint equation IDs have been combined. This is due to some limits being represented by several constraint equations to either:

- Move each generator from a maximum calculation onto the LHS of separate constraint equations (such as the NSW to Qld voltage stability limit)
- Manage the same limit under different network configurations (such as Yallourn W1 switched into 500 kV or 220 kV mode)
- Combining different values of network support for the same generator(s)

Out of the top 20 binding results (see Table 3 and Table 4 below) the majority are system normal constraint equations and not those for outage cases.

5.1.1 Network constraint equations

Table 3: Top 20 binding network constraint equations

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
T_TAMARCCGT_GCS	911 (647)	*Limit output of Tamar Valley Power Station based on load available for shedding by Tamar Valley 220 kV generation control scheme (GCS)* The Tamar Valley output is dependent on the GCS so it is expected that this constraint equation will bind for a high number of hours in 2013
N_X_MBTE_3A & N_X_MBTE_3B	503 (350)	*Out = all three Directlink cables* All three Directlink cables were out for 20.9 hours in 2012 compared to 14.5 hours in 2011 - see Table 19
Q>NIL_BI_FB	484 (13)	*Out = Nil, avoid overloading on Boyne Island feeder bushing on Gladstone to Boyne Island 132 kV lines, for the contingent loss of a single Gladstone to Boyne Island 132 kV line*
N_X_MBTE2_A & N_X_MBTE2_B	483 (797)	*Out = two Directlink cables* Two of the Directlink cables were out for 60.0 hours in 2012 compared to 90.0 hours in 2011 - see Table 19
S>>V_NIL_SETX_SETX	444 (207)	*Out = Nil, avoid overloading a South East 275/132 kV transformer on trip of the remaining South East 275/132 kV transformer*

[1] https://mms.prod.nemnet.net.au/Mms/login.aspx
[2] http://www.aemo.com.au/Electricity/Resources/Information-Systems/Market-Management-System-Data-Model

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
		This constraint equation binds when there is export from South Australia to Victoria and high generation from the wind farms and gas turbines in the south east of South Australia.
V::N_NILxxx	420 (1,132)	*Out = Nil, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* There are 12 constraint equations that make up the transient stability export limit from Victoria and all the binding results have been combined. These constraint equations were updated in late 2012[3]. These constraint equations last bound in June 2012. The updated versions generally give higher values and it is expected these will bind for very few hours in 2013.
NSA_Q_GSTONE34_xxx	367 (695)	*Gladstone 3 + 4 >= various levels for Network Support Agreement* The binding results from 6 constraint equations that set the minimum level of Gladstone 3 and 4 generation have been combined.
V_T_NIL_FCSPS	325 (193)	*Basslink limit from Victoria to Tasmania for load enabled for the Basslink frequency control special protection scheme (FCSPS)* This constraint equation binds when there is high import to Tasmania or a low amount of load is enabled for tripping.
SVML_000	283 (69)	*South Australia to Victoria on Murraylink upper transfer limit of 0 MW* This constraint equation is normally invoked for Murraylink out of service. Murraylink was out for 13.8 days in 2012 compared to 5.2 days in 2011 – see Table 19.
Q>>NIL_855_871	279 (217)	*Out = Nil, avoid overload on Calvale to Wurdong (871) 275 kV line on trip of Calvale to Stanwell (855) 275 kV line* This constraint equation is expected to bind for a similar amount in 2013 until Powerlink constructs double circuit 275kV lines between Calvale and Stanwell in late 2013[4]
V^^S_NIL_MAXG_xxx	244 (1,121)	*Out = Nil, Victoria to SA long term voltage stability limit for loss of the largest credible generation contingency in SA, South East capacitor bank on / off* There are 2 constraint equations that make up the voltage stability export limit from Victoria to South Australia and all the binding results have been combined. These constraint equations were updated in January 2013 and it is expected these constraint equations will bind for very few hours in 2013.
T>T_NIL_BL_IMP_6E	234 (1)	*Out = Nil, avoid overloading Sheffield to Georgetown No. 1 220 kV line (flow to Georgetown) on trip of the Sheffield to Georgetown No. 2 220 kV line with no SPS action*

[3] http://www.aemo.com.au/Electricity/Market-Operations/Congestion-Information-Resource/Network-Status-and-Capability/Limit-Advice
[4] http://www.powerlink.com.au/Projects/Central/Calvale_to_Stanwell.aspx

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
		This constraint equation is only activated if the NCSPS is off. The binding hours have increased significantly due to the NCSPS being taken out of service for a significant period of time from May 2012[5].
S>VML_NWCB6033_TX2	210 (6)	*Out = North West Bend CB6033, avoid overloading North West Bend #2 132/66 kV transformer on trip of North West Bend to Monash #2 132 kV line* This circuit breaker was out for 9.3 days in 2012 compared to 0.2 days in 2011 - see Table 19
S>V_X_6021+6022_TX2	184 (0)	*Out = North West Bend CB6021 & CB6022, avoid overloading North West Bend #2 132/66 kV transformer on trip of North West Bend to Robertstown #1 132 kV line* These circuit breakers were out for 8.1 days in 2012 compared to 0 days in 2011 - see Table 19
V>>V_NIL_2A_R & V>>V_NIL_2B_R & V>>V_NIL_2_P	164 (207)	*Out = Nil, avoid overloading the South Morang 500/330 kV (F2) transformer for no contingencies, for radial/parallel modes and Yallourn W1 on the 500 or 220 kV* These constraint equations maintain flow on the South Morang F2 transformer below its continuous rating. It is expected that the combination of these 3 constraint equations will bind for a similar amount in 2013.
NC_V_APS	162 (167)	*Non Conformance constraint equation for Anglesea Power Station*
N_MBTE1_B	158 (75)	*Out = one Directlink cable, Queensland to NSW limit* One Directlink cable was out for 280.7 days in 2012 compared to 194.3 days in 2011 – see Table 19.
S>V_CB6024+6023_TX2	128 (0)	*Out = North West Bend CB6024 and CB6023, avoid overloading North West Bend #2 132/66 kV transformer on trip North West Bend #3 132/66 kV transformer* The North West Bend CB6024 and CB6023 were out for 5.4 days in 2012 compared to zero days in 2011.
T>>T_NIL_NCSPS6_1	125 (2)	*Out = Nil, ensure Basslink is able to fully compensate fast NCSPS action from Western NCSPS generation* This constraint equation was implemented in late 2011 as an interim solution to the Tas NCSPS issues[6] and to allow higher flows on Basslink. This constraint equation was removed in July 2012.
Q:N_NIL_BCK2L-G	115 (38)	*Out = Nil, avoid transient instability for a 2 phase to ground fault on a Bulli Creek to Dumaresq 330 kV line at Bulli Creek* Prior to 14 May 2012 for high flows from Queensland to NSW either this constraint equation or Q:N_NIL_BI_POT or Q:N_NIL_OSC bound. After 14 May 2012 this constraint equation has bound instead of Q:N_NIL_BI_POT or Q:N_NIL_OSC.

[5] http://www.aemo.com.au/Electricity/Resources/Reports-and-Documents/~/link.aspx?_id=1025E01FD4AA4DD7AE04E60BF645A7E5&_z=z
[6] http://www.aemo.com.au/Electricity/Resources/Reports-and-Documents/~/link.aspx?_id=BC68149F878842D0BF052D3285A611D4&_z=z

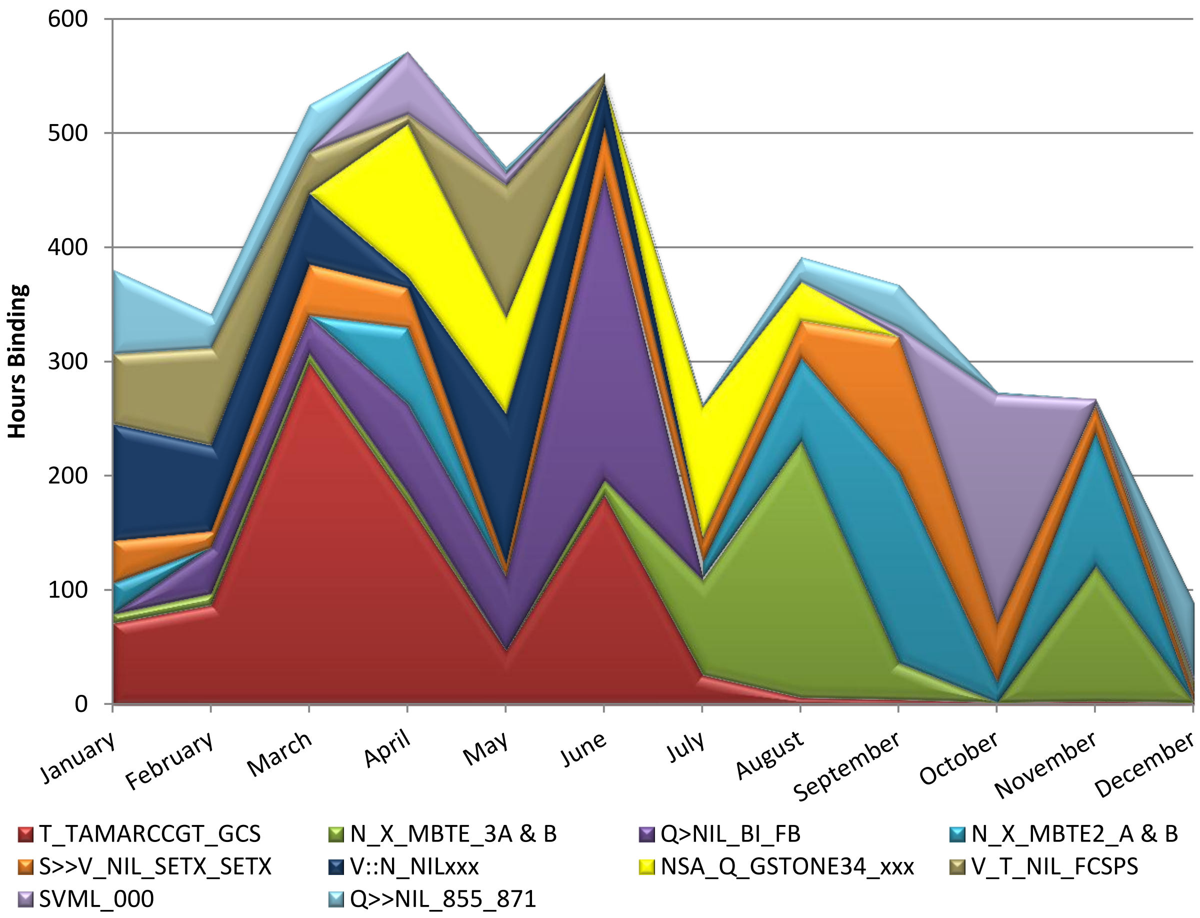

Figure 5: Top 10 binding constraint equations per month

5.1.2 FCAS

In general for FCAS constraint equations it is expected that the system normal constraint equations will continue to be in the top 20 binding list unless there are transmission outages for significant periods of time requiring FCAS. For the Basslink trip constraint equations (such as F_T+NIL_BL_R6_1) these only bind when Basslink is transferring into Tasmania so the binding hours will reflect this.

Table 4: Top 20 binding FCAS constraint equations

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
F_I+NIL_MG_R5	7,498 (8,063)	*NEM raise 5 minute requirement for a NEM generation event* The largest unit is usually Kogan Creek or one of the large NSW units.
F_I+NIL_DYN_LREG	6,618 (7,443)	*NEM lower regulation requirement*
F_I+NIL_MG_R6	6,375 (7,612)	*NEM raise 6 second requirement for a NEM generation event*
F_I+NIL_MG_R60	6,280 (7,440)	*NEM raise 60 second requirement for a NEM generation event*
F_I+ML_L5_0400	5,999 (7,109)	*NEM lower 5 minute requirement for a NEM load event* The largest single load in the NEM is 400 MW at Boyne Island in Queensland.

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
F_T++NIL_TL_L60	4,007 (2,498)	*Tasmania lower 60 second requirement for loss of 2 Comalco potlines, Basslink able to transfer FCAS*
F_T++NIL_TL_L6	3,470 (2,000)	*Tasmania lower 6 second requirement for loss of 2 Comalco potlines, Basslink able to transfer FCAS*
F_MAIN++NIL_MG_R60	2,655 (1,184)	*Mainland raise 60 second requirement for a mainland generation event, Basslink able transfer FCAS*
F_MAIN++NIL_MG_R6	2,256 (811)	*Mainland raise 6 second requirement for a mainland generation event, Basslink able transfer FCAS*
F_I+ML_L6_0400	1,962 (2,323)	*NEM lower 6 second requirement for a NEM load event*
F_MAIN++NIL_MG_R5	1,729 (758)	*Mainland raise 5 minute requirement for a mainland generation event, Basslink able transfer FCAS*
F_MAIN++ML_L5_0400	1,693 (2,115)	*Mainland lower 5 minute requirement for a mainland load event, Basslink able transfer FCAS*
F_T+NIL_BL_R6_1 & F_T++NIL_BL_R6_x	1,648 (2,801)	*Tasmania raise 6 second requirement for loss of Basslink, FCSPS available* In November 2011 the 4 constraint equations were replaced with 2 constraint equations due to advice that the loss of link time on Basslink was changed to 400ms. The binding results from all the constraint equations have been combined.
F_I+NIL_DYN_RREG	1,615 (1,742)	*NEM raise regulation requirement*
F_I+APHY_L5	1,494 (413)	*Out = Alcoa Portland to Heywood 500 kV line, NEM lower 5 minute requirement for the loss of the other Alcoa Portland to Heywood 500 kV line* One Alcoa Portland to Heywood 500 kV line was out for 75.4 days in 2012 compared to 23.7days in 2011.
F_T+NIL_BL_R60_1 & F_T++NIL_BL_R60_x	1,387 (2,245)	*Tasmania raise 60 second requirement for loss of Basslink, FCSPS available* See note for F_T+NIL_BL_R6_1 & F_T++NIL_BL_R6_x
F_MAIN++ML_L6_0400	1,301 (1,492)	*Mainland lower 6 second requirement for a mainland load event, Basslink able transfer FCAS*
F_MAIN++NIL_BL_L60	1,267 (1,976)	*Mainland lower 60 second requirement for loss of Basslink, Basslink flow into Tasmania, Basslink able to transfer FCAS*
F_T++NIL_MIG_R5	1,070 (1,569)	*Tasmania raise 5 minute requirement for a Tasmania generation event (loss of the largest inertia), Basslink able to transfer FCAS*
F_T+NIL_BL_R5	1,042 (1,208)	*Tasmania raise 5 minute requirement for loss of Basslink, FCSPS available*

5.1.3 Binding trends

Figure 6, Figure 7 and Figure 8 show the binding constraint equations categorised by region, limit type and system normal/outage for the past 6 years. The FCAS in Figure 7 excludes the system normal FCAS constraint equations (as these would dominate the graph). Binding FCAS hours (whether system normal or outage) are excluded from Figure 8 for the same reason. The trends indicated by these two graphs:

- There was a peak in 2008 and a secondary peak in 2010 in the total number of binding hours
- NSW and South Australia have increased in the number of binding hours since 2007
- Queensland and Victoria have decreased the number of binding constraint hours since 2007, although there was a spike for Queensland in 2010
- Tasmania has increased since 2007 however, the binding hours in 2011 were less than the binding hours in 2009
- Voltage stability constraint equations are binding at lower levels compared to 2007 (956 hours versus 693 hours in 2012), however, there was a peak of 2091 hours in 2011
- Thermal overload constraint equations bound between 3000 and 4000 hours. However, there was a large increase in 2010 (5134 hours) and a decrease in 2008 (2555 hours)
- Transient stability binding constraint equations have increased steadily from 469 hours in 2007 to 1618 hours in 2011 with a spike in 2010 of 2243 hours. The binding hours in 2012 were much lower at 811 binding hours and this can mainly be attributed to the reduced binding hours of the Victoria to NSW transient stability constraint equations.
- Binding hours due to outages of Directlink cables increased from 329 hours in 2007 to a peak of 1997 hours in 2010 and falling to 1144 hours in 2012
- Overall binding hours (excluding FCAS) has been slowly declining in the past 6 years
- The number of outage binding hours has been less than the system normal binding hours since 2008
- System normal binding hours have been declining from a peak of 9756 hours in 2008 to 5333 hours in 2012

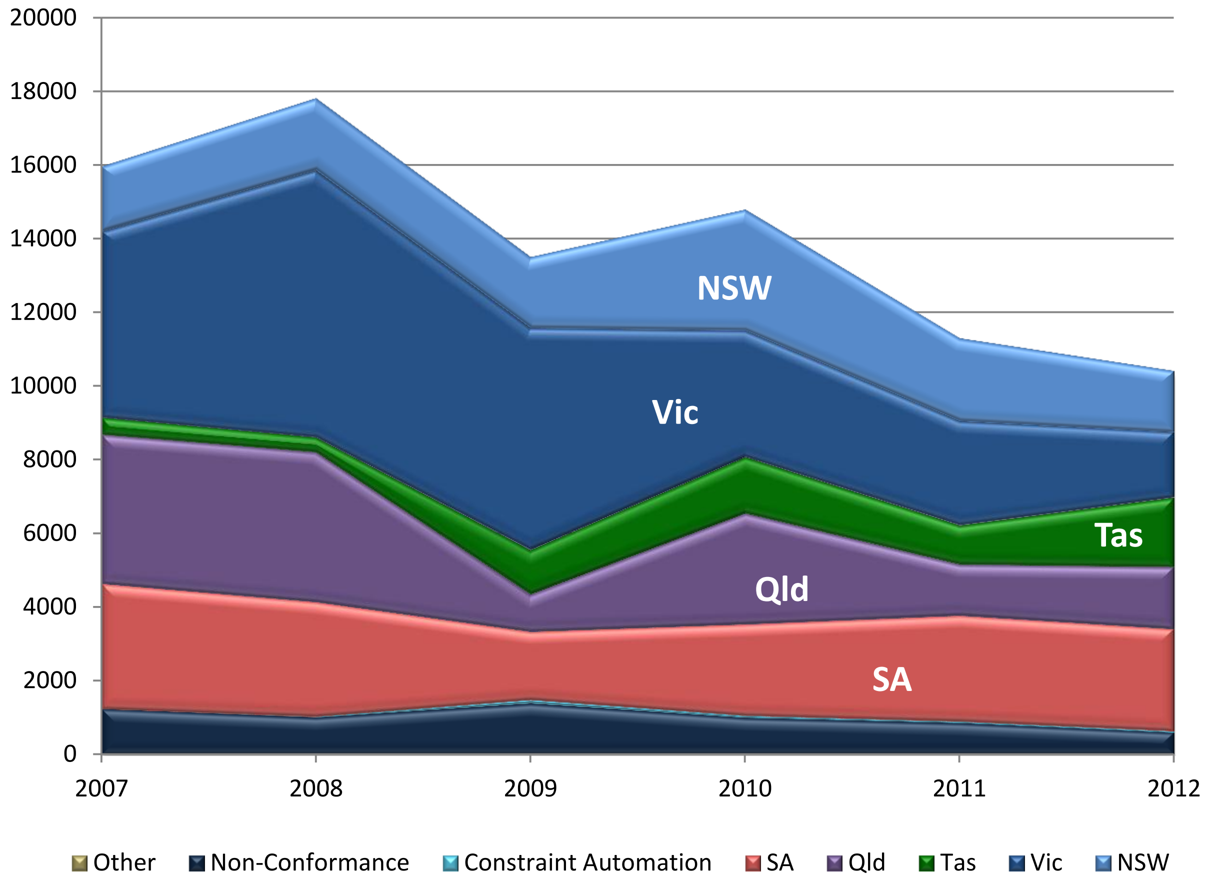

Figure 6: Binding constraint equations by region

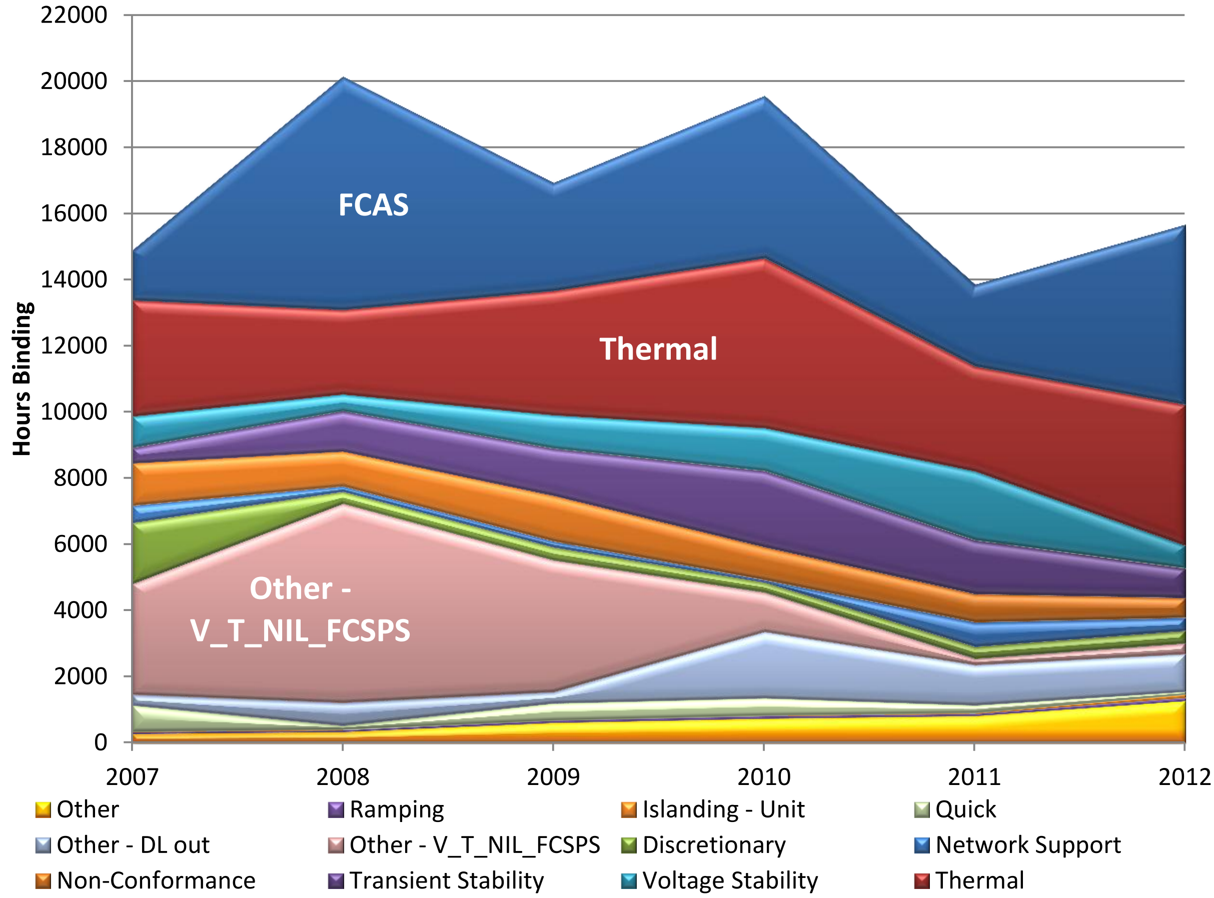

Figure 7: Binding constraint equations by limit type

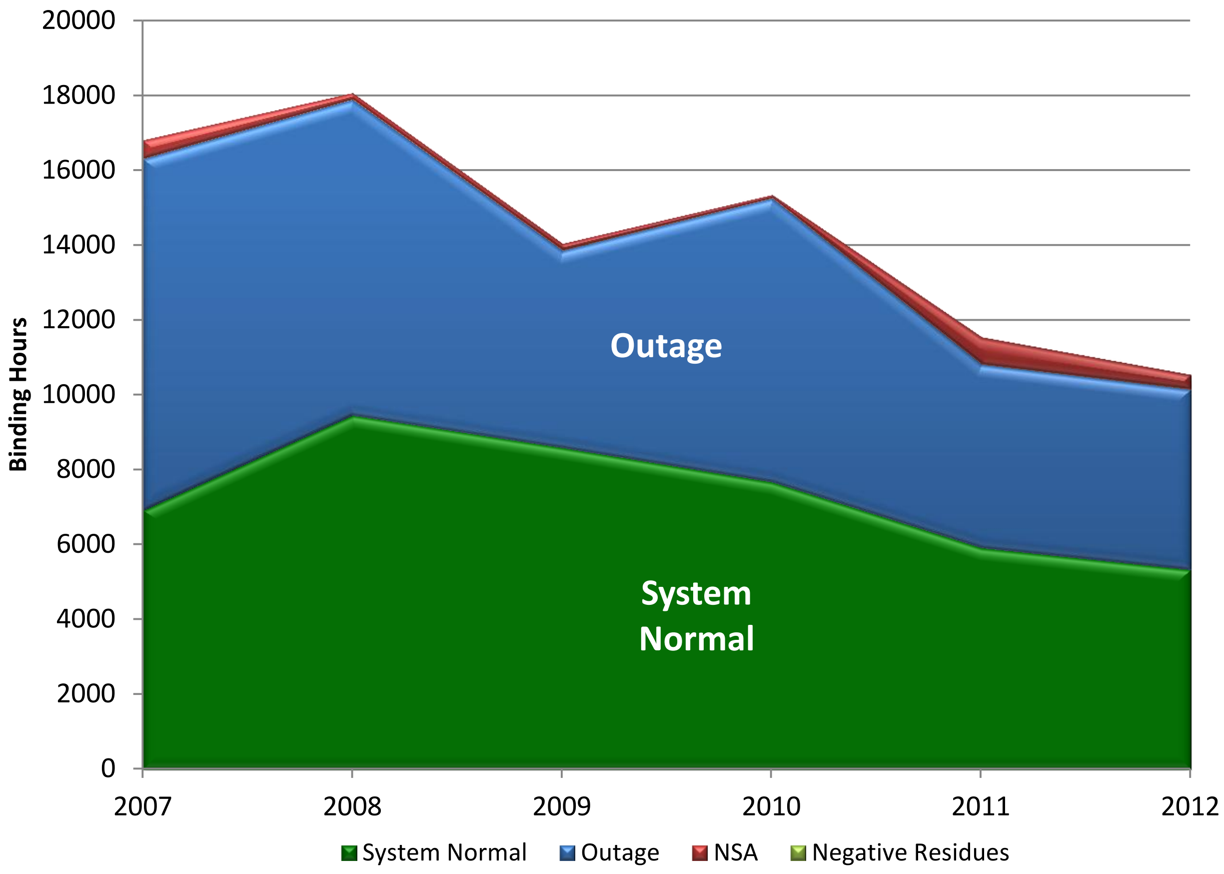

Figure 8: Binding hours for system normal and outages

5.2 Violating constraint equations

A constraint equation is violating when NEMDE is unable to dispatch the entities on the LHS so the summated LHS value is less than or greater than the RHS value (depending on the mathematical operator selected for the constraint equation).

Table 5: Top 20 violating constraint equations

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
V>SML_BUDP_2	5 (0)	*Out = Buronga to Balranald to Darlington Pt. (X5) 220 kV line, avoid overloading on Horsham to Waubra 220 kV line section on trip of Bendigo to Kerang 220 kV line* This constraint equation violated for 36 consecutive DI on 12/12/2012 and 15 consecutive DI on 13/12/2012 with a max violation of 105.62 MW. Violation was due to competing requirement on Murraylink which was set by S>V_NIL_NIL_RBNW. On 13/12/2012 a further unplanned outage of the Robertstown- North West Bend 132 kV transmission line occurred in the South Australia region and RTCA indicated post contingent overloads on the Waubra – Horsham 220 kV transmission line for a trip of the Bendigo – Kerang 220 kV transmission line. A power system incident report is being prepared on this issue.
NRM_VIC1_NSW1	4 (0)	*Negative Residue Management constraint equation for VIC to NSW flow* This constraint equation violated for 48 consecutive DI on 11/09/2012 with a max violation of 147.25 MW. VIC1-NSW1 was limited by its import limit which was set by V>>V-LTWG_RADIAL_2 constraint equation.

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
		V>>V-LTWG_RADIAL_2 belongs to N-LTWG_RADIAL constraint set which was invoked for planned outage of Lower Tumut to Wagga 330kV line. This constraint equation is part of the automated negative residue process which was implemented in July 2012[7].
NSA_V_BDL01_20	4 (2.1)	*Bairnsdale Unit 1 >= 20 MW for network support agreement* This constraint equation violated on a number of occasions in 2012 with a max violation of 20 MW. Bairnsdale unit 1 was limited by its fast start profile.
S>VML_NWCB6033_TX2	4 (0)	*Out = North West Bend CB6033, avoid overloading North West Bend #2 132/66 kV transformer on trip of North West Bend to Monash #2 132 kV line* This constraint equation violated for 10 consecutive DI on 21/09/2012 from 0815hrs and for 32 consecutive DI on 26/09/2012 from 1425 hrs. The violations were due to Murraylink limited by its export limit that was set by the either VSML_VFRB_OFF or VSML_000. VSML_VFRB_OFF was invoked for the unplanned outage of the Murraylink fast runback scheme on 21/09/2012 and VSML_000 was invoked due to the trip of Murraylink on 26/09/2012. The power system was assessed to be secure during both periods. Contingency plan for overload of North Bend transformer #2 was managed by the overcurrent protection on transformer.
NSA_Q_GSTONE34_400	3 (0)	*Gladstone 3 + 4 >= 400 for Network Support Agreement* This constraint equation violated for 40 DIs on multiple occasions in April with a max violation of 30.58 MW. The violation was due to the reduced availability of Gladstone unit 4 from 280 to150 MW. Gladstone unit 3 was limited by its ramp rate. This constraint equation was invoked for the planned outage of Wurdong - Boyne Island (866) 275 kV line.
F_T+NIL_MG_R6	3 (0.4)	*Tasmania raise 6 second requirement for a Tasmania generation event, Basslink unable to transfer FCAS* Constraint equation violated on a number of occasions in 2012 with a max violation of 27.08 MW in July. Violation was due to insufficient availability of R6 services in Tasmania.
S>SETX_SETX_SGKH	3 (7.6)	*Out = one South East 275/132 kV transformer, avoid overload on Snuggery to Keith 132 kV line on trip of the other South East 275/132 kV transformer* This constraint equation violated for 28 DIs on multiple occasions in December with a max violation of 67.45 MW on 04/12/2012 at 1035hrs. There were outage and contingency events in South East SA prior to this DI which required NEMDE to rapidly reduce generation in South East SA. NEMDE was unable to reduce generation in Southern SA fast enough to meet the requirement of the constraint.
Q>NIL_BI_FB	2 (0.5)	*Out = Nil, avoid overloading on Boyne Island feeder bushing on Gladstone to Boyne Island 132 kV lines, for the contingent loss of a single Gladstone to Boyne Island 132 kV line*

[7] http://www.aemo.com.au/Electricity/Market-Operations/Congestion-Information-Resource/~/media/Files/Other/Dispatch/Brief_on_Automation_of_Negative_Residue_Management.ashx

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
		This constraint equation violated for 28 DIs on multiple occasions in April, May and June with a max violation of 234.48 MW on 18/06/2012 at 1750 hrs. Gladstone unit 1, 2, 3 and 4 were limited by their ramp down rate.
F_T+NIL_MIG_R6	2 (0.3)	*Tasmania raise 6 second requirement for a Tasmania generation event (largest inertia), Basslink unable to transfer FCAS* This constraint equation violated on multiple occasions in 2012 and mostly in April. This was due to insufficient availability of R6 services in TAS.
NC_V_MORTLK12	2 (0.4)	*Non Conformance Constraint for Mortlake GT unit 2* This constraint equation violated on multiple occasions in May and June. Max violation of 3 MW occurred on 30/05/2012 at 1955 hrs. This was due to commissioning tests on Mortlake GT unit 2.
NSA_V_BDL02_20	2 (0.6)	*Bairnsdale Unit 2 >= 20 MW for network support agreement* This constraint equation violated on a number of occasions in 2012 with a max violation of 20 MW. Bairnsdale unit 2 was limited by its fast start profile.
S>S_SNTX3A	2 (0)	*Out = Snuggery #3 132/33 kV transformer, avoid overloading Snuggery #4 132/33 kV transformer on trip of Snuggery to Blanche 132 kV line* This constraint equation violated for 18 DI on 26/08/2012. Max violation of 24.19 MW occurred at 0900 hrs. This was due to the high wind generation of Lake Bonney unit 1. This unit is a non-scheduled wind farm and with a negative factor of one is on the right hand side of the equation.
NSA_Q_GSTONE34_350	2 (0)	*Gladstone 3 + 4 >= 350 for Network Support Agreement* This constraint equation violated on multiple occasions in April, May and July with a max violation of 17.85 MW on 28/04/2012 at 0210 hrs. This was due to the reduced availability of Gladstone unit 3 from 280 to140 MW. Gladstone unit 3 was limited by its ramp rate. This constraint equation was invoked for the planned outage of Wurdong - Boyne Island (866) 275 kV line
S>SE132CB_SETX_SGKH	1 (0.4)	*Out = South East CB6160 or CB6162, avoid overloading Snuggery to Keith 132 kV line on trip of a South East 275/132 kV transformer* This constraint equation violated on multiple occasions in April and June with a max violation of 17.43 MW on 18/06/2012 at 1410 hrs. Lake Bonney unit 2 and 3 were limited by their ramp down rate.
S>S_SNTX3B	1 (0)	*Out = Snuggery #3 132/33 kV transformer, avoid overloading Snuggery #2 132/33 kV transformer on trip of Snuggery to Blanche 132 kV line* This constraint equation violated for 13 DI on 26/08/2012 with a max violation of 29.11 MW at 0900 hrs. Violation reason is the same as for S>S_SNTX3A.
V>SML_BUDP_3	1 (0)	*Out = Buronga to Balranald to Darlington Pt. (X5) 220 kV line, avoid overloading on Kerang to Wemen 220 kV line section on trip of Ballarat to Waubra to Horsham 220 kV line* This constraint equation violated for 12 DI on 13/12/2012. Constraint equation violated for 11 consecutive DIs on 13/12/2012 from 1230hrs with a max violation of 80.29 MW at 1250hrs. The reason for this constraint

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
		equation violation is same as V>SML_BUDP_2.
V>SML_BUDP_1	1 (0)	*Out = Buronga to Balranald to Darlington Pt. (X5) 220 kV line, avoid overloading on Bendigo to Kerang 220 kV line on trip of Ballarat to Waubra to Horsham 220 kV line* This constraint equation violated for 10 consecutive DIs on 13/12/2012 from 1240hrs to 1325hrs with a max violation of 30.08 MW at 1250hrs. The reason for this constraint violation is same as V>SML_BUDP_2.
F_T+NIL_BL_R6_1	1 (0.3)	*Tasmania raise 6 second requirement for loss of Basslink, FCSPS available* This constraint equation violated on multiple occasions in July and December. The violation was due to Insufficient availability of R6 services in Tasmania.
T_TAMARCCGT_GCS	1 (0.5)	*Limit output of Tamar Valley Power Station based on load available for shedding by Tamar Valley 220 kV generation control scheme (GCS)* This constraint equation violated on a number of occasions in 2012. Max violation of 19.41 MW occurred on 10/04/2012 1205 hrs. Tamar Valley CCGT was limited by GCS load block availability.
F_T+LREG_0050	1 (1.8)	*Tasmania lower regulation requirement greater than 50 MW, Basslink unable to transfer FCAS* This constraint equation violated on a number of occasions in 2012. Max violation of 50 MW occurred on multiple occasions in September. Tasmania lower regulation was less than the requirement.

6 Market impact of constraint equations

Constraint equations can be compared using their market impact. The market impact is determined by summating the marginal values from the marginal constraint cost (MCC) re-run. This re-run removes any violating constraint equations as well as relaxing (slightly) any constraint equations with a marginal value equal to the constraint equation's CVP x market price cap (MPC) (for example 200000 or 3600000). For the purposes of the calculation the marginal value in each dispatch interval is capped at the MPC valid on that date (MPC was increased to \$12,900 on 1st July 2012).

Similar to the binding and violating constraint equations tables in the previous section Table 6 indicates system normal constraint equations in bold and the number of binding hours for 2011 is indicated in brackets below the 2012 hours. The 2011 summated marginal values are indicated in brackets below the 2012 hours.

The constraint equations NSA_Q_BARCALDN, NSA_Q_GSTONE34_xxx, NSA_V_BDL0xxx, S_PLN_ISL1, SPLN_ISL2 and S_PLN_ISL31 are all for the output of a one or two generators equal to or greater than or equal to the RHS. These are either for network support from a generator or an outage of the radial transmission line connecting to the unit. While it appears they have a large market impact, this is more due to the bidding of the individual generator.

Table 6: Top 20 market impact constraint equations in 2012

EQUATION ID (SYSTEM NORMAL IN BOLD)	∑MARGINAL VALUES	HOURS (2011)	*DESCRIPTION* / NOTES
NSA_Q_GSTONE34_xxx	\$11,981,412 (\$2,962,336)	366.3 (693.8)	*Gladstone 3 + 4 >= various levels for Network Support Agreement*

EQUATION ID (SYSTEM NORMAL IN BOLD)	∑MARGINAL VALUES	HOURS (2011)	*DESCRIPTION* / NOTES
			See Table 3 for comments
Q_BARCALDN_ISL	$2,878,964 (0)	26.9 (0)	*Out = Lilyvale to Clermont or Clermont to Barcaldine 132 kV line, Barcaldine PS islanded* *This constraint equation was removed in earl 2013.*
NSA_Q_BARCALDN	$1,436,430 ($3,677,819)	17.7 (25.3)	*Network Support Agreement for Barcaldine GT to meet local islanded demand at Clermont and Barcaldine for the outage of Clermont to Lilyvale (7153) 132 kV line* *This constraint equation is used for planned outages of the Clermont to Lilyvale (7153) or Barcaldine to Clermont (7154) 132 kV lines*
Q>>NIL_855_871	$1,431,065 ($74,016)	278.6 (216.7)	*Out = Nil, avoid overload on Calvale to Wurdong (871) 275 kV line on trip of Calvale to Stanwell (855) 275 kV line* See Table 3 for comments
S_PLN_ISL1	$1,361,364 (0)	9.3 (0)	*Out = Whyalla to Yadnarie 132 kV line, Port Lincoln units 1 and 2 islanded* The Whyalla to Yadnarie 132 kV line was out for 0.9 days in 2012 compared to 0.1 days in 2011
Q<QBCG_02	$1,289,255 ($2,427,766)	8.8 (20.4)	*Out = Barcaldine to Clermont (7154) 132 kV line, Barcaldine power station islanded* *This constraint equation was relabelled in early 2012 and replaced by Q_BARCALDN_ISL.*
S_PLN_ISL2	$1,178,809 ($156,568)	21.4 (3.4)	*Out = Yadnarie to Port Lincoln 132 kV line, Port Lincoln units 1 and 2 islanded* The Port Lincoln to Yadnarie 132 kV line was out for 0.4 days in 2012 compared to zero days in 2011
Q>>NIL_871_855	$895,184 ($20,711)	99.8 (35.5)	*Out = Nil, avoid overload on Calvale to Stanwell (855) 275 kV line on trip of Calvale to Wurdong (871) 275 kV line* This constraint equation is expected to bind for a similar amount in 2013 until Powerlink constructs double circuit 275kV lines between Calvale and Stanwell in late 2013
S_PLN_ISL31	$451,567 (0)	8.1 (0)	*Out = Whyalla to Yadnarie 132 kV line, Port Lincoln unit #3 islanded* The Whyalla to Yadnarie 132 kV line was out for 0.9 days in 2012 compared to 0.1 days in 2011
S_HALWF_0	$385,130 ($68,905)	31.3 (5.4)	*Discretionary upper limit for Hallett wind farm generation of 0 MW*
Q>NIL_TR_TX1_4	$312,478 ($61,446)	25.8 (47.9)	*Out = Nil, avoid overloading a Tarong 275/132 kV transformer (#1 or #4) on trip of the other Tarong 275/132 kV transformer (#1 or #4)* This constraint equation binds at times of high Roma and Condamine generation.
S_LB3_0	$244,861	83.5	*Discretionary upper limit for Lake Bonney 3 generation of 0*

EQUATION ID (SYSTEM NORMAL IN BOLD)	∑MARGINAL VALUES	HOURS (2011)	*DESCRIPTION* / NOTES
	($128,661)	(17.7)	*MW*
T_TAMARCCGT_GCS	$214,829 ($149,210)	911.3 (646.8)	*Limit output of Tamar Valley Power Station based on load available for shedding by Tamar Valley 220 kV generation control scheme (GCS)* See Table 3 for comments
V>>V_NIL_1B	$199,598 ($36,520)	7.3 (29.6)	*Out = Nil, avoid overloading Dederang to Murray #2 330 kV line for trip of the Dederang to Murray #1 330 kV line* This constraint equation binds for high transfers from NSW to Victoria with the DBUSS (Dederang bus splitting scheme) active.
NSA_V_BDL0xxx	$186,792 ($811,280)	1.3 (6.3)	*Bairnsdale Unit 1 or 2 >= various levels for Network Support Agreement* The binding results from 2 constraint equations that set the minimum level of Bairnsdale 1 or 2 generation have been combined.
V>V_HWTS_TX3_3-5_MOD	$184,356 ($71,137)	15.8 (6.0)	*Out = Hazelwood #3 or #4 500/220 kV transformer, 3-5 Parallel, Jeeralang split with JLGS A connected to Hazelwood #3 or #4 220 kV bus, avoid overloading Rowville to Yallourn #5, #6, #7or #8 220 kV lines for loss of Hazelwood #4 or #3 500/220 kV transformer* A Hazelwood A3 or A4 transformer was out for 2.5 days in 2012 compared to 1.2 days in 2011.
S_PF_4_UNITS	$179,452 ($76,113)	14.6 (6.2)	*Out = 4 Playford generators, upper limit on Playford generation of 0MW*
@OSBTOA_3	$168,458 (0)	44.8 (0)	*Control room quick constraint equation to avoid overloading New Osborne to Torrens Island #3 66 kV line on trip of Parafield Gardens West #1 275/66 kV transformer*
S>>V_NIL_RBTXW_RBTX1	$158,347 ($17,083)	48.3 (123.7)	*Out = Nil, avoid overloading Robertstown #1 275/132 kV transformer on trip of the Robertstown #2 275/132 kV transformer* This constraint equation normally binds when there is high generation from Northern, Hallett GT and the wind farms connected to the 275 kV between Robertstown and Davenport.
S>>V_NIL_SETX_SETX	$156,867 ($76,861)	444.1 (206.5)	*Out = Nil, avoid overloading a South East 275/132 kV transformer on trip of the remaining South East 275/132 kV transformer* See Table 3 for comments

6.1 Market impact trends

In this section the trends on market impact are examined. As the MCC data is only available from July 2008 onwards only the calendar years after 2009 are examined. The trend over the past 4 years is the market impact for system normal and outages is reducing and the market impact due to network support agreements are increasing (see Figure 11).

From 2009 to 2011, with the exception of Queensland, the trend was each region had a reduction in their market impact (see Figure 9). In 2012 there was a significant increase in South Australian and Queensland market impact. The market impact increase in Queensland can be attributed to the high market impact of network support constraint equations and the thermal constraint equations for the 855 and 871 lines (see Table 6 and Figure 10). The increase in South Australia is due to the network support for outages of the Port Lincoln to Yadnarie or Yadnarie to Whyalla 132 kV lines.

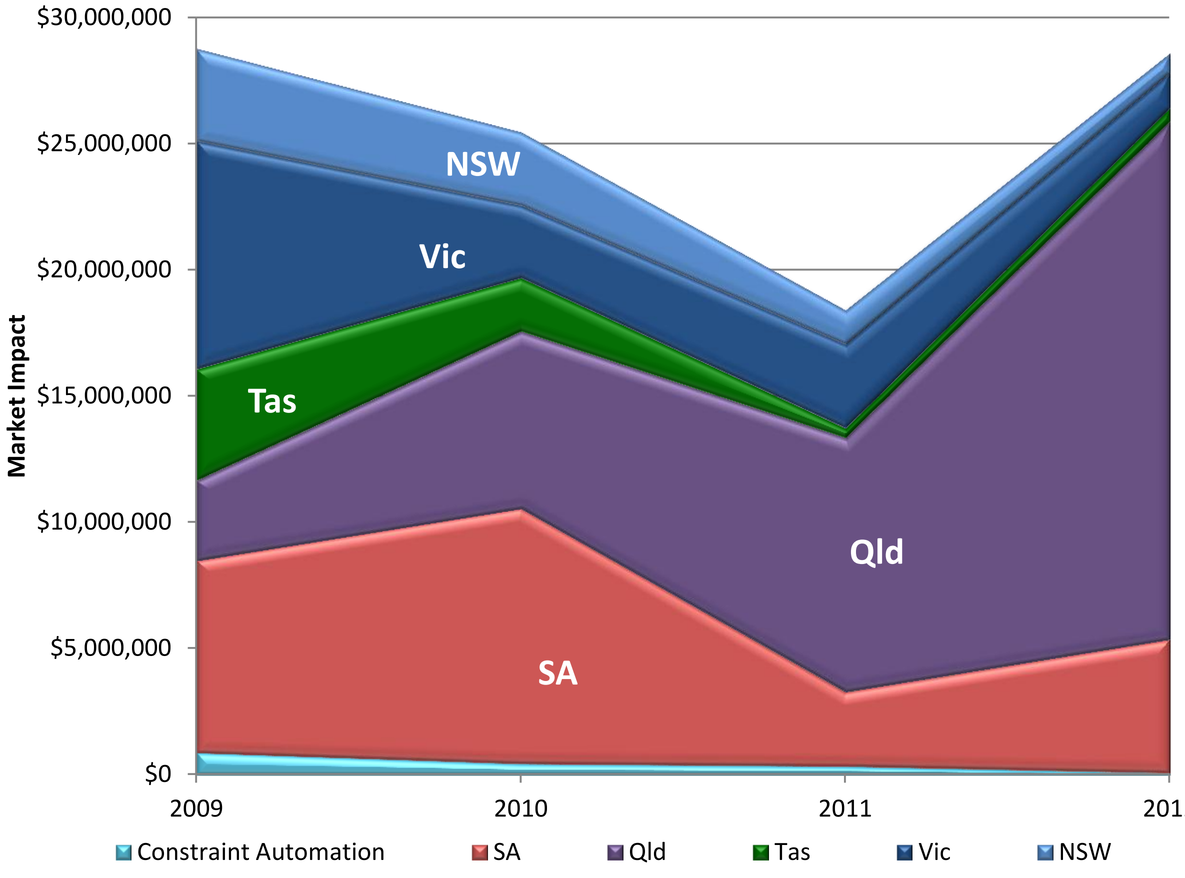

Figure 9: Market impact by region

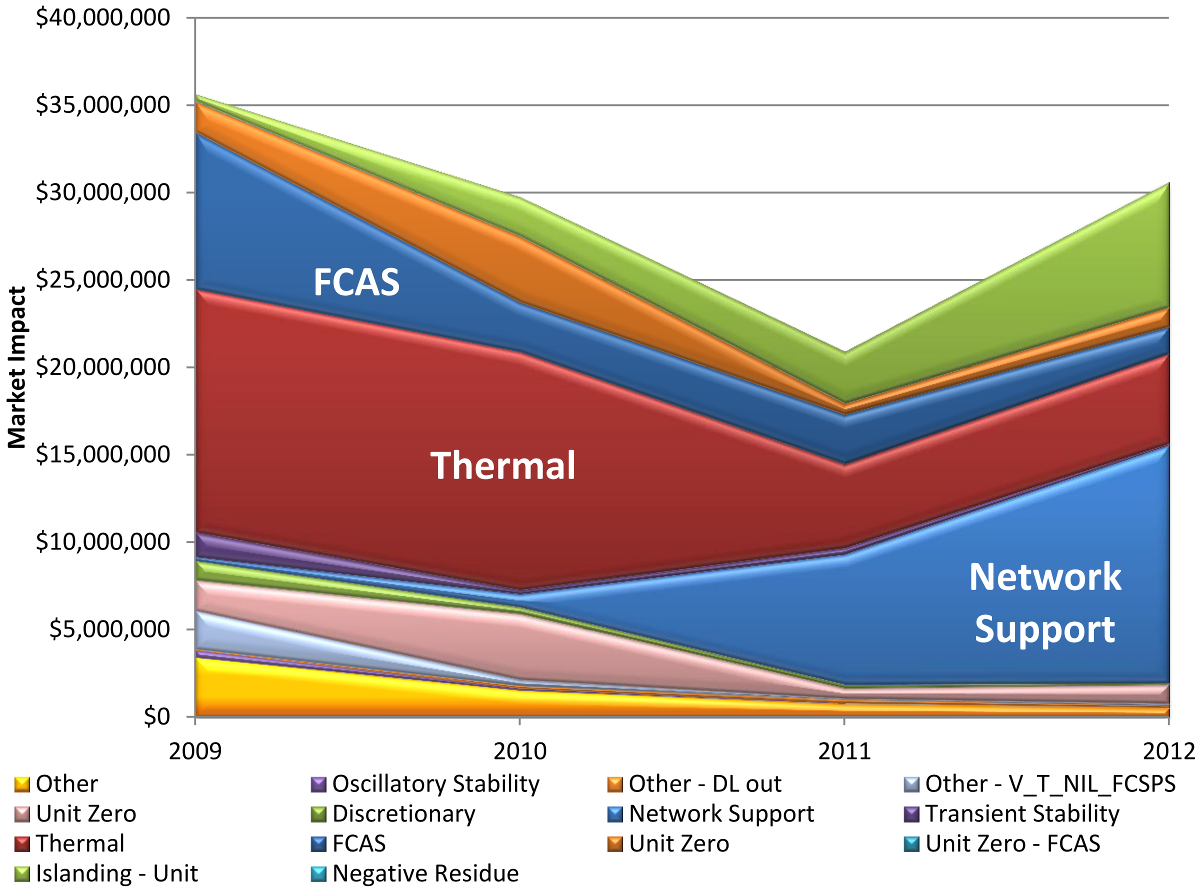

Figure 10: Market impact by constraint equation limit type

Comparing the market impact by the limit type of the constraint equation (see Figure 10) again shows an overall decrease in market impact with the exception of network support and islanding constraint equations. Contrast this with the binding hours per limit type (Figure 7) where FCAS binds for a large number of hours and network support has a low number of binding hours.

Note the FCAS in Figure 10 includes the impact due to system normal FCAS constraint equations whereas this is excluded from Figure 7.

The market impact of outages to system normal is compared in Figure 11 and this graph indicates that while the impact of outages has increased since 2009 the impact due to system normal constraint equations has decreased at a greater rate. This reduction in market impact of system normal constraint equations has led to the overall reduction in market impact since 2009. There has been (since 2009) a slight reduction in binding system normal hours (see Figure 8), however, there has been a fall in the number of hours of outage binding hours. The outage binding hours have been below the system normal hours since 2008. The market impact due to network support agreement constraint equations has increased significantly in 2011 and 2012.

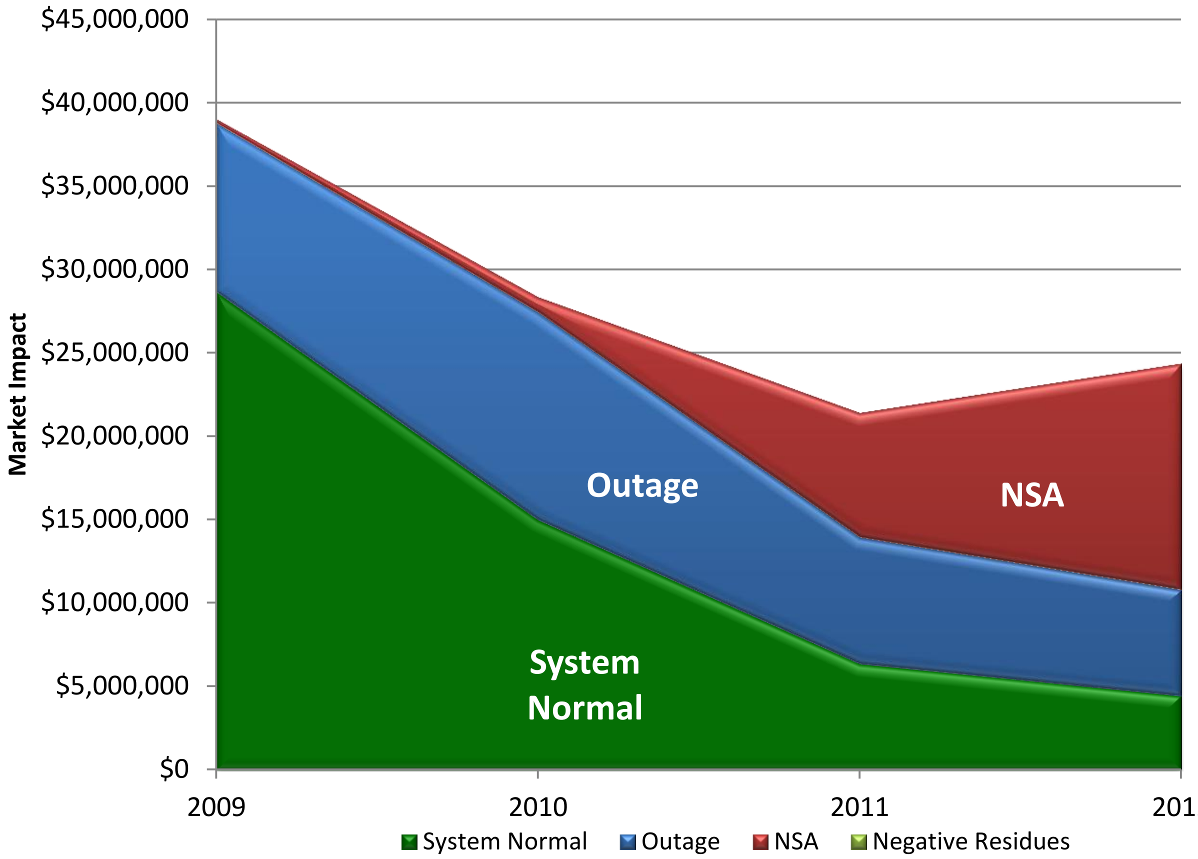

Figure 11: Market impact for system normal and outages

7 Constraint equations setting interconnector limits

Constraint equations with an interconnector on the LHS can set the reported limits on the interconnector. This section examines each of the interconnectors in the NEM and the binding constraint equations that most often set the interconnector limits. For each interconnector there is a graph of the monthly binding hours, a histogram of the flows at which constraint equations bound and tables of the top 10 binding interconnector limit setters in each direction.

As only one constraint equation can be reported as setting the import or export limit for an interconnector at a particular time, the binding hours will differ from section 5 when two (or more) constraint equations could set the limit. In these cases when calculating the interconnector limit AEMO's market systems software selects a constraint equation based on the following priority order:

1) Single interconnector on the LHS
2) Multiple interconnectors and generators (energy) on the LHS
3) Multiple interconnectors, FCAS requirements and generators (FCAS) on the LHS

The monthly graphs in this section show the binding hours per month for each direction on each interconnector. The results exclude the outage ramping constraint equations. The export binding hours are indicated as positive numbers and import with negative values. Each month is further categorized into 5 types:

- System normal
- Outage
- FCAS: This includes all constraint equations that start with "F" even those which are in the FCAS system normal set

- Constraint automation: All the constraint equations created by the constraint automation application
- Quick: constraint equations created by AEMO's control room staff. These all start with "#" and exclude the outage ramping constraint equations.

The histograms in this section show the flows for the top 5 (for each direction of flow) binding interconnector limit setting constraint equations. The remaining binding interconnector limit setting constraint equations are summated as “Other”. For comparison the summated binding hours for the previous year is included on the primary axis and on the secondary axis is the number of hours the interconnector target was at each flow level (binding or not binding) for the current and past calendar year.

Note that in cases where the constraint equations setting the import and export limits on an interconnector are both binding, then both constraint equations are counted in the results.

7.1 Terranora interconnector (N-Q-MNSP1)

The Terranora interconnector comprises the two 110 kV lines from Terranora in NSW to Mudgeeraba in Queensland. However, the controllable element is a 180 MW DC link between Terranora and Mullumbimby known as Directlink, which consists of 3 separate DC lines. The DC lines were commissioned in 2000 forming the first connection between NSW and Queensland. Normally flows on this interconnector are towards NSW and so both the import and export values are negative (unlike the other interconnectors in the NEM). It is usually constrained by thermal limits in northern NSW or rate of change on Directlink. However, it often appears on the LHS of constraint equations with the Queensland to NSW interconnector so both may be constrained at the same time.

In 2012 the majority of the flow on Terranora was restricted by the system normal constraints to avoid voltage collapse on loss of the largest Queensland generator or to avoid overloading on Lismore to Dunoon 132 kV line (9U6 or 9U7) on trip of the other Lismore to Dunoon 132 kV line (9U7 or 9U6) (see Figure 13).

The hours at each flow level on Terranora were similar in 2011 and 2012 and the binding hours are similar except there were more binding hours for flows from -100 to -60 MWs in 2011 (see Figure 13).

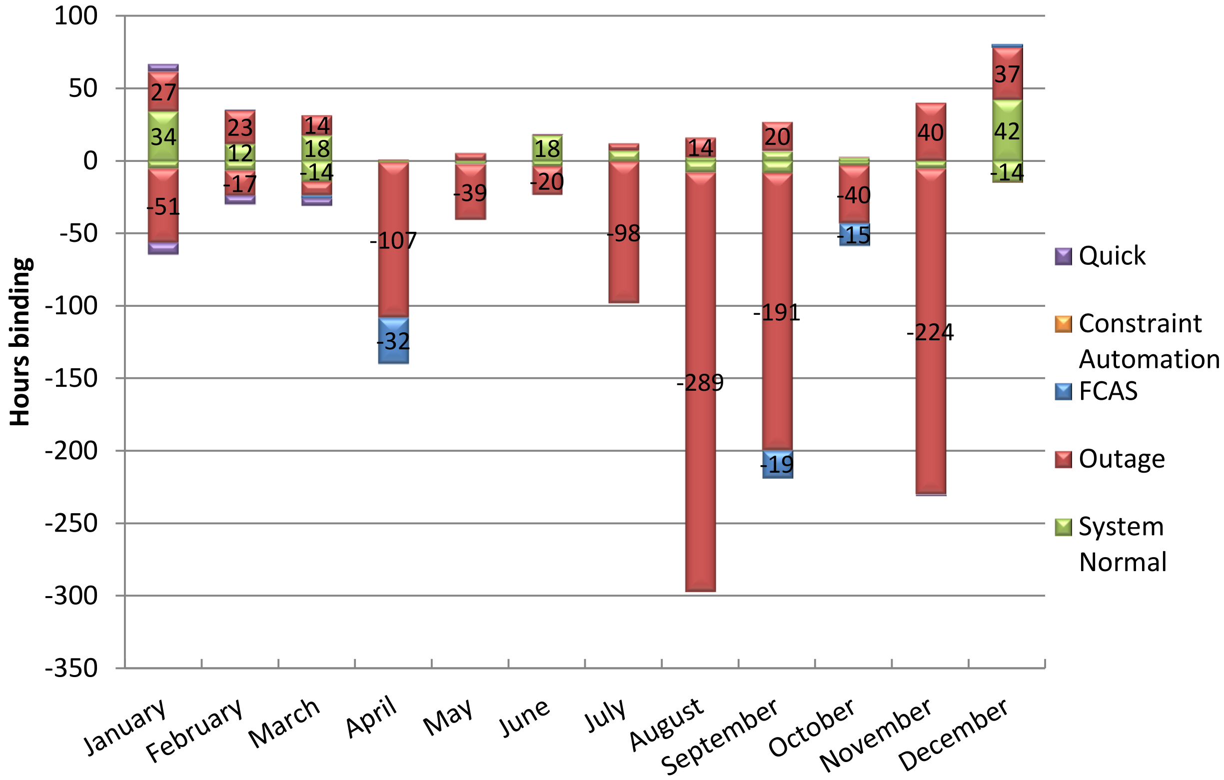

Figure 12: Categorized binding intervals per month for N-Q-MNSP1

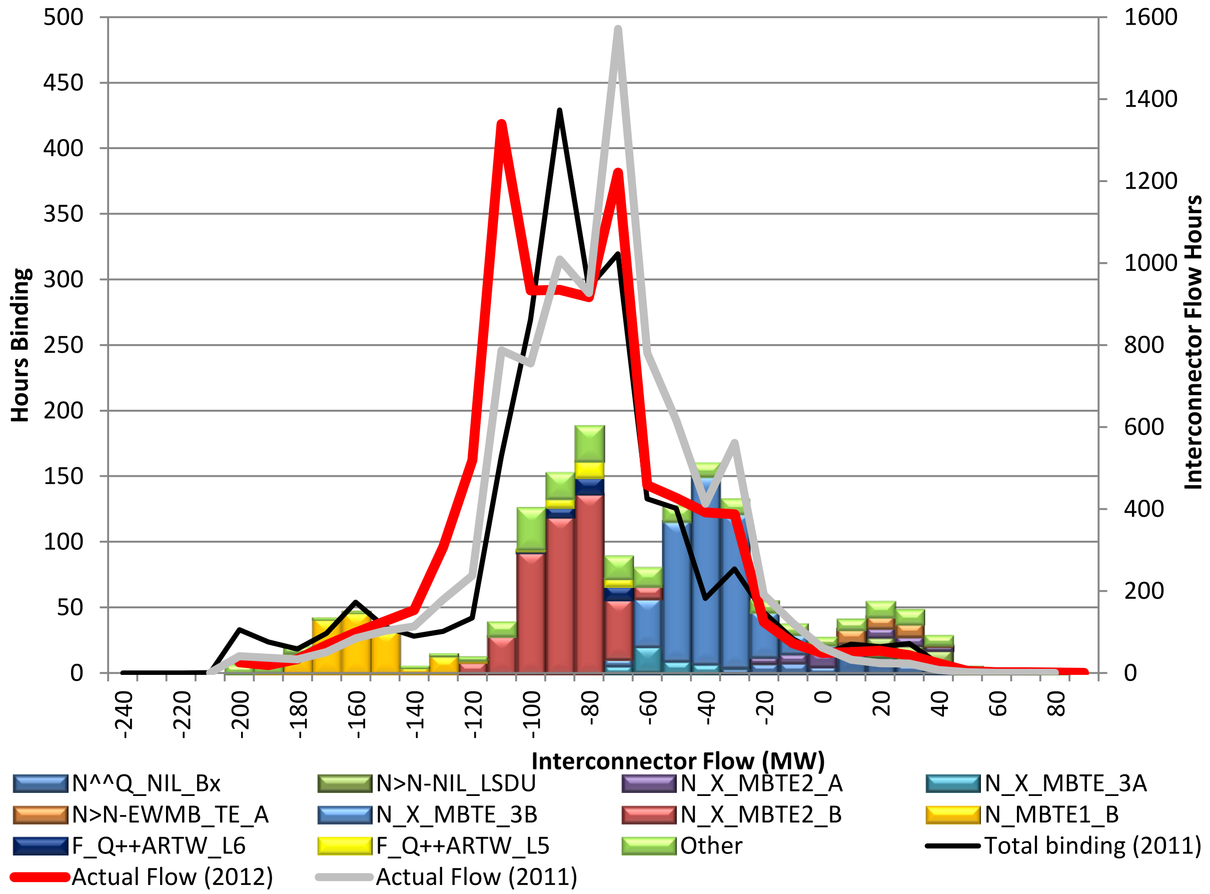

Figure 13: Binding constraint equation distribution for N-Q-MNSP1

Table 7: Binding constraint equations setting the NSW to Qld limit on N-Q-MNSP1

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
N^^Q_NIL_B1, 2, 3, 4, 5, 6 & N^Q_NIL_B	66.9 (51.8)	*Out = Nil, avoid voltage collapse for loss of the largest Queensland generator* This voltage collapse limit is split into 7 constraint equations to co-optimise with each of the 6 largest generators in Queensland. Overall N^^Q_NIL_B1 (for trip of Kogan Creek) binds for the most number of intervals.
N>N-NIL_LSDU	53.9 (22.8)	*Out = Nil, avoid overloading Lismore to Dunoon line (9U6 or 9U7) 132 kV line on trip of the other Lismore to Dunoon line (9U7 or 9U6) 132 kV line* This constraint equation only binds when all three Directlink cables are in service.
N_X_MBTE2_A	43.2 (25.7)	*Out = two Directlink cables, NSW to Queensland limit* See Table 3 for comments
N_X_MBTE_3A	42.3 (104.3)	*Out = all three Directlink cables, NSW to Queensland limit* See Table 3 for comments
N>N-EWMB_TE_A	32.3 (0.7)	*Out = Ballina to Lennox Head 66 kV line, avoid overloading Lismore to Dunoon 132 kV line on trip of the other Lismore to Dunoon 132 kV line* One of the Ballina to Lennox Head to Ewingsdale to Mullumbimby 66 kV lines (8504, 8505 or 8508) or Mullumbimby 132/66 kV transformer was out for 58.3 days in 2012 compared to 0 days in 2011 - see Table 19
NQTE_ROC	25.0 (13.0)	*Out = Nil, rate of change (NSW to Queensland) limit (80 MW / 5 minute) for Terranora interconnector*
N^N_KKLS_1	18.0 (101.8)	*Out = Koolkhan to Lismore (967) 132 kV line, avoid voltage collapse on trip of Coffs Harbour to Lismore (89) 330 kV line* Tripping of 89 line only leaves Lismore connected by the Tenterfield to Lismore (96L) 132 kV line. 96L is the weaker of the 2 lines into Lismore and support is usually required from Terranora interconnector. It is expected that this constraint equation will continue bind for a reasonable portion of any future outage times. The Koolkhan to Lismore (967) 132 kV line was out for 9.1 days in 2012 compared to 21.9 days in 2011 - see Table 19
NC_Q_DLNKQLD	12.4 (0)	*Non Conformance Constraint for Terranora from QLD to NSW*
N>Q_LSLS_9U8	8.9 (0.4)	*Out = one Lismore 330 to Lismore 132 lines (9U8 or 9U9 or 9W1) 132 kV lines, avoid overloading on one Lismore 330 to Lismore 132 line on loss of the remaining line* One of the Lismore 330 to Lismore 132 (9U8 or 9U9 or 9W1) 132 kV lines was out for 4.3 days in 2012 compared to 0 days in 2011 - see Table 19
N^^Q_ARDM_B1	6.5 (0)	*Out = one Armidale to Dumaresq 330 kV line, avoid voltage collapse on loss of Kogan Creek* One Armidale to Dumaresq (8C or 8E) line was out for 0.8 days in 2012 compared to 0.2 days in 2011 - see Table 19

Table 8: Binding constraint equations setting the Qld to NSW limit on N-Q-MNSP1

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
N_X_MBTE_3B	460.8 (244.9)	*Out = all three Directlink cables, Queensland to NSW limit* See Table 3 for comments
N_X_MBTE2_B	439.8 (770.9)	*Out = two Directlink cables, Queensland to NSW limit* See Table 3 for comments
N_MBTE1_B	157.8 (73.8)	*Out = one Directlink cable, Queensland to NSW limit* See Table 3 for comments
F_Q++ARTW_L6	31.1 (205.6)	*Out = Armidale to Tamworth (85 or 86) 330 kV line, Queensland lower 6 second requirement* One of the Armidale to Tamworth (85 or 86) 330 kV lines was out for 2.7 days in 2012 compared to 24.3 days in 2011 - see Table 19
F_Q++ARTW_L5	26.3 (35.3)	*Out = Armidale to Tamworth (85 or 86) 330 kV line, Queensland lower 5 minute requirement* See comment for F_Q++ARTW_L6
Q>NIL_MUTE_757 & Q>NIL_MUTE_758	18.8 (18.6)	*Out = Nil, avoid overloading a Mudgeeraba to Terranora (757 or 758) 110 kV line on no contingencies* These constraint equations are dependent on the Terranora load as well as all 3 cables of Directlink being in service. In May 2011 the constraint equation Q>NIL_757+758_B was replaced with two constraint equations Q>NIL_MUTE_757 and Q>NIL_MUTE_758. The binding results for each have been combined.
QNTE_ROC	18.3 (9.2)	*Out = Nil, Rate of Change (Qld to NSW) constraint (80 MW / 5 Min) for Terranora Interconnector*
NRM_QLD1_NSW1	16.6 (0)	*Negative Residue Management constraint equation for QLD to NSW flow* This constraint equation is part of the automated negative residue process which was implemented in July 2012[8].
N>N-NIL_MBDU	14.9 (84.7)	*Out = Nil, avoid overloading Mullumbimby to Dunoon (9U6 or 9U7) 132 kV line on trip of the other Mullumbimby to Dunoon (9U7 or 9U6) 132 kV line* This constraint equation only binds when all three Directlink cables are in service.
N>N_LSDU_9U6_2	11.0 (0)	*Out = one of Lismore to Dunoon (9U6 or 9U7) 132 kV line, avoid overloading on the Mullumbimby 132/66 kV transformer on trip of the remaining Lismore to Dunoon (9U6 or 9U7) 132 kV line* The Lismore to Dunoon 132 kV line was out for 1.8 days in 2012 compared to 0 days in 2011 - see Table 19

[8] http://www.aemo.com.au/Electricity/Market-Operations/Congestion-Information-Resource/~/media/Files/Other/Dispatch/Brief_on_Automation_of_Negative_Residue_Management.ashx

7.2 Queensland to NSW Interconnector (NSW1-QLD1)

The Queensland to NSW (QNI) interconnector is the AC interconnection between Dumaresq in NSW and Bulli Creek in Queensland. It was commissioned in 2001 as a pair of 330 kV lines between Armidale and Braemar and a pair of 275 kV lines between Braemar and Tarong. The flow is normally from Queensland into NSW. However, at times of high generation in NSW or low generation in Queensland the flow can reverse and go from NSW to Queensland. Due to their close electrical proximity on the NSW side, both QNI and Terranora often appear on the LHS of constraint equations.

Transfer from NSW to Queensland is mainly limited by the system normal constraint equations for thermal limits on Calvale to Wurdong (871) line in Queensland or the voltage collapse on loss of the largest Queensland unit (this is dependent on Kogan Creek generation). Transfer from Queensland to NSW is mainly limited by the transient stability limits for fault on a Hazelwood to South Morang line or Bulli Creek to Dumaresq line.

In 2012 the flow was normally from Queensland to NSW, the majority of the time flows were between 450 and 750 MW into NSW. Flows between 1000 and 1050 MW were the most constrained (see Figure 15).

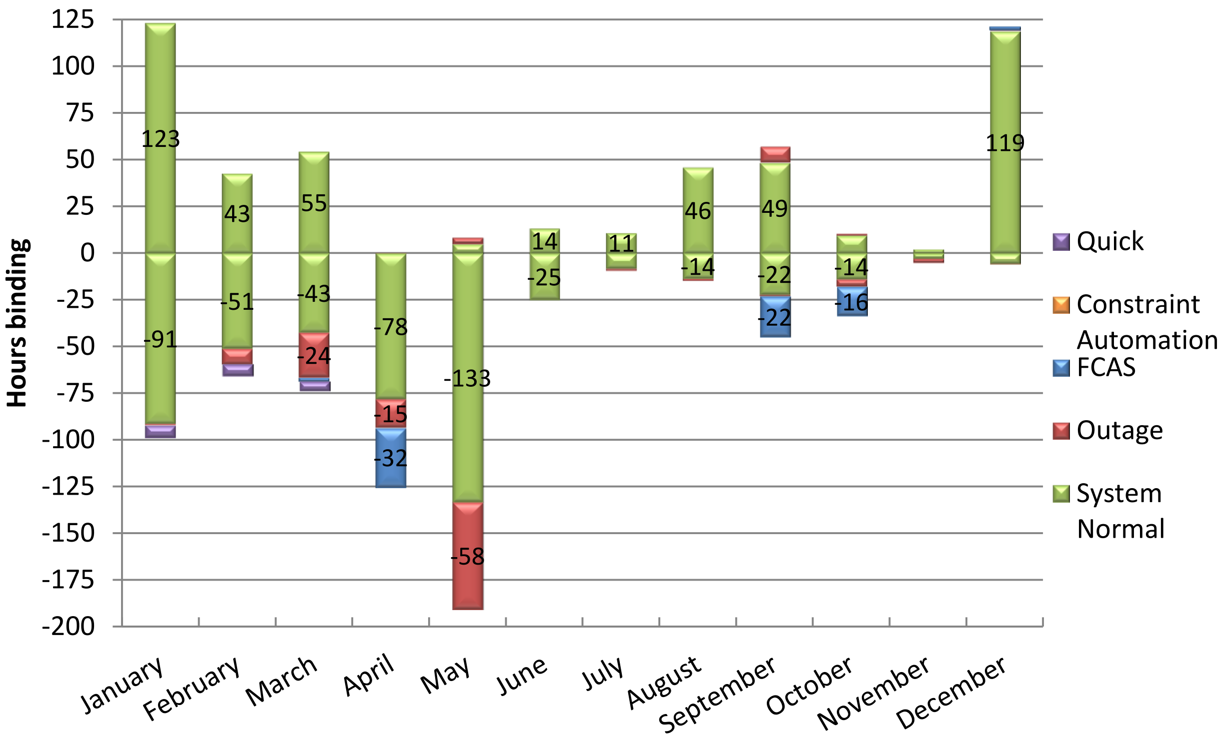

Figure 14: Categorized binding intervals per month for NSW1-QLD1

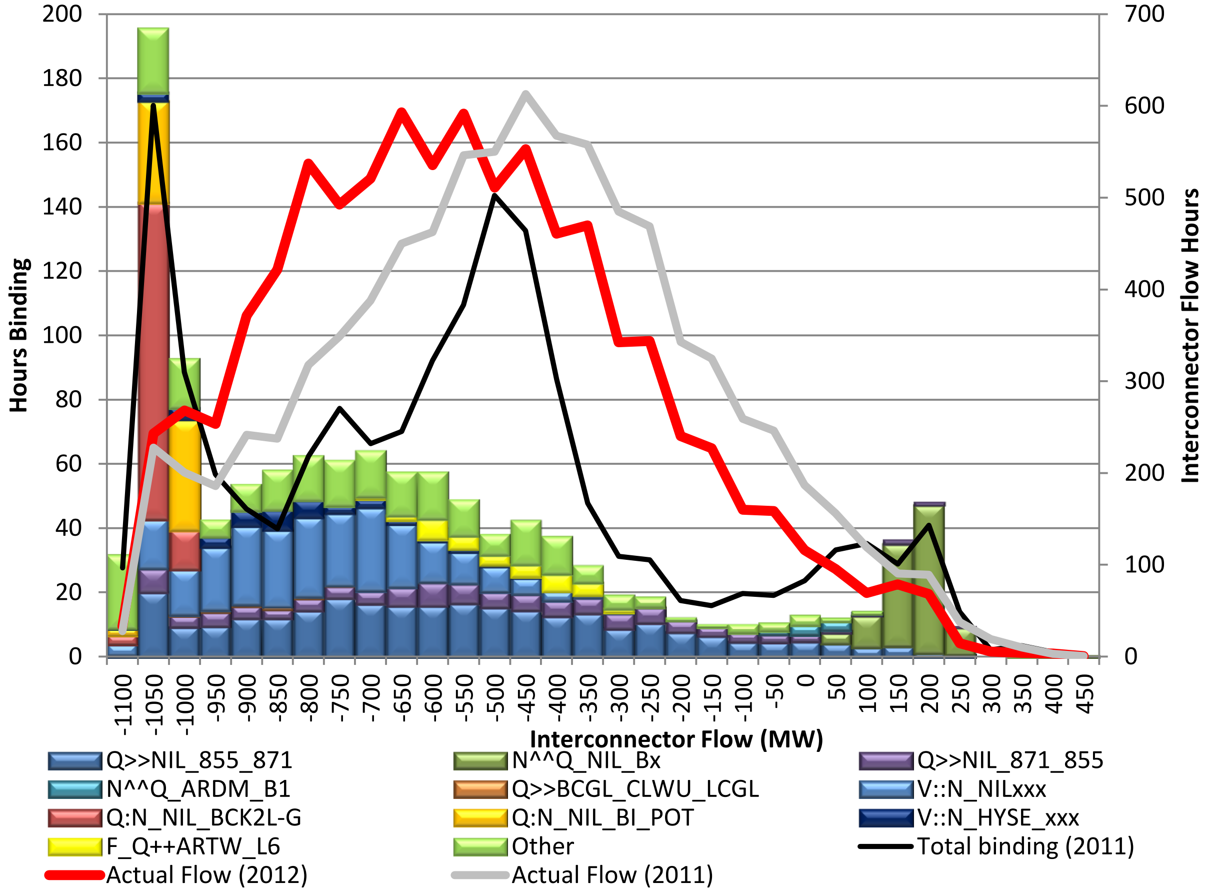

Figure 15: Binding constraint equation distribution for NSW1-QLD1

Table 9: Binding constraint equations setting the NSW to Qld limit on NSW1-QLD1

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
Q>>NIL_855_871	276.2 (215.6)	*Out = Nil, avoid overload on Calvale to Wurdong (871) 275 kV line on trip of Calvale to Stanwell (855) 275 kV line* See Table 3 for comments
N^^Q_NIL_B1, 2, 3, 4, 5, 6 & N^Q_NIL_B	99.5 (80.3)	*Out = Nil, avoid voltage collapse for loss of the largest Queensland generator* See Table 7 for comments
Q>>NIL_871_855	98.3 (35.3)	*Out = Nil, avoid overload on Calvale to Stanwell (855) 275 kV line on trip of Calvale to Wurdong (871) 275 kV line* See Table 6 for comments
N^^Q_ARDM_B1	7.3 (0)	*Out = one Armidale to Dumaresq 330 kV line, avoid voltage collapse on loss of Kogan Creek* See Table 7 for comments
Q>>BCGL_CLWU_LCGL	2.4 (0)	*Out = Bouldercombe to Gladstone (812) 275 kV line , avoid overloading Larcom Creek to Gladstone (8859) 275 kV line on trip of Calvale to Wurdong (871) 275 kV line* The Bouldercombe to Gladstone (812) 275 kV line was out for 20.5 days in 2012 compared to 0 days in 2011 - see Table 19

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
Q>>NIL_MRTX5_MRTX4	1.5 (0.7)	*Out = Nil, avoid overloading Middle Ridge #4 330/275 kV transformer on trip of Middle Ridge #5 330/275 kV transformer*
F_Q++LDTW_R6	1.3 (0)	*Out = Liddell to Tamworth (84) 330 kV line, Queensland raise 6 second requirement* The Liddell to Tamworth (84) 330 kV line was out for 0.5 days in 2012 compared to 0.5 days in 2011 - see Table 19
N>N-NIL__4_15M	1.2 (0)	*Out = Nil, avoid overloading Muswellbrook to Tamworth (88) 330 kV line on trip of Liddell to Tamworth (84) 330 kV line*
N:Q_LDTW_1	0.9 (0)	*Out = Liddell to Tamworth (84) 330 kV line, avoid transient instability for loss of the largest Queensland generator* The Liddell to Tamworth (84) 330 kV line was out for 0.5 days in 2012 compared to 0.5 days in 2011 - see Table 19
#R007434_002_RAMP_F	0.8 (0)	*Hard Ramping constraint for constraint N^^Q_ARDM_B1* Invoked for an outage on 12 September 2012

Table 10: Binding constraint equations setting the Qld to NSW limit on NSW1-QLD1

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
V::N_NILxxx	234.0 (501.0)	*Out = Nil, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 3 for comments
Q:N_NIL_BCK2L-G	113.5 (37.5)	*Out = Nil, avoid transient instability for a 2 phase to ground fault on a Bulli Creek to Dumaresq 330 kV line at Bulli Creek* See Table 3 for comments
Q:N_NIL_BI_POT	68.0 (87.3)	*Out = Nil, avoid transient instability for a trip of a Boyne Island potline (400 MW)* Prior to 14 May 2012 for high flows from Queensland to NSW either this constraint equation or Q:N_NIL_OSC or Q:N_NIL_BCK2L-G will bind. However, this constraint equation has not bound since it was revised on 14 May 2012. Also see note on Q:N_NIL_BCK2L-G in Table 3.
V::N_HYSE_xxx	33.5 (7.8)	*Out = Heywood to South East 275 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* One Heywood to South East 275 kV line was out for 34.1 days in 2012 compared to 4.0 days in 2011 - see Table 19
F_Q++ARTW_L6	31.2 (218.9)	*Out = Armidale to Tamworth (85 or 86) 330 kV line, Queensland lower 6 second requirement* See Table 8 for comments
Q_N_NIL-1078	30.4 (23.5)	*Out = Nil, reduce QNI when it is over the 1078 MW limit by 1078 minus the MW over the 1078 MW limit (capped at 1000 MW)* This constraint equation only operates when the NSW1-QLD1 interconnector flow is greater than 1103 MW from Queensland to NSW. It ensures that the interconnector flow does not excessively exceed the

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
		1078 MW limit as a thermal overload limit exists at 1105 MW.
F_Q++ARTW_L5	26.3 (41.4)	*Out = Armidale to Tamworth (85 or 86) 330 kV line, Queensland lower 5 minute requirement* See Table 8 for comments
Q:N_NIL_OSC	22.7 (16.3)	*Out = Nil, Queensland to NSW oscillatory stability limit* This constraint equation sets the upper limit from Queensland to NSW to 1078 MW.
NRM_QLD1_NSW1	19.4 (0)	*Negative Residue Management constraint equation for QLD to NSW flow* See Table 8 for comments
V::N_DDMS_xxx	11.7 (23.7)	*Out = Dederang to Murray 330 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* There are 12 constraint equations that make up the transient stability export limit from Victoria for this outage and all the binding results have been combined. One of the Dederang to Murray (67 or 68) 330 kV lines was out for 9.2 days in 2012 compared to 13.3 days in 2011 - see Table 19

7.3 Basslink (T-V-MNSP1)

Basslink is a DC interconnection between George Town in Tasmania and Loy Yang in Victoria which was commissioned in early 2006 after Tasmania joined the NEM. Unlike the other DC lines in the NEM, Basslink has a frequency controller and is able to transfer FCAS. Basslink is mainly limited by FCAS or the FCSPS constraint equations. The energy constraint equations that can limit Basslink flow from Victoria to Tasmania are the transient stability limit for a fault and trip of a Hazelwood to South Morang line. Flows from Tasmania to Victoria are mainly limited by the South Morang F2 transformer overload constraint equations.

The flow and binding hours on Basslink were different in 2011 and 2012. Although in both years the majority of time flow was from Tasmania to Victoria the flow was mostly higher in 2012, mainly between 400 and 480 MW. Binding hours were also different in 2011 and 2012. Binding hours were generally higher in 2011 except there were more binding hours for flows from 300 and 500 to Tasmania in 2012 (see Figure 17).

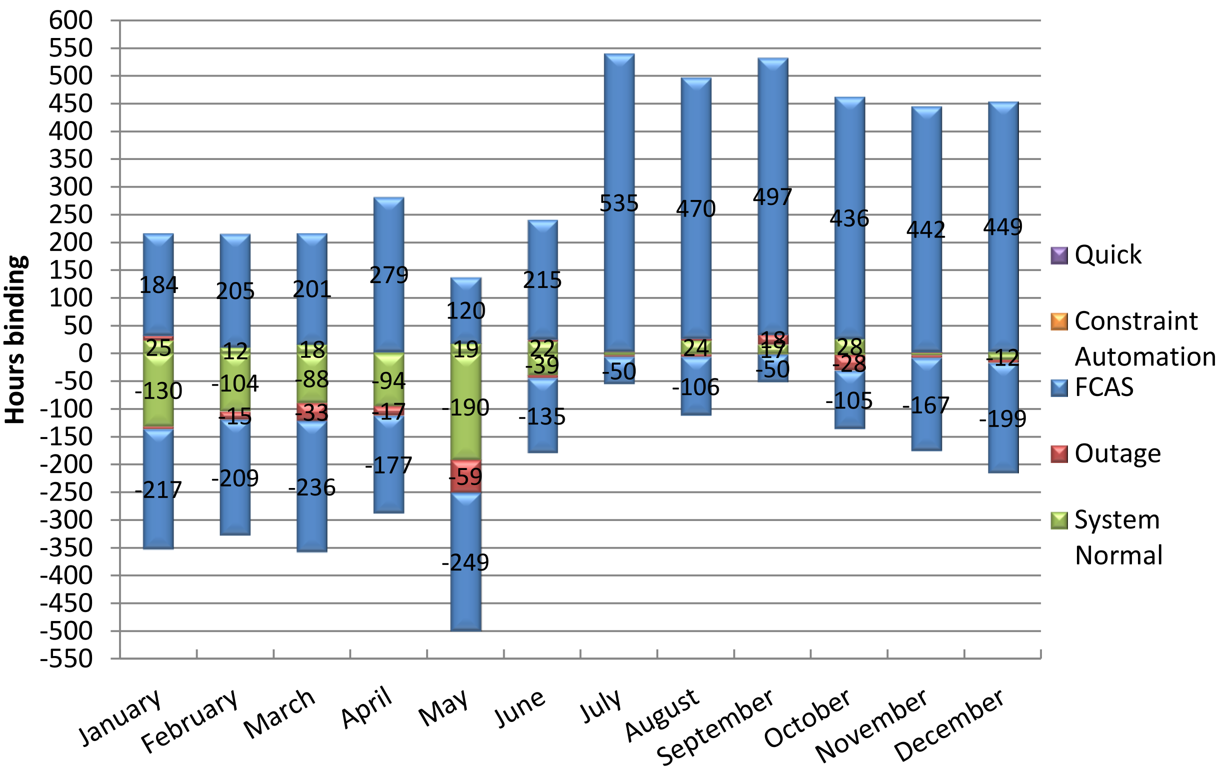

Figure 16: Categorized binding intervals per month for Basslink

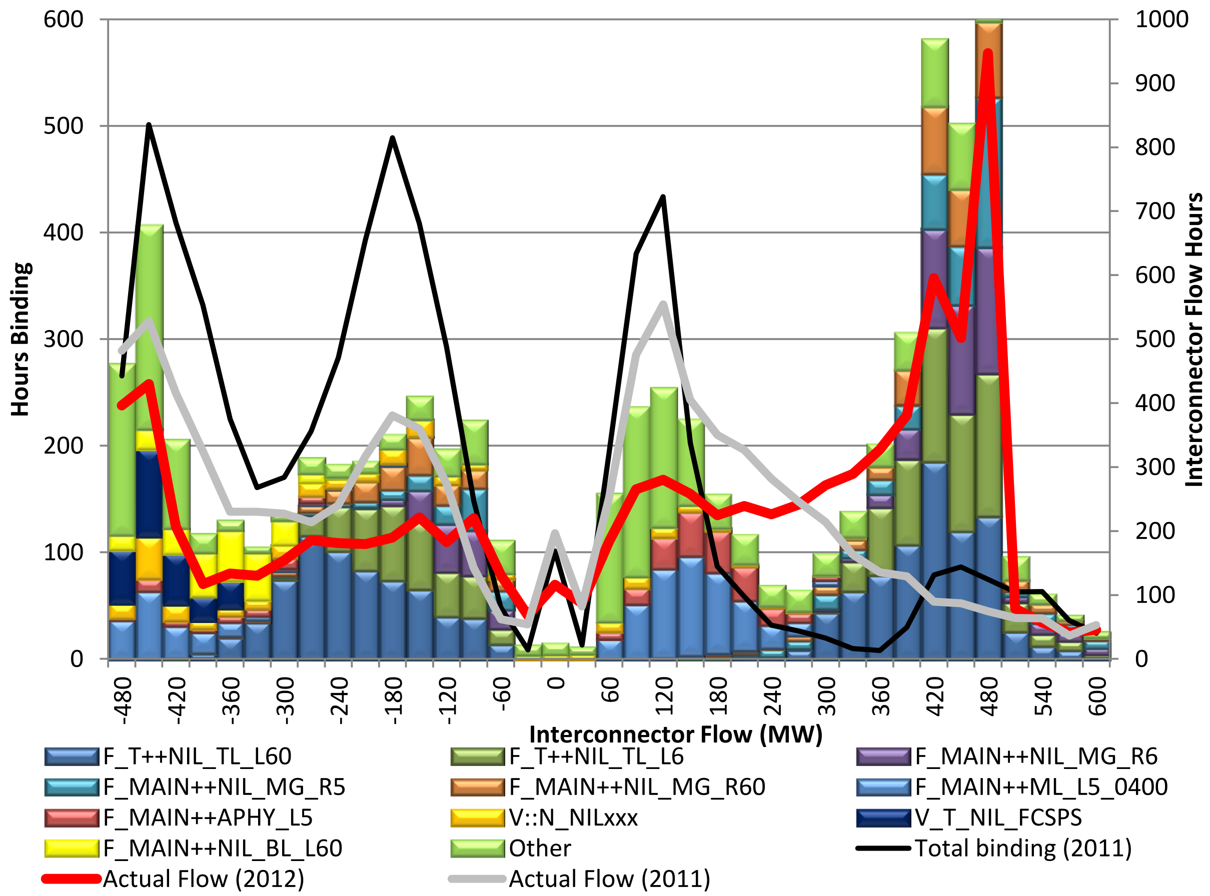

Figure 17: Binding constraint equation distribution for Basslink

Table 11: Binding constraint equations setting the Tas to Vic limit on Basslink

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
F_T++NIL_TL_L60	1465.3 (964.6)	*Tasmania lower 60 second requirement for loss of 2 Comalco potlines, Basslink able to transfer FCAS* See Table 4 for comments
F_T++NIL_TL_L6	951.2 (610.3)	*Tasmania lower 6 second requirement for loss of 2 Comalco potlines, Basslink able to transfer FCAS* See Table 4 for comments
F_MAIN++NIL_MG_R6	534.4 (222.2)	*Mainland raise 6 second requirement for a mainland generation event, Basslink able transfer FCAS* See Table 4 for comments
F_MAIN++NIL_MG_R5	461.6 (251.1)	*Mainland raise 5 minute requirement for a mainland generation event, Basslink able transfer FCAS* See Table 4 for comments
F_MAIN++NIL_MG_R60	432.5 (214.9)	*Mainland raise 60 second requirement for a mainland generation event, Basslink able transfer FCAS* See Table 4 for comments
V>>V_NIL_2A_R & V>>V_NIL_2B_R & V>>V_NIL_2_P	149.6 (185.7)	*Out = Nil, avoid overloading the South Morang 500/330 kV (F2) transformer for no contingencies, for radial/parallel modes and Yallourn W1 on the 500 or 220 kV* See Table 3 for comments
F_T++NIL_TL_L5	113.1 (137.3)	*Tasmania lower 5 minute requirement for loss of 2 Comalco potlines, Basslink able to transfer FCAS*
F_T++LREG_0050	64.7 (7.0)	*Tasmania lower regulation requirement greater than 50 MW, Basslink able transfer FCAS*
TVBL_ROC	15.8 (20.3)	*Out = Nil, rate of change (Tasmania to Victoria) limit (200 MW / 5 minute) for Basslink*
T_V_NIL_BL1	15.1 (6.8)	*Out = Nil, Basslink no go zone limits Tasmania to Victoria*

Table 12: Binding constraint equations setting the Vic to Tas limit on Basslink

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
F_MAIN++ML_L5_0400	586.1 (681.4)	*Mainland lower 5 minute requirement for a mainland load event, Basslink able transfer FCAS* See Table 4 for comments
F_MAIN++APHY_L5	241.9 (49.4)	*Out = Alcoa Portland to Heywood 500 kV line, Mainland lower 5 minute requirement for the loss of the remaining Alcoa Portland to Heywood 500 kV line Basslink able to transfer FCAS* The Heywood to Alcoa Portland 500 kV line was out for 75.4 days in 2012 compared to 0 days in 2011 - see Table 19
V::N_NILxxx	240.7	*Out = Nil, avoid transient instability for fault and trip of a Hazelwood to*

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
	(814.2)	*South Morang 500 kV line* See Table 3 for comments
V_T_NIL_FCSPS	230.8 (133.3)	*Basslink limit from Victoria to Tasmania for load enabled for the Basslink frequency control special protection scheme (FCSPS)* See Table 3 for comments
F_MAIN++NIL_BL_L60	221.1 (480.8)	*Mainland lower 60 second requirement for loss of Basslink, Basslink flow into Tasmania, Basslink able to transfer FCAS* See Table 4 for comments
F_T++NIL_MIG_R5	177.0 (288.1)	*Tasmania raise 5 minute requirement for a Tasmania generation event (loss of the largest inertia), Basslink able to transfer FCAS* See Table 4 for comments
F_MAIN++ML_L6_0400	159.4 (239.4)	*Mainland lower 6 second requirement for a mainland load event, Basslink able transfer FCAS* See Table 4 for comments
T>>T_NIL_NCSPS6_1	124.5 (2.4)	*Out = Nil, ensure Basslink is able to fully compensate fast NCSPS action from Western NCSPS generation* See Table 3 for comments
F_MAIN++ML_L60_0400	82.7 (76.8)	*Mainland lower 60 second requirement for a mainland load event, Basslink able transfer FCAS*
F_T++RREG_0050	75.2 (72.3)	*Tasmania raise regulation requirement greater than 50 MW, Basslink able transfer FCAS*

7.4 Victoria to NSW (VIC1-NSW1)

The Victoria to NSW interconnector comprises the 330kV lines between Murray and Upper Tumut (65), Murray and Lower Tumut (66), Jindera and Wodonga (060) and the 220 kV line between Buronga and Red Cliffs (0X1). This interconnector was formed on 1 July 2008 as a part of the Snowy region abolition and replaced the previous “SNOWY1” and “V-SN” interconnectors. Some of the existing stability limits are still defined for these interconnectors and AEMO has translated these to work with the “new” interconnector.

VIC1-NSW1 can bind in either direction for high demand in NSW or Victoria. Transfer from Victoria to NSW is mainly limited by the transient stability limit for a fault and trip of a Hazelwood to South Morang line (although these constraint equations rarely bound in the second half of 2012) or the thermal limits on the South Morang F2 transformer or the Murray to Upper Tumut line. Transfer from NSW to Victoria is mainly limited by voltage collapse for loss of the largest Victorian generator or the thermal limits on the Murray to Dederang or Wagga to Lower Tumut (051) lines.

The hours at each flow level on VIC1-NSW1 were similar in 2011 and 2012. The binding hours were similar for flows into Victoria and low flows into NSW. However, flows into NSW at higher levels were constrained for a lower number of hours in 2012 compared to 2011 (see Figure 19).

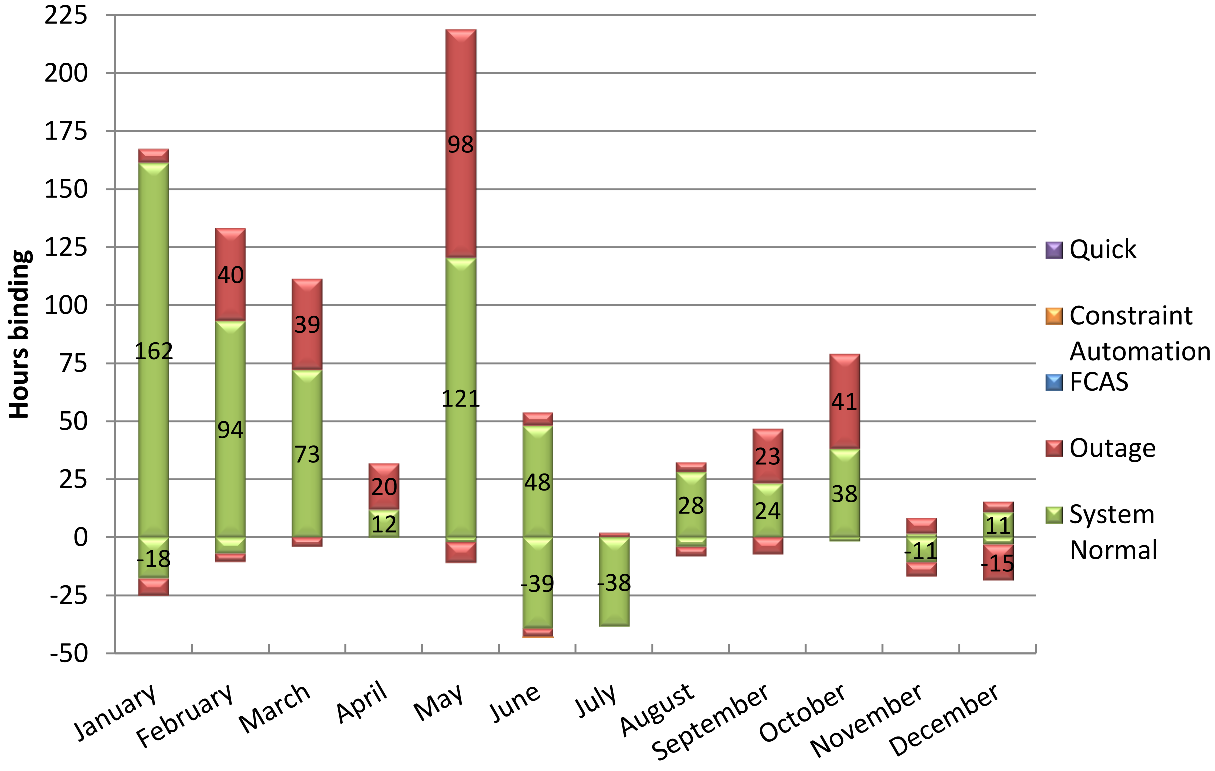

Figure 18: Categorized binding intervals per month for VIC1-NSW1

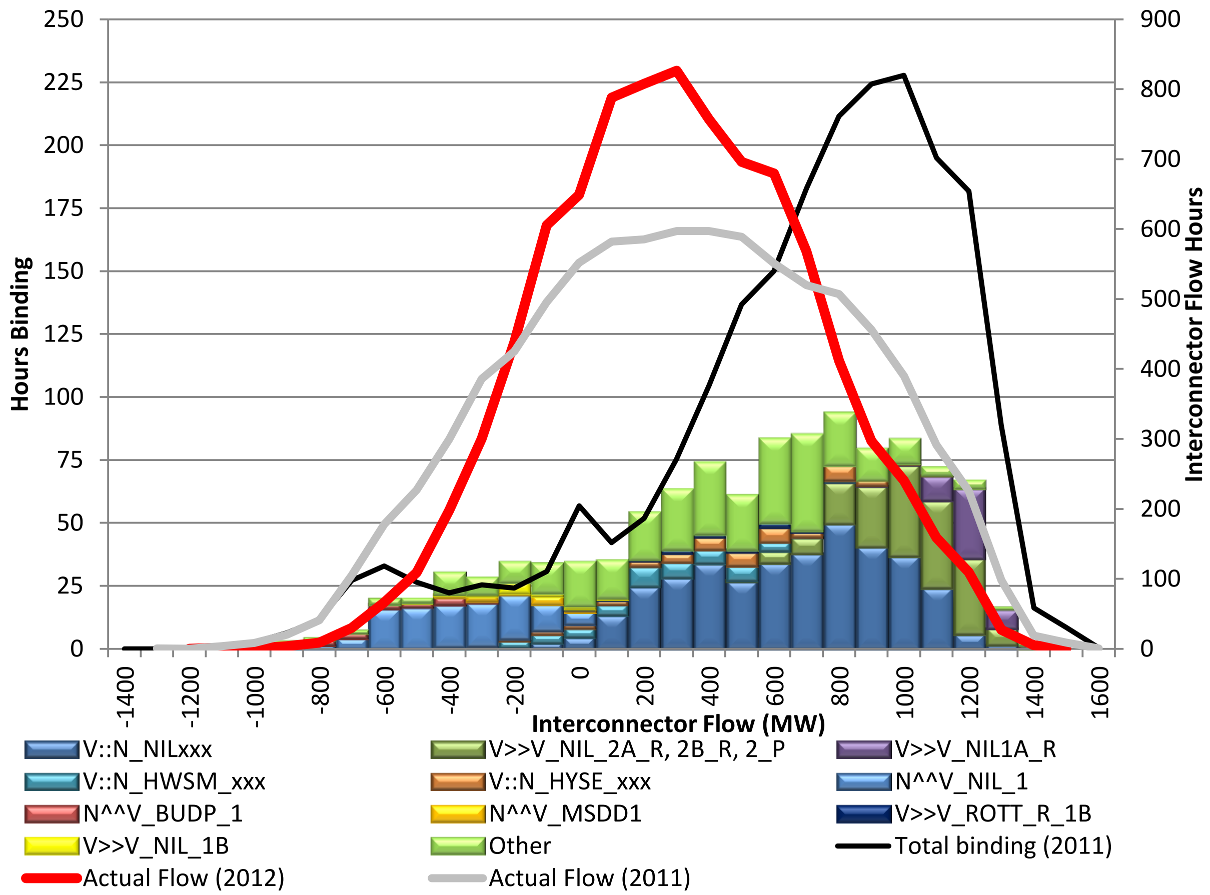

Figure 19: Binding constraint equation distribution for VIC1-NSW1

Table 13: Binding constraint equations setting the Vic to NSW limit on VIC1-NSW1

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
V::N_NILxxx	364.0 (994.2)	*Out = Nil, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 3 for comments
V>>V_NIL_2A_R & V>>V_NIL_2B_R & V>>V_NIL_2_P	161.0 (189.7)	*Out = Nil, avoid overloading the South Morang 500/330 kV (F2) transformer for no contingencies, for radial/parallel modes and Yallourn W1 on the 500 or 220 kV* See Table 3 for comments
V>>V_NIL1A_R	46.0 (151.3)	*Out = Nil, avoid overloading a South Morang to Dederang 330 kV line for trip of the parallel line* This constraint equation only binds for high flows from Victoria to NSW.
V::N_HWSM_xxx	44.8 (4.9)	*Out = Hazelwood to South Morang 500 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* There are 12 constraint equations that make up the transient stability export limit from Victoria for this outage and all the binding results have been combined. The Hazelwood to Cranbourne #4 500 kV line was out for 5.4 days in 2012 compared to 0 days in 2011 - see Table 19
V::N_HYSE_xxx	38.8 (12.2)	*Out = Heywood to South East 275 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 10 for comments
V::N_MSUT_xxx	15.4 (8.6)	*Out = Upper Tumut to Murray 330 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* The Murray to Upper Tumut (65) 330 kV line was out for 4.5 days in 2012 compared to 5.3 days in 2011 - see Table 19
V>>SML_NIL_7A	13.6 (16.9)	*Out = Nil, avoid overloading Ballarat North to Buangor 66 kV line on trip of the Ballarat to Waubra to Horsham 220 kV line* This constraint equation only binds during periods of high demands in the Victorian state grid (220 kV system in northern – western Victoria) and for high flows on Murraylink into SA.
V::N_DDMS_xxx	12.0 (30.3)	*Out = Dederang to Murray 330 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 10 for comments
V::N_EPTT_xxx	11.7 (5.3)	*Out = Eildon to Thomastown 220 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* The Eildon to Thomastown 220 kV line was out for 16.1 days in 2012 compared to 11.4 days in 2011 - see Table 19
V::N_DDSM2	10.5 (2.5)	*Out = Dederang to South Morang 330 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* One Dederang to South Morang 330 kV line was out for 1.7 days in 2012 compared to 3.1 days in 2011 - see Table 19

Table 14: Binding constraint equations setting the NSW to Vic limit on VIC1-NSW1

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
N^^V_NIL_1	108.1 (0)	*Out = Nil, avoid voltage collapse for loss of the largest Victorian generating unit*
N^^V_BUDP_1	11.8 (0)	*Out = Buronga to Darlington Point 220 kV line (X5/1 or X5/3), avoid voltage collapse for trip of the largest Vic generating unit or Basslink* The Buronga to Darlington Point (X5) 220 kV line was out for 2.8 days in 2012 compared to 6.8 days in 2011 - see Table 19
N^^V_MSDD1	8.3 (0)	*Out = Murray to Dederang #1 or #2 330 kV line, avoid voltage collapse for trip of the largest Victorian generating unit or Basslink* One Dederang to Murray (67 or 68) 330 kV line was out for 9.2 days in 2012 compared to 13.3 days in 2011 - see Table 19
V>>V_ROTT_R_1B	7.4 (0)	*Out = Rowville to Thomastown 220 kV line, avoid pre-contingent overload of the Richmond to Brunswick 220 kV cable* The Rowville to Thomastown 220 kV line was out for 1.3 days in 2012 compared to 3.3 days in 2011 - see Table 19
V>>V_NIL_1B	7.3 (0)	*Out = Nil, avoid overloading Dederang to Murray #2 330 kV line for trip of the Dederang to Murray #1 330 kV line* See Table 6 for comments
V>>V-LTWG_RADIAL_2	6.4 (0)	*Out = Lower Tumut to Wagga (051) 330 kV line, avoid overloading Murray to Dederang #1 330 kV line on loss of the parallel #2 line* The Lower Tumut to Wagga line was out for 0.7 days in 2012 compared to 0.1 days in 2011 - see Table 19
N^^V_NIL_2	4.9 (0)	*Out = Nil, avoid voltage collapse for loss of a Dederang to Murray 330 kV line*
V>>V_SMSY_KTSM_1B_R	4.5 (0)	*Out = one South Morang to Sydenham 500 kV line, avoid overloading South Morang to Keilor 500 kV line on loss of the remaining South Morang to Sydenham 500 kV line* One South Morang to Sydenham 500 kV line was out for 2.1 days in 2012 compared to 0.9 days in 2011 - see Table 19
N^^V_BUDP_2	3.7 (0)	*Out = Buronga to Darlington Point 220 kV line, avoid voltage collapse for loss of a Dederang to Murray 330 kV line* The Buronga to Darlington Point (X5) 220 kV line was out for 2.8 days in 2012 compared to 6.8 days in 2011 - see Table 19
N>>V-MSUT_5	3.3 (0)	*Out = Murray to Upper Tumut (65) 330 kV line, avoid overloading Lower Tumut to Murray (66) 330 kV line on trip of Lower Tumut to Wagga (051) 330 kV line* The Murray to Upper Tumut (65) 330 kV line was out for 4.5 days in 2012 compared to 5.3 days in 2011 - see Table 19

7.5 Heywood interconnector (V-SA)

The Vic – SA (or Heywood) interconnector is an AC interconnector between Heywood in Victoria and South East in South Australia. It was originally commissioned in 1989 as a connection from the western 500 kV network in Victoria to the nearest 275 kV substation in South Australia, Para. It includes a number of connections to the parallel 132 kV network in south eastern SA. Up until recently the vast majority of the time the flow was from Victoria to SA. With an increasing number of wind farms in SA the flow is now often from SA to Victoria. In March 2010 the limit from SA to Victoria on Heywood was increased from 300 to 460 MW and the combined Heywood and Murraylink limit was increased to 580 MW in January 2011.

Victoria to SA flow is most often restricted by the transient stability limit for fault on a Hazelwood to South Morang 500 kV line or the voltage collapse for the loss of the largest generator in SA. Export from SA is mainly restricted by the thermal limits on the South East substation 275/132 kV transformers and the South Morang F2 transformer. V-SA appears in many of the Victorian constraint equations and these can limit both directions of flow on this interconnector.

The hours at each flow level on V-SA were very similar in 2011 and 2012 except for a less number of hours for high flows into South Australia (between 250 and 350 MW). The binding hours in 2012 were lower for greater than 250 MW flow into South Australia – see Figure 21.

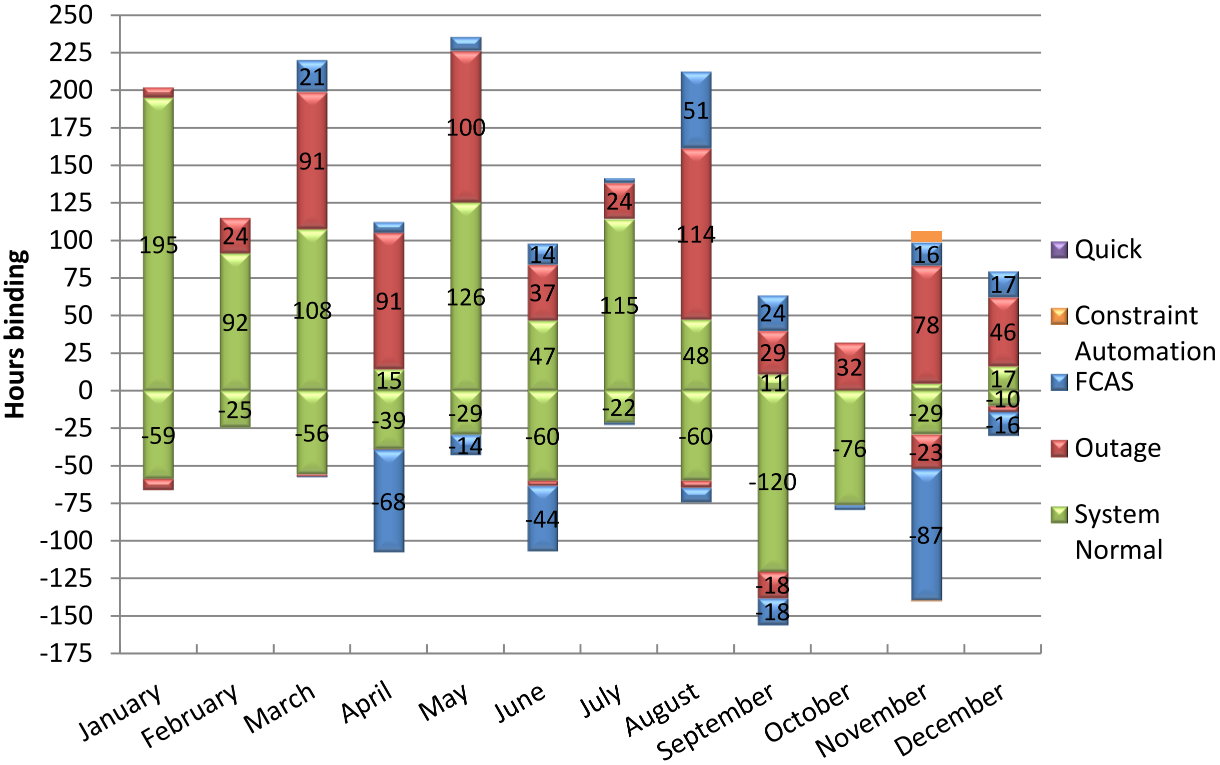

Figure 20: Categorized binding intervals per month for V-SA

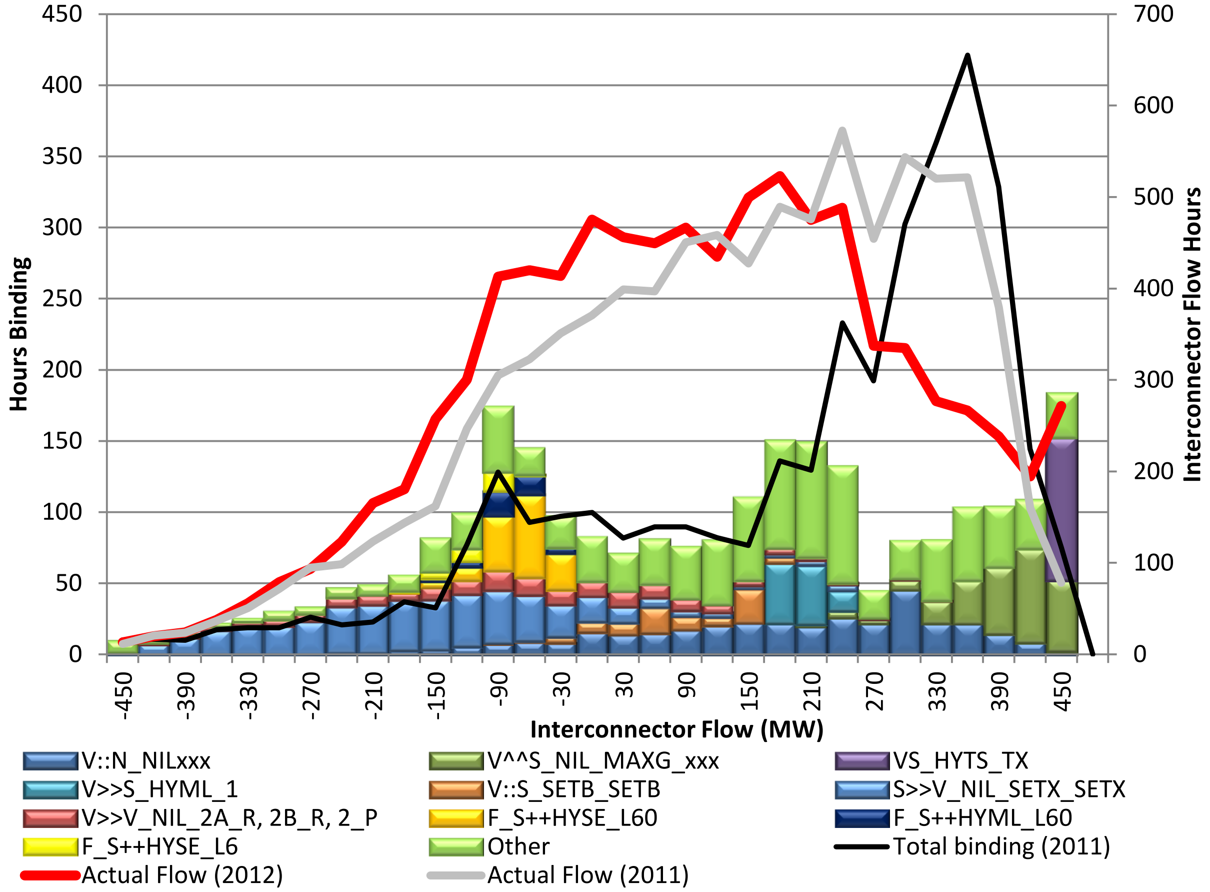

Figure 21: Binding constraint equation distribution for V-SA

Table 15: Binding constraint equations setting the Vic to SA limit on V-SA

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
V::N_NILxxx	348.9 (864.5)	*Out = Nil, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 3 for comments
V^^S_NIL_MAXG_xxx	220.3 (1026.7)	*Out = Nil, Victoria to SA long term voltage stability limit for loss of the largest credible generation contingency in SA, South East capacitor bank on / off* See Table 3 for comments
VS_HYTS_TX	99.7 (15.1)	*Upper transfer limit from Victoria to SA on Vic-SA based on Heywood transformer 30 minute rating and tertiary winding MW load*
V>>S_HYML_1	96.9 (30.6)	*Out = Heywood to Moorabool to Alcoa Portland 500 kV line, avoid overloading Heywood 500/275 kV (M1 or M2) transformer for trip of Northern Power Station unit 1* The Heywood to Moorabool 500 kV line was out for 43.8 days in 2012 compared to 27.5 days in 2011 - see Table 19
V::S_SETB_SETB	81.3 (0)	*Out = South East to Tailem Bend 275 kV line, avoid transient instability for loss of the parallel South East to Tailem Bend 275 kV line* One South East to Tailem Bend 275 kV line was out for 8.6 days in 2012 compared to 0 days in 2011 - see Table 19

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
V::N_HWSM_xxx	44.4 (4.9)	*Out = Hazelwood to South Morang 500 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 13 for comments
F_ESTN++HYML_L60	44.1 (53.5)	*Out = one Heywood to Moorabool or one Moorabool to Sydenham 500 kV line, Eastern lower 60 second requirement* The Heywood to Moorabool 500 kV line was out for 10.4 days in 2012 compared to 11.0 days in 2011 - see Table 19
V>>S_HYML_4	37.3 (0)	*Out = one Heywood 500/275 kV transformer, avoid overloading remaining Heywood 500/275 kV transformer for loss of a Pelican Point GT and consequent offloading of Pelican Point ST* The Heywood to Moorabool 500 kV line was out for 38.3 days in 2012 compared to 24.9 days in 2011 - see Table 19
F_ESTN++HYMO_L60	34.7 (4.3)	*Out = Heywood to Mortlake 500 kV line, Eastern lower 60 second requirement* The Heywood to Mortlake #2 500 kV line was out for 6.5 days in 2012 compared to 2.6 days in 2011 - see Table 19
VS_250	33.6 (74.3)	*Victoria to South Australia on Heywood upper transfer limit of 250 MW* This constraint equation is included in a number of constraint sets which are used for outages of the 500 kV lines in from Sydenham to Heywood and the 275 kV lines from Heywood to South East. These lines were out for a total of 113.7 days in 2012 compared to 35.5 days in 2011 - see Table 19

Table 16: Binding constraint equations setting the SA to Vic limit on V-SA

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
S>>V_NIL_SETX_SETX	422.3 (195.3)	*Out = Nil, avoid overloading a South East 275/132 kV transformer on trip of the remaining South East 275/132 kV transformer* See Table 3 for comments
V>>V_NIL_2A_R & V>>V_NIL_2B_R & V>>V_NIL_2_P	149.3 (195.7)	*Out = Nil, avoid overloading the South Morang 500/330 kV (F2) transformer for no contingencies, for radial/parallel modes and Yallourn W1 on the 500 or 220 kV* See Table 3 for comments
F_S++HYSE_L60	135.3 (36.7)	*Out = one Heywood to South East 500 kV line or one Heywood 500/275 kV (M1 or M2) transformer, SA lower 60 second requirement* One Heywood to South East 275 kV line was out for 34.1 days in 2012 compared to 4.0 days in 2011 - see Table 19
F_S++HYML_L60	40.2 (77.4)	*Out = one Heywood to Moorabool 500 kV line or one Moorabool to Sydenham 500 kV line, SA lower 60 second requirement* The Heywood to Moorabool 500 kV line was out for 16.4 days in 2012 compared to 13.7 days in 2011 - see Table 19

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
F_S++HYSE_L6	27.8 (3.1)	*Out = one Heywood to South East 500 kV line or one Heywood 500/275 kV (M1 or M2) transformer, SA lower 6 second requirement* See comment on F_S++HYSE_L60
F_S++HYSE_L5	26.8 (1.9)	*Out = one Heywood to South East 500 kV line or one Heywood 500/275 kV (M1 or M2) transformer, SA lower 5 minute requirement* See comment on F_S++HYSE_L60
S>>V_CGTB_TUTB_MOTB	21.3 (46.5)	*Out = Cherry Gardens to Tailem Bend 275 kV line, avoid overloading Mobilong to Tailem Bend 132 kV line on trip of Tailem Bend to Tungkillo 275 kV line* The Cherry Gardens to Tailem Bend 275 kV line was out for 4.5 days in 2012 compared to 6.1 days in 2011 - see Table 19
F_S++HYML_L5	15.8 (21.5)	*Out = one Heywood to Moorabool 500 kV line or one Moorabool to Sydenham 500 kV line, SA lower 5 minute requirement* See comment on F_S++HYML_L60
F_S++HYML_L6	15.2 (23.8)	*Out = one Heywood to Moorabool 500 kV line or one Moorabool to Sydenham 500 kV line, SA lower 6 second requirement* See comment on F_S++HYML_L60
S>V_NIL_HYTX_HYTX	8.3 (4.3)	*Out = Nil, avoid overloading a Heywood 275/500 kV transformer on trip of the other Heywood 275/500 kV transformer*

7.6 Murraylink (V-S-MNSP1)

Murraylink is a 220 MW DC link between Red Cliffs in Victoria and Monash in South Australia, which was commissioned in 2002. Transfers from Victoria to South Australia are mainly limited by constraint equations that affect the export from Victoria as a whole, such as the South Morang F2 transformer overload, or the transient stability limit for exports from Victoria. Many of the thermal issues closer to Murraylink are dealt with by the Murraylink runback scheme. Transfers from SA to Victoria are limited by the 132 kV lines from Robertstown to Monash and Robertstown to Waterloo as well as the Robertstown 275/132 kV transformers.

The hours at each flow level on Murraylink were almost the same in 2011 and 2012; however the binding hours were different. Binding hours were lower for flows to Victoria and higher for low flows to SA in 2012 (see Figure 23).

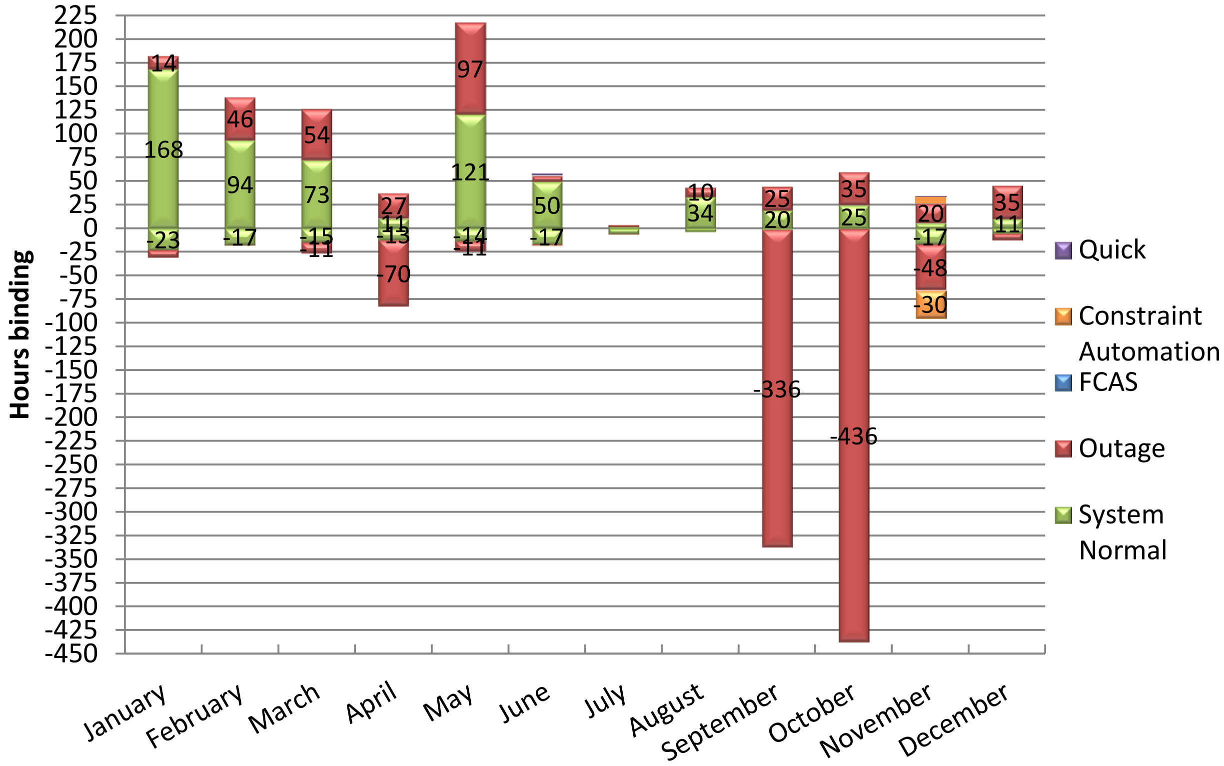

Figure 22: Categorized binding intervals per month for Murraylink

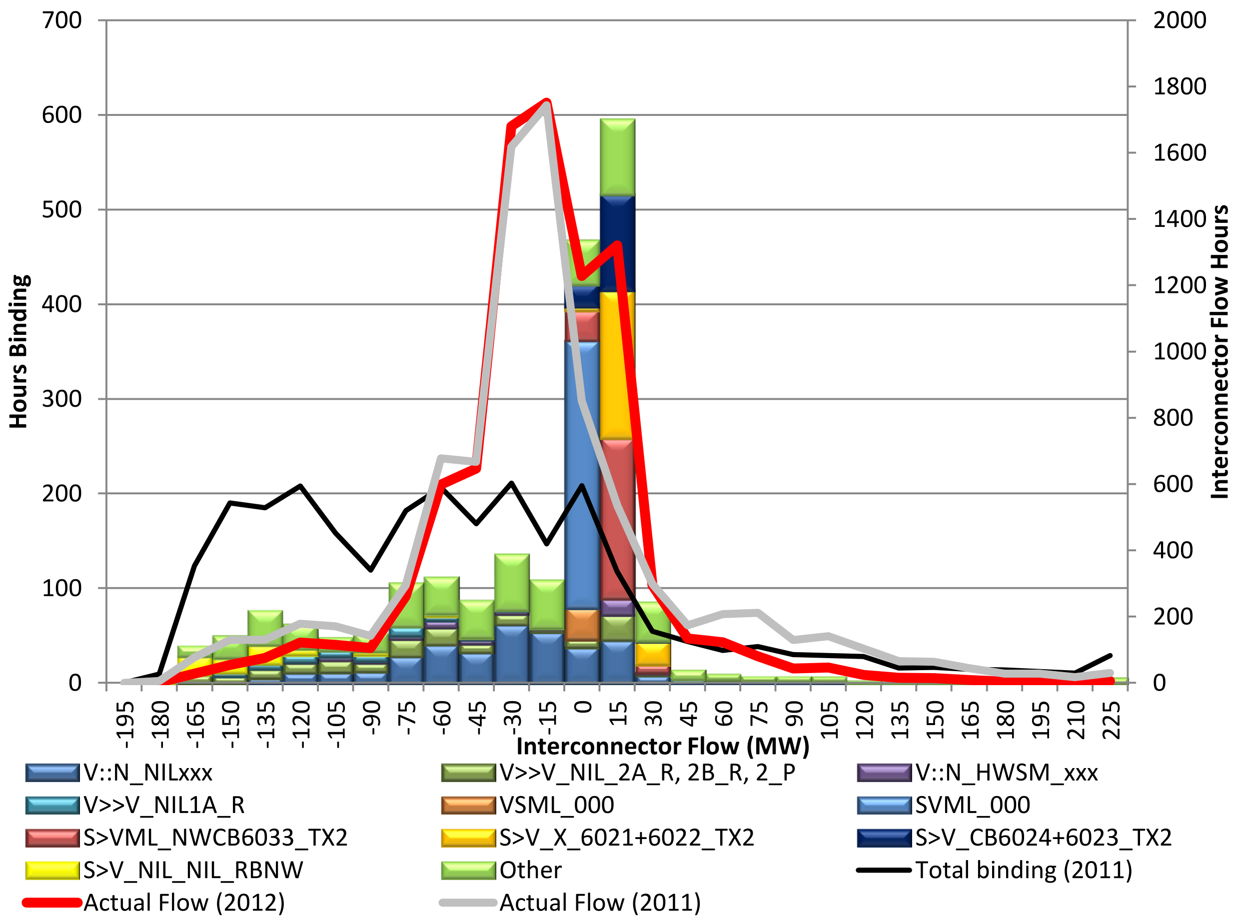

Figure 23: Binding constraint equation distribution for Murraylink

Table 17: Binding constraint equations setting the Vic to SA limit on Murraylink

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
V::N_NILxxx	362.3 (968.8)	*Out = Nil, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 3 for comments
V>>V_NIL_2A_R & V>>V_NIL_2B_R & V>>V_NIL_2_P	157.3 (184.7)	*Out = Nil, avoid overloading the South Morang 500/330 kV (F2) transformer for no contingencies, for radial/parallel modes and Yallourn W1 on the 500 or 220 kV* See Table 3 for comments
V::N_HWSM_xxx	44.8 (4.9)	*Out = Hazelwood to South Morang 500 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 13 for comments
V>>V_NIL1A_R	44.8 (151.4)	*Out = Nil, avoid overloading a South Morang to Dederang 330 kV line for trip of the parallel line* See Table 13 for comments
VSML_000	33.3 (41.4)	*Victoria to South Australia on Murraylink upper transfer limit of 0 MW* This constraint equation is normally invoked for Murraylink out of service. Murraylink out of service for 13.8 days in 2012 compared to 5.2 days in 2011 - see Table 19
V>SML_BUDP_2	32.7 (0)	*Out = Buronga to Balranald to Darlington Pt. (X5) 220 kV line, avoid overloading on Horsham to Waubra 220 kV line section on trip of Bendigo to Kerang 220 kV line* The Buronga to Darlington Point (X5) 220 kV line was out for 3.5 days in 2012 compared to 7.5 days in 2011 - see Table 19
V::N_HYSE_xxx	27.7 (12.2)	*Out = Heywood to South East 275 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 10 for comments
V::N_MSUT_xxx	15.4 (8.4)	*Out = Upper Tumut to Murray 330 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 13 for comments
V>>SML_NIL_7A	13.6 (17.2)	*Out = Nil, avoid overloading Ballarat North to Buangor 66 kV line on trip of the Ballarat to Waubra to Horsham 220 kV line* See Table 13 for comments
V::N_DDMS_xxx	11.8 (30.1)	*Out = Dederang to Murray 330 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 10 for comments

Table 18: Binding constraint equations setting the SA to Vic limit on Murraylink

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
SVML_000	281.6 (67.4)	*South Australia to Victoria on Murraylink upper transfer limit of 0 MW* See Table 3 for comments
S>VML_NWCB6033_TX2	209.9 (5.5)	*Out = North West Bend CB6033, avoid overloading North West Bend #2 132/66 kV transformer on trip of North West Bend to Monash #2 132 kV line* See Table 3 for comments
S>V_X_6021+6022_TX2	184.1 (0)	*Out = North West Bend CB6021 & CB6022, avoid overloading North West Bend #2 132/66 kV transformer on trip of North West Bend to Robertstown #1 132 kV line* See Table 3 for comments
S>V_CB6024+6023_TX2	126.2 (0)	*Out = North West Bend CB6024 and CB6023, avoid overloading North West Bend #2 132/66 kV transformer on trip North West Bend #3 132/66 kV transformer* See Table 3 for comments
S>V_NIL_NIL_RBNW	72.5 (174.0)	*Out = Nil, avoid overloading the North West Bend to Robertstown 132 kV line on no line trips* This constraint equation normally sets the upper limit on Murraylink and is expected to bind with similar frequency in 2012.
S>V_CB6021+6225_TX1	49.4 (0)	*Out= North West Bend CB6021 and CB6225, avoid overloading North West Bend #1 132/66 kV transformer on trip of North West Bend to Robertstown #2 132 kV line* The North West Bend CBs 6021 and 6225 was out for 7.2 days in 2012 compared to 0 days in 2011 - see Table 19
S>>V_NIL_RBTXW_RBTX1	46.8 (123.7)	*Out = Nil, avoid overloading Robertstown #1 275/132 kV transformer on trip of the Robertstown #2 275/132 kV transformer* See Table 6 for comments
CA_MQS_3FAAB8EA_01	29.5 (0)	*Constraint Automation, avoid overloading North West Bend #3 132/66 kV transformer on trip of North West Bend to Berri 132 kV line* Created on 6 November 2012 for the planned outage of CB 6024 and CB 6025 at North West Bend and unplanned outage of North West Bend to Robertstown 132 kV line
S>V_NWRB2_RBNW1	15.3 (0)	*Out = North West Bend to Robertstown #2 line, avoid overloading on Robertstown to North West Bend #1 132 kV line* The North West Bend to Robertstown #2 132 kV line was out for 11.6 days in 2012 compared to 0 days in 2011 - see Table 19
S>>V_DB_RBTU-2_RBTX1	13.6 (0.8)	*Out = Davenport to Brinkworth 275 kV line, avoid overloading Robertstown #1 275/132 kV transformer on trip of Robertstown to Para and Robertstown to Tungkillo 275 kV lines* This constraint equation is invoked for an outage of the Davenport to Brinkworth line and the loss of the Robertstown to Para and Robertstown to Tungkillo lines have been reclassified as a credible contingency.

8 Transmission outages

8.1 Major outages

The following table shows the duration of the network outages in 2012 that required any of the binding constraint equations included in the tables in sections 5, 6 and 7 to be invoked. This list excludes the "#" constraint equations as these are generally not associated with a particular outage.

The outage times were calculated from the times that the constraint sets were invoked.

Table 19: Top 40 outages associated with binding constraint equations

CONSTRAINT SET ID	DAYS (2011)	*OUTAGE* / NOTES
N-MBTE_1	280.7 (194.3)	*One Directlink cable*
F-V-APHY_ONE	75.4 (23.7)	*Heywood to Alcoa Portland 500 kV line* Outage due to the cut-in of the Tarrone terminal station
N-X_MBTE_2	60.0 (90.0)	*Two Directlink cables*
N-EWMB_8505	58.3 (39.3)	*One Ballina to Lennox Head to Ewingsdale to Mullumbimby 66 kV line (8504, 8505 or 8508) or Mullumbimby 132/66 kV transformer* These lines were out for major upgrading work between Ballina and Mullumbimby to increase the normal operating voltage from 66 kV to 132 kV[9]
I-HYSE	34.1 (4.0)	*One Heywood to South East 275 kV line*
V-HYTX	28.5 (13.8)	*One Heywood 500/275 kV (M1 or M2) transformer* Outage due to the cut-in of the Tarrone terminal station
N-X_MBTE_3	20.9 (14.5)	*All three Directlink cables*
Q-BCGL_812	20.5 (6.2)	*Bouldercombe to Gladstone (812) 275 kV line* This line was out for work associated with the commissioning of the Calliope River substation.
V-EPTT_R	16.1 (11.4)	*Eildon to Thomastown 220 kV line*
I-ML_ZERO	13.8 (5.2)	*Limit Murraylink to zero in either direction*
S-SE_TX_1	11.9 (6.2)	*One South East 275/132 kV transformer*
S-NWRB2	11.6 (0)	*North West Bend to Robertstown #2 132 kV line*
S-PWSE	11.5 (0)	*Penola West to South East 132 kV line*
S-NW_CB6033	9.3 (0.2)	*North West Bend CB6033*

[9] http://www.essentialenergy.com.au/content/lismore-to-mullumbimby-via-ballina-upgrade

CONSTRAINT SET ID	DAYS (2011)	*OUTAGE* / NOTES
V-DDMS	9.2 (13.3)	*One Dederang to Murray (67 or 68) 330 kV line*
N-KKLS_967	9.1 (21.9)	*Koolkhan to Lismore (967) 132 kV line*
V-HYML	8.8 (11.0)	*Heywood to Moorabool 500 kV line* Outage due to the cut-in of the Tarrone terminal station
S-NW_CB6021+CB6022	8.1 (0)	*North West Bend CBs 6021 and CB6022*
S-NWCB6021+6225	7.2 (0)	*North West Bend CBs 6021 and 6225*
V-HYMO	6.5 (2.6)	*Heywood to Mortlake #2 500 kV line*
S-TBSE	6.4 (0)	*One South East to Tailem Bend 275 kV line*
S-NWCB6024+23	5.4 (0)	*North West Bend CBs 6023 and 6024*
S-MTSE	5.3 (0.6)	*Mt Gambier to South East 132 kV line*
S-SE_CB6160-CB6162	4.7 (0)	*South East 132 kV circuit breaker CB6160 or CB6162*
I-MSUT	4.5 (5.3)	*Murray to Upper Tumut (65) 330 kV line*
@OSBTOA_3_O/L	4.3 (0)	*Control room quick constraint set to avoid overloading New Osborne to Torrens Island #3 66 kV line on trip of Parafield Gardens West #1 275/66 kV transformer*
N-LSLS_9U8	4.3 (0)	*One Lismore 330 to Lismore 132 (9U8 or 9U9 or 9W1) 132 kV line*
N-BUDP	2.8 (6.8)	*Buronga to Darlington Point (X5) 220 kV line*
V-HWTS_TX3_35PR_OPT1	2.5 (1.2)	*Hazelwood A3 or A4 500/220 kV transformer*
S-CGTB	2.4 (6.1)	*Cherry Gardens to Tailem Bend 275 kV line*
S-TB_CB6536	2.2 (0)	*Tailem Bend CB 6536 or CB 6595*
S-X_CGTB_TBKH1	2.1 (0)	*Cherry Gardens to Tailem Bend 275 kV line and Keith to Tailem Bend #1 132 kV line*
V-SMSY	2.1 (0.9)	*One South Morang to Sydenham 500 kV line*
V-HWRO3	2.1 (0)	*Hazelwood to Rowville #3 500 kV line*
N-ARTW_86	2.0 (22.3)	*Armidale to Tamworth (86) 330 kV line*
N-LSDU_9U6	1.8 (0.2)	*Lismore to Dunoon 132 kV line*

CONSTRAINT SET ID	DAYS (2011)	*OUTAGE* / NOTES
V-DDSM	1.7 (3.1)	*One Dederang to South Morang 330 kV line*
V-HWSM	1.7 (0.2)	*Hazelwood to South Morang 500 kV line*
V-HWCB4	1.6 (0)	*Hazelwood to Cranbourne #4 500 kV line*
V-MLSY	1.6 (0)	*Moorabool to Sydenham 500 kV line*

8.2 Trends for submit times

The following graph shows the trends on the length of time from when a network outage is submitted to AEMO's network outage schedule (NOS) or the outage timing is modified and the actual outage start time. The times are categorized into 4 categories:

- Unplanned: the outage was submitted on or after the start time for the outage.
- Short-notice: the outage was submitted within 4 days of the start time
- ≤ 30 days: the outage was submitted within 30 days of the start time
- > 30 days: the outage was submitted greater than 30 days of the start time

Where an outage was submitted previously and then rescheduled for a new time this is recorded as a new outage in the NOS. Outages for multiple items of related plant which are submitted in a single entry are only counted as a single outage.

The following trends have been observed:

- Over 80% of the outages from APT (who operate Murraylink and Directlink DC cables) are unplanned or short notice
- For other NSPs less than 10% of outages are forced and majority of the outages are either short notice or within 30 days
- Compared to other TNSPs ElectraNet, TransGrid and Transend have a higher percentage of outages submitted greater than 30 days
- Very few outages are submitted by Essential Energy, Powerlink, SPAusNet or APT for greater than 30 days out

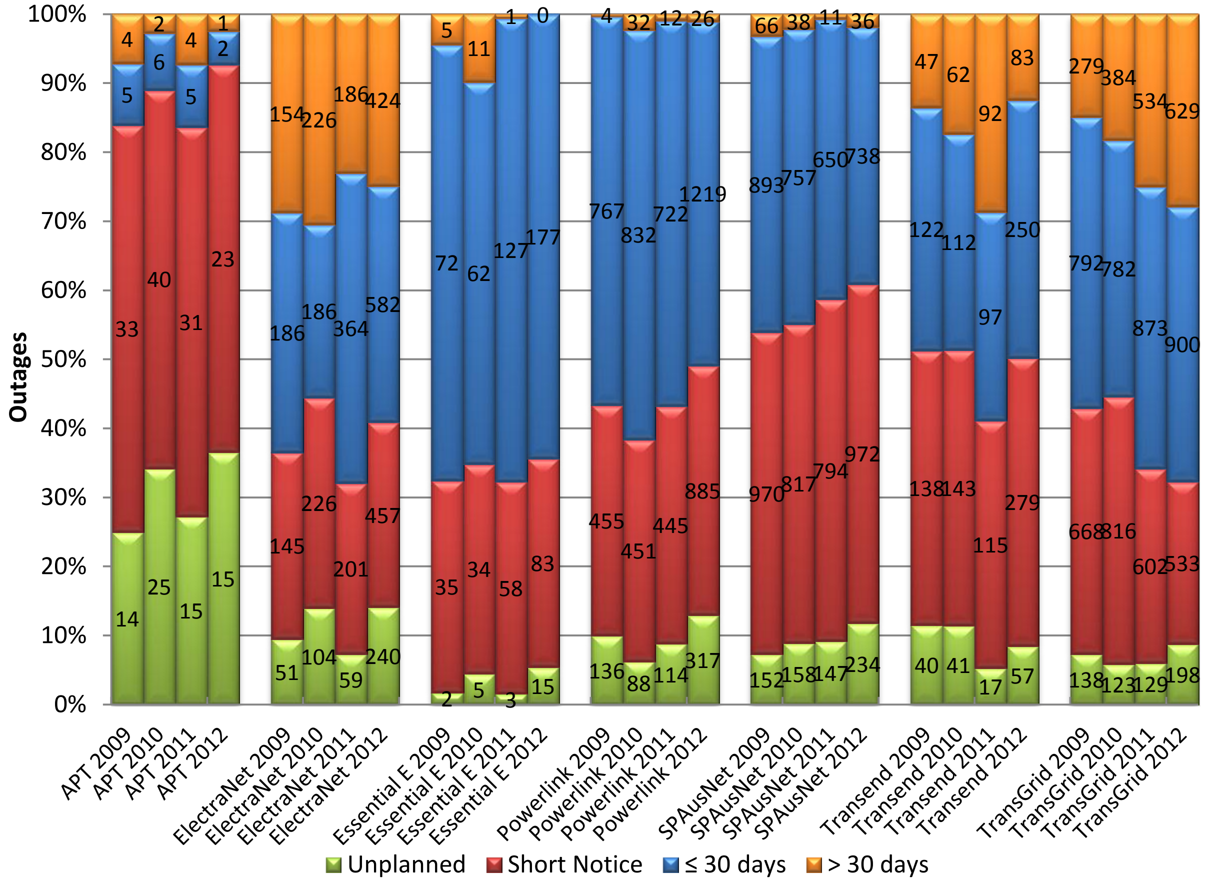

Figure 24: Outage submit times

9 Other developments

9.1 Constraint automation

The constraint automation is an application in AEMO's EMS which generates thermal overload constraint equations based on the current or planned state of the power system. The next stage of the constraint automation is to create and update all of the required thermal constraint equations in real time automatically[10]. The software changes for this stage were completed in late 2012 and have been undergoing an extended trial in AEMO's pre-production systems. It is expected that this stage of the constraint automation will be operational in April/May 2013.

9.2 Dynamic rating forecasts in Pre-dispatch

In late 2011 AEMO identified that the new demand forecasting system (DFS) had the potential to be used to forecast dynamic line ratings in *pre-dispatch*. Selected lines were identified and models created and results benchmarked against the existing methodology. The results indicated the DFS based forecasts provided an improvement over the existing methodology. A report on the analysis will be published in early 2013.

The DFS based forecast rating for the Calvale to Stanwell (855) and Calvale to Wurdong (871) lines was implemented in the constraint equations in December 2012. Further lines will be implemented in 2013.

[10] http://www.aemo.com.au/Electricity/Market-Operations/Congestion-Information-Resource/Constraint-Automation-Closing-the-Loop-Discussion-Paper

10 Appendix 1: Regional Binding and Market Impact

10.1 Queensland

Table 20: Top 10 binding network constraint equations for Queensland

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
Q>NIL_BI_FB	484 (13)	*Out = Nil, avoid overloading on Boyne Island feeder bushing on Gladstone to Boyne Island 132 kV lines, for the contingent loss of a single Gladstone to Boyne Island 132 kV line* See Table 3 for comments
NSA_Q_GSTONE34_xxx	367 (695)	*Gladstone 3 + 4 >= various levels for Network Support Agreement* See Table 3 for comments
Q>>NIL_855_871	279 (217)	*Out = Nil, avoid overload on Calvale to Wurdong (871) 275 kV line on trip of Calvale to Stanwell (855) 275 kV line* See Table 3 for comments
Q:N_NIL_BCK2L-G	115 (38)	*Out = Nil, avoid transient instability for a 2 phase to ground fault on a Bulli Creek to Dumaresq 330 kV line at Bulli Creek* See Table 3 for comments
Q>>NIL_871_855	100 (36)	*Out = Nil, avoid overload on Calvale to Stanwell (855) 275 kV line on trip of Calvale to Wurdong (871) 275 kV line* See Table 6 for comments
Q>NIL_MUTE_757 & Q>NIL_MUTE_758	90 (34)	*Out = Nil, avoid overloading a Mudgeeraba to Terranora (757 or 758) 110 kV line on no contingencies* See Table 8 for comments
Q:N_NIL_BI_POT	70 (103)	*Out = Nil, avoid transient instability for a trip of a Boyne Island potline (400 MW)* See Table 10 for comments
Q_N_NIL-1078	33 (29)	*Out = Nil, reduce QNI when it is over the 1078 MW limit by 1078 minus the MW over the 1078 MW limit (capped at 1000 MW)* See Table 10 for comments
Q_BARCALDN_ISL	27 (0)	*Out = Lilyvale to Clermont or Clermont to Barcaldine 132 kV line, Barcaldine PS islanded* See Table 6 for comments
Q>NIL_TR_TX1_4	26 (48)	*Out = Nil, avoid overloading a Tarong 275/132 kV transformer (#1 or #4) on trip of the other Tarong 275/132 kV transformer (#1 or #4)* See Table 6 for comments

Table 21: Top 10 market impact constraint equations for Queensland

EQUATION ID (SYSTEM NORMAL IN BOLD)	∑MARGINAL VALUES	HOURS (2011)	*DESCRIPTION* / NOTES
NSA_Q_GSTONE34_xxx	$11,981,412 ($2,962,336)	366.3 (693.8)	*Gladstone 3 + 4 >= various levels for Network Support Agreement* See Table 3 for comments
Q_BARCALDN_ISL	$2,878,964 (0)	26.9 (0)	*Out = Lilyvale to Clermont or Clermont to Barcaldine 132 kV line, Barcaldine PS islanded*

EQUATION ID (SYSTEM NORMAL IN BOLD)	∑MARGINAL VALUES	HOURS (2011)	*DESCRIPTION* / NOTES
			See Table 6 for comments
NSA_Q_BARCALDN	$1,436,430 ($3,677,819)	17.7 (25.3)	*Network Support Agreement for Barcaldine GT to meet local islanded demand at Clermont and Barcaldine for the outage of Clermont to Lilyvale (7153) 132 kV line* See Table 6 for comments
Q>>NIL_855_871	$1,431,065 ($74,016)	278.6 (216.7)	*Out = Nil, avoid overload on Calvale to Wurdong (871) 275 kV line on trip of Calvale to Stanwell (855) 275 kV line* See Table 3 for comments
Q<QBCG_02	$1,289,255 ($2,427,766)	8.8 (20.4)	*Out = Barcaldine to Clermont (7154) 132 kV line, Barcaldine power station islanded* See Table 6 for comments
Q>>NIL_871_855	$895,184 ($20,711)	99.8 (35.5)	*Out = Nil, avoid overload on Calvale to Stanwell (855) 275 kV line on trip of Calvale to Wurdong (871) 275 kV line* See Table 6 for comments
Q>NIL_TR_TX1_4	$312,478 ($61,446)	25.8 (47.9)	*Out = Nil, avoid overloading a Tarong 275/132 kV transformer (#1 or #4) on trip of the other Tarong 275/132 kV transformer (#1 or #4)* See Table 6 for comments
Q>NIL_BI_FB	$131,585 ($3,493)	484.1 (12.8)	*Out = Nil, avoid overloading on Boyne Island feeder bushing on Gladstone to Boyne Island 132 kV lines, for the contingent loss of a single Gladstone to Boyne Island 132 kV line* See Table 3 for comments
Q>NIL_CLBCN_7350	$76,271 ($22,501)	6.1 (1.8)	*Out = Nil, avoid overloading Chinchilla to Columboola (7350) 132 kV line on trip of Chinchilla to Columboola (7349) 132 kV line*
Q:N_NIL_BCK2L-G	$38,412 ($158,605)	114.8 (38.0)	*Out = Nil, avoid transient instability for a 2 phase to ground fault on a Bulli Creek to Dumaresq 330 kV line at Bulli Creek* See Table 3 for comments

10.2 New South Wales

Table 22: Top 10 binding network constraint equations for New South Wales

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
N_X_MBTE_3A & N_X_MBTE_3B	503 (350)	*Out = all three Directlink cables* See Table 3 for comments
N_X_MBTE2_A & N_X_MBTE2_B	483 (797)	*Out = two Directlink cables* See Table 3 for comments
N_MBTE1_B	158 (75)	*Out = one Directlink cable, Queensland to NSW limit* See Table 3 for comments
N^^V_NIL_1	108	*Out = Nil, avoid voltage collapse for loss of the largest Victorian*

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
	(88)	*generating unit* See Table 14 for comments
N^^Q_NIL_B1, 2, 3, 4, 5, 6 & N^Q_NIL_B	103 (81)	*Out = Nil, avoid voltage collapse for loss of the largest Queensland generator* See Table 7 for comments
N>N-NIL_LSDU	62 (44)	*Out = Nil, avoid overloading Lismore to Dunoon line (9U6 or 9U7) 132 kV line on trip of the other Lismore to Dunoon line (9U7 or 9U6) 132 kV line* See Table 7 for comments
N>N-EWMB_TE_A	40 (1)	*Out = Ballina to Lennox Head 66 kV line, avoid overloading Lismore to Dunoon 132 kV line on trip of the other Lismore to Dunoon 132 kV line* See Table 7 for comments
NQTE_ROC	25 (14)	*Out = Nil, rate of change (NSW to Queensland) limit (80 MW / 5 minute) for Terranora interconnector* See Table 7 for comments
NRM_QLD1_NSW1	20 (0)	*Negative Residue Management constraint equation for QLD to NSW flow* See Table 8 for comments
N^N_KKLS_1	19 (132)	*Out = Koolkhan to Lismore (967) 132 kV line, avoid voltage collapse on trip of Coffs Harbour to Lismore (89) 330 kV line* See Table 7 for comments

Table 23: Top 10 market impact constraint equations for New South Wales

EQUATION ID (SYSTEM NORMAL IN BOLD)	∑MARGINAL VALUES	HOURS (2011)	*DESCRIPTION* / NOTES
N_WOODLWN1_ZERO	$128,716 ($17,522)	10.3 (1.4)	*Discretionary upper limit for Woodlawn generation of 0 MW*
N>N-NIL_LSDU	$115,282 ($14,923)	62.0 (44.3)	*Out = Nil, avoid overloading Lismore to Dunoon line (9U6 or 9U7) 132 kV line on trip of the other Lismore to Dunoon line (9U7 or 9U6) 132 kV line* See Table 7 for comments
N^^V_BUDP_2	$73,214 (0)	3.9 (0)	*Out = Buronga to Darlington Point 220 kV line, avoid voltage collapse for loss of a Dederang to Murray 330 kV line* See Table 14 for comments
N^^Q_NIL_B1, 2, 3, 4, 5, 6 & N^Q_NIL_B	$73,013 ($9,548)	102.7 (80.6)	*Out = Nil, avoid voltage collapse for loss of the largest Queensland generator* See Table 7 for comments
N_X_MBTE2_A	$55,884 ($379)	43.2 (26.1)	*Out = two Directlink cables, NSW to Queensland limit* See Table 7 for comments
NQTE_ROC	$44,818 ($12,249)	25.0 (13.8)	*Out = Nil, rate of change (NSW to Queensland) limit (80 MW / 5 minute) for Terranora interconnector* See Table 7 for comments
N>N-EWMB_TE_A	$43,648	40.4	*Out = Ballina to Lennox Head 66 kV line, avoid*

EQUATION ID (SYSTEM NORMAL IN BOLD)	∑MARGINAL VALUES	HOURS (2011)	*DESCRIPTION* / NOTES
	($93)	(1.1)	*overloading Lismore to Dunoon 132 kV line on trip of the other Lismore to Dunoon 132 kV line* See Table 7 for comments
N_X_MBTE_3A & N_X_MBTE_3B	$39,316 (0)	503.1 (0)	*Out = all three Directlink cables* See Table 3 for comments
N>>N-X_DTMN_LDTM_02	$28,675 (0)	2.9 (0)	*Out = Dapto to Marulan (8) and Liddell to Tomago (82), avoid overloading Marulan to Avon (16) on Kangaroo Valley to Dapto (18)*
N_X_MBTE2_B	$28,321 ($27,574)	439.7 (767.1)	*Out = two Directlink cables, Queensland to NSW limit* See Table 8 for comments

10.3 Victoria

Table 24: Top 10 binding network constraint equations for Victoria

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
V::N_NILxxx	420 (1,132)	*Out = Nil, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 3 for comments
V_T_NIL_FCSPS	325 (193)	*Basslink limit from Victoria to Tasmania for load enabled for the Basslink frequency control special protection scheme (FCSPS)* See Table 3 for comments
V>>V_NIL_2A_R & V>>V_NIL_2B_R & V>>V_NIL_2_P	164 (207)	*Out = Nil, avoid overloading the South Morang 500/330 kV (F2) transformer for no contingencies, for radial/parallel modes and Yallourn W1 on the 500 or 220 kV* See Table 3 for comments
VS_HYTS_TX	101 (15)	*Upper transfer limit from Victoria to SA on Vic-SA based on Heywood transformer 30 minute rating and tertiary winding MW load* See Table 15 for comments
V_T_NIL_BL1	53 (64)	*Out=Nil, Basslink no go zone limits Victoria to Tasmania*
V>S_NIL_HYTX_HYTX	48 (0)	*Out = Nil, avoid overloading the remaining Heywood 275/500 kV transformer on trip of one Heywood 275/500 kV transformer*
V::N_HWSM_xxx	48 (6)	*Out = Hazelwood to South Morang 500 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 13 for comments
V>>V_NIL1A_R	47 (159)	*Out = Nil, avoid overloading a South Morang to Dederang 330 kV line for trip of the parallel line* See Table 13 for comments
V::N_HYSE_xxx	42 (14)	*Out = Heywood to South East 275 kV line, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* See Table 10 for comments

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
VS_250	39 (76)	*Victoria to South Australia on Heywood upper transfer limit of 250 MW* See Table 15 for comments

Table 25: Top 10 market impact constraint equations for Victoria

EQUATION ID (SYSTEM NORMAL IN BOLD)	∑MARGINAL VALUES	HOURS (2011)	*DESCRIPTION* / NOTES
V>>V_NIL_1B	$199,598 ($36,520)	7.3 (29.6)	*Out = Nil, avoid overloading Dederang to Murray #2 330 kV line for trip of the Dederang to Murray #1 330 kV line* See Table 6 for comments
NSA_V_BDL0xxx	$186,792 ($811,280)	1.3 (6.3)	*Bairnsdale Unit 1 or 2 >= various levels for Network Support Agreement* See Table 6 for comments
V>V_HWTS_TX3_3-5_MOD	$184,356 ($71,137)	15.8 (6.0)	*Out = Hazelwood #3 or #4 500/220 kV transformer, 3-5 Parallel, Jeeralang split with JLGS A connected to Hazelwood #3 or #4 220 kV bus, avoid overloading Rowville to Yallourn #5, #6, #7or #8 220 kV lines for loss of Hazelwood #4 or #3 500/220 kV transformer* See Table 6 for comments
V_T_NIL_FCSPS	$94,121 ($37,663)	325.4 (192.8)	*Basslink limit from Victoria to Tasmania for load enabled for the Basslink frequency control special protection scheme (FCSPS)* See Table 3 for comments
V>>SML_NIL_1	$92,355 ($8,633)	3.3 (1.1)	*Out = Nil, avoid overloading Ballarat to Moorabool #1 220 kV line on trip of parallel #2 line*
V>SMLBAHO4	$73,526 ($73)	11.9 (3.5)	*Out = Ballarat to Horsham or Bendigo to Kerang line, avoid overloading Buronga to Redcliffs (0X1) line for trip of Bendigo to Kerang, or Ballarat to Horsham line*
V_HYML1_4	$62,545 ($12,538)	0.5 (0.3)	*Out = Heywood to Tarrone, or Tarrone to Moorabool #1 500 kV line, limit voltage unbalance at the APD 500 kV bus, one Mortlake unit in service*
V_HYMO2_1	$56,365 ($499,601)	2.8 (3.8)	*Out = Heywood to Mortlake #2 500 kV line, limit voltage unbalance at the APD 500 kV bus, one Mortlake unit in service*
V>SML_BUDP_2	$48,799 (0)	31.5 (0)	*Out = Buronga to Balranald to Darlington Pt. (X5) 220 kV line, avoid overloading on Horsham to Waubra 220 kV line section on trip of Bendigo to Kerang 220 kV line* See Table 17 for comments
V_HYML1_2	$38,731 (0)	0.3 (0)	*Out = Heywood to Tarrone, or Tarrone to Moorabool #1 500 kV line, limit voltage unbalance at the APD 500 kV bus, one Mortlake unit in service*

10.4 South Australia

Table 26: Top 10 binding network constraint equations for South Australia

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
S>>V_NIL_SETX_SETX	444 (207)	*Out = Nil, avoid overloading a South East 275/132 kV transformer on trip of the remaining South East 275/132 kV transformer* See Table 3 for comments
SVML_000	283 (69)	*South Australia to Victoria on Murraylink upper transfer limit of 0 MW* See Table 3 for comments
V^^S_NIL_MAXG_xxx	244 (1,121)	*Out = Nil, Victoria to SA long term voltage stability limit for loss of the largest credible generation contingency in SA, South East capacitor bank on / off* See Table 3 for comments
S>VML_NWCB6033_TX2	210 (6)	Out = North West Bend CB6033, avoid overloading North West Bend #2 132/66 kV transformer on trip of North West Bend to Monash #2 132 kV line See Table 3 for comments
S>V_X_6021+6022_TX2	184 (0)	*Out = North West Bend CB6021 & CB6022, avoid overloading North West Bend #2 132/66 kV transformer on trip of North West Bend to Robertstown #1 132 kV line* See Table 3 for comments
S>V_CB6024+6023_TX2	128 (0)	*Out = North West Bend CB6024 and CB6023, avoid overloading North West Bend #2 132/66 kV transformer on trip North West Bend #3 132/66 kV transformer* See Table 3 for comments
V>>S_HYML_1	107 (40)	*Out = Heywood to Moorabool to Alcoa Portland 500 kV line, avoid overloading Heywood 500/275 kV (M1 or M2) transformer for trip of Northern Power Station unit 1* See Table 15 for comments
V::S_SETB_SETB	86 (0)	*Out = South East to Tailem Bend 275 kV line, avoid transient instability for loss of the parallel South East to Tailem Bend 275 kV line* See Table 15 for comments
S_LB3_0	83 (18)	*Discretionary upper limit for Lake Bonney 3 generation of 0 MW* See Table 6 for comments
S>V_NIL_NIL_RBNW	73 (175)	*Out = Nil, avoid overloading the North West Bend to Robertstown 132 kV line on no line trips* See Table 18 for comments

Table 27: Top 10 market impact constraint equations for South Australia

EQUATION ID (SYSTEM NORMAL IN BOLD)	∑MARGINAL VALUES	HOURS (2011)	*DESCRIPTION* / NOTES
S_PLN_ISL1	$1,361,364 (0)	9.3 (0)	*Out = Whyalla to Yadnarie 132 kV line, Port Lincoln units 1 and 2 islanded* See Table 6 for comments
S_PLN_ISL2	$1,178,809 ($156,568)	21.4 (3.4)	*Out = Yadnarie to Port Lincoln 132 kV line, Port Lincoln units 1 and 2 islanded* See Table 6 for comments
S_PLN_ISL31	$451,567 (0)	8.1 (0)	*Out = Whyalla to Yadnarie 132 kV line, Port Lincoln unit #3 islanded* See Table 6 for comments
S_HALWF_0	$385,130 ($68,905)	31.3 (5.4)	*Discretionary upper limit for Hallett wind farm generation of 0 MW* See Table 6 for comments
S_LB3_0	$244,861 ($128,661)	83.5 (17.7)	*Discretionary upper limit for Lake Bonney 3 generation of 0 MW* See Table 6 for comments
S_PF_4_UNITS	$179,452 ($76,113)	14.6 (6.2)	*Out = 4 Playford generators, upper limit on Playford generation of 0MW* See Table 6 for comments
S>>V_NIL_RBTXW_RBTX1	$158,347 ($17,083)	48.3 (123.7)	*Out = Nil, avoid overloading Robertstown #1 275/132 kV transformer on trip of the Robertstown #2 275/132 kV transformer* See Table 6 for comments
S>>V_NIL_SETX_SETX	$156,867 ($76,861)	444.1 (206.5)	*Out = Nil, avoid overloading a South East 275/132 kV transformer on trip of the remaining South East 275/132 kV transformer* See Table 3 for comments
S^CMWF_30	$142,790 (0)	24.1 (0)	*Out = Brinkworth to Redhill 132 kV line (Redhill to Bungama 132 kV line section in service), avoid voltage collapse on trip of Bungama 275/132 kV transformer*
S>V_NIL_NIL_RBNW	$113,505 ($478,247)	69.4 (175.3)	*Out = Nil, avoid overloading the North West Bend to Robertstown 132 kV line on no line trips* See Table 18 for comments

10.5 Tasmania

Table 28: Top 10 binding network constraint equations for Tasmania

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
T_TAMARCCGT_GCS	911 (647)	*Limit output of Tamar Valley Power Station based on load available for shedding by Tamar Valley 220 kV generation control scheme (GCS)* See Table 3 for comments
T>T_NIL_BL_IMP_6E	234 (1)	*Out = Nil, avoid overloading Sheffield to Georgetown No. 1 220 kV line (flow to Georgetown) on trip of the Sheffield to Georgetown No. 2 220 kV line with no SPS action*

EQUATION ID (SYSTEM NORMAL IN BOLD)	HOURS (2011)	*DESCRIPTION* / NOTES
		See Table 3 for comments
T>>T_NIL_NCSPS6_1	125 (2)	*Out = Nil, ensure Basslink is able to fully compensate fast NCSPS action from Western NCSPS generation* See Table 3 for comments
T>T_GTSH_IMP_4K	83 (0)	*Out = Sheffield to Georgetown 220 kV line, avoid overloading Palmerston to Sheffield 220 kV line (flow to Palmerston) for trip of remaining Sheffield to Georgetown 220 kV line with no NCSPS action*
T>T_NIL_BL_IMP_7C	64 (3)	*Out = Nil, avoid overloading Farrell to Sheffield #1 220 kV line for trip of the Farrell to Sheffield #2 220 kV line with no SPS action*
T>T_NIL_NCSPS5_6E	59 (18)	*Out = Nil, avoid overloading the line terminal equipment of the Sheffield to Georgetown #1 220 kV line (flow to North) for trip of the Sheffield to Georgetown #2 220 kV line*
T_LIPM_PMWA_2_N-3	40 (0)	*Out = Nil, loss of both Liapootah to Waddamana (tee) to Palmerston 220 kV lines and Palmerston to Waddamana 110 kV line classified credible, limit southern generators to >= southern load - 15 MW*
T>T_GTHA_IMP_4L	33 (0)	*Out = Hadspen to Georgetown 220 kV line, avoid overloading Sheffield to Georgetown #1 220 kV line (flow to Georgetown) for trip of Sheffield to Georgetown #2 220 kV line with no NCSPS action*
T>T_NIL_BL_110_8	29 (45)	*Out = Nil, avoid overloading the New Norfolk to Creek Road 110 kV line (flow to south) for loss of the New Norfolk to Chapel St 110 kV line*
T>T_NIL_BL_IMP_5F	27 (0)	*Out = Nil, avoid overloading Hadspen to Georgetown #1 220 kV line (flow to North) for trip of the Hadspen to Georgetown #2 220 kV line with no SPS action*

Table 29: Top 10 market impact constraint equations for Tasmania

EQUATION ID (SYSTEM NORMAL IN BOLD)	∑MARGINAL VALUES	HOURS (2011)	*DESCRIPTION* / NOTES
T_TAMARCCGT_GCS	$214,829 ($149,210)	911.3 (646.8)	Limit output of Tamar Valley Power Station based on load available for shedding by Tamar Valley 220 kV generation control scheme (GCS) See Table 3 for comments
T>T_NIL_BL_IMP_6E	$65,499 ($55)	234.3 (0.7)	*Out = Nil, avoid overloading Sheffield to Georgetown No. 1 220 kV line (flow to Georgetown) on trip of the Sheffield to Georgetown No. 2 220 kV line with no SPS action* See Table 3 for comments
T_X_PMSH+GTSH_1	$29,772 (0)	1.9 (0)	*Out = Palmerston to Sheffield 220 kV line and one Georgetown to Sheffield 220 kV line, limit West Coast + Sheffield generation <= West Coast + North West load + 10MW, limiting Georgetown to Sheffield line flow to 10 MW*
T>>T_PMSH_EXP_3B	$29,416 (0)	0.3 (0)	*Out = Palmerston to Sheffield 220 kV line, avoid overloading Hadspen to Georgetown 220 kV line (flow North) for trip of the other Hadspen to Georgetown 220 kV line considering NCSPS action, ensure Basslink can compensate NCSPS action to remove overload.*
T>>T_NIL_NCSPS6_1	$22,534 ($435)	124.6 (2.4)	*Out = Nil, ensure Basslink is able to fully compensate fast NCSPS action from Western NCSPS generation*

EQUATION ID (SYSTEM NORMAL IN BOLD)	∑MARGINAL VALUES	HOURS (2011)	*DESCRIPTION* / NOTES
			See Table 3 for comments
T>T_NIL_BL_IMP_1B	$21,712 (0)	4.8 (0)	*Out = Nil, avoid overloading either Gordon to Chapel St 220 kV line for trip of the other Gordon to Chapel St 220 kV line with no SPS action*
T>T_NIL_BL_IMP_7C	$20,781 ($293)	63.9 (3.4)	*Out = Nil, avoid overloading Farrell to Sheffield #1 220 kV line for trip of the Farrell to Sheffield #2 220 kV line with no SPS action*
T>T_GTSH_IMP_4K	$12,631 (0)	83.2 (0)	*Out = Sheffield to Georgetown 220 kV line, avoid overloading Palmerston to Sheffield 220 kV line (flow to Palmerston) for trip of remaining Sheffield to Georgetown 220 kV line with no NCSPS action*
T>T_NIL_NCSPS5_6E	$12,435 ($1,637)	59.2 (17.7)	*Out = Nil, avoid overloading the line terminal equipment of the Sheffield to Georgetown #1 220 kV line (flow to North) for trip of the Sheffield to Georgetown #2 220 kV line*
T>T_GTSH_220_1_N-2	$12,044 ($1,647)	11.3 (5.6)	*Out = Nil, loss of both Georgetown to Sheffield 220 kV lines declared credible, avoid overloading the Sheffield to Palmerston 220 kV line (flow to south) for loss of both Georgetown to Sheffield 220 kV lines*