NEM CONSTRAINT REPORT 2016

FOR THE NATIONAL ELECTRICITY MARKET

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AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

IMPORTANT NOTICE

Purpose

AEMO has prepared this document to provide information about constraint equation performance and related issues, as at the date of publication. It provides electricity market professionals with an overview of the trends that affect the amount and value of congestion in the NEM.

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EXECUTIVE SUMMARY

AEMO uses constraint equations to model power system congestion in the National Electricity Market dispatch engine (NEMDE), and projected assessment of system adequacy (PASA). Constraint equations can have an impact on pricing and dispatch in the electricity market. AEMO publishes this report annually to provide market participants with information about changes in congestion patterns, comparing last year's outcome with those of the previous five years.

This report details constraint equation performance, and issues related to transmission congestion for the 2016 calendar year.

Key Insights

The 2016 calendar year experienced the second largest number of constraint equation changes since the start of the National Electricity Market (NEM) (see chapter 2). This was mainly due to the constraint equation changes associated with the upgrade of the Heywood Interconnector between Victoria and South Australia.

The binding hours in 2016 were the largest seen in the past six years (see chapter 3). The increase can be attributed to the feeder bushing limit at Boyne Island, new constraint equations in South Australia following the black system event, and Tasmanian frequency control ancillary service (FCAS) constraint equations following the Basslink outage.

South Australian constraint equations dominated the top 20 market impact constraint equations. This was driven by constraint equations for 35 MW of regulation FCAS and network constraint equations in South Australia (which were in place for the Heywood interconnector upgrade project). The increase in regulation FCAS from 2015 was $8.7 million for the regulation FCAS (see section 4.2).

Table 1: Constraint equation changes and market impact in the past six years

Year	Constraint changes	Market impact ($/MW/DI)
2011	4,776	$21.3 million
2012	4,130	$30.3 million
2013	5,817	$37.5 million
2014	8,121	$30.5 million
2015	11,967	$46.6 million
2016	10,477	$63.3 million

The performance of the interconnectors was relatively consistent between 2015 and 2016, with three exceptions:

- The flows on the Queensland to New South Wales interconnector (QNI) increased in the direction of New South Wales to Queensland, a change from previous years.
- Basslink was out of service due to physical damage for the first half of 2016
- The Heywood interconnector was uprated after the Black Range series capacitors were commissioned.

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1. CURRENT CONSTRAINT STATISTICS

On 31 December 2016, the total number of constraint sets, equations and functions available in AEMO's electricity market management system (MMS) were:

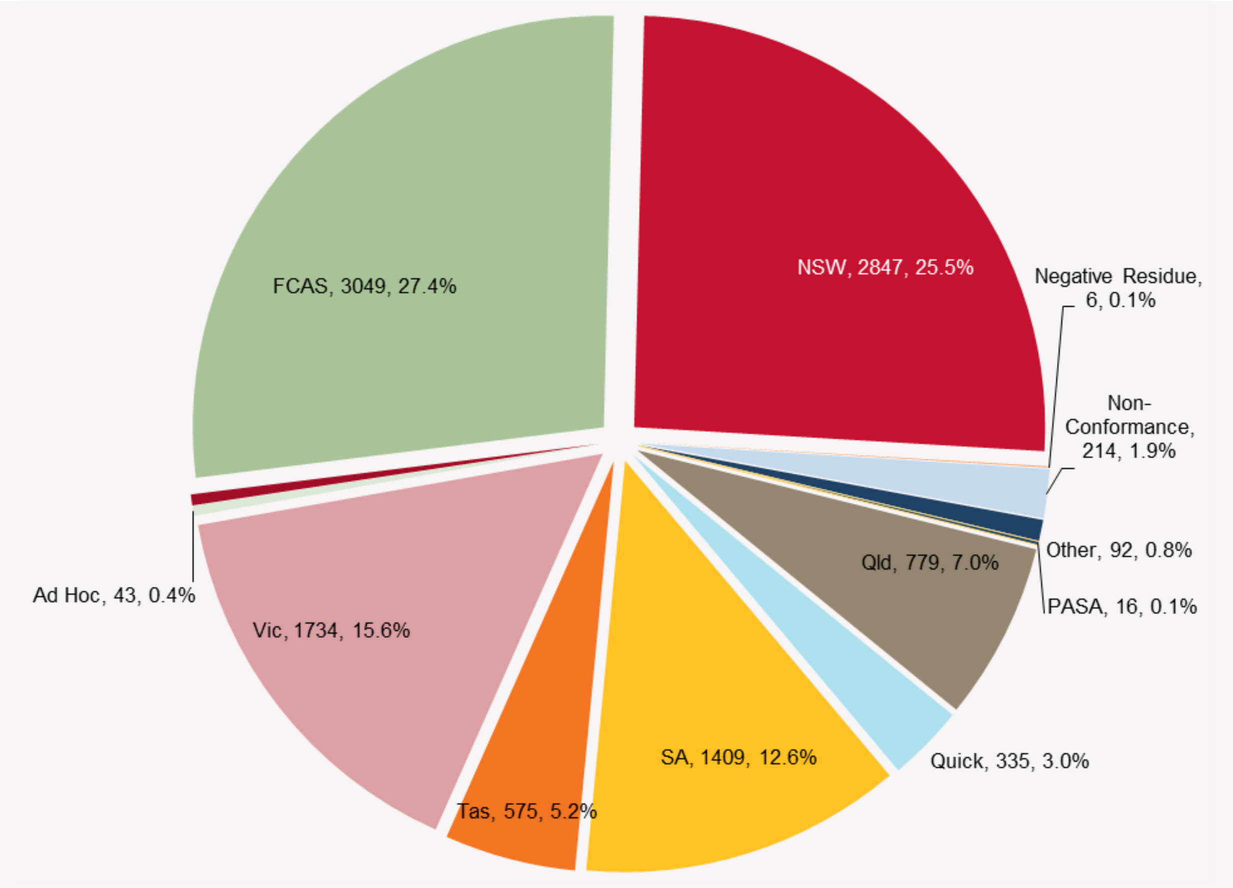
- 3,778 constraint sets – an increase of 149 from 3,629 in 2015.
- 11,660 constraint equations – an increase of 430 from 11,230 in 2015.
- 373 constraint functions – an increase of 9 from 364 in 2015.

Excluded from these totals are any constraint sets, equations or functions archived before December 2016, and any created by the outage ramping process.[1] Outage ramping constraint sets and equations are generated for single use by AEMO's control room staff, so are excluded from the above results.

Figures 1 and 2 exclude outage ramping and constraint automation-built constraint equations, to prevent the results being swamped. Also excluded are any constraint equations not in a constraint set (and therefore cannot be active in the NEMDE).

These figures show the breakup of constraint equations by region, FCAS, non-conformance and miscellaneous constraint types (Figure 1), and by limit type (Figure 2).

Figure 1 Constraint equations by region, FCAS, and other type



[1] Outage ramping constraint equations have IDs of the form #Rxxxxx_yyy_RAMP.

From Figure 1, it can be seen that the largest number of constraint equations are for FCAS, followed by New South Wales, and then Victoria.

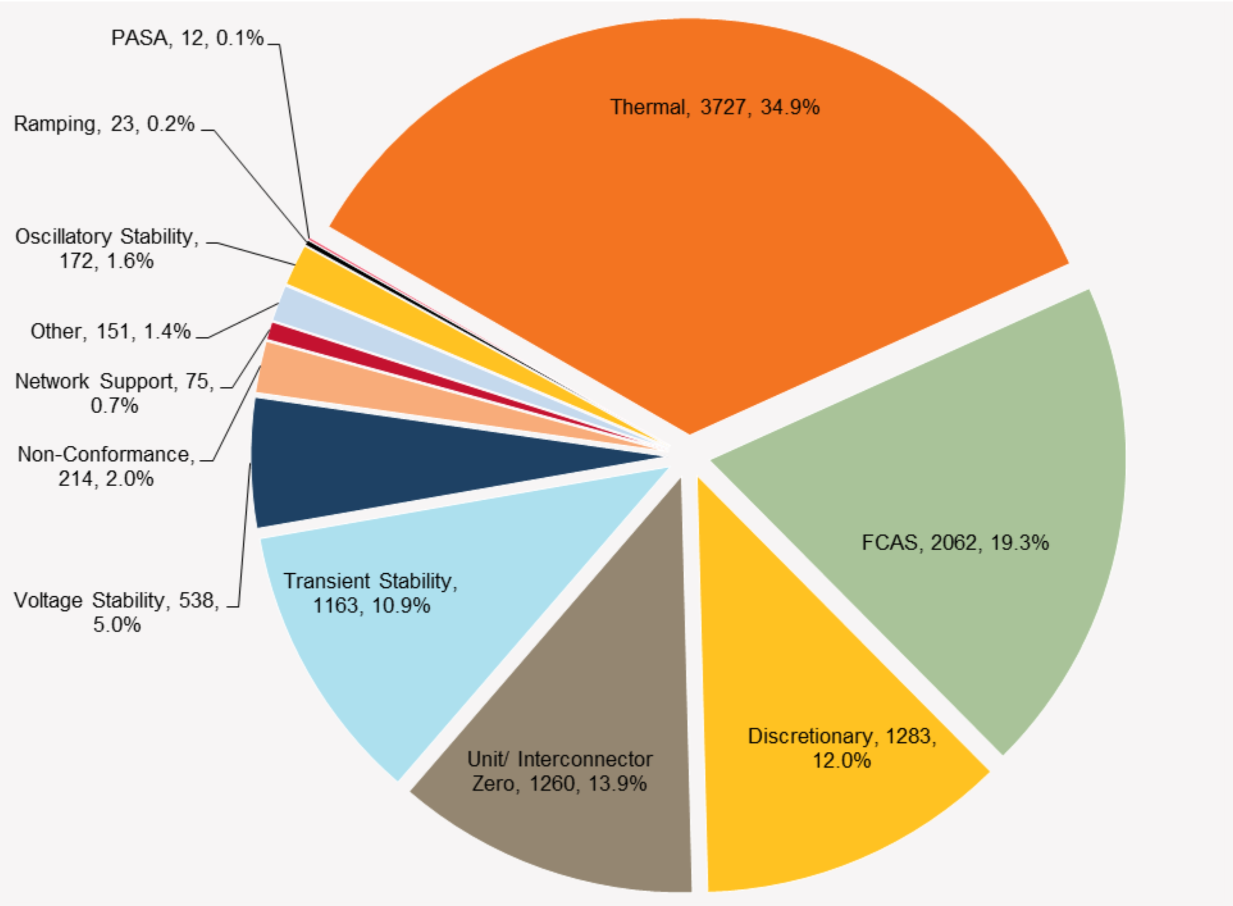
There were only a few changes to the breakup of the constraint equations in 2016, compared with the previous year, specifically:

- NSW increased from 2,580 to 2,847 (+267).
- Victoria increased from 1,677 to 1,734 (+57).
- South Australia decreased from 1,482 to 1,409 (-73).
- Total thermal constraint equations increased from 3,624 to 3,727 (+103). This is due to the increase in NSW and Victorian constraint equations.

Figure 2 below shows that the main types of constraint equations are for thermal overloads (35%) and FCAS (19.3%).

In Figure 2, "other" combines the constraint equations with the following limit types: Quality of Supply, Islanding–Unit, Region Separation, Negative Residue, Default, and rate of change of Frequency (RoCoF). Similarly "Unit/Interconnector Zero" combines the limit types Unit Zero–FCAS, Unit Zero, and "Interconnector Zero".

Figure 2 Constraint equations by limit type



2. CONSTRAINT EQUATION CHANGES

The main driver for either updating or creating new constraint equations is power system changes, i.e., plant additions or removals (either generation or transmission).

The tables in this chapter list transmission system and generator changes separately. Only changes on the main high voltage (greater than 110 kV) transmission system are listed, as these normally cause changes to the constraint equations.

In 2016, the number of constraint equation changes was the second highest since the start of the national electricity market (NEM). The major contributor to the high number of constraint equation changes was the Heywood upgrade project in South Australia.

2.1 Generators added or removed in 2016

The following list includes all scheduled and semi-scheduled generators either added to or removed from the power system in 2016. It also includes non-scheduled plant large enough to have caused constraint equation changes.

In 2016, a number of generators were de-registered in Victoria and South Australia; Morwell in Victoria and Northern and Playford in South Australia.

In Tasmania, a number of diesel generators were added temporarily due to the extended outage of Basslink following physical damage to undersea power cable.

There were two new generators registered; one solar farm in New South Wales (Moree Solar Farm) and one wind farm in South Australia (Hornsdale wind farm.)

Table 1 Generator changes in 2016

Generator	Registration Date	Region	Notes
Lonsdale GT	12 January 2016	SA	Re-registered as scheduled
Port Stanvac GT	12 January 2016	SA	Re-registered as scheduled
Moree Solar Farm	9 February 2016	NSW	New Generator
Catagunya Diesel	08 March 2016	Tasmania	New generator
Morwell (Units 1, 2 & 3 Aggregated)	11 March 2016	Victoria	Deregistered Generator
Morwell Unit 4	11 March 2016	Victoria	Deregistered Generator
Morwell Unit 5	11 March 2016	Victoria	Deregistered Generator
George Town Diesel #1	18 March 2016	Tasmania	New Generator. Deregistered on 27 June 2016
George Town Diesel #2	18 March 2016	Tasmania	New Generator. Deregistered on 27 June 2016
Meadowbank Diesel	18 March 2016	Tasmania	New Generator. Deregistered on 27 June 2016
Port Latta Diesel	29 March 2016	Tasmania	New Generator. Deregistered on 27 June 2016
Que River Diesel	14 April 2016	Tasmania	New generator. Deregistered on 27 June 2016
Bell Bay Diesel	11 May 2016	Tasmania	New generator. Deregistered on 23 August 2016
Angaston GT	27 May 2016	SA	Angaston GT registered to aggregated unit
Hornsdale Wind Farm	2 June 2016	SA	New Generator
Northern Unit 1	1 September 2016	SA	Deregistered
Northern Unit 2	1 September 2016	SA	Deregistered
Playford (4 Aggregated Units)	1 September 2016	SA	Deregistered

2.2 Transmission changes in 2016

In 2016, the number of transmission changes decreased compared to previous years mainly due to the smaller number of transmission changes in Queensland (historically the region with the most number of changes).

In 2016, for the first time since AEMO started producing this report (in 2009), most transmission changes were in South Australia.

Table 2 Transmission changes in 2016

Generator	Registration Date	Region	Notes
Adaptive Under Frequency Load Shedding Scheme (AUFLS)	29 January 2016	Tasmania	
Para Substation 275 kV Reactor	29 May 2016	SA	New Reactor
Mt Lock 275kV substation	15 June 2016	SA	New substation cut into Davenport to Canowie 275 kV line
Ararat Terminal Station (ARTS)	29 June 2016	Victoria	New substation cut into former Horsham to Waubra 220 kV line.
Ararat Wind Farm 132kV Transmission line	03 July 2016	Victoria	New 132kV Transmission line commissioned between Ararat Terminal Station – Ararat Wind Farm.
South East (SE) control scheme	05 July 2016	SA	This scheme is designed to limit overloading of either a South East 275/132 kV transformer or the South East Snuggery - Mayurra line following a contingency.
Keith to Snuggery 132 kV transmission line	15 July 2016	SA	Decommissioned
Tailem Bend to Keith No.1 132 kV transmission line	15 July 2016	SA	Decommissioned
Mackay to Proserpine 7125/2 132 kV transmission line	15 July 2016	Qld	Decommissioned
Mackay to Proserpine 7126/2 132 kV transmission line	28 July 2016	Qld	Decommissioned
Black Range Series Capacitors	5 August 2016	SA	Black Range series capacitors commissioned on the 275 kV lines between Tailem Bend and South East substations.
Bell Bay Circuit Breakers	20 October 2016	Tasmania	Commissioned 220 kV bus-tie circuit breaker and line circuit breaker at Bell Bay Aluminium.
Ballarat to Horsham 66kV tie split control scheme commissioning	23 December 2016	Victoria	New control scheme

2.3 Comparisons of constraint equation changes

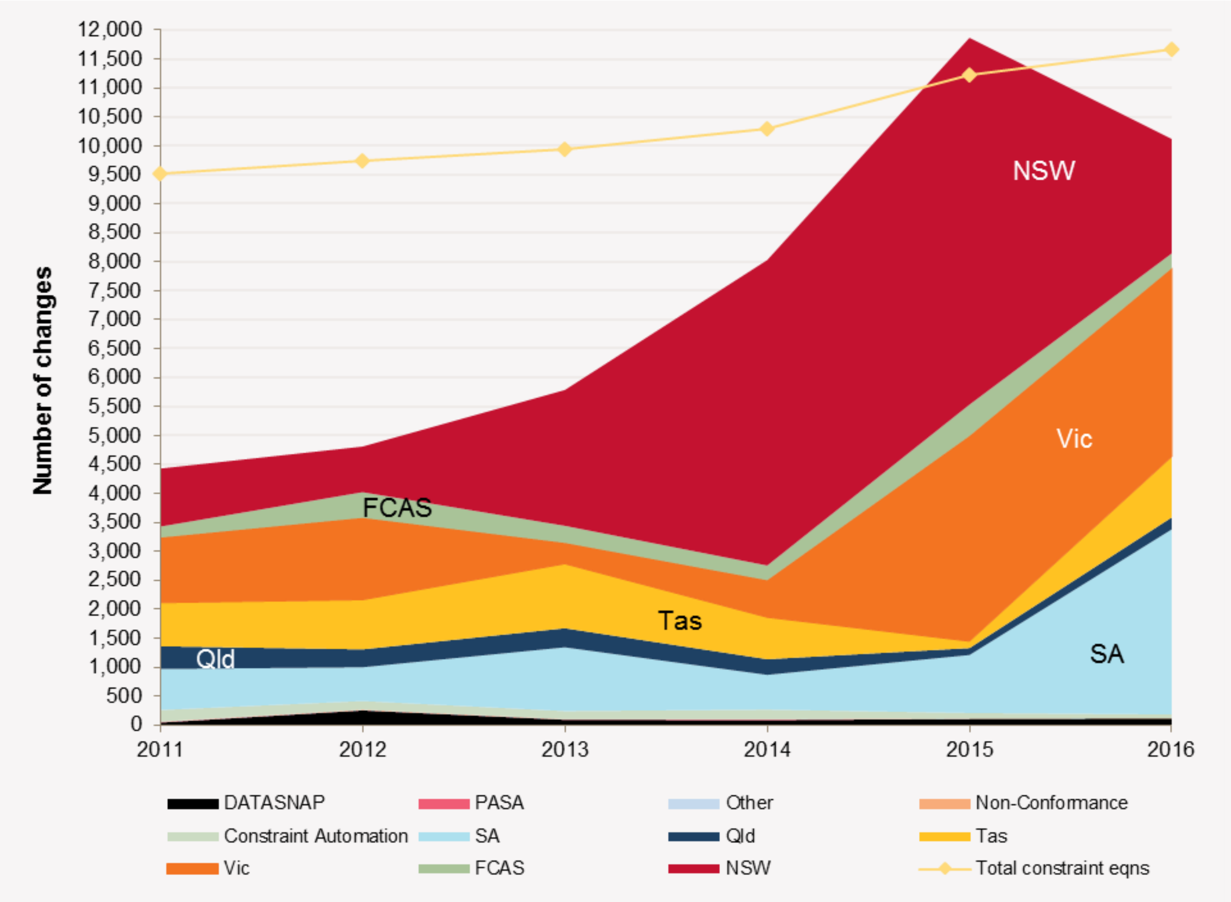
Figure 3 compares the annual constraint equation changes by region and the total number of constraint equations in the NEM each year.

It does not include changes to constraint sets, 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 simple description fixes, while others are more complex and require several days of work.

These results measure when the constraints were updated, not when they became active. For example, an FCAS change made active on 1 Jan 2009 but loaded into the database in late-2008, is included in the 2008 results, not the 2009 results.

The number of changes for 2013 does not include changes due to the constraint violation penalty factor (CVP) update in August 2013[2], which required 8,833 constraint equation updates. Nor does it include changes due to real time constraint automation.[3]

Figure 3 Constraint equation changes per calendar year, 2011 to 2016



As shown in Figure 3, 2016 had the second highest number of constraint equation changes (at 10,477) since the start of the NEM. The highest number of changes was 11,967 in 2015 which was mainly due to:

- Registration of solar farms in NSW, including at Broken Hill (and the work to include Nyngan continued in 2016).
- New wind farm at Bald Hill.
- The disaggregation of Laverton North and Valley Power.
- De-registration of Anglesea.

In 2016, South Australia and Victoria dominated with each 31% of the changes (up from 8% and 29% respectively in 2015) followed by NSW with 19% (down from 53% in 2015).

The 10,477 changes in 2016 were well above the 10-year average of 6,914. In the past five years, the number of changes was due to:

2 AEMO. *Schedule of CVP Factors*. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Congestion-information. Viewed: 8 March 2017.

3 AEMO. *Constraint Automation – Closing the Loop - Discussion Paper*. Available at:http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Congestion-information/Related-Resources/Constraint-Automation---Closing-the-Loop---Discussion-Paper. Viewed: 8 March 2017.

- 2013: changes to operating margins across multiple regions; Gullen Range Wind Farm in NSW; and Musselroe Wind Farm in Tasmania.
- 2014: de-registering Wallerawang and Munmorah; the new wind farms at Boco Rock and Taralga; and solar farm at Nyngan resulting in a high number of changes to New South Wales constraint equations.
- 2015: Registration of solar farms in NSW (the constraint equation work to include Nyngan continued in 2015) and a new solar farm at Broken Hill; new wind farm at Bald Hills; the disaggregation of Laverton North and Valley Power; and de-registration of Anglesea.
- 2016: Heywood interconnector upgrade project and associated transmission changes in South Australia.

3. BINDING

This chapter examines the top 20 binding constraint equations in 2016.

Definition: Binding Constraint
A constraint equation is binding when the power system flow it manages reach applicable thermal or stability limits, or when a constraint equation is setting an FCAS requirement. When a constraint equation is binding, NEMDE changes the generator and interconnector targets to satisfy the constraint equation. The market impact of this is discussed in Chapter 4.

Full descriptions, and the left hand side (LHS) and right hand side (RHS) terms of the constraint equations, can be obtained from either the plain English converter[4] or via the MMS data model[5].

At any time, at least one constraint equation is setting the requirement for each of the eight FCAS services. This leads to many more hours of binding for FCAS constraint equations. These would dominate the top 20 binding results, so FCAS and network binding results are separated into two tables (see Table 3 and Table 4 below).

In the tables below, system normal constraint equations are listed in bold, and the number of binding hours for 2015 (if any) is indicated in brackets below the 2016 hours. The tables also contain a brief description of the constraint equation (in italics) along with any comments.

Some constraint equations only bind at certain times of the year (such as winter or summer). Figure 4 shows a monthly breakdown for the top 10 binding network constraint equations.

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 New South Wales to Queensland voltage stability limit).
- Manage the same limit under different network configurations (such as Yallourn W1 switched into 500 kV or 220 kV mode).
- Combine different values of network support for the same generator(s).

Most of the top 20 binding results listed in Table 3 and Table 4 below are system normal constraint equations and not for outage cases.

3.1 Network constraint equations

Table 3 Top 20 binding network constraint equations

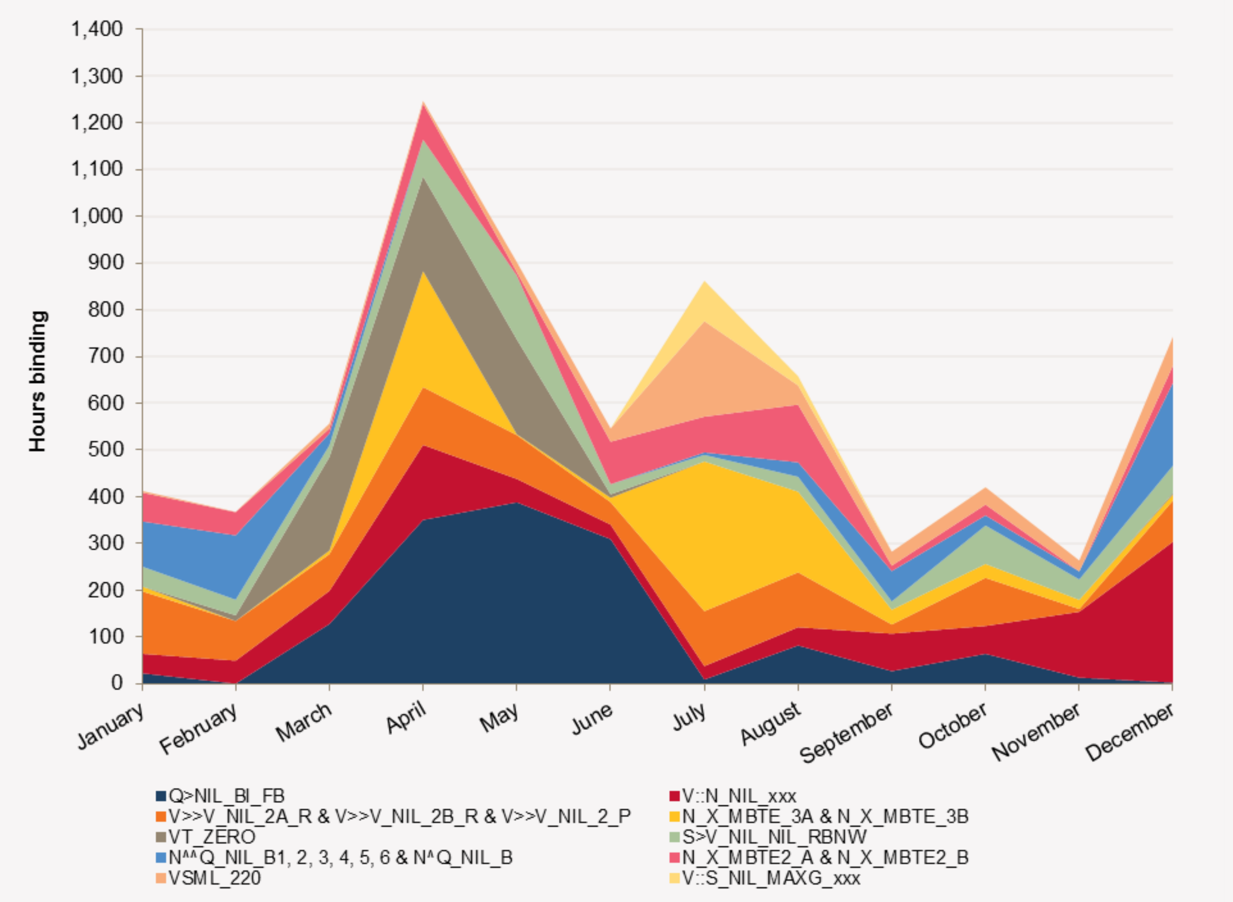
Constraint Equation ID (System Normal Bold)	2016 Hours (2015 Hours)	*Description* Notes
Q>NIL_BI_xxx	*1,409* *(259)*	*Out = Nil, avoid overloading on Boyne Island feeder bushing on Calliope River to Boyne Island 132 kV lines, for the contingent loss of a single Calliope River to Boyne Island 132 kV line* There are three constraint equations that make up the thermal limit on the Boyne Island feeder bushing (for each of the 132 kV network configurations). All the binding results have been combined.

[4] Available at: https://mms.prod.nemnet.net.au/Mms/login.aspx.
[5] Available at: http://www.aemo.com.au/About-the-Industry/Information-Systems/Data-Interchange

Constraint Equation ID (System Normal Bold)	2016 Hours (2015 Hours)	*Description* Notes
V::N_NIL_xxx	1,054 (1,091)	*Out = Nil, avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line* There are twelve constraint equations that make up the transient stability export limit from Victoria and all the binding results have been combined.
V>>V_NIL_2A_R & V>>V_NIL_2B_R & V>>V_NIL_2_P	1,015 (951)	*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.
N_X_MBTE_3A & N_X_MBTE_3B	865 (1,312)	*Out = all three Directlink cables* All three Directlink cables were out for 55.1 days in 2015 compared to 70.3 days in 2014. See Table 6
VT_ZERO	628 (8)	*Victoria to Tasmania on Basslink upper transfer limit of 0 MW*
S>V_NIL_NIL_RBN W	587 (452)	*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.
N^^Q_NIL_B1, 2, 3, 4, 5, 6 & N^Q_NIL_B	577 (177)	*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_X_MBTE2_A & N_X_MBTE2_B	569 (1,044)	*Out = two Directlink cables* Two Directlink cables were out for 251.4 days in 2015 compared to 169.8 days in 2014. See Table 6
VSML_220	468 (124)	*Upper transfer limit of 220 MW on VIC to SA on Murraylink*
V::S_NIL_MAXG_xx x	398 (243)	*Out = Nil, avoid transient instability for trip of the largest generation unit in South Australia* There are two constraint equations that make up the transient stability export limit from Victoria to South Australia and all the binding results have been combined.
V_S_NIL_ROCOF	393 (0)	*Out = Nil, limit Victoria to SA on Heywood flow to prevent Rate of Change of Frequency exceeding 3 Hz/sec in SA immediately following loss of Heywood interconnector.* This constraint equation was introduced in 2016 on advice from the South Australian government that the RoCoF needed to be limited to 3 Hz/sec.
V>>N-NIL_HA	368 (36)	*Out = Nil, avoid overload on Murray to Upper Tumut (65) 330 kV line on trip of Murray to lower Tumut (66) 330 kV line*
VSML_ZERO	302 (81)	*Victoria to South Australia on Murraylink upper transfer limit of 0 MW* This constraint equation is normally invoked for Murraylink out of service. The Limit Murraylink to zero in either direction was out for 6.6 days in 2015 compared to 10.0 days in 2014. See Table 6
VS_250_DYN	245 (18)	*Victoria to SA on Heywood upper transfer limit of 250 MW. Limit is dynamically reduced when actual flow exceeds limit by at least 10 MW. Limit is reduced by amount of exceedance, capped at 25 MW* One Heywood to South East 275 kV line was out for 28.3 days in 2015 compared to 4.9 days in 2014. See Table 6

Constraint Equation ID (System Normal Bold)	2016 Hours (2015 Hours)	*Description* Notes
V::S_TB_275KV_W_B_1	232 (0)	*Out= Tailem Bend 275 kV West Bus; Vic to SA transient stability limit for loss of the parallel South East - Tailem Bend line (South East Capacitor available)*
S-STTX_SNWF	210 (1)	*Out = Snowtown 132/33 kV transformer or Snowtown CB4593 or CB6265, limit Snowtown windfarm generation to 0 MW*
V:S_600_HY_TEST_DYN	182 (0)	*VIC to SA on Heywood upper transfer limit of 600 MW, limit for testing of Heywood interconnection upgrade, dynamic headroom, DS formulation only.*
V^S_NIL_SA_RECLASS	179 (0)	*Out = Nil, limit generation in SA to prevent flow on Heywood interconnector exceeding 700 MW following reduction in MW output from multiple generating units in SA.* *This constraint equation was revoked on 24 December following changes to SA windfarm protection settings.*
SVML_ZERO	174 (67)	*Upper transfer limit of 0 MW on SA to VIC on Murraylink* The Limit Murraylink to zero in either direction was out for 6.6 days in 2015 compared to 10.0 days in 2014. See Table 6
V::S_NIL_TBSE	166 (21)	*Out = Nil; Vic to SA Transient Stability limit for loss of one of the Tailem Bend-South East 275kV lines (South East Capacitor Available).*

Figure 4 Top 10 binding constraint equations per month



3.2 Frequency Control Ancillary Service

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

Table 4 Top 20 binding FCAS constraint equations

Constraint Equation ID (System Normal Bold)	2016 Hours (2015 Hours)	*Description* Notes
F_T+LREG_0050	4,177 (747)	*Tasmania lower regulation requirement greater than 50 MW, Basslink unable to transfer FCAS*
F_T+RREG_0050	4,175 (802)	*Tasmania raise regulation requirement greater than 50 MW, Basslink unable to transfer FCAS*
F_MAIN+NIL_MG_R6	4,170 (1,202)	*Out = Nil, raise 6 sec requirement for a Mainland generation event, Basslink unable transfer FCAS*
F_MAIN+NIL_MG_R5	4,170 (1,200)	*Out = Nil, raise 5 min requirement for a Mainland generation event, Basslink unable transfer FCAS*
F_MAIN+NIL_MG_R60	4,170 (1,200)	*Out = Nil, raise 60 sec requirement for a Mainland generation event, Basslink unable transfer FCAS*
F_I+NIL_MG_R5	4,108 (7,338)	*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_MAIN+APD_TL_L5	4,087 (1,257)	*Mainland lower 5 min Service Requirement for the loss of APD potlines, Basslink unable to transfer FCAS*
F_MAIN+APD_TL_L60	4,079 (1,250)	*Mainland lower 60 sec Service Requirement for the loss of APD potlines, Basslink unable to transfer FCAS*
F_MAIN+NIL_DYN_LREG	4,040 (501)	*Mainland lower regulation requirement, increase by 60 MW for each 1s of time error above 1.5s, Basslink unable transfer FCAS*
F_T+NIL_TL_L6	3,974 (1,068)	*Tasmania lower 6 second requirement for loss of 2 Comalco potlines, Basslink unable to transfer FCAS*
F_T+NIL_TL_L60	3,972 (1,068)	*Tasmania lower 60 second requirement for loss of 2 Comalco potlines, Basslink unable to transfer FCAS*
F_I+NIL_MG_R6	3,955 (7,102)	*NEM raise 6 second requirement for a NEM generation event*
F_I+NIL_MG_R60	3,886 (6,974)	*NEM raise 60 second requirement for a NEM generation event*
F_MAIN+ML_L6_0400	3,591 (1,213)	*Out = Nil, lower 6 sec requirement for a Mainland load event, ML = 400, Basslink unable transfer FCAS*
F_T+NIL_TL_L5	3,245 (1,068)	*Tasmania lower 5 minute requirement for loss of 2 Comalco potlines, Basslink unable to transfer FCAS*
F_I+NIL_APD_TL_L5	3,203 (4,626)	*NEM lower 5 min Service Requirement for the loss of APD potlines*
F_I+NIL_APD_TL_L60	3,141 (3,724)	*NEM lower 60 sec Service Requirement for the loss of APD potlines*
F_I+NIL_DYN_LREG	3,042 (3,935)	*NEM lower regulation requirement*
F_I+NIL_DYN_RREG	3,019 (767)	*NEM raise regulation requirement*
F_T+NIL_MG_R6	2,952 (2,139)	*Tasmania raise 6 second requirement for a Tasmania generation event, Basslink unable to transfer FCAS*

3.3 Binding Trends: 6 Year Comparison

Figure 5 and Figure 6 show the binding constraint equations for the past six years, categorised by region, and whether the system is normal or in outage. Note that both figures exclude binding FCAS hours, because FCAS constraints bind frequently and would otherwise dominate the graphs. Also, specific to Figure 5, in most cases, FCAS cannot be attributed to a single region.

Figure 5 indicates a number of trends in each region:

- Total binding hours in 2016 was the highest in the past five years.
- Victoria had the highest number of binding hours in 2016 and the highest in the past five years (at 6,854 hours) The high binding hours in 2016 were mainly due to:
  - High binding hours for the transient export limit constraint equation (V::N_NIL_xxx). This remained unchanged from 2015 – see Figure 12.
  - A large increase in hours of flow from Victoria to Tasmania (see Figure 11). This is because Basslink was out of service and VT_ZERO constraint.
  - An increase in export into South Australia (see Figure 13) increased the binding hours of VSML_220 and the new V_S_NIL_ROCOF constraint.
- The region with the second highest binding hours in 2016 was South Australia (at 3,995 hours). It was also a peak in binding hours in the past five years (previous highest was 3,383 hours in 2015). This was mainly due to:
  - The transient stability limit for loss of the largest South Australian generator (V::S_NIL_MAXG_xxx) increasing binding hours from 243 in 2015 to 398 hours in 2016.
  - An increase in binding hours (from 452 to 587 hours) for the North West Bend to Robertstown overload constraint equation (S>V_NIL_NIL_RBNW).
  - Outage constraints of V::S_TB_275KV_W_B_1 for outage of Tailem Bend 275kV West Bus bound for 232 hours. This outage was related to Heywood upgrade project.
  - Outage constraint equation S-STTX_SNWF (for outage of Snowtown 132/3 3kV transformer) bound for 210 hours.
  - The new V^S_NIL_SA_RECLASS constraint equation (added after the South Australian Black system event) bound for 179 hours. This was revoked on 24 December 2016.
- Queensland had 1,756 binding constraint hours in 2016, much higher than the record low of 913 hours in 2015.
  - This was due to the constraint equation for the thermal overload on the Boyne Island feeder bushing increasing binding constraint hours to 1,409 in 2016 from 259 hours in 2015.
- The Tasmanian binding hours peak in 2013 was due to the commissioning of the Musselroe wind farm.

Figure 5 Binding constraint equations by region

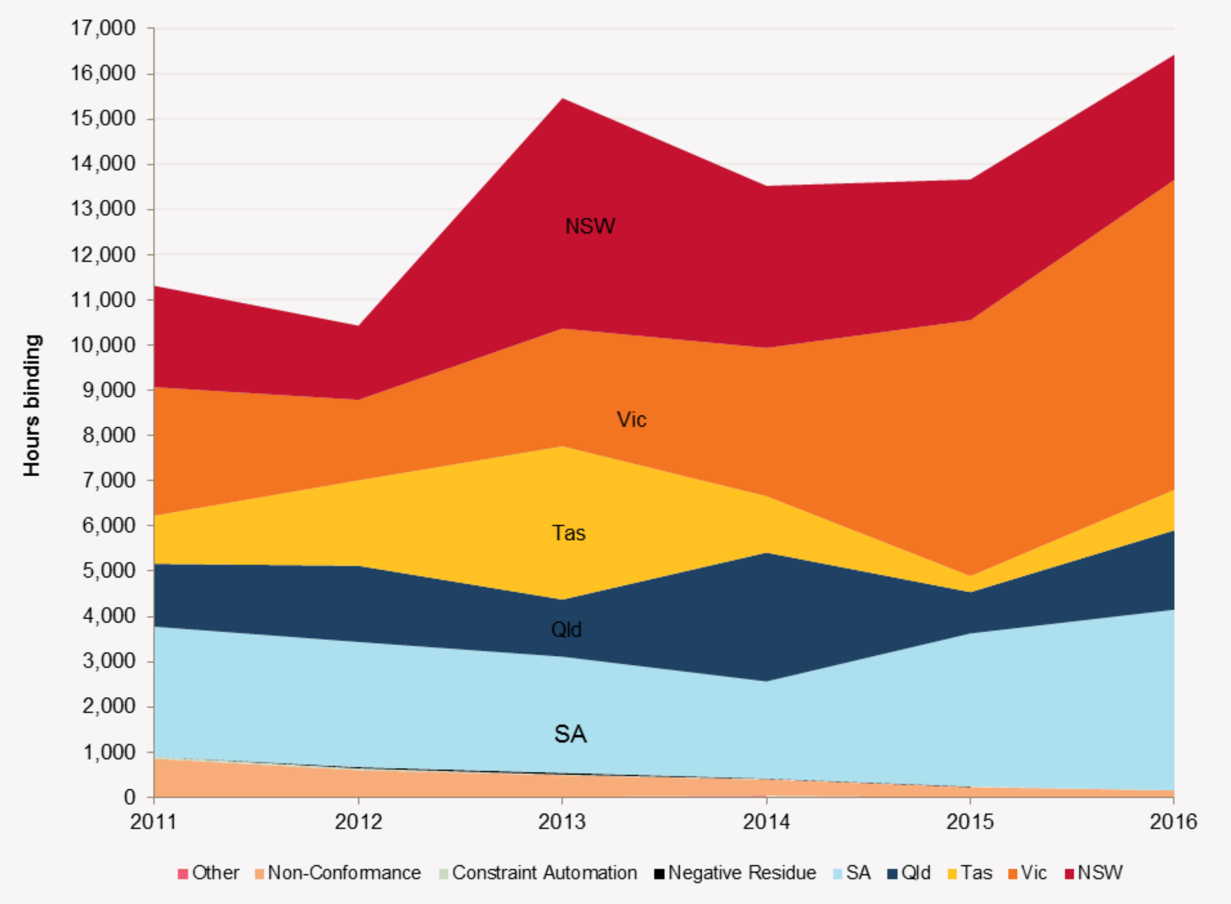
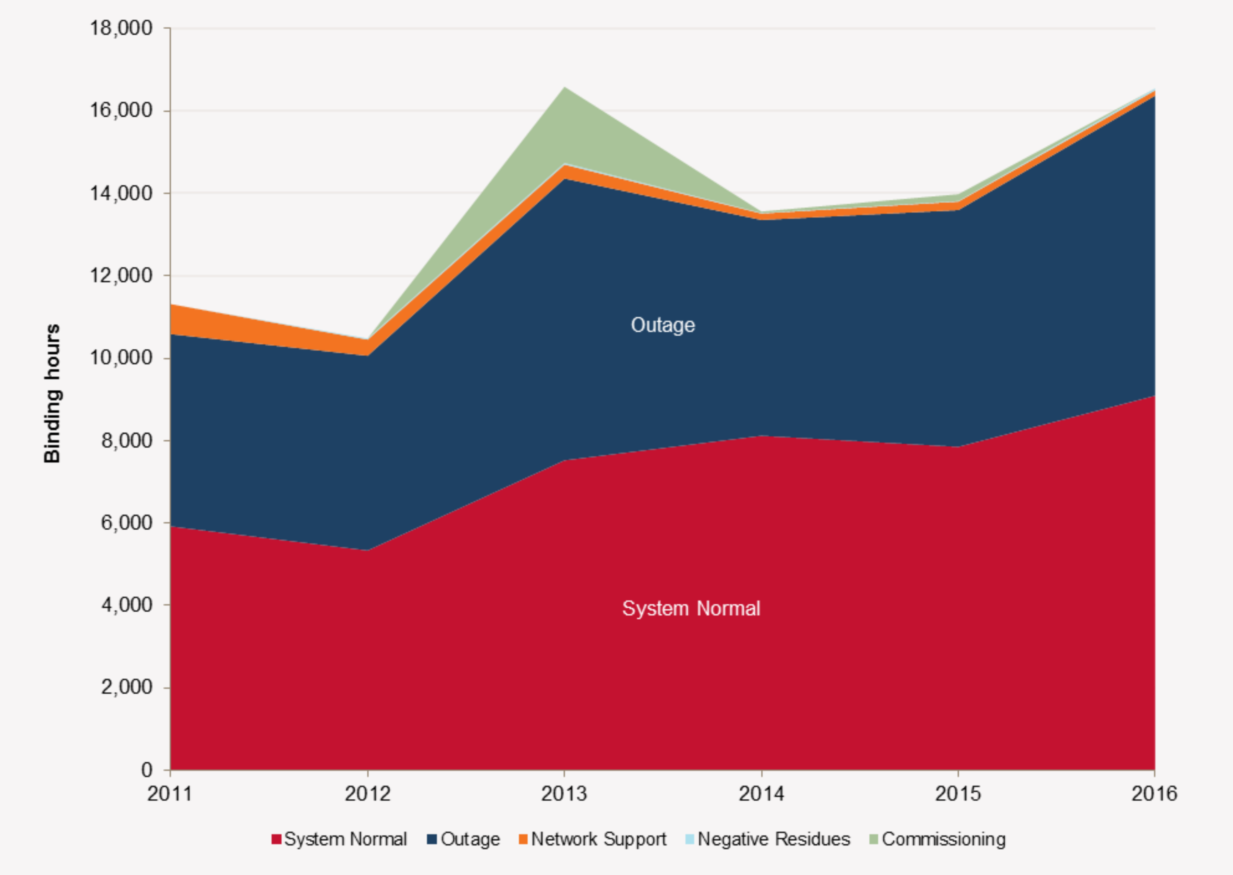


Figure 6 shows the trends regarding the category of constraints (system normal, outage):

- System-normal binding hours in 2016 were the highest in the past five years (at 9,090 hours).
- Outage binding hours were the highest in the past five years at 7,285 hours.

Figure 6 Binding constraint equations by category (system normal; outages)



3.4 Binding Insights

The feeder bushing limit at Boyne Island (Q>NIL_BI_xxx) increased its binding constraint hours to 1,409 in 2016 from 259 hours in 2015. Most of these binding hours were between March and June 2016. When there is high generation on Gladstone unit 3 and 4 (the only generators on the LHS) it is likely that the constraint will bind or violate.

A number of constraint equations were added in 2016 to manage the power system following the blackout events in South Australia (including V_S_NIL_ROCOF and V^S_NIL_SA_RECLASS). For further details, see the AEMO report[6]. V_S_NIL_ROCOF is expected to bind when there are low levels of synchronous generation online in South Australia. V^S_NIL_SA_RECLASS, initially used to manage the loss of South Australian wind farms following multiple faults, was revoked on 24 December 2016 following changes to wind farm protection settings.

In 2016 there was an increase in the number of binding hours for Tasmanian FCAS equations in 2016 (see Table 4). This is directly related to the extended outage of Basslink[7] (December 2016 – June 2016), and Tasmania needing to supply 50 MW of regulation services locally instead of some of the requirement being provided from the mainland regions. The 2017 binding results are expected to return to similar levels as seen in 2015.

[6] AEMO. *Black System South Australia – Final Integrated Report*. Available at: http://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2017/Integrated-Final-Report-SA-Black-System-28-September-2016.pdf. Viewed: 17 May 2017.

[7] Basslink. Basslink Interconnector update, 13 June 2016. Available at: http://www.basslink.com.au/wp-content/uploads/2016/06/Media-statement-13-June-final1.pdf

4. MARKET IMPACT

Binding constraint equations affect electricity market pricing. The relative importance of binding constraints are determined by their market impacts.

Definition: Market Impact

The market impact of a constraint is derived by summarising the marginal value for each dispatch interval (DI) from the marginal constraint cost (MCC) re-run[8] over the period considered. The marginal value is a mathematical term for the market impact arising from relaxing the RHS of a binding constraint by one MW. As the market clears each DI, the market impact is measured in $/MW/DI.

The market impact in $/MW/DI is a relative comparison but is not otherwise a meaningful measure. However, it can be converted to $/MWh by dividing the market impact by 12 (as there are 12 DIs per hour). This value of congestion is still only a proxy (and always an upper bound) of the value per MW of congestion over the period calculated; any change to the limits (RHS) may cause other constraints to bind almost immediately after.

Table 5 lists system normal constraint equations in bold, and 2015 values in brackets below the 2016 values.

The constraint equations NSA_Q_BARCALDN, NSA_Q_GSTONE34_xxx, NSA_S_PORxxx, T_MRWF_100, T_MRWF_120 all relate to the output of one or two generators 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 5 Top 20 market impact constraint equations

Constraint Equation ID (System Normal Bold)	2016 Market Impact (2015 Market Impact)	2016 Hours (2015 Hours)	*Description* Notes
F_S+LREG_0035	$9,234,806 ($4,643,040)	531.0 (620.6)	*South Australia lower regulation FCAS requirement greater than 35 MW* This constraint equation is normally invoked for a risk of islanding or an islanded South Australia
F_S+RREG_0035	$8,814,511 ($4,630,036)	531.7 (618.6)	*South Australia raise regulation FCAS requirement greater than 35 MW* This constraint equation is normally invoked for a risk of islanding or an islanded South Australia
NSA_S_PORxxx	$7,120,984 ($5,306,096)	42.8 (32.3)	*Network Support Agreement for Port Lincoln Units 1 and 2*
T>T_NIL_110_1	$1,976,230 ($1,370,198)	153.9 (107.1)	*Out = Nil, avoid overloading the Derby to Scottsdale Tee 110 kV line on no line trips* This constraint equation was implemented in mid-2013 with the Musselroe Wind Farm commissioning. It binds with high output from Musselroe.

8 MCC re-run: The MCC re-run relaxes any violating constraint equations and constraint equations with a marginal value equal to the constraint equation's violation penalty factor (CVP) x market price cap (MPC). The calculation caps the marginal value in each DI at the MPC value valid on that date (MPC was increased to $14,000 on 1st July 2016).

Constraint Equation ID (System Normal Bold)	2016 Market Impact (2015 Market Impact)	2016 Hours (2015 Hours)	*Description* Notes
Q>NIL_BI_xxx	$1,777,995 ($223,253)	1,408.8 (258.8)	*Out = Nil, avoid overloading on Boyne Island feeder bushing on Calliope River to Boyne Island 132 kV lines, for the contingent loss of a single Calliope River to Boyne Island 132 kV line* See Table 3 for comments
V^S_NIL_SA_RECLASS	$1,702,651 (0)	178.3 (0)	*Out = NIL, limit generation in SA to prevent flow on Heywood interconnector exceeding 700 MW following reduction in MW output from multiple generating units in SA.* This constraint equation was implemented following the South Australian blackout. It was invoked from 3 October to 24 December 2016.
S-STTX_SNWF	$1,362,930 ($1,238)	210.0 (1.2)	*Out = Snowtown 132/33 kV transformer or Snowtown CB4593 or CB6265, limit Snowtown wind farm generation to 0 MW*
SVML_000	$1,217,528 (0)	134.8 (0)	*South Australia to Victoria on Murraylink upper transfer limit of 0 MW* This constraint equation is normally invoked for Murraylink out of service.
V::S_TB_275KV_W_B_1	$1,180,827 (0)	232.3 (0)	*Out= Tailem Bend 275 kV West Bus; Vic to SA transient stability limit for loss of the parallel South East - Tailem Bend line (South East Capacitor available)*
S_PLN_ISL2	$988,797 (0)	7.4 (0)	*Out = Yadnarie to Port Lincoln 132 kV line, Port Lincoln units 1 and 2 islanded*
S>NIL_HUWT_STBG	$968,995 ($738)	78.9 (0.9)	*Out = Nil; Limit Snowtown WF generation to avoid Snowtown - Bungama line overload on loss of Hummocks - Waterloo line*
VSML_220	$890,029 ($183,598)	468.1 (123.4)	*Upper transfer limit of 220 MW on VIC to SA on Murraylink*
S_V_000_HY_DYN	$850,076 (0)	69.8 (0)	*SA to VIC on Heywood upper transfer limit of 0 MW, dynamic headroom, DS formulation only.*
F_S+TL_L6_OD	$749,800 ($110,400)	4.5 (0.7)	*Lower 6 sec Service Requirement for SA Network Event, Loss of Davenport to Olympic Dam West 275kV line offload the entire Olympic Dam load*
VT_ZERO	$710,463 ($13,408)	628.3 (8.3)	*Victoria to Tasmania on Basslink upper transfer limit of 0 MW*
F_S+PPT_R5	$691,000 (0)	4.2 (0)	*Raise 5 min Service Requirement for SA Generation Event, where Pelican Point GT11 or GT12 or ST is the largest generation risk in SA*
NSA_Q_GSTONE34_xxx	$645,921 ($16,446,885)	13.6 (149.7)	*Gladstone 3 + 4 >= various levels for Network Support Agreement* See Table 3 for comments
VSML_ZERO	$640,207 ($99,360)	301.6 (78.2)	*Victoria to South Australia on Murraylink upper transfer limit of 0 MW* This constraint equation is normally invoked for Murraylink out of service.
NSA_Q_BARCALDN	$597,006 ($145,049)	46.4 (10.8)	*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
F_S+TL_L5_OD	$555,400 ($100,800)	4.5 (0.7)	*Lower 5 min Service Requirement for SA Network Event, Loss of Davenport to Olympic Dam West 275kV line offload the entire Olympic Dam load*

4.1 Market Impact Trends: 6 Year Comparison

Figure 7 and Figure 8 show the binding constraint equations for the past six years, categorised by region, and whether the system is normal or in outage.

Figure 7 Market impact by region

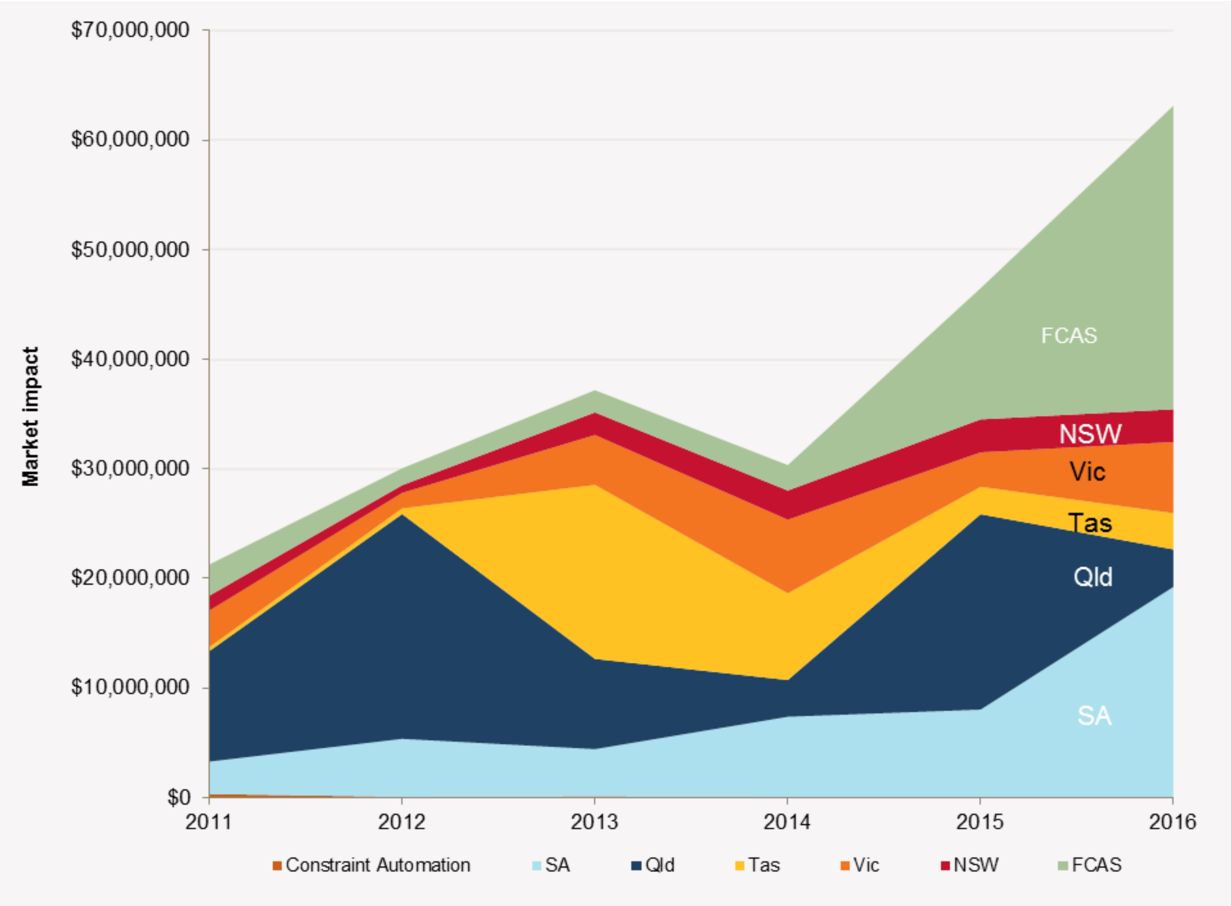
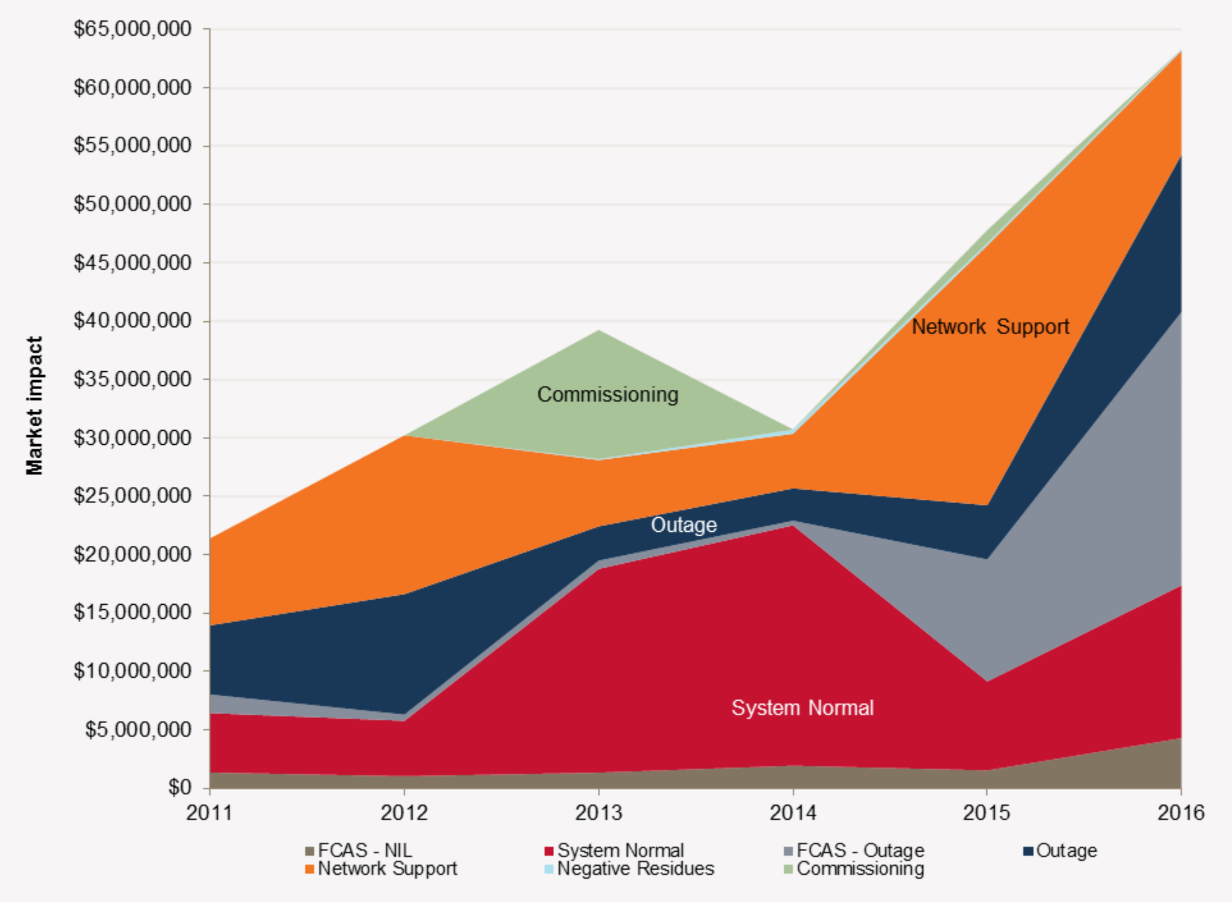


Figure 8 Market impact for system normal and outages



From 2011 to 2016, with the exception of 2014, the market impact of system normal constraint equations and outage constraint equations increased.

- In 2012, network support and outages increased, while system normal slightly decreased. The network support increase was due to network support agreements in Queensland and South Australia.
- In 2013, there was a sharp increase in system normal impact and commissioning. This was due to the commissioning of Musselroe wind farm in Tasmania.
- In 2014, only system normal increased. This was mainly due to constraint equations on Tamar Valley generation in Tasmania and Robertstown – North West Best 132 kV line in South Australia.
- In 2015, the market impact increased again. This was mainly due to an increase in network support agreements in Queensland and South Australia, and FCAS for outages between South Australia and Victoria (a total impact of $9.3 million). System normal decreased mainly due to Tamar Valley not generating, removal of the Tarong transformer constraint equation (due to commissioning of the Coolumboola 275 kV) and lower binding hours on the Robertstown – North West Bend 132 kV line.
- In September 2015, AEMO introduced new system security requirements in South Australia: a minimum regulation FCAS enablement of 35 MW to be in place for South Australia during times when it is operating as an island, or has a credible risk of separation from the NEM.

- In 2016, the market impact increased further. This was primarily due to FCAS requirements in South Australia for system normal and outages between South Australia and Victoria (a total impact of $27.7 million). Outages between South Australia and Victoria had a high impact of $13.5 million; $8.9 million higher than 2015.

4.2 Market Impact Insights

Generally, with the exception of 2014, the market impact has increased in the past six years.

In 2016, South Australian constraint equations dominated the top 20 market impact equations. This can be attributed primarily to a large number of outages related to the Heywood interconnector upgrade project, as well as new constraint equations implemented following the South Australian blackout in September. For full detail of the South Australian outages, refer to Table 6.

The extended outage of the Basslink interconnector saw an increase to market impact. In 2015, the constraint holding Basslink to 0MW bound for only 8.3 hours, whilst in 2016, this constraint bound for 628.3 hours, reflective of the fact that most of the outage occurred in 2016.

Compared to 2015, there was an increase of $8.7 million (almost double) in the market impact associated with South Australian regulation FCAS equations in 2016. These constraint equations were in place for all of 2016, however, they bound for less hours thus indicating a higher volatility in the SA regulation prices.

The network constraint associated with the feeder bushing limit at Boyne Island (Q>NIL_BI_xxx) also had a substantial increase in the market impact between 2015 and 2016. For information on binding results, see section 3.4. The increase in 2016 relates to the Gladstone units 3 and 4 being on extended outages for maintenance in 2015.

5. CONSTRAINT EQUATIONS SETTING INTERCONNECTOR LIMITS

This chapter examines each NEM interconnector and the binding constraint equations that most often set the limits on that interconnector.[9]

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 therefore differ from Chapter 3 where two (or more) constraint equations can 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 histograms in this chapter show flows for the top five (for each direction of flow) binding interconnector limit setting constraint equations. Those that remain are summated as "other".

For comparison, the primary axis shows the summated binding hours for the previous year, while the secondary axis shows the number of hours the interconnector target was at each flow level (binding or not binding) for the current and past calendar year.

In instances where both constraint equations setting the import and export limits on an interconnector are binding, both constraint equations are counted in the results.

5.1 Terranora interconnector (N-Q-MNSP1)

The Terranora interconnector consists of the two 110 kV lines from Terranora in NSW to Mudgeeraba in Queensland. The controllable element is a 180 MW direct current (DC) link between Terranora and Mullumbimby. The three separate DC cables that make up this link are known as Directlink. The DC cables were commissioned in 2000 and formed the first connection between New South Wales and Queensland.

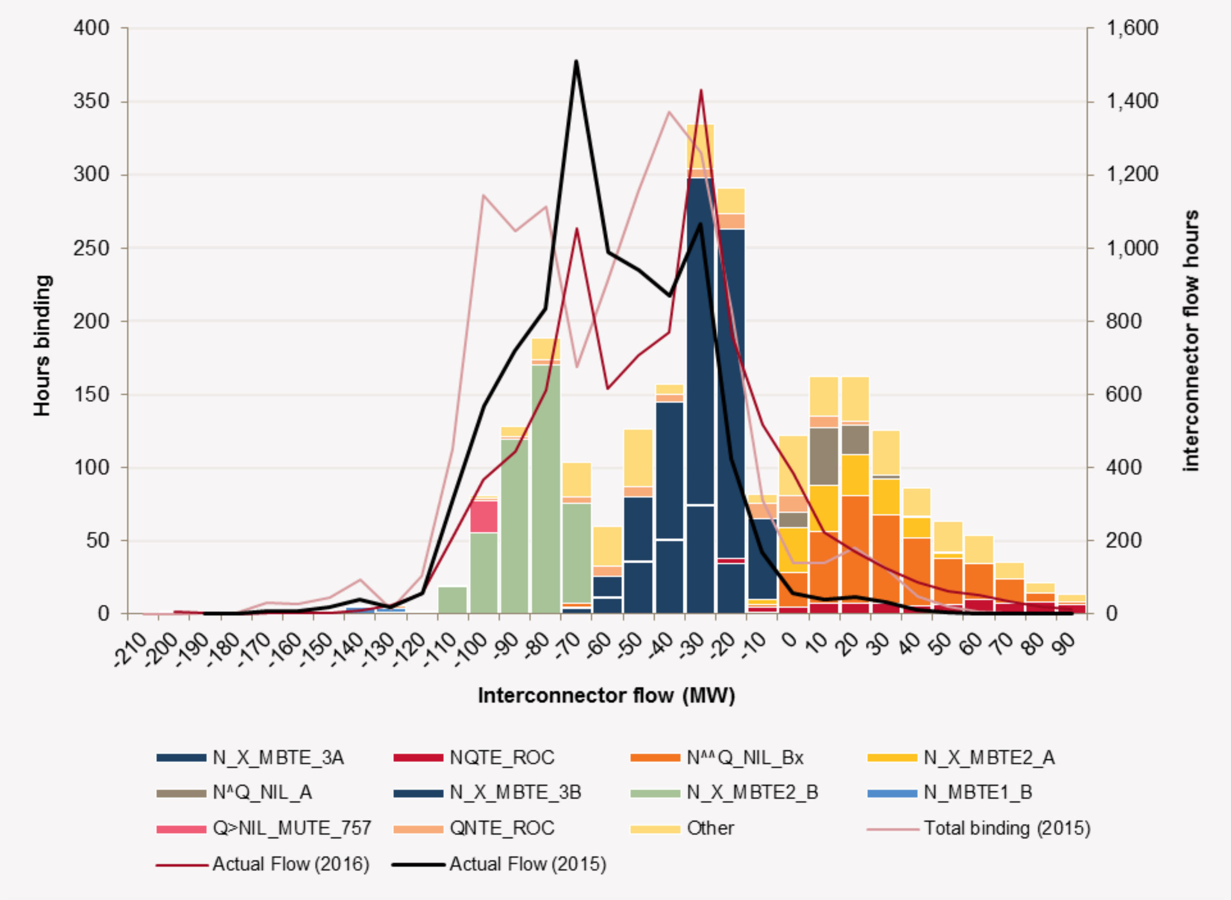
Most of this interconnector's flows are towards New South Wales, so both import and export values are negative (unlike the other NEM interconnectors). It is usually constrained by thermal limits in northern New South Wales (N>N-NIL_LSDU) or by the rate of change on Directlink (NQTE_ROC, QNTE_ROC).

The Terranora interconnector normally appears with the Queensland to New South Wales interconnector on the LHS of the stability constraint equations, so both interconnectors may be constrained at the same time (normally by N^^Q_NIL_B1, 2, 3, 4, 5, 6 and N^Q_NIL_B and N^Q_NIL_A).

In 2016, most of the time that Terranora was restricted was due to either stability constraint equations, the outage of all three Directlink cables or single Directlink cable outages (see Figure 9).

[9] AEMO. *Interconnector Capabilities*. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Congestion-information/Network-status-and-capability. Viewed: 6 March 2017.

Figure 9 Binding constraint equation distribution for N-Q-MNSP1



5.2 Queensland to New South Wales Interconnector (NSW1–QLD1)

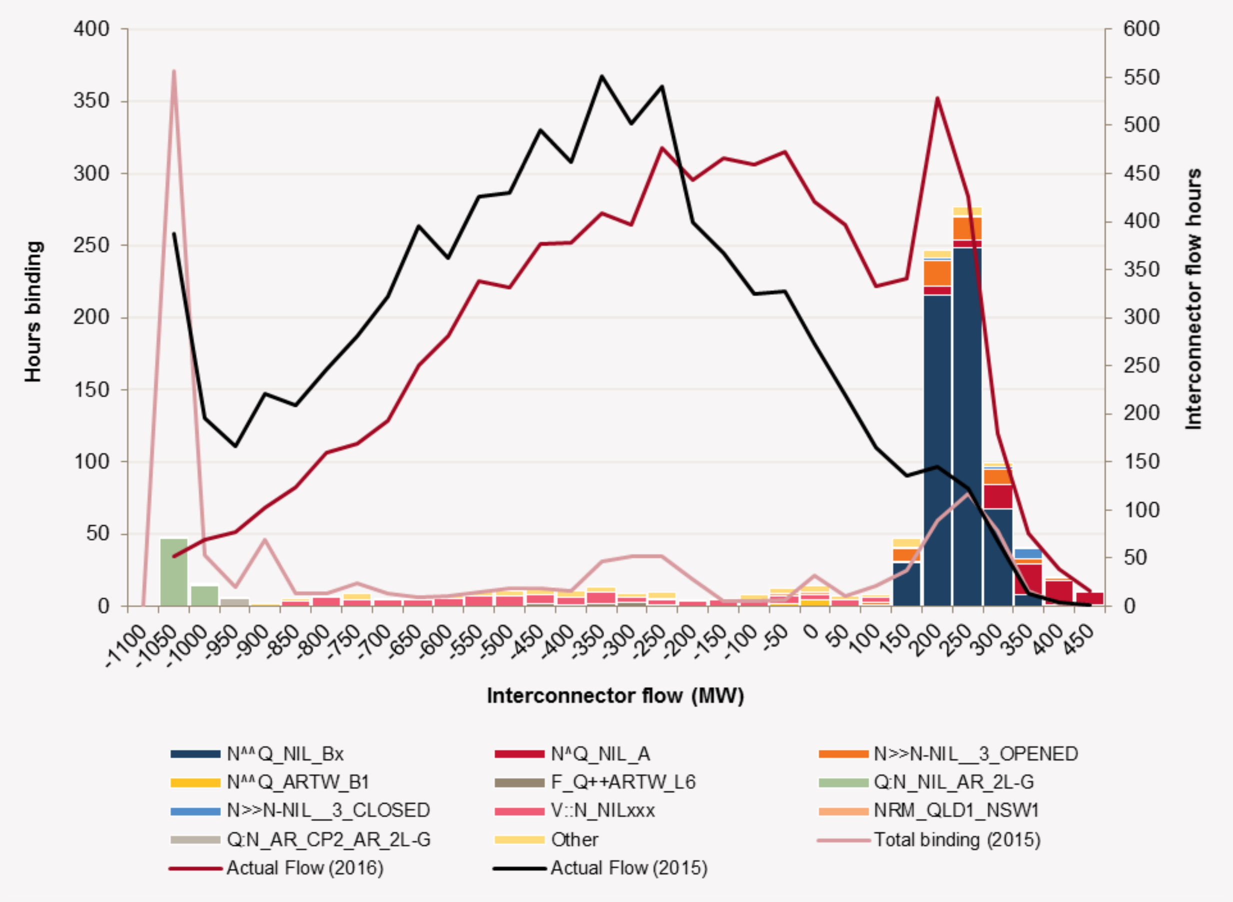
The Queensland to New South Wales interconnector (QNI) is a 330 kV alternating current (AC) interconnection between Dumaresq in New South Wales and Bulli Creek in Queensland. It was commissioned in 2001 as a double-circuit 330 kV line between Armidale and Braemar, and a double-circuit 275 kV line between Braemar and Tarong. Due to their close electrical proximity on the New South Wales side, both QNI and Terranora often appear on the LHS of constraint equations.

Historically, the transfer from New South Wales to Queensland is mainly limited by the system normal constraint equations for the voltage collapse on loss of the largest Queensland unit (N^^Q_NIL_B1, 2, 3, 4, 5, 6 and N^Q_NIL_B) or trip of the Liddell to Muswellbrook (83) 330 kV line (N^Q_NIL_A).

Transfer from Queensland to New South Wales is normally limited by the transient stability limits for a two-line to ground fault between Armidale and Bulli Creek, or by FCAS requirements for outages of lines between Bulli Creek to Liddell.

Historically, most of the time flows were from Queensland into New South Wales at levels greater than 500 MW. In 2016, while most interconnector flows were from Queensland to New South Wales, they were predominantly at lower values, ranging from 50 MW to 350 MW. Compared to 2015, there was a large increase in flows from New South Wales to Queensland, with the largest number of hours (in any direction) at 200 MW (see Figure 10).

Figure 10 Binding constraint equation distribution for NSW1-QLD1



5.3 Basslink (T-V-MNSP1)

Basslink is a DC interconnection between George Town in Tasmania and Loy Yang in Victoria. It was commissioned in early 2006 after Tasmania joined the NEM. Unlike the other DC lines in the NEM, Basslink has a frequency controller and can transfer FCAS between Victoria and Tasmania. Along with the other interconnections to Victoria (VIC1-NSW1, V-SA and Murraylink), Basslink appears in many Victorian constraint equations. This can lead to situations where many or all of these interconnectors can be limited due to the same network limitation.

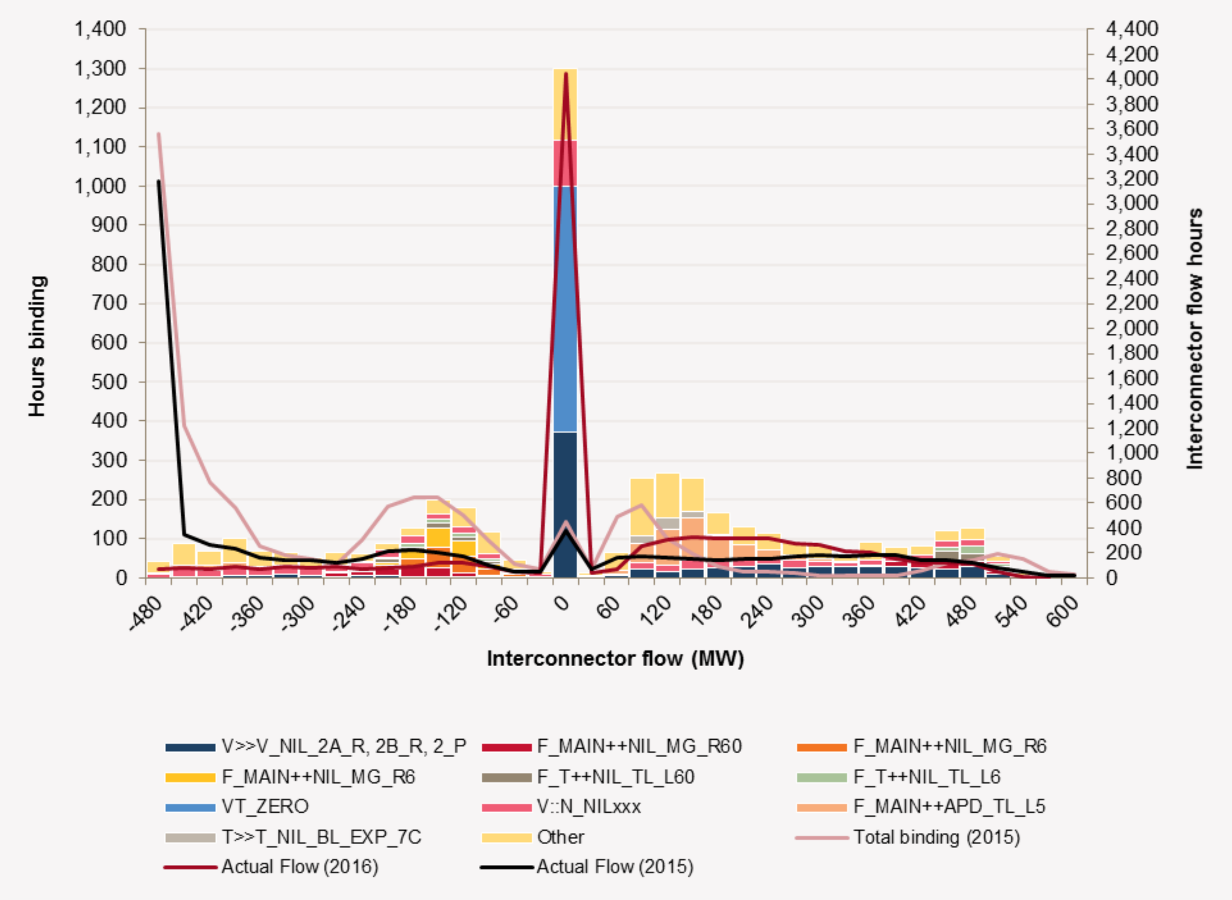
Most limitations on Basslink transfers are due to FCAS constraint equations for both mainland and Tasmanian contingency events.

Tasmania to Victoria transfers are mainly limited by the energy constraint equations for the South Morang F2 transformer overload (V>>V_NIL_2A_R and V>>V_NIL_2B_R and V>>V_NIL_2_P) or the transient over-voltage at George Town (T^V_NIL_BL_6).

For Basslink flows from Victoria to Tasmania, the energy limitations are due to the transient stability limit for a fault and trip of a Hazelwood to South Morang line (V::N_NILxxx and outage cases).

In 2016, Basslink was out of service for more than 100 days due to physical damage to the undersea power cable, and its flow was limited to zero for one-third of the year (see Figure 11).

Figure 11 Binding constraint equation distribution for Basslink



5.4 Victoria to New South Wales (VIC1–NSW1)

The Victoria to New South Wales interconnector combines the 330 kV lines between Murray and Upper Tumut (65), Murray and Lower Tumut (66), Jindera and Wodonga (060), the 220 kV line between Buronga and Red Cliffs (0X1), and the 132 kV bus tie at Guthega (which is normally open).

This interconnector was formed on 1 July 2008 as a part of the Snowy region abolition. It replaced the previous “SNOWY1” and “V-SN” interconnectors. VIC1–NSW1 appears in many of the Victorian constraint equations along with the other interconnections to Victoria (Basslink, V-SA, and Murraylink). This can lead to situations where many or all of these interconnectors can be limited due to the same network limitation.

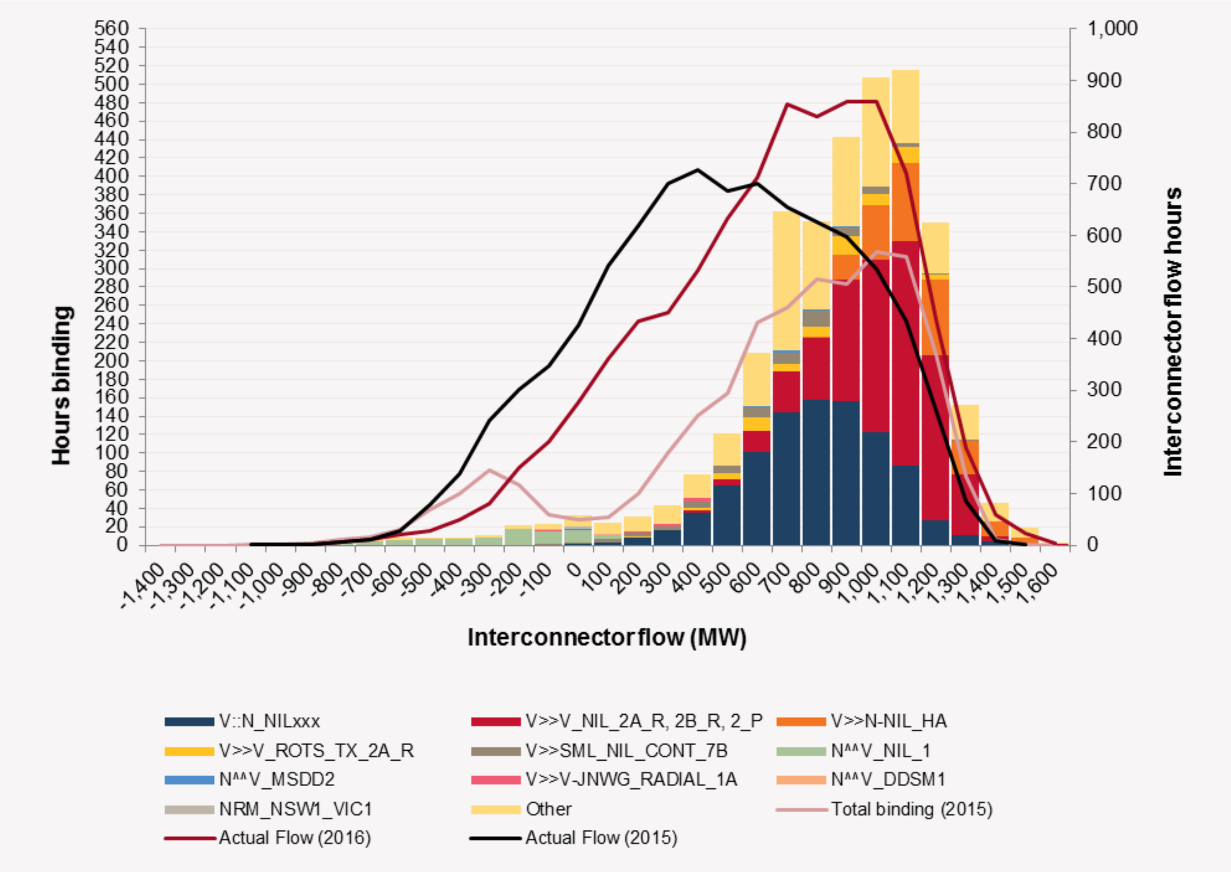
VIC1–NSW1 can bind in either direction for high demand in New South Wales or Victoria. Transfer from Victoria to New South Wales is mainly limited by the thermal overload limits on the South Morang F2 transformer (V>>V_NIL_2A_R and V>>V_NIL_2B_R and V>>V_NIL_2_P), the South Morang to Dederang 330 kV line (V>>V_NIL1A_R), the Ballarat to Bendigo 220 kV line (V>>SML_NIL_8), or the Ballarat to Moorabool No.1 220 kV line (V>>SML_NIL_1).

The transient stability limit for a fault and trip of a Hazelwood to South Morang line (V::N_NILxxx and outage cases) can also set the Victoria to New South Wales limits.

Transfer from New South Wales to Victoria is mainly limited by voltage collapse for loss of the largest Victorian generator (N^^V_NIL_1) or thermal overload limits on the Murray to Dederang 330 kV lines (V>>V_NIL_1B).

In 2015 and 2016, the hours at each flow level and the binding hours on VIC1–NSW1 were similar. The main difference in 2016 (from 2015) was that the high flow levels into New South Wales were constrained for more hours. This is shown in Figure 12.

Figure 12 Binding constraint equation distribution for VIC1–NSW1



5.5 Heywood interconnector (V-SA)

The Victoria to South Australia (or Heywood) interconnector is an AC interconnector between Heywood in Victoria and the South East of South Australia.

It was originally commissioned in 1989 as a connection from the western 500 kV network in Victoria to Para, the nearest 275 kV substation in South Australia. It includes a number of connections to the parallel 132 kV network in south-eastern South Australia. With the other interconnections to Victoria (VIC1–NSW1, Basslink, and Murraylink), V-SA appears in many Victorian constraint equations. This can lead to situations where many or all these interconnectors can be limited due to the same network limitation.

The Heywood interconnector was upgraded in stages in 2015 and 2016. In December 2015, the third 500/275 kV transformer at Heywood was commissioned and the limit increased to 500 MW. In July 2016, both the Keith to Snuggery 132 kV line and Keith to Tailem Bend No.1 132 kV lines were decommissioned. At the same time a number of related control schemes were commissioned. In August 2016, series capacitors were commissioned at Black Range substation, half way between South East and Tailem Bend substations. The limits are being increased progressively following a program of inter-network tests[10]. At the time of writing this

[10] Available at: http://www.aemo.com.au/Stakeholder-Consultation/Consultations/Heywood-interconnector-upgrade---program-for-inter-network-tests.

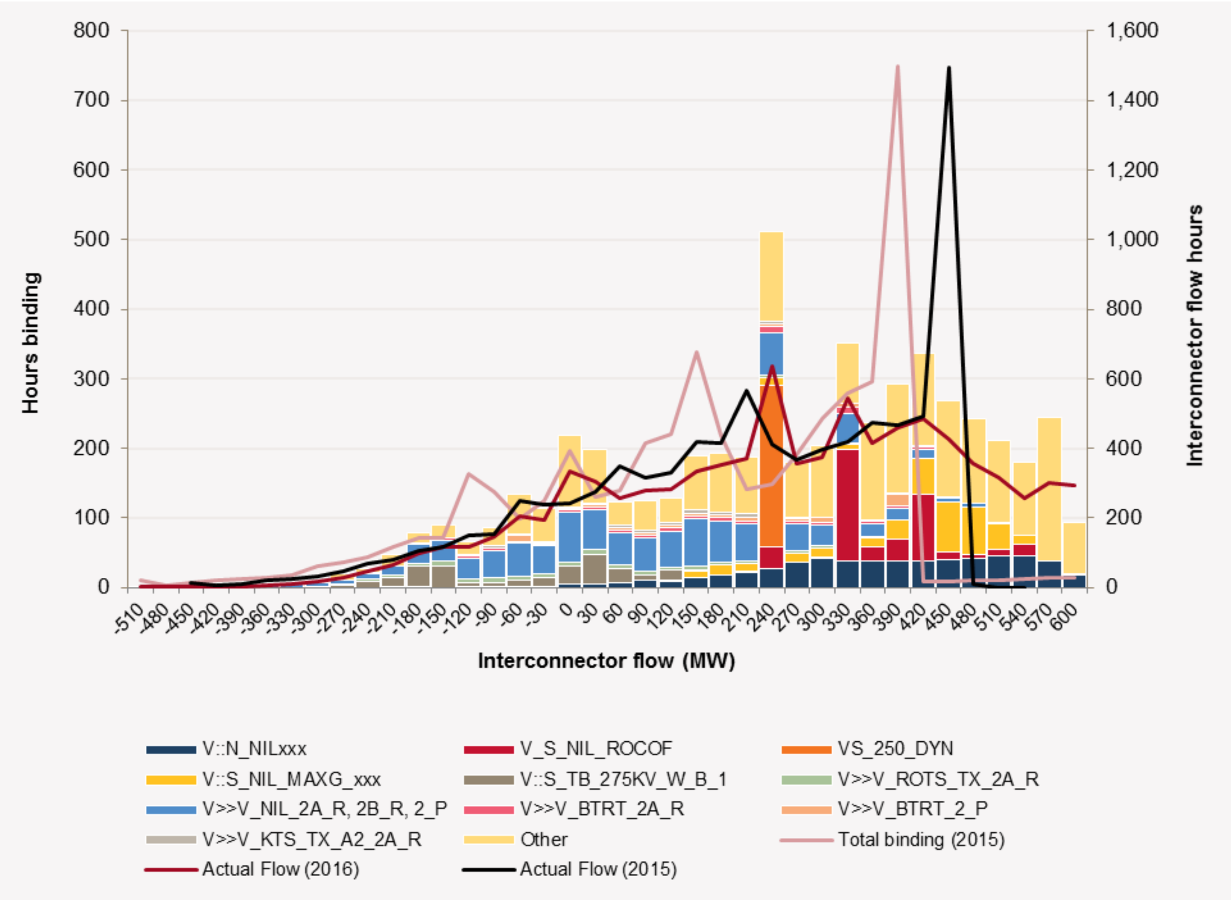
report, the Victoria to South Australia limit has been increased to 600 MW (from the original 460 MW).

Before the upgrade, Victoria to South Australia flows were most often restricted by thermal overloads on the Snuggery to Keith 132 kV line (V>>S_NIL_SETB_SGKH), transient stability limit for loss of the largest South Australian generator (V::S_NIL_MAXG_xxx) and the Heywood 500/275 kV transformers (V>S_460 and V>S_NIL_HYTX_HYTX). South Australia to Victoria transfers were mainly restricted by the thermal overload limits on the South East substation 275/132 kV transformers (S>>V_NIL_SETX_SETX) and the South Morang F2 transformer (V>>V_NIL_2A_R and V>>V_NIL_2B_R and V>>V_NIL_2_P).

Following the upgrade, flows from Victoria to South Australia were mostly limited by the transient stability limit for a fault and trip of a Hazelwood to South Morang 500 kV line (V::N_NILxxx), rate of change of frequency limit of 3 Hz/sec in South Australia (V_S_NIL_ROCOF), transient stability limit for loss of the largest South Australian generator (V::S_NIL_MAXG_xxx) and the 250 MW upper limit (VS_250_DYN) for outages that put South Australia at a risk of separating from the rest of the NEM.

The hours at each flow level on V-SA were different in 2015 and 2016. In 2015, there were high flows into South Australia (at the 450 MW flow level). In 2016, while flows were mostly from Victoria to South Australia, outages associated with the interconnector upgrade limited flows to 250 MW for 232 hours. There was a second peak at 330 MW due to the V_S_NIL_ROCOF constraint equation - this is reflected in Figure 13.

Figure 13 Binding constraint equation distribution for V-SA



5.6 Murraylink (V-S-MNSP1)

Murraylink is a 220 MW DC link between Red Cliffs in Victoria and Monash in South Australia, commissioned in 2002.

Many of the thermal issues closer to Murraylink are handled by the South Australian or Victorian Murraylink runback schemes. Along with the other interconnections to Victoria (VIC1–NSW1, V–SA and Basslink), Murraylink appears in many of the Victorian constraint equations. This can lead to situations where many or all these interconnectors can be limited due to the same network limitation.

Transfers from Victoria to South Australia on Murraylink are mainly limited by thermal overloads on the:

- South Morang F2 transformer (V>>V_NIL_2B_R and V>>V_NIL_2_P).
- Ballarat North to Buangor 66 kV line (V>>SML_NIL_7A).
- South Morang to Dederang 330 kV line (V>>V_NIL1A_R).
- Ballarat to Bendigo 220 kV line (V>>SML_NIL_8).

Or they can be limited by the voltage collapse limit for loss of the Darlington Point to Buronga (X5) 220 kV line for an outage of the NSW Murraylink runback scheme (V^SML_NSWRB_2).[11]

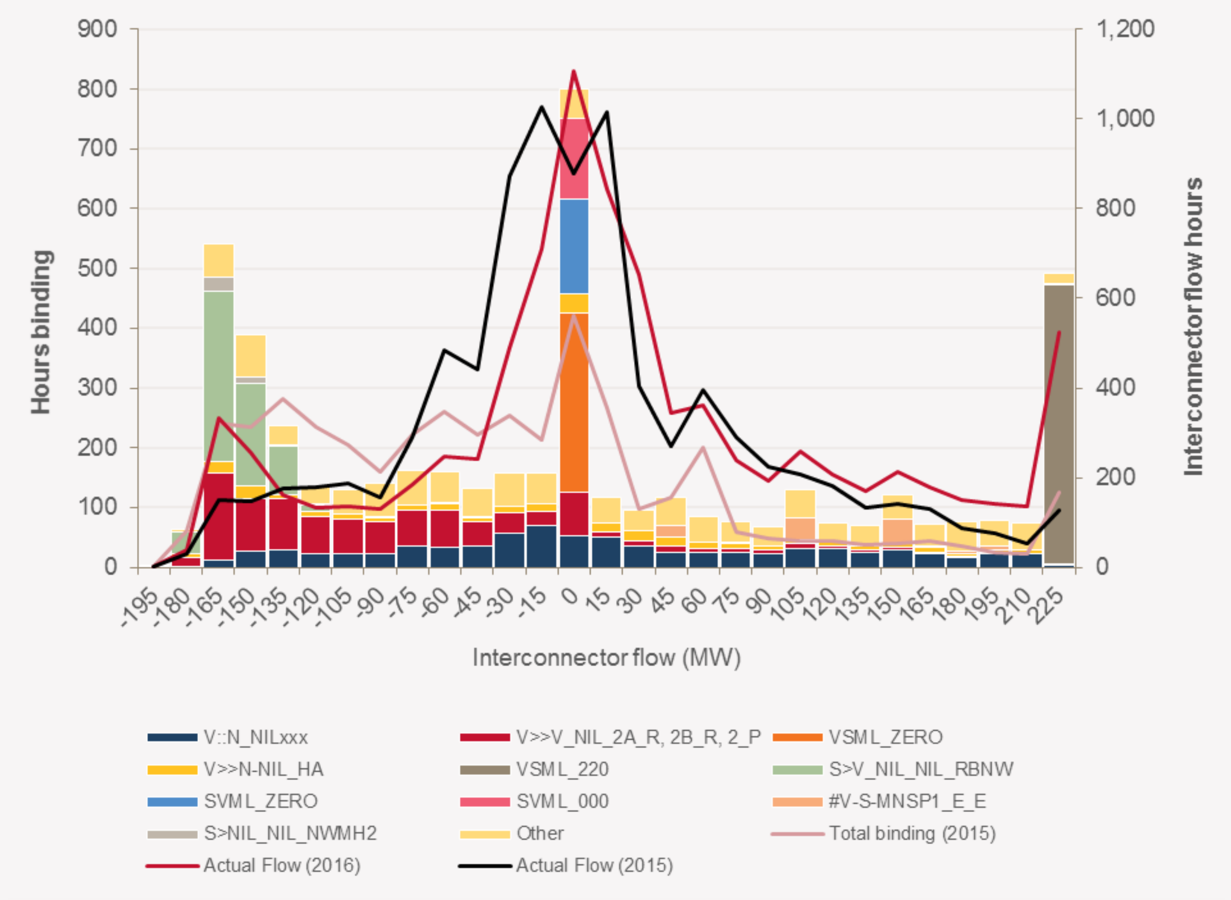
Transfers from South Australia to Victoria on Murraylink are limited by thermal overloads on the:

- Robertstown to Monash 132 kV lines (S>V_NIL_NIL_RBNW).
- Dederang to Murray 330 kV lines (V>>V_NIL_1B).

In 2015 and 2016, the number of hours at each flow level on Murraylink was very similar. The main difference in 2016 was an increase at higher flows in both directions, and an increase in binding hours at 0 MW. This is shown in Figure 14.

[11] The NSW Murraylink runback scheme has not yet been commissioned so this constraint equation is currently part of the Victorian system normal constraint set.

Figure 14 Binding constraint equation distribution for Murraylink



6. TRANSMISSION OUTAGES

This chapter details the major transmission outages in 2016, and compares outage submission and start times for each Transmission Network Service Provider (TNSP).

6.1 Major outages

Table 6 shows the duration of 2016 network outages requiring any of the binding constraint equations delineated in the chapter 3, 4, and 5 tables to be invoked. This list excludes outage ramping constraint equations (starting with #) as these are generally not associated with a particular outage. Outage times are calculated from when the constraint sets are invoked.

Table 6 Top 40 outages associated with binding constraint equations

Constraint Set ID	2016 Days (2015 Days)	Outage Notes
N-MBTE_1	258.1 (359.8)	*One Directlink cable*
N-X_MBTE_2	122.3 (251.4)	*Two Directlink cables*
I-BL_ZERO	100.9 (0.6)	*Limit Basslink to zero in either direction*
N-CHKK_96H	69.1 (1.9)	*Coffs Harbour to Koolkhan (96H) 132 kV line*
V-BTRT_R	59.9 (0)	*Brunswick to Richmond 220kV line, Radial Mode*
N-BAMB_132_OPEN	54.9 (1.6)	*Any one 132 kV line between Ballina and Mullumbimby that opens the 132 kV path.*
S-PA_VC1	42.3 (0)	*One Para SVC , (Note: with both Black Range Series caps I/S)*
N-X_MBTE_3	37.0 (55.1)	*All three Directlink cables*
F-T-BBGT	27.6 (6.3)	*One Bell Bay - Georgetown 110 kV line, all four Bell Bay GTs on remaining 110 kV line, FCAS requirements*
I-ML_ZERO	20.3 (6.6)	*Limit Murraylink to zero in either direction*
T-GTSH	14.8 (0.1)	*One George Town to Sheffield 220kV line*
V-ROTX_R	14.7 (1.8)	*Rowville 500/220kV (A) transformer, Radial*
F-ESTN_ISLE	13.4 (0.0)	*Eastern separation between Heywood and South East (HYTS - SESS) - FCAS Requirements*
I-SV_000	11.2 (0)	*SA to Victoria on VicSA upper transfer limit of 0 MW*
V-HY_500BUS	10.6 (0)	*Heywood (HYTS) No. 1 or No. 2 500 kV bus.*
S-TB_275KV_W_BUS	10.5 (0)	*Tailem Bend 275 kV West Bus, for use prior to decommissioning of Keith - Snuggery 132 kV line and Keith - Tailem Bend #1 132 kV lines and prior to commissioning of Black Range Series Caps*
S-STTX	8.9 (0.5)	*Snowtown 132/33 kV transformer or Snowtown CB4593 or CB6265*
I-SVML_000	8.7 (0)	*SA to Vic on ML upper transfer limit of 0 MW*
I-HYSE	8.3 (28.3)	*One Heywood to South East 275 kV line*
V-DDMS	7.7 (0.8)	*One Dederang to Murray (67 or 68) 330 kV line*
N-LSDU_9U6	7.1 (2.3)	*Lismore to Dunoon 132 kV line*
S-TBSE_1	6.5 (0)	*One South East - Tailem Bend 275 kV line (Post decommissioning of Keith - Snuggery 132 kV line and Keith - Tailem Bend #1 132 kV line)*
S-PA_EAST_BUS_R	6.4 (0)	*Para 275kV East bus Right Section (i.e. either SVC2 or SVC1, Tx2, CB6509, CB6512,CB6543, CB6600 O/S), with both Black Range Series caps in service*
S-PA_WEST_BUS_R	6.1 (4.9)	*Para 275 kV West Bus Right Section*
I-SV_000_DYN	6.1 (0)	*SA to Victoria on VicSA upper transfer limit of 0 MW, dynamic headroom*

Constraint Set ID	2016 Days (2015 Days)	Outage Notes
T-TU_MB_NN1	5.1 (2.4)	*Tungatinah to Meadowbank to New Norfolk No.1 110kV line*
N-NYNGANSF_051	4.7 (0)	*Nyngan Solar Farm upper limit of 51 MW (50% capacity)*
V-HWSM	3.4 (2.9)	*Hazelwood to South Morang 500 kV line*
V-HYMO	2.7 (1.9)	*Heywood to Mortlake No.2 500 kV line*
V-MTMERCER_ZERO	2.2 (7.2)	*Mt Mercer Windfarm upper limit of 0 MW*
V-MLTR	2.1 (0.3)	*Moorabool to Tarrone No.1 500 kV line*
NSA-Q_BARCALDN	1.9 (0.4)	*Clermont to Lilyvale (7153) 132 kV line, Network Support Agreement for Barcaldine GT to meet local islanded demand at Clermont and Barcaldine* This NSA constraint set is included as it is only invoked under outage conditions
I-CTRL_ISSUE_TE	1.8 (4.9)	*DC Link Control Issue Constraint for Terranora*
N-ARTW_86	1.5 (3.5)	*Armidale to Tamworth (86) 330 kV line*
F-N-MUTW_88 & N-MUTW_88	1.4 (1.1)	*Muswellbrook to Tamworth (88) 330 kV line*
N-ARTW_85	1.4 (0.8)	*Armidale to Tamworth (85) 330 kV line*
N-NYNGANSF_010	1.2 (0)	*Nyngan Solar Farm upper limit of 10 MW*
I-MSUT	1.1 (2.2)	*Murray to Upper Tumut (65) 330 kV line*
V-MLMO	1.0 (2.5)	*Moorabool to Mortlake 500 kV line*
N-X_96H_LS_SVC	1.0 (0)	*Coffs Harbour to Koolkhan (96H) 132kV line and Lismore SVC O/S or in reactive power control mode*

6.2 Trends for submit times

Figure 15 shows the trends relating to the time between when a network outage is submitted to AEMO’s network outage schedule (NOS), and the actual outage start time. The times are divided into four categories:

- Unplanned: the outage was submitted on or after the start time for the outage.
- Short notice: the outage was submitted within four days of its start time.
- ≤ 30 days: the outage was submitted within 30 days of its start time.
- > 30 days: the outage was submitted more than 30 days before its start time.

Outages previously submitted and then rescheduled for a new time are recorded as new outages in the NOS. Outages for multiple items of related plant submitted in a single entry are only counted as a single outage.

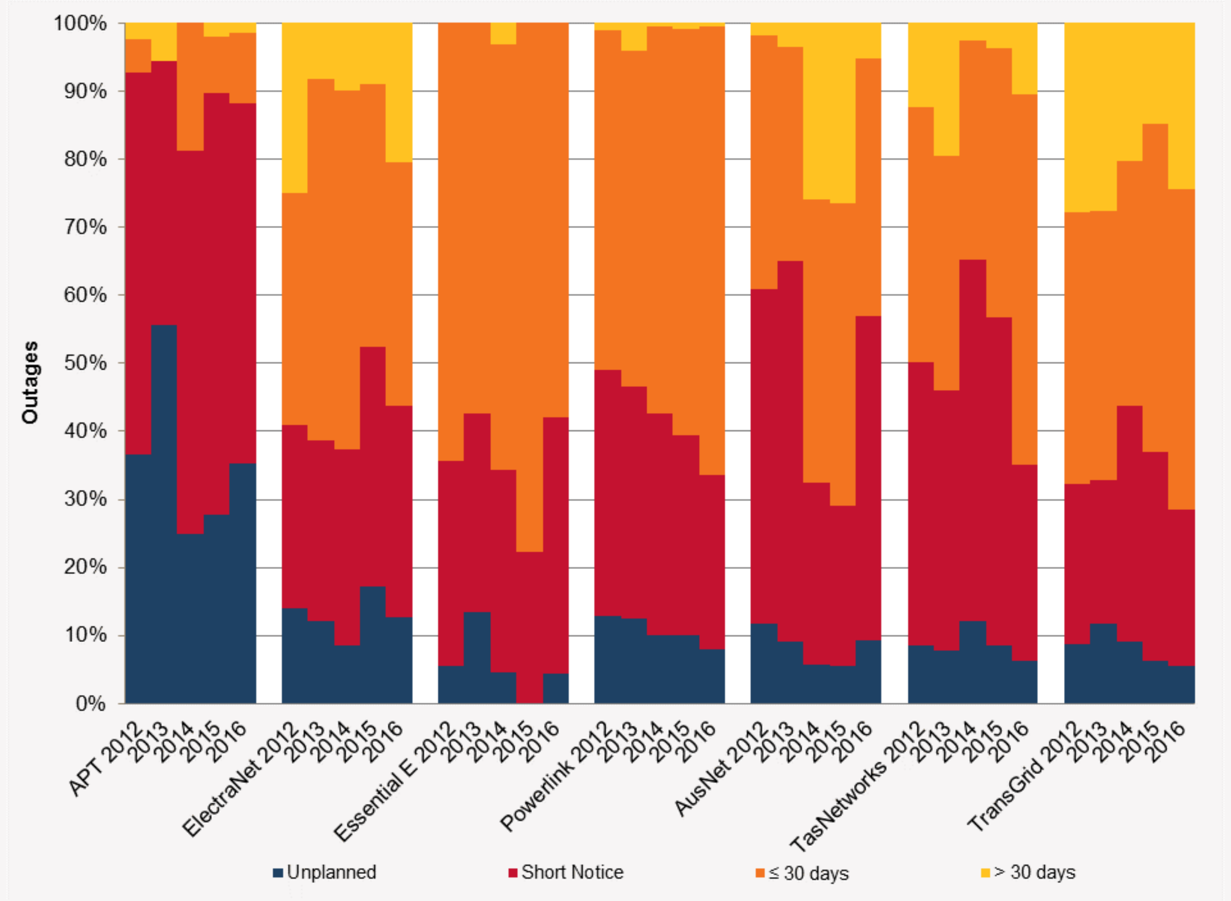
Australian Pipeline Trust (APT), Essential Energy, TransGrid and TasNetworks submit their 13-month outage plans via NOS. Powerlink, ElectraNet and AusNet Services submit their 13-month outage plans as spreadsheets, and are not included in these statistics.

AEMO has observed the following trends:

- Since 2010, more than 80% of APT outages are unplanned or short notice. (APT operates the Murraylink and Directlink HVDC interconnectors.)
- For other Network Service Providers (NSPs), less than 18% of outages are unplanned. Most outages are either short notice or within 30 days.
- Compared to other Transmission Network Service Providers (TNSPs), TransGrid submits a higher percentage of their outages more than 30 days before the start time.

- Very few outages are submitted by Essential Energy, Powerlink, AusNet Services or APT for more than 30 days out. For Powerlink and AusNet Services, this can be explained by the fact that their 13-month outage plans are submitted as spreadsheets and not via the Network Outage System (NOS) so are not included in these statistics.
- The percentage of outages submitted by ElectraNet more than 30 days from the start time has increased.

Figure 15 Outage submit times versus start time



7. MEASURES AND ABBREVIATIONS

7.1 Units of measure

Unit of measure	Expanded name
MW	A watt (W) is a measure of power and is defined as one joule per second. It measures the rate of energy conversion or transfer. A Megawatt is one million watts.

7.2 Abbreviations

Abbreviation	Expanded name
AC	Alternating current
AEMO	Australian Energy Market Operator
CVP	Constraint violation penalty factor
DC	Direct current
DI	Dispatch Interval
DNSP	Distribution network service provider
EMS	Energy management system
FCAS	Frequency control ancillary service
GT	Gas turbine generator
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.
MCC	Marginal constraint cost
MMS	Market management system
MNSP	Market network service provider
MPC	Market price cap (previously called VOLL)
NEM	National electricity market
NEMDE	National electricity market dispatch engine
NSA	Network Support Agreement
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.
ROC	
SCADA	Supervisory control and data acquisition. Information such as line flows and generator outputs are delivered via SCADA.
TNSP	Transmission network service provider

GLOSSARY

Term	Definition
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.
Mainland	The NEM regions: Queensland, New South Wales, Victoria and South Australia.
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.