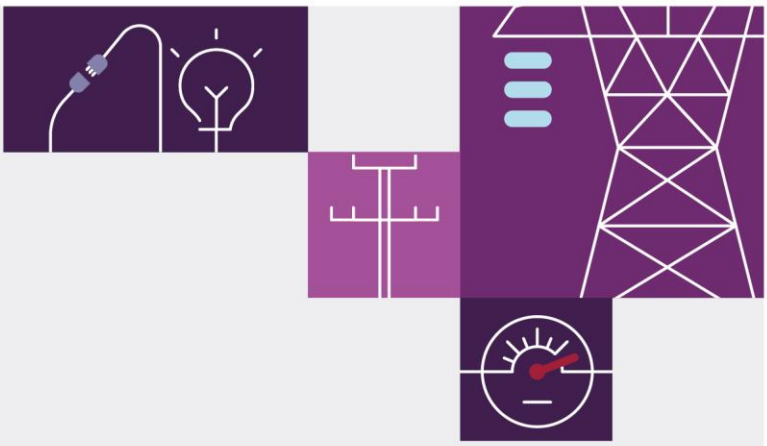
AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Monthly Constraint Report

July 2023

A report for the National Electricity Market on Constraint results.



Important notice

Purpose

This publication has been prepared by AEMO to provide information about constraint equation performance and related issues, as at the date of publication.

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1 Introduction

This report details constraint equation performance and transmission congestion related issues for July 2023. Included are investigations of violating constraint equations, usage of the constraint automation and performance of Pre-dispatch constraint equations. Transmission and generation changes are also detailed along with the number of constraint equation changes.

2 Constraint Equation Performance

2.1 Top 10 binding constraint equations

A constraint equation is binding when the power system flows managed by it have reached the applicable thermal or stability limit or the constraint equation is setting a Frequency Control Ancillary Service (FCAS) requirement. Normally there is one constraint equation setting the FCAS requirement for each of the eight services at any time. This leads to many more hours of binding for FCAS constraint equations - as such these have been excluded from the following table.

Table 1 Top 10 binding network constraint equations

Constraint Equation ID (System Normal Bold)	Description	#DIs (Hours)	Limit Type
T::T_NIL_1	Out = NIL, prevent transient instability for fault and trip of a Farrell to Sheffield line, Swamp if less than 3 synchronous West Coast units generating or Farrell 220kV bus coupler open or Hampshire 110kV line is closed.	5723 (476.91)	Transient Stability
N^N-LS_SVC	Out= Lismore SVC O/S or reactive power control mode, avoid Voltage collapse on Armidale to Coffs Harbour (87) trip; [Swamped for three DLK cables are O/S or Swamped when ECS is enabled with DLK is exporting to QLD, sets DLK to -29 MW for -29< DLK FLOW<0)	3344 (278.66)	Voltage Stability
V^^N_NIL_1	Out = Nil, avoid voltage collapse around Murray for loss of all APD potlines	1723 (143.58)	Voltage Stability
N_X_MBTE_3A	Out= all three Directlink cables, Terranora_I/C_import <= Terranora_Load	1480 (123.33)	Unit Zero
SVML^NIL_MH-CAP_ON	Out=NIL, SA to Vic on ML upper transfer limit to manage voltage collapse at Monash (Note: applies when capacitor banks at Monash are available and I/S for switching.)	1190 (99.16)	Voltage Stability
S>NIL_MHNW1_MHNW2	Out= Nil, avoid O/L Monash-North West Bend #2 132kV on trip of Monash-North West Bend #1 132kV line, Feedback	1008 (84.0)	Thermal
N^^N_NIL_X5_BEKG	Out= Nil, limit power flow on line X5 from Balranald to Darlington Point (X5) to avoid voltage collapse at Balranald for contingency trip of Bendigo to Kerang 220kV line and other nearby lines in NW Victoria	911 (75.91)	Voltage Stability
N_X_MBTE_3B	Out= all three Directlink cables, Terranora_I/C_import <= Terranora_Load	870 (72.5)	Unit Zero
N>>NIL_964_84_S	Out= NIL, avoid O/L Port Macquarie to Herron Creek Tee (964/2) on trip of Tamworth to Liddell (84) line, Feedback	840 (70.0)	Thermal
T_MRWF_GCS	Musselroe wind farm Generator Control Scheme (GCS) constraint to maintain TAS FOS for a Tasmania generator event. Limit Musselroe wind farm based on load available/armed by Musselroe GCS	736 (61.33)	Other

2.2 Top 10 binding impact constraint equations

Binding constraint equations affect electricity market pricing. The binding impact is used to distinguish the severity of different binding constraint equations.

The binding impact of a constraint is derived by summarising the marginal value for each dispatch interval (DI) from the marginal constraint cost (MCC) re-run[1] over the period considered. The marginal value is a mathematical term for the binding impact arising from relaxing the RHS of a binding constraint by one MW. As the market clears each DI, the binding impact is measured in $/MW/DI.

The binding impact in $/MW/DI is a relative comparison and a helpful way to analyse congestion issues. It can be converted to $/MWh by dividing the binding 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 2 Top 10 binding impact network constraint equations

Constraint Equation ID (System Normal Bold)	Description	∑ Marginal Values	Limit Type
S>>BWMP_TWPA_TPRS	Out= Blyth West- Munno Para 275kV line with Blyth West CB8002 OPEN, avoid O/L Templers-Roseworthy 132kV line on trip of Templers West-Para 275kV line, Feedback	459,092	Thermal
N^^N_NIL_X5_BEKG	Out= Nil, limit power flow on line X5 from Balranald to Darlington Point (X5) to avoid voltage collapse at Balranald for contingency trip of Bendigo to Kerang 220kV line and other nearby lines in NW Victoria	401,369	Voltage Stability
S>NIL_HUWT_STBG3	Out = Nil; Limit Snowtown WF generation to avoid Snowtown - Bungama line OL on loss of Hummocks - Waterloo line.[Note: Constraint Swamped when Wattle PT when generating >=60 MW)	318,028	Thermal
V_BANSF_BBD_S1	Out = Nil, Bannerton SF limitation segment 1 if Boundary Bend (BBD) loading is less than 5 MW, DS only. Swamp out if BBD loading is outside the range.	273,706	Discretionary
S>NIL_MHNW1_MHNW2	Out= Nil, avoid O/L Monash-North West Bend #2 132kV on trip of Monash-North West Bend #1 132kV line, Feedback	204,815	Thermal
N>NIL_94T	Out= Nil, avoid O/L Molong to Orange North (94T) on trip of Nil, Feedback	193,533	Thermal
S>>X_RBTU+RBTX_10	Out= One Robertstown TX + Robertstown-Tungkillo 275kV line O/S, avoid O/L Templers- Roseworthy 132kV line on trip of Templers West-Para 275kV line, Feedback	176,006	Thermal
V>>NIL_ARWB_KGBE	Out= Nil, avoid O/L Ararat to Waubra 220kV line on trip of Kerang to Bendigo 220kV line, Feedback	168,075	Thermal
T::T_NIL_1	Out = NIL, prevent transient instability for fault and trip of a Farrell to Sheffield line, Swamp if less than 3 synchronous West Coast units generating or Farrell 220kV bus coupler open or Hampshire 110kV line is closed.	165,116	Transient Stability
S>S_WERB_TWPA_TPRS	Out= Robertstown - MWP4 - Waterloo East O/S(offloads MWP4 SF), avoid O/L Templers-Roseworthy 132kV line on trip of Templers West-Para 275kV line, Feedback	146,573	Thermal

[1] 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 is increased annually on 1st July.

2.3 Top 10 violating constraint equations

A constraint equation is violating when NEMDE is unable to dispatch the entities on the left-hand side (LHS) so the summated LHS value is less than or equal to, or greater than or equal to, the right-hand side (RHS) value (depending on the mathematical operator selected for the constraint equation). The following table includes the FCAS constraint equations. Reasons for the violations are covered in 2.3.1.

Table 3 Top 10 violating constraint equations

Constraint Equation ID (System Normal Bold)	Description	#DIs (Hours)	Limit Type
Q_STR_SMSF_ZERO	Limit 0MW to Sun Metals Solar farm for system strength requirement	11 (0.91)	System Strength
S_PPT+SNPT_270	SA Pelican Point + Snapper Point generation <= 270 MW	5 (0.41)	Discretionary
V_COHUNASF_0INV	Constraint to violate if Cohuna Solar Farm inverter availability greater than zero. Constraint swamp out otherwise. DS only	5 (0.41)	System Strength
F_T+NIL_MG_RECL_R6	Out = Nil, Raise 6 sec requirement for a Tasmania Reclassified Woolnorth Generation Event (both largest MW output and inertia), Basslink unable to transfer FCAS	4 (0.33)	FCAS
S>LFPP_PGPA_PGPS	Out= Lefevre-Pelican Point 275kV line, avoid O/L Parafield Gardens West-Parafield Gardens 66kV line on trip of Parafield Gardens West-Para 275kV line, Feedback	3 (0.25)	Thermal
N^N-LS_SVC	Out= Lismore SVC O/S or reactive power control mode, avoid Voltage collapse on Armidale to Coffs Harbour (87) trip; [Swamped for three DLK cables are O/S or Swamped when ECS is enabled with DLK is exporting to QLD, sets DLK to -29 MW for -29< DLK FLOW<0)	3 (0.25)	Voltage Stability
V_GANNSF_12INV	Limit Gannawarra Solar Farm upper limit to 0 MW if number of inverter available exceed 12. Constraint swamp out if number of inverter available not exceed 12. This is to manage voltage oscillation. DS only	3 (0.25)	System Strength
V_GANWRSF_0INV	Constraint to violate if Gannawarra Solar Farm inverter availability greater than zero. Constraint swamp out otherwise. DS only	2 (0.16)	System Strength
SVML^NIL_MH-CAP_ON	Out=NIL, SA to Vic on ML upper transfer limit to manage voltage collapse at Monash (Note: applies when capacitor banks at Monash are available and I/S for switching.)	2 (0.16)	Voltage Stability
V_WEMENSF_21INV	Limit Wemen Solar Farm upper limit to 0 MW if number of inverter available exceed 21. Constraint swamp out if number of inverter available not exceed 21. This is to manage voltage oscillation. DS only	2 (0.16)	System Strength

2.3.1 Reasons for constraint equation violations

Table 4 Reasons for constraint equation violations

Constraint Equation ID (System Normal Bold)	Description
Q_STR_SMSF_ZERO	Constraint equation violated for 11 consecutive DIs on 05/07/2023 from 0905 hrs to 0955 hrs with a violation degree of 0.001 MW. Constraint equation violated due to Sun Metals Solar Farm exceeding its MW limit.
S_PPT+SNPT_270	Constraint equation violated for 5 non-consecutive DIs from 02/07/2023 1115 hrs to 04/07/2023 1330 hrs with a max violation degree of 95.45 MW occurring on 04/07/2023 at 1330 hrs. Constraint equation violated due to Pelican Point gas turbine being limited by its ramp down rate.
V_COHUNASF_0INV	Constraint equation violated for 5 consecutive DIs on 25/07/2023 from 0705 hrs and 0725 hrs with a violation degree of 0.001 MW. Constraint equation violated due to Cohuna Solar Farm exceeding its inverter limit.

Constraint Equation ID (System Normal Bold)	Description
F_T+NIL_MG_RECL_R6	Constraint equation violated for 4 non-consecutive DIs from 13/07/2023 0410 hrs to 29/07/2023 1645 hrs with a max violation degree of 29.76 MW occurring on 13/07/2023 at 0410 hrs. Constraint equation violated due to Tasmania raise 6 sec service availability less than requirement.
S>LFPP_PGPA_PGPS	Constraint equation violated for 3 consecutive DIs on 02/07/2023 from 1115 hrs to 1125 hrs with a max violation degree of 59.12 MW occurring on 02/07/2023 at 1115 hrs. Constraint equation violated due to Pelican Point gas turbine being limited by its ramp down rate.
N^N-LS_SVC	Constraint equation violated for 3 non-consecutive DIs on 01/07/2023 1730 hrs, 03/07/2023 0715 hrs and 28/07/2023 1120 hrs with a max violation degree of 44.6 MW occurring on 28/07/2023 at 1120 hrs. Constraint violated due to competing requirements with the import limits on DirectLink which were set by N_X_MBTE_3B.
V_GANNSF_12INV	Constraint equation violated for 3 consecutive DIs on 19/07/2023 from 0715 hrs to 0725 hrs with a violation degree of 0.001 MW. Constraint equation violated due to Gannawarra Solar Farm exceeding its inverter limit.
V_GANWRSF_0INV	Constraint equation violated for 2 consecutive DIs on 27/07/2023 at 1355 hrs and 1400 hrs with a violation degree of 0.01 MW. Constraint equation violated due to Gannawarra Solar Farm exceeding its inverter limit.
SVML^NIL_MH-CAP_ON	Constraint equation violated for 2 non-consecutive DIs on 14/07/2023 at 0400 hrs and 0510 hrs with a max violation degree of 0.0013 MW occurring on 14/07/2023 at 0400 hrs. Constraint equation violated due to competing requirements with the export limit on Murraylink which was set by S>>BWMP_TWPA_TPRS.
V_WEMENSF_21INV	Constraint equation violated for 2 consecutive DIs on 19/07/2023 at 0720 hrs and 0725 hrs with a violation degree of 0.001 MW. Constraint equation violated due to Wemen Solar Farm exceeding its inverter limit.

2.4 Top 10 binding interconnector limit setters

Binding constraint equations can set the interconnector limits for each of the interconnectors on the constraint equation left-hand side (LHS). Table 5 lists the top (by binding hours) interconnector limit setters for all the interconnectors in the NEM and for each direction on that interconnector.

Table 5 Top 10 binding interconnector limit setters

Constraint Equation ID (System Normal Bold)	Interconnector	Description	#DIs (Hours)	Average Limit (Max)
N^N-LS_SVC	N-Q-MNSP1 Export	Out= Lismore SVC O/S or reactive power control mode, avoid Voltage collapse on Armidale to Coffs Harbour (87) trip; [Swamped for three DLK cables are O/S or Swamped when ECS is enabled with DLK is exporting to QLD, sets DLK to -29 MW for -29< DLK FLOW<0)	3329 (277.42)	-52.42 (-29.0)
F_MAIN++NIL_MG_R5	T-V-MNSP1 Export	Out = Nil, Raise 5 min requirement for a Mainland Generation Event, Basslink able transfer FCAS	1821 (151.75)	381.11 (447.0)
V^^N_NIL_1	VIC1-NSW1 Export	Out = Nil, avoid voltage collapse around Murray for loss of all APD potlines	1583 (131.92)	1183.42 (1553.68)
N_X_MBTE_3A	N-Q-MNSP1 Export	Out= all three Directlink cables, Terranora_I/C_import <= Terranora_Load	1480 (123.33)	-33.49 (17.5)
V^^N_NIL_1	V-S-MNSP1 Export	Out = Nil, avoid voltage collapse around Murray for loss of all APD potlines	1456 (121.33)	-96.72 (169.51)
F_MAIN++NIL_MG_R6	T-V-MNSP1 Export	Out = Nil, Raise 6 sec requirement for a Mainland Generation Event, Basslink able transfer FCAS	1409 (117.42)	405.65 (447.0)
SVML^NIL_MH-CAP_ON	V-S-MNSP1 Import	Out=NIL, SA to Vic on ML upper transfer limit to manage voltage collapse at Monash (Note: applies when capacitor banks at Monash are available and I/S for switching.)	1130 (94.17)	-152.61 (-176.35)
S>NIL_MHNW1_MHNW2	V-S-MNSP1 Export	Out= Nil, avoid O/L Monash-North West Bend #2 132kV on trip of Monash-North West Bend #1 132kV line, Feedback	923 (76.92)	162.12 (185.43)

Constraint Equation ID (System Normal Bold)	Interconnector	Description	#DIs (Hours)	Average Limit (Max)
N_X_MBTE_3B	N-Q-MNSP1 Import	Out= all three Directlink cables, Terranora_I/C_import <= Terranora_Load	869 (72.42)	-18.72 (-57.8)
N>>NIL_964_84_S	NSW1-QLD1 Import	Out= NIL, avoid O/L Port Macquarie to Herron Creek Tee (964/2) on trip of Tamworth to Liddell (84) line, Feedback	807 (67.25)	-906.16 (-1199.11)

2.5 Constraint Automation Usage

The constraint automation is an application in AEMO's energy management system (EMS) which generates thermal overload constraint equations based on the current or planned state of the power system. It is currently used by on-line staff to create thermal overload constraint equations for power system conditions where there were no existing constraint equations or the existing constraint equations did not operate correctly.

The following section details the reason for each invocation of the non-real time constraint automation constraint sets and the results of AEMO's investigation into each case.

Table 1 – Non-Real-Time Constraint Automation usage

Constraint Set ID	Date Time	Description
CA_SYDS_53C9C000	19/07/2023 11:00 to 19/07/2023 13:25	CA_SYDS_535465AD was created to manage the overloading of Darlington Point no. 4 330/220kV transformer for loss of Bendigo - Kerang 220 kV line.

2.5.1 Further Investigation

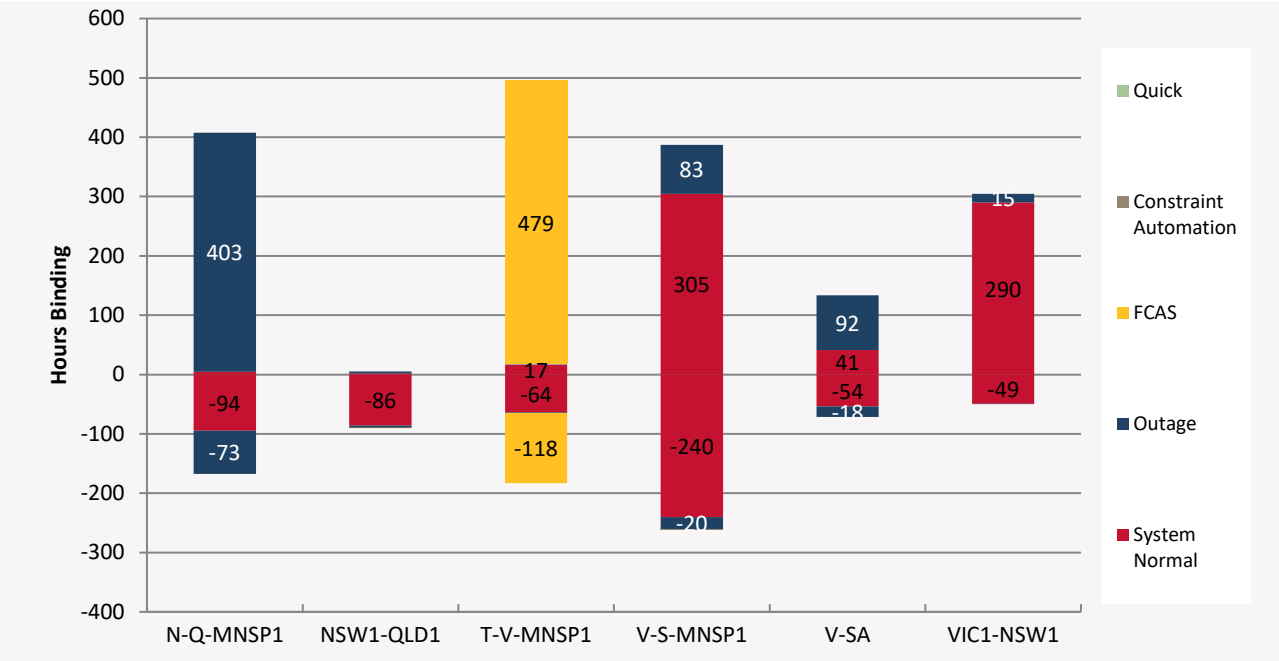
CA_SYDS_53C9C000: Constraint was invoked and binding. Constraints V>>BUCW_DPTX_KGBE and V>>BUCW_X5DP_KGBE were created to manage ongoing and future violation issues. V>>BUCW_DPTX_KGBE was binding, which cleared the violation.

2.6 Binding Dispatch Hours

This section examines the number of hours of binding constraint equations on each interconnector and by region. The results are further categorized into five types: system normal, outage, FCAS (both outage and system normal), constraint automation and quick constraints.

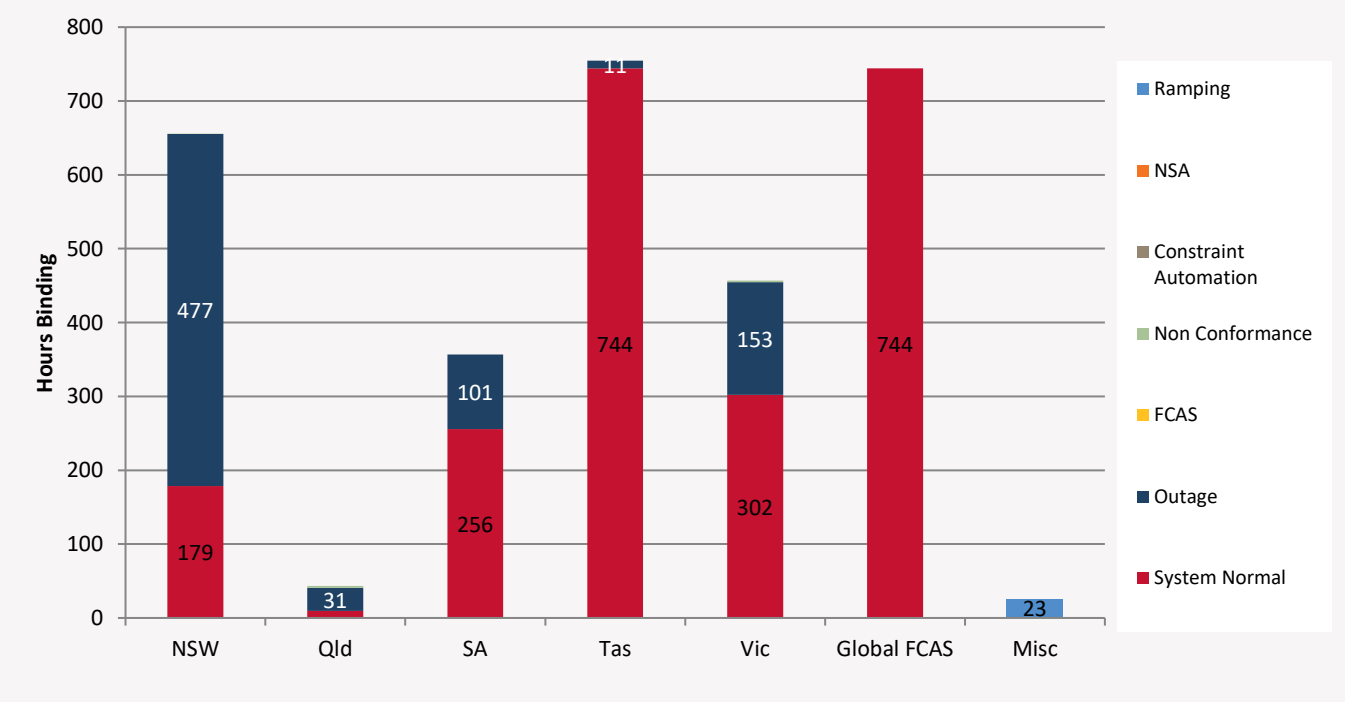
In the following graph the export binding hours are indicated as positive numbers and import with negative values.

Figure 1 Interconnector binding dispatch hours



The regional comparison graph below uses the same categories as in Figure 1 as well as non-conformance, network support agreement and ramping. Constraint equations that cross a region boundary are allocated to the sending end region. Global FCAS covers both global and mainland requirements.

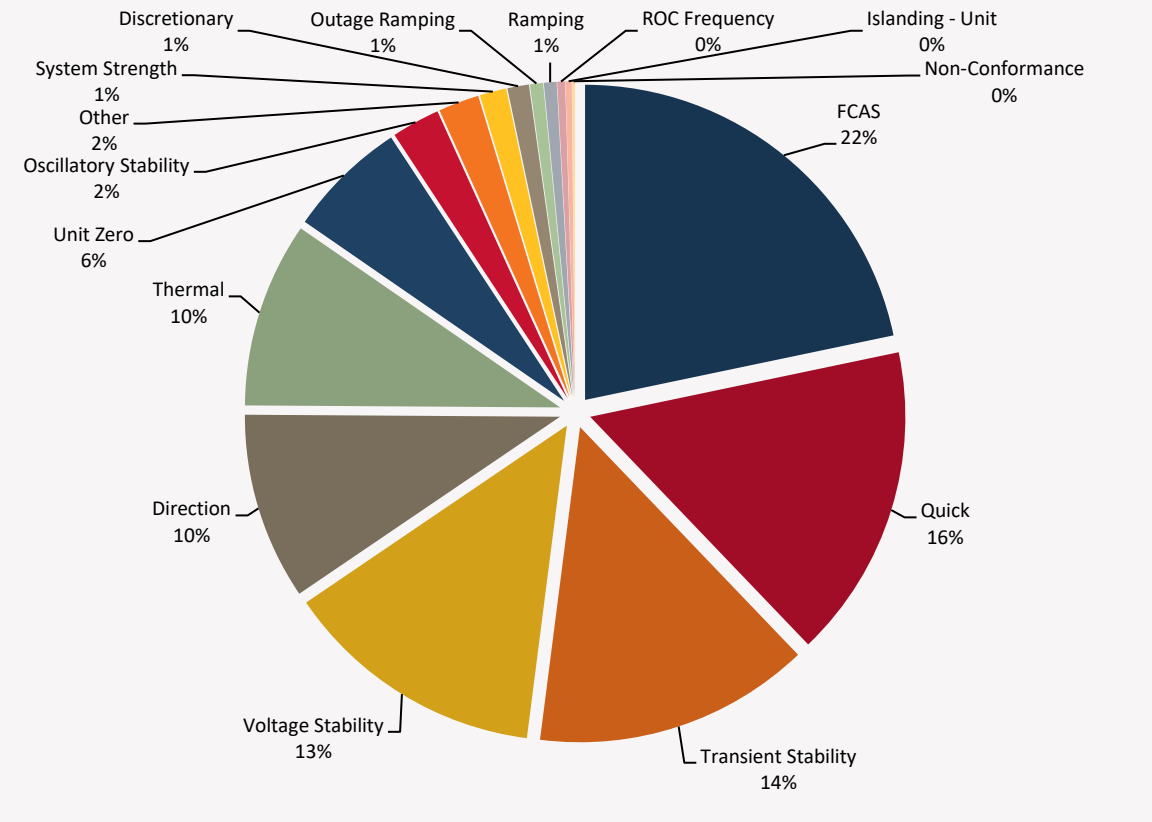
Figure 2 Regional binding dispatch hours



2.7 Binding Constraint Equations by Limit Type

The following pie charts show the percentage of dispatch intervals for July 2023 that the different types of constraint equations bound.

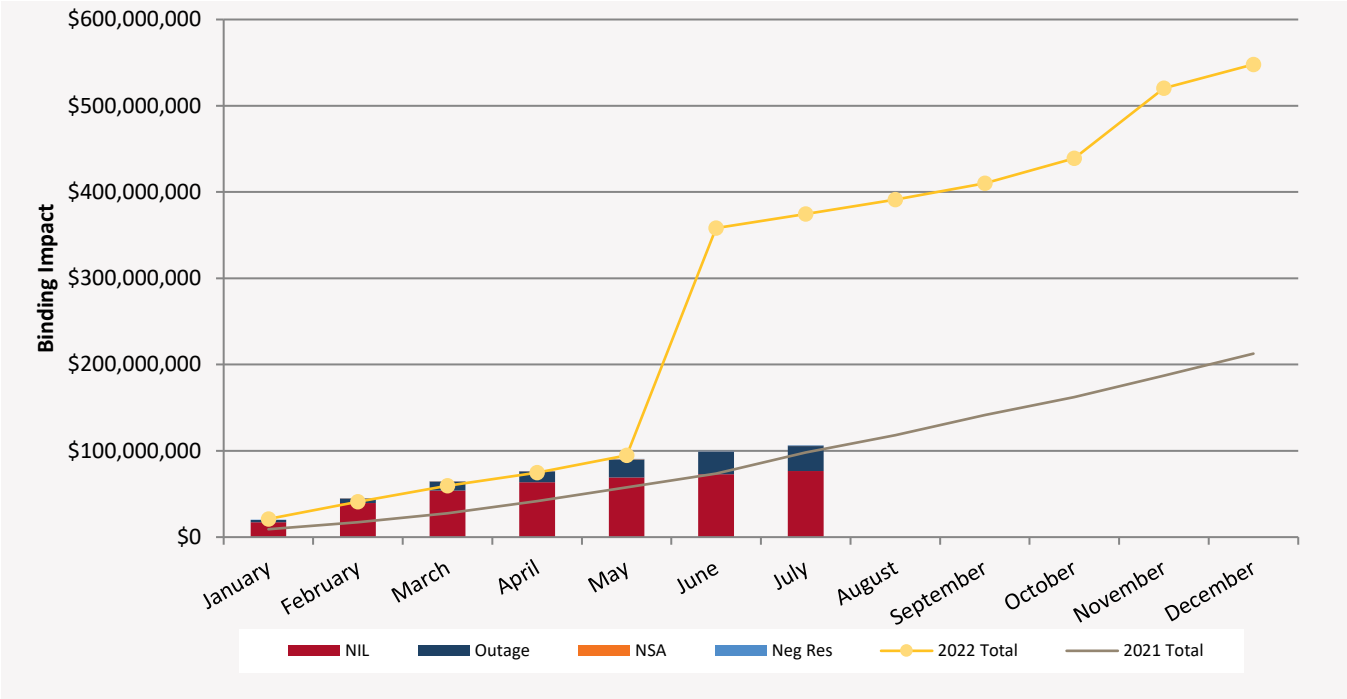
Figure 3 Binding by limit type



2.8 Binding Impact Comparison

The following graph compares the cumulative binding impact (calculated by summating the marginal values from the MCC re-run – the same as in section 2.2) for each month for the current year (indicated by type as a stacked bar chart) against the cumulative values from the previous two years (the line graphs). The current year is further categorised into system normal (NIL), outage, network support agreement (NSA) and negative residue constraint equation types.

Figure 4 Binding Impact comparison



2.9 Pre-dispatch RHS Accuracy

Pre-dispatch RHS accuracy is measured by the comparing the dispatch RHS value and the pre-dispatch RHS value forecast four hours in the future. The following table shows the pre-dispatch accuracy of the top ten largest differences for binding (in dispatch or pre-dispatch) constraint equations. This excludes FCAS constraint equations, constraint equations that violated in Dispatch, differences larger than ±9500 (this is to exclude constraint equations with swamping logic) and constraint equations that only bound for one or two Dispatch intervals. AEMO investigates constraint equations that have a Dispatch/Pre-dispatch RHS difference greater than 5% and ten absolute difference which have either bound for greater than 25 dispatch intervals or have a greater than $1,000 binding impact. The investigations are detailed in 2.9.1.

Table 6 Top 10 largest Dispatch / Pre-dispatch differences

Constraint Equation ID (System Normal Bold)	Description	#DIs	% + Max Diff	% + Avg Diff
V::N_NIL_V2	Out = NIL, prevent transient instability for fault and trip of a HWTS-SMTS 500 kV line, VIC accelerates. Yallourn W G1 on 500kV.	49	1,974% (157.39)	62.01% (56.18)
N_X_MBTE_3A	Out= all three Directlink cables, Terranora_I/C_import <= Terranora_Load	282	420% (25.1)	30.85% (7.31)
N_X_MBTE_3B	Out= all three Directlink cables, Terranora_I/C_import <= Terranora_Load	181	382% (25.1)	41.14% (8.12)
N^N-LS_SVC	Out= Lismore SVC O/S or reactive power control mode, avoid Voltage collapse on Armidale to Coffs Harbour (87) trip; [Swamped for three DLK cables are O/S or Swamped when ECS is enabled with DLK is exporting to QLD, sets DLK to -29 MW for -29< DLK FLOW<0)	284	255% (75.15)	39.07% (19.23)
N^^V_DTSS_1	Out = Dapto-Sydney South(11), avoid voltage collapse at Southern NSW for loss of the largest Vic generating unit or Basslink	4	156% (207.6)	66.83% (140.17)

Constraint Equation ID (System Normal Bold)	Description	#DIs	% + Max Diff	% + Avg Diff
V::N_NIL_O2	Out = NIL, prevent transient instability for fault and trip of a HWTS-SMTS 500 kV line, Other than VIC accelerates. Yallourn W G1 on 500kV.	66	154% (263.08)	19.96% (58.99)
N^^V_NIL_1	Out = Nil, avoid voltage collapse at Southern NSW for loss of the largest Vic generating unit or Basslink	59	139.37% (260.59)	30.75% (85.71)
V::N_NIL_V1	Out = NIL, prevent transient instability for fault and trip of a HWTS-SMTS 500 kV line, VIC accelerates. Yallourn W G1 on 220kV.	10	104.03% (287.01)	36.5% (83.5)
V^^SML_NIL_3	Out = Nil, avoid voltage collapse for loss of Bendigo to Kerang 220kV line	18	57.57% (216.13)	34.47% (103.57)

2.9.1 Further Investigation

The following constraint equation(s) have been investigated:

V::N_NIL_O2: Investigated and no improvement can be made to the constraint equation at this stage.

V^^SML_NIL_3: Investigated and no improvement can be made to the constraint equation at this stage.

V::N_NIL_V2: Investigated and no improvement can be made to the constraint equation at this stage.

N_X_MBTE_3A: Investigated and the mismatch was due to issues with forecasting of the Terranora load. The forecasting of the Terranora load has been improved in November 2018.

N_X_MBTE_3B: Investigated and the mismatch was due to issues with forecasting of the Terranora load. The forecasting of the Terranora load has been improved in November 2018.

N^N-LS_SVC: Investigated and constraint equation was updated on 27/08 to improve PD performance.

N^^V_NIL_1: The Pre-dispatch formulation for this constraint equation was recalculated in early November 2017 (with an update to the limit advice). No further improvements can be made at this stage.

T_ROCOF_3: Investigated and the mismatch is due to the calculation of Tasmanian inertia in PD. This cannot be calculated more accurately due to uncertainty around the future dispatch of aggregated generating units in Tasmania.

3 Generator / Transmission 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 following table details changes that occurred in July 2023.

Table 7 Generator and transmission changes

Project	Date	Region	Notes
Bouldercombe BESS (Gen Component)	11 July 2023	Qld	New Battery
Bouldercombe BESS (Load Component)	11 July 2023	Qld	New Battery
Goyder South Wind Farm 1a	11 July 2023	SA	New Generator
Glenrowan W1 220kV/33kV Transformer	13 July 2023	VIC	Transformer commissioned for Glenrowan Solar Farm
Wagga No 4 330kV 100 MVAR Capacitor	22 July 2023	NSW	
Capital Battery (Load Mode)	25 July 2023	NSW	New Battery
Capital Battery (Gen Mode)	25 July 2023	NSW	New Battery

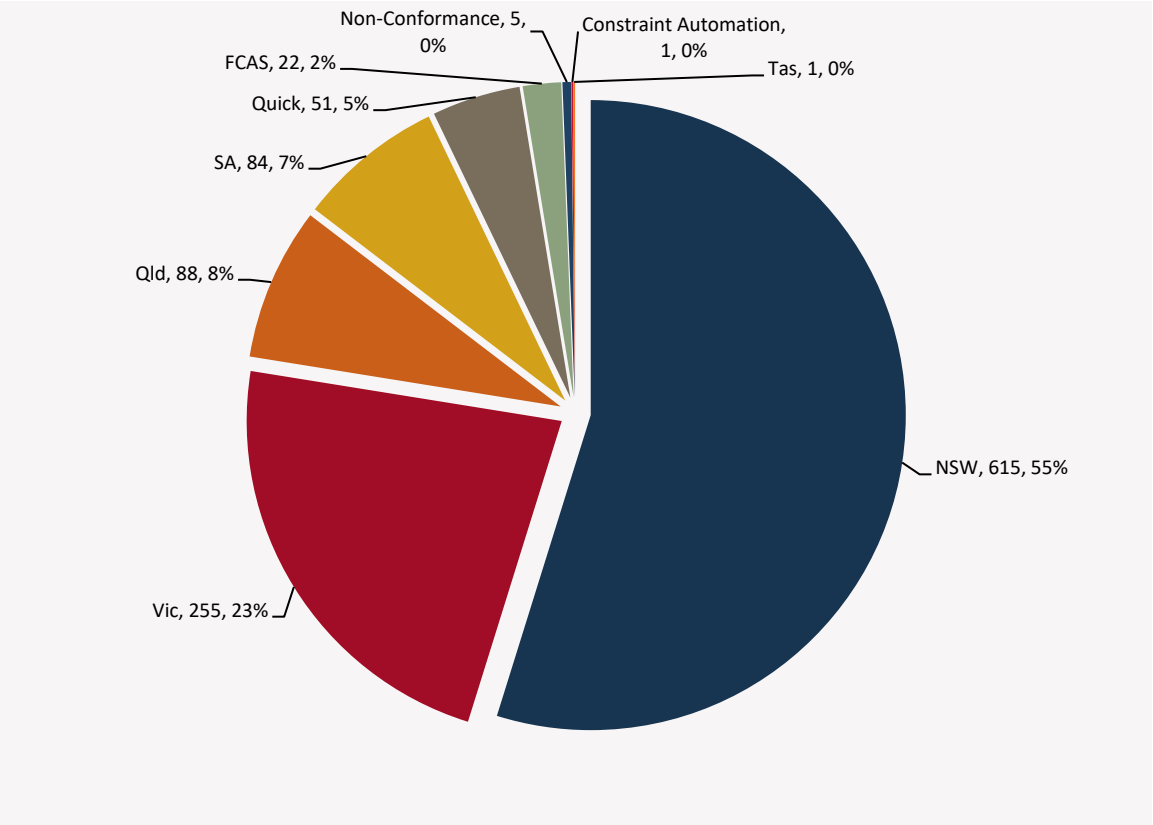
3.1 Constraint Equation Changes

The following pie chart indicates the regional location of constraint equation changes. For details on individual constraint equation changes refer to the Weekly Constraint Library Changes Report[2] or the constraint equations in the MMS Data Model[3].

[2] AEMO. *NEM Weekly Constraint Library Changes Report.* Available at: http://www.nemweb.com.au/REPORTS/CURRENT/Weekly_Constraint_Reports/

[3] AEMO. *MMS Data Model*. Available at: https://www.aemo.com.au/energy-systems/market-it-systems/nem-guides/wholesale-it-systems-software

Figure 5 Constraint equation changes



The following graph compares the constraint equation changes for the current year versus the previous two years. The current year is categorised by region.

Figure 6 Constraint equation changes per month compared to previous two years