C Types of constraints

This Appendix provides additional details on the three broad types of constraints used in the dispatch process to reflect the underlying physical network and the effects each has on regional reference prices.

The three broad types of constraints are:

1. Pure intra-regional (Pure intra-regional limits);
2. Pure inter-regional constraints (Pure Interconnector Limits); or
3. Trans-regional constraints, involving either:
    (a) A single interconnector and local generation units (i.e. hybrid constraint);
    (b) Multiple interconnectors and local generation units; or
    (c) Interactions between two or more interconnectors, without any local generation involved.[234]

This Appendix also provides an indication of the prevalence each type of constraint, based on analysis of a single dispatch interval on a working day afternoon in July 2007, which is representative of "system normal" conditions (i.e. conditions with no prior outages of network elements that are normally switched into service).

C.1 Pure intra-regional constraints

A pure intra-regional constraint restricts the flow of power through a constrained network element within a region, but is not affected by power flows from other regions. That is, the physical effects of the constraint are limited to one region. If a binding pure intra-regional constraint affects power transfers to and from the reference node, then the regional reference price will reflect the impact of the constraint binding. The price at the reference node will not be affected in any way if a binding pure intra-regional constraint does not affect power transfers to and from the reference node. These concepts are illustrated below. All examples assume no network losses and that each generator offers all its capacity at the offer price indicated.

C.1.1 Pure intra-regional constraint that affects the regional reference price

A pure intra-regional constraint binds in such a way that power flows to the regional reference node are affected. In order to balance supply with demand at the reference

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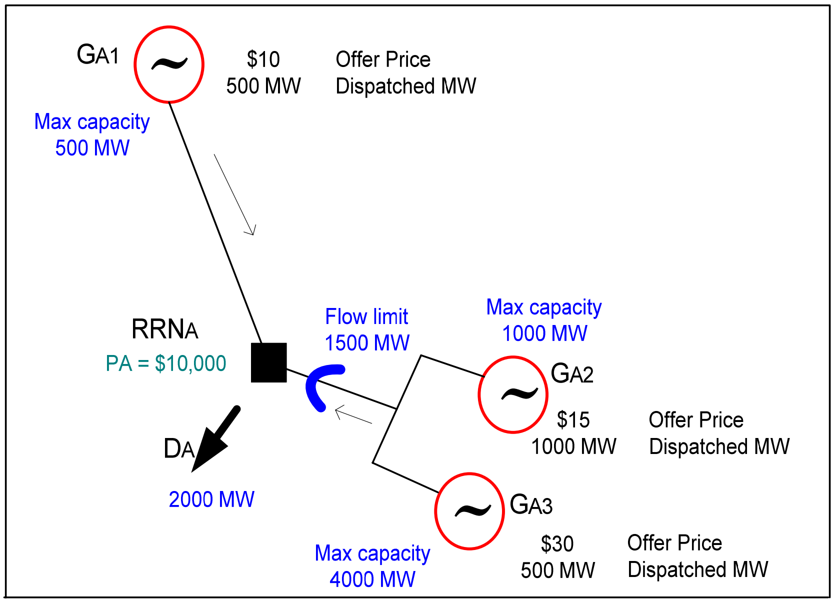
[234] For further discussion of trans-regional constraints and their pricing impacts, see the CRA report, *NEM Interconnector Congestion: Dealing with Interconnector Interactions*, Report to NEMMCO, Wellington, 2003. Available at http://www.mce.gov.au/assets/documents/mceinternet/InterconnectorInteractions20041123171938%2Epdf

node, either additional energy is required or demand must be reduced. The incremental cost of procuring additional supplies of energy at the reference node as a direct result of the constraint binding is the congestion cost of the constraint. This congestion cost is reflected in the regional reference price. In Figure C.1, there is no way of increasing generation to meet a 1 MW increase in load at the reference node because G_{A1} is at maximum output and the 1500 MW transmission limit restricts additional output from G_{A3}, so in the absence of any demand-side bids, the marginal price at the reference node is set by VoLL, $10,000/MWh. It can be shown that the marginal economic cost of the congestion equals $9970/MWh.

If this flow limit persisted over time, then the congestion costs implicit in the reference node price could provide incentives for economically efficient investments to:

- Upgrade the transmission line from G_{A3} and G_{A2} to the reference node;
- Increase the amount of generation capacity located on the other side of the constraint, which has unrestricted access to the reference node price; and
- Reduce demand at the reference node through demand-side management.

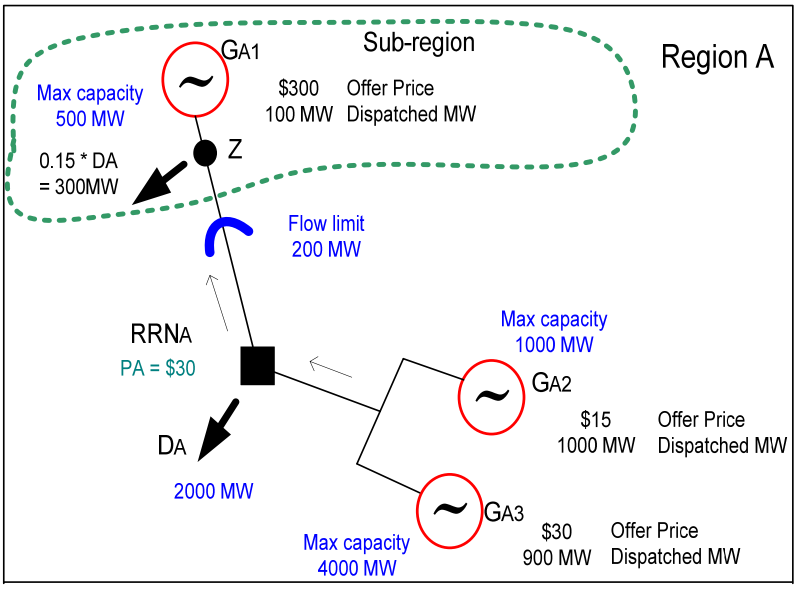
Figure C.1: Pure intra-regional constraint that affects the regional reference price



C.1.2 Pure intra-regional constraint with no impact on regional reference price

Figure C.2 illustrates the case of a pure intra-regional constraint binding that has no effect on the regional reference price. In Figure C.2, total demand at the reference node is 2000 MW but fifteen per cent of this load (i.e. 300MW) occurs physically in the sub-region containing node Z. Incremental demand at the reference node can be met by G_{A3}, at a price of $30, which sets the regional reference price. At that price, G_{A1} would not expect to be dispatched based on its offer price of $300. However, in order to meet the 300MW demand at node Z, generator G_{A1} will have to be constrained on to meet the 100 MW of the sub-regional load at *Z* that can not be met because the 200MW flow limit is binding.[235] Under the Rules generator G_{A1} would be paid the $30/MWh reference price for all its output because it is constrained on generation that has no effect on the ability to balance supply and demand at the regional reference node.

Figure C.2: Pure intra-regional constraint with no impact on regional reference price



The Rules also state that if a generator is initially unavailable, but is directed by NEMMCO to start generating, it may apply for compensation payments when the regional price is below the price at which it is prepared to offer its capacity.

These pricing arrangements can provide incentives for:

- G_{A1} to declare itself unavailable, so that it can be compensated at a higher price than the reference price;[236] and
- The local TNSP and G_{A1} to enter into a NSA.

C.2 Pure inter-regional constraints

A pure inter-regional constraint is one in which the ability to transfer power between regional reference nodes is unaffected by power flows through a constrained element

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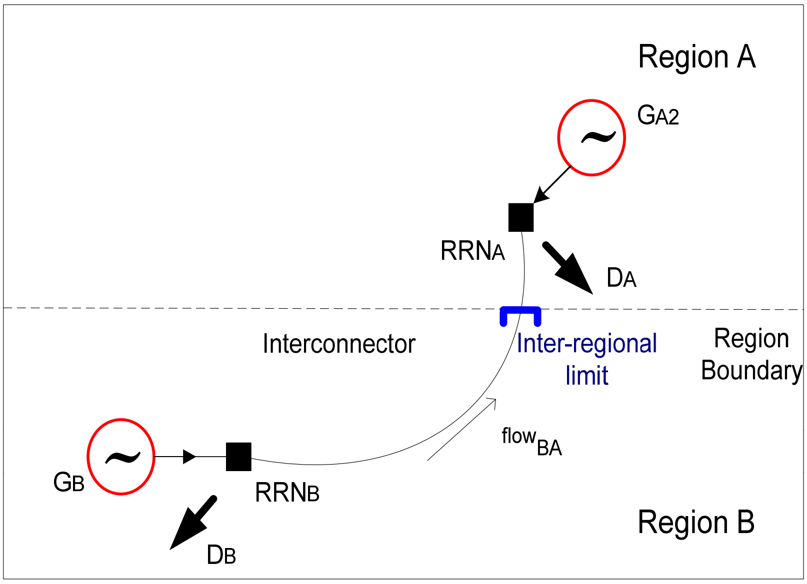
[235] Although all load is notionally treated as being at the reference node, in reality load occurs at different locations of the network. TNSPs and NEMMCO are both required to meet loads across the physical transmission network, not just at reference nodes.

[236] This might occur if: a) G_{A1} has SRMC that are substantially above the prevailing spot price; b) G_{A1} is seeking to exercise its localised market power; or c) GA1 wishes to capture underlying economic rents that are not explicit because of the NEM's regional pricing structure.

within a region, but only affected by the (security constrained) physical capabilities of the interconnector itself (see Figure C.3 below).

Pure inter-regional constraints relate to Pure Interconnector Limits (PILs). A Pure Interconnector Limit represents the sum of bounds on the actual physical lines joining adjacent regions, which may imply binding limits on the corresponding notional interconnector.

Figure C.3: Pure inter-regional constraint



Under the NEM's pricing rules, pure inter-regional constraints will be fully reflected in the price of energy at the boundary between two regions.

When there is a pure inter-regional constraint it is usually necessary for additional generation in the importing region to be dispatched to meet load in that region, even though it may have a higher offer price than generators located in the exporting region. Under these circumstances the price in the importing region will usually rise, with all customers in the importing region paying and generators in the importing region receiving the higher price, while customers and generators in the exporting region face a relatively lower price.

C.3 Trans-regional constraints

Trans-regional constraints, involve both intra-regional generation and inter-regional flow terms. Trans-regional constraints are typically of non-radial form.

Most network limits, when expressed correctly in a fully optimised formulation, produce "trans-regional" constraints.

There are three classes of trans-regional constraint, which each have different characteristics and implications for pricing and the financial settlement positions of market participants:

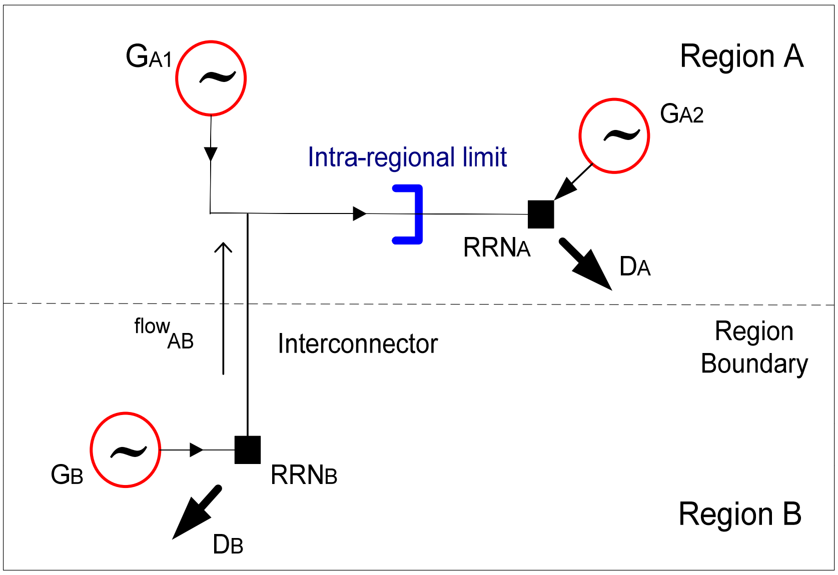
1. A single interconnector and local generation units (i.e. hybrid constraint);
2. Multiple interconnectors and local generation units; or
3. Interactions between two or more interconnectors.

C.3.1 Single interconnector and local generation units (Hybrid)

A constraint involving a single interconnector and generation units within a region has been referred to by the Commission as "hybrid" constraint.

With a hybrid constraint, power flows through the constrained network element are affected by a combination of flows along a single interconnector and flows through constrained network elements within a region. Figure C.4 illustrates this. In Figure C.4 there is a network limit between generator G_{A1} and the Region A regional reference node (RRN_A). This limit affects the ability of both G_{A1} and the interconnector to supply power through the constrained element of the network. In this case, when the constraint binds, additional demand at RRN_A will be met by output from generator G_{A2}, whose ability to deliver power to the reference node is unaffected by the constraint. Given that G_{A2} will be the marginal supplier at the reference node, under the NEM Rules it will set the price at RRN_A. The price at Reference Node B (RRN_B) could also be affected by the constraint if flows on the interconnector change the marginal cost of balancing supply and demand at RRN_B.

Figure C.4: Hybrid constraint, involving a single interconnector and local generation units



The relative locations of the point of congestion, the reference node, generation, and the interconnector all play a role in determining the extent to which the congestion affects the regional reference prices in the region with the constraint and the regions linked by the interconnector.

C.3.2 Multiple interconnectors and local generation units

In a trans-regional constraint involving *multiple interconnectors and local generation units*, power flows through the constrained network element are affected by a combination of flows along more than one interconnector and flows through constrained network elements within a region. These types of constraints typically involve either:

- A physical transmission loop wholly within one region to which are connected local generators and interconnectors; or
- A physical transmission loop that spans two or more regions.[237]

Figure C.5 provides an example of this type of constraint, where the loop is wholly within one region.

In Figure C.5 it is assumed that the network is unconstrained, demand in Region B is high, and the least cost security constrained dispatch results in:

- Region B importing power from regions C and A; and
- Dispatch of generation in region B to meet region B demand.

In this case, power flows around the loop within region B towards the Region B reference node (RRN_B or node 0), with the nature of the flow depending on the relative electrical impedence of the two alternate routes around the loop, measured at each of the five injection points 1 to 5, where generators (G_{B1} to G_{B5}) or interconnectors join the loop.

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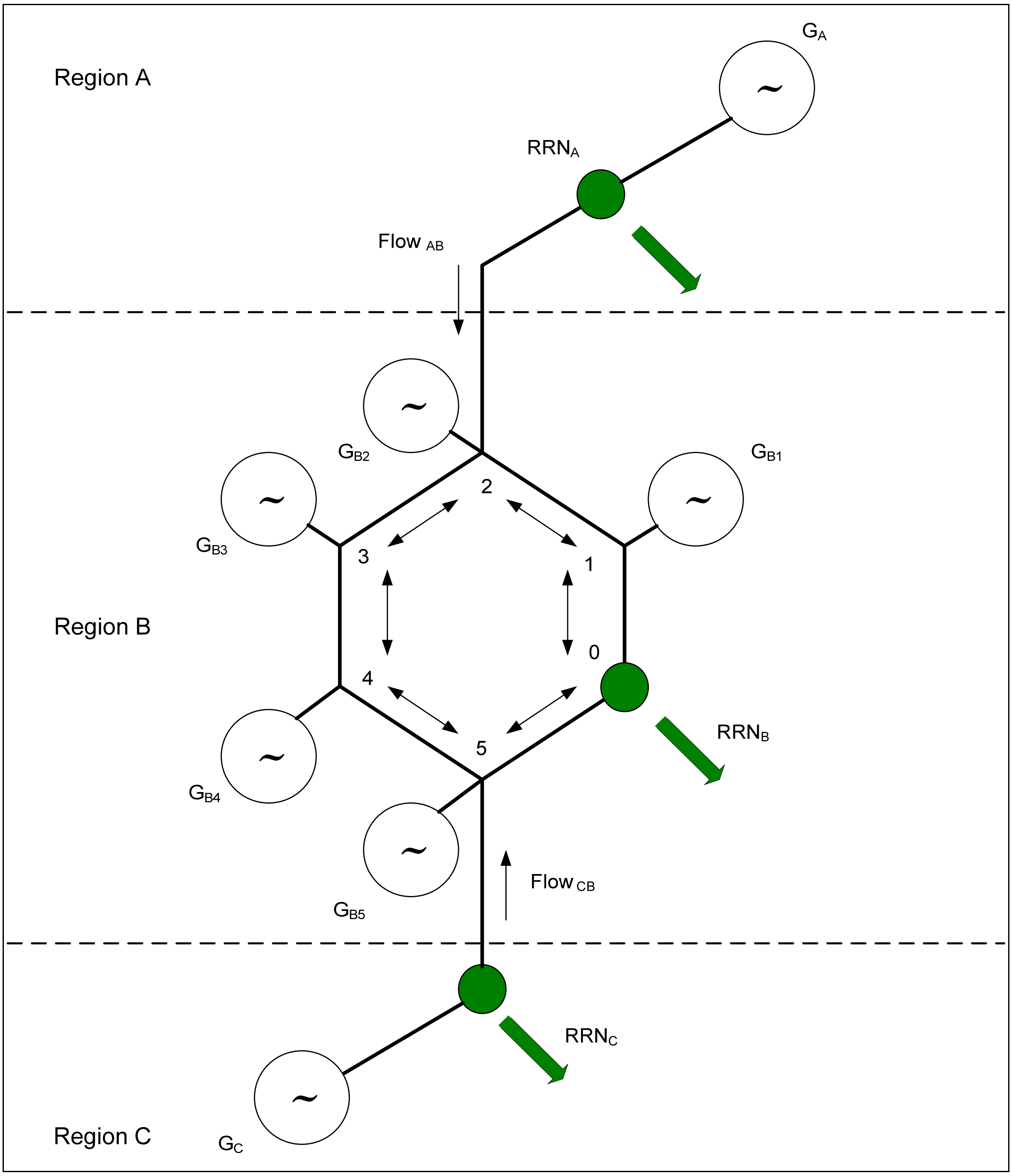
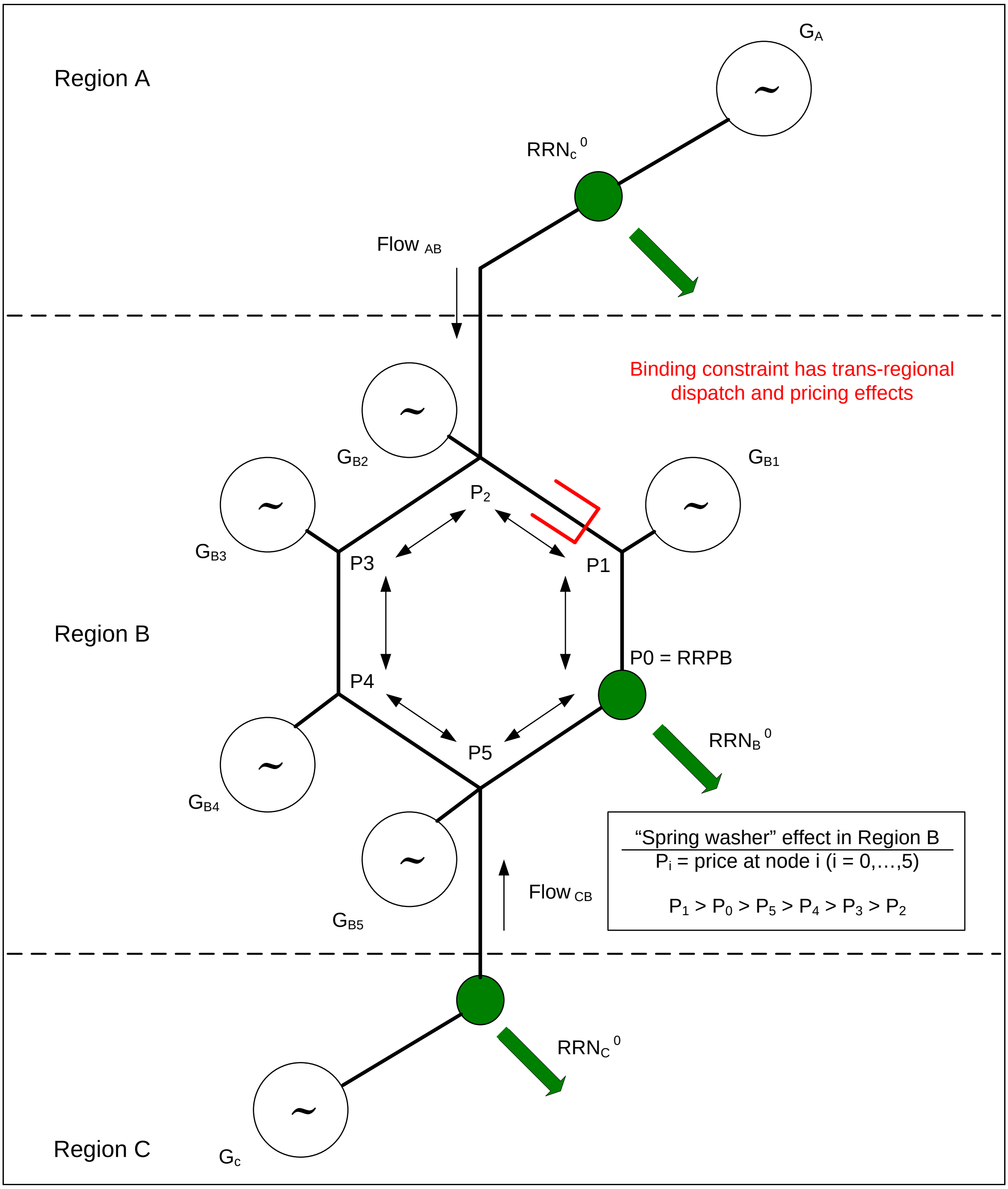
[237] For example, the transmission loop spanning the Victoria, NSW and Snowy regions, prior to the abolition of the Snowy region. This Snowy loop and its pricing effects are discussed in Appendix A of AEMC 2006, *Management of negative settlement residues in the Snowy region*, Final Rule Determination, 14 September 2006, Sydney, pp. A2-A4.

Figure C.5: Multiple interconnectors and local generation units, uncongested



Now assume that a constraint binds within Region on the live connection G_{B2} to G_{B1} – i.e. nodes 2 and 1 (see Figure C.6). This binding constraint affects the ability to deliver power to RRN_B (node 0)

Figure C.6: Multiple interconnectors and local generation units, congested



The binding constraint in region B between nodes 2 and 1 has the following effects:

1. Spring washer pricing effect arises within region B, in which the there is pattern of nodal prices in region B, whereby the highest price occurs at the point where G_{B1} connects to the loop and lowest price occurs where G_{B2} connects to the loop, with nodal prices falling in a clockwise manner. In this situation all the generators in Region B being constrained on or off relative to RRP_B, to some degree;

2. Generation and interconnector flow that most adds to congestion has to be backed off — that is G_{B2} and $flow_{AB}$; and .

3. Generation that most relieves the binding constraint has to be increased — that is, G_{B1};

4. Generation and interconnector flow at all other points of the network will have to be adjusted, so that the constraint is not violated — i.e. G_{B3}, G_{B4}, G_{B5}, $flow_{CB}$. The adjustments in the volume of power injections at these locations will be related to the marginal impact that the change has on power flowing through the constrained network element;

5. The mathematical coefficients relating to the generator and interconnector flow variables are indicative of the impact that a marginal change in the value of the variable will have in relieving the binding constraint;

6. The value of changes in interconnector flows is captured in the NEM's pricing and settlement Rules, and accrues to the inter-regional settlement residue funds for $flow_{AB}$ and $flow_{CB}$;

7. The value of locationally adjusting generation within region B to relieve the constraint (or not violate it) is not reflected in the settlement prices paid to generators within region B. Instead, they are settled at RRP_B. However, the dispatched generation *volumes* of generators G_{B1} to G_{B5} do reflect the value that power injections at each location (based on offers) have in relieving the constraint. This can result in generators being constrained on or constrained off, relative to the settlement price, RRP_B. When generators are constrained on or off in Region B, they face dispatch risk and have incentives to alter their offers to mitigate that dispatch risk by aligning their dispatch volumes with the volumes they are willing to supply at RRP_B. This can result in 'disorderly bidding', which can potentially have a negative impact on the economic efficiency of dispatch, and increase uncertainty about the level of interconnector flows and inter-regional price differences. That is, 'disorderly bidding' can reduce the firmness of the inter-regional settlement residues, thereby diminishing the usefulness of IRSR units as means of managing inter-regional trading risks;

8. Note, this single binding constraint within region B affects dispatch, pricing and settlements across the entire market:

   (a) With local demand unchanged in Region A, and generator offers unchanged, the price in Region A will fall — both relative to RRP_B and in absolute terms — because the effective demand in Region A (i.e. load in Region A plus net exports) has fallen relative to the supply curve in Region A;

   (b) Similarly, with local demand in Region C unchanged, the price in region C will rise towards that in Region B, as more costly generation in Region C is dispatched to meet the higher level of net exports from C to B;

As before, the relative locations of the point of congestion, the reference node, generation, and the interconnectors all play a role in determining the extent to which the congestion affects the regional reference prices in the region with the constraint and the regions linked by the interconnectors.

Further discussion of trans-regional constraints and their pricing impacts, see the CRA report, *NEM Interconnector Congestion: Dealing with Interconnector Interactions.*[238]

C.3.3 Interactions between two or more interconnectors and that do not involve generation

Interactions between two or more interconnectors and that do not involve generation are very rare (see Section C.4 below). However, there are a few examples that occur in the NEM, which primarily relate to stability constraints.

In these cases where there is no generation directly represented in the constraint, flows on one interconnector are affected by flows on at least one other interconnector. That is, there is interconnector interaction. These pure interconnector interactions can take several forms, for example:

- Requiring greater flow on one interconnector in order for flow on the other to increase;
- Requiring counter-price flow on one interconnector to support flows on other interconnectors in order to minimise the total costs of dispatch; and
- Stability constraints designed to keep the six regions of the NEM electrically intact in the event of a contingency that creates a transient stability or voltage stability issue.

The most common type of interacting interconnector constraints also involve generation (see Section C.4 below). These are discussed in Section C.3.2.

C.4 Incidence of constraint types

The incidence of the three broad types of constraints provides an indication of how likely they are to affect the setting of regional reference prices in any dispatch interval.

A snapshot view of the incidence of the various constraint types can be gauged from examining the constraints that were invoked during a dispatch interval.

NEMMCO randomly sampled a dispatch interval in the mid to late afternoon of 17 July 2007, and classified the constraints that were invoked. There are only a few

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[238] CRA(2003b) *Dealing with NEM Interconnector Congestion: A Conceptual Framework*. Released by the National Electricity Market Management Company of Australia, March 2003.

CRA(2004c) *NEM Interconnector Congestion: Dealing with Interconnector Interactions*. Released by the National Electricity Market Management Company of Australia, October 2004 http://www.mce.gov.au/assets/documents/mceinternet/InterconnectorInteractions20041123171938%2Epdf prior outages of transmission plant on the day, so the dispatch interval seems to be representative of system normal conditions.

Based on the analysis of that single dispatch interval, the following findings were made:

1. At any point in time under system normal conditions, it can be expected that up to about 400 constraints to be invoked and active in the dispatch process;

2. Of these 400, around 80 (or 20%) are associated with FCAS requirements, and half of these FCAS constraints are for Tasmania;

3. Around 75% (i.e. 300) of all the total constraints are trans-regional constraints that involve at least one interconnector;

4. Of the 300 non-FCAS constraints that involved interconnectors, about 230 of these also involved generating units. That is, around 77% of the non-FCAS constraints were trans-regional constraints that involved either:

    (a) A single interconnector and local generation units (i.e. hybrid constraint); or

    (b) Multiple interconnectors and local generation units;

5. Put another way, around 58% of the total of 400 constraints (i.e. 230/400) invoked in the dispatch interval, were trans-regional constraints involving generation interacting with one or more interconnectors;

6. Around 31% (i.e. 120) of all constraints are trans-regional constraints involving more than one interconnector;

7. Of the 120 trans-regional constraints involving multiple interconnectors, about half had two interconnector terms. However, there a six trans-regional constraint equations that include all five interconnectors (including Basslink) in them. These six constraints most likely related to stability constraints; and

8. Of these 120 constraints, about 55% have different signs on the interconnectors and 45% had the same sign. This indicates an interaction between the interconnectors, which could include: a) one interconnector supporting flows one or more other interconnectors; b) one interconnector blocking flows one or more other interconnectors; c) the minimisation of electrical losses on flows across two or more interconnectors; and d) stability constraints designed to keep the NEM electrically intact in the event of a disturbance.

9. Only around 20 constraints (i.e. 5% of the 400 total and 6.25% of the 320 non-FCAS constraints) were either:

    (a) Outage related;[239]

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[239] There were around 12 network outages and restrictions that day, comprising: a) 1 constraint arising from one of the three Directlink cables being out of service; b) About 6 constraints to manage an

(b) Pure intra-regional; or

(c) Pure inter-regional.

The conclusion of this analysis is that, under system normal conditions, the majority of active transmission constraints in the NEM are trans-regional constraints. The bulk of these trans-regional constraints involve one or more interconnectors interacting with generation in a region.

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outage on the Ballarat to Kerang 220kV circuit; c) Several constraints relating to the Armidale transformer, which restricted flows into the 132kV system that parallels QNI; and d) a limit on power flows between Central Queensland and Southern Queensland.