PROPORTIONING INTER-REGIONAL LOSSES TO REGIONS

PREPARED BY:	Keng Loh
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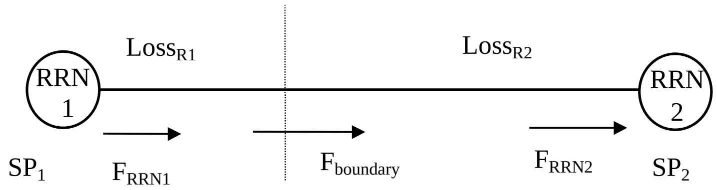
1. Introduction

Notional interconnectors are used to provide a simple radial link representation of all the individual transmission lines that form the physical interconnection between adjacent regional reference nodes. This allows a simple, but effective, model to be used for processes such as dispatch and settlements in the National Electricity Market (NEM). From 1 July 2008, following the abolition of the Snowy region, there are five notional interconnectors:

- the South Pine 275 kV Regional Reference Node (RRN) in the Queensland region and Sydney West 330 kV RRN in the NSW region – (QNI & Terranora);
- the Thomastown 66 kV RRN in the Victorian region and Sydney West 330 kV RRN in the NSW region;
- the Torrens Island 66 kV RRN in the South Australian region and Thomastown 66 kV bus in the Victorian region – (Heywood & Murray Link).

Integration of the inter-regional (MLF-1) equations is used to determine the losses on each notional interconnector. The following report considers how this inter-regional loss can be separated into the amount belonging to each of the two regions connected by the link.

This separation of losses is required to allow the inter-regional flow at each end of the link to be determined from the flow at the region boundary. By doing this the inter-regional settlement surplus can be determined.



For the above simple model:

$F_{boundary}$ = Inter-regional flow at the region boundary

$Loss_{R1}$ = Proportion of inter-regional loss located in Region 1

$Loss_{R2}$ = Proportion of inter-regional loss located in Region 2

F_{RRN1} = Inter-regional flow at Regional Reference Node 1

$= F_{boundary} + Loss_{R1}$

F_{RRN2} = Inter-regional flow at Regional Reference Node 2

$= F_{boundary} - Loss_{R2}$

If SP_1 is the Spot Price in region 1 and SP_2 is the Spot Price in region 2 then the Inter-regional Settlement Surplus (IRSS) can be calculated from:

$$IRSS = F_{RRN2} * SP_2 - F_{RRN1} * SP_1$$

2. Determining the Marginal Loss Factor Between Reference Node and Boundary

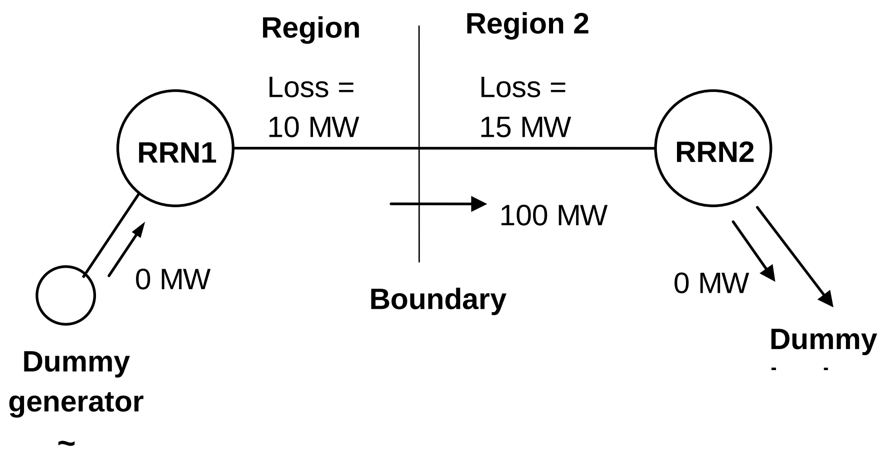
The inter-regional loss factor between Regional Reference Nodes (RRNs) can be determined by injecting 1 MW of load at the receiving end reference node, and recording the generation required to supply this load from the sending end reference node.

In the National Electricity Market this is performed for a wide range of system conditions, and regression analysis is used to produce an equation describing the variation of inter-regional loss factors with important system parameters. The average loss for a notional interconnector is determined by integrating its inter-regional loss factor equation with respect to notional link flow.

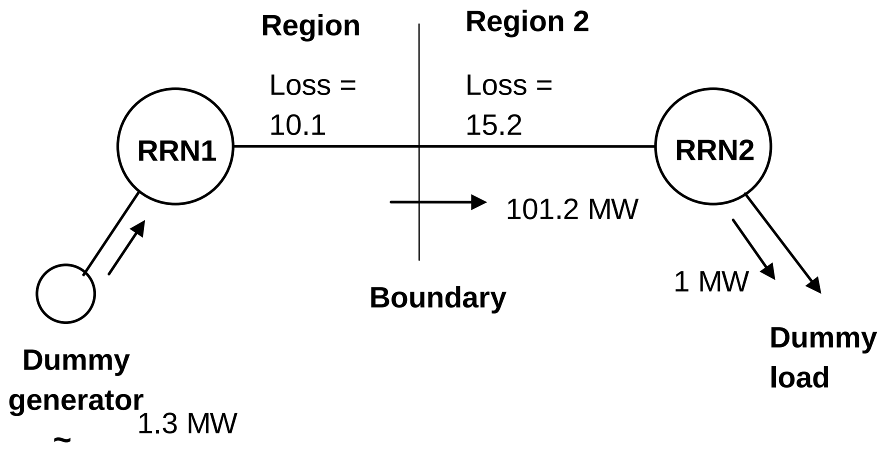
It is proposed that a similar approach be adopted to allow the average losses in each region traversed by the notional link to be determined. This will ensure consistency between the methods used to determine the total losses and individual region losses.

This approach is illustrated below:

1. **Prior to 1 MW load injection**



2. 1 MW load injection



3. Calculation of Loss Factors

- **RRN2 loss factor relative to RRN1 :**

  Is equal to the generation required at RRN1 to supply an increase in load of exactly 1 MW at RRN2, ie.,

  MLF_{21} = 1.30

- **RRN2 Loss factor relative to the region boundary :**

  This is obtained in the same way as above by moving the dummy generator to region boundary. The corresponding generation for 1 MW load injection at RRN2 is 1.2 MW. Thus,

  MLF_{2B} = 1.20

- **Region Boundary loss factor relative to RRN1 :**

  can be obtained as above by determining the dummy generation at RRN1 corresponding to a 1 MW load injection at the boundary, or

  $MLF_{B1} = MLF_{21} / MLF_{2B}$

  $= 1.30 / 1.20$

  $= 1.083$

In the NEM, several of the region boundaries are defined by more than one bus. In such cases, it is not possible to obtain the loss factors between the region boundaries and RRNs by applying this approach directly. Rather, the loss factors for the each of the boundary buses are first calculated. They are then averaged to give a single loss factor at the region boundary.

In this example, the MLFs are calculated for a flow of 100 MW and the corresponding losses are as shown. It can be seen that when calculating the MLFs by injecting 1 MW at the receiving and end and calculating the additional generation at the sending end, it is not important that the value of losses be available. Thus the MLFs can be calculated simply for any flows.

By performing a large number of loadflow studies covering a wide range of inter-regional flows at different levels of demand and following the process outlined above, equations describing the variation of region boundary loss factor against important system parameters can be determined. By integrating these equations the average inter-regional losses for each region traversed by the notional link can be determined.

4. Calculation of Losses

As the MLF is a measure of the additional losses for an increment of a MW of load at various levels of line flows, integrating the MLF equation with respect to line flow will give the losses as a function of line flow. Losses and MLFs increase with distance and impedance. However, additional line flow only increases losses if it flows in the same direction as the existing net flow and the resulting MLF is greater than one. If the flow is against the current net flow, total losses on the system will be reduced and the MLF will then be less than one.

The resulting loss equation for the example above from integrating the MLF equation will give the variation in losses with line flows. This equation is relatively easy to obtain, because the integration constant is simply zero due to the initial condition of zero loss for zero line flow. However, the NEM is a five region (node) model with notional interconnectors between them linking the regional reference node (RRN) of one region to an adjacent RRN. An equivalent five node system with all loads and generation attached to the RRNs is extremely difficult to determine. And as the interconnector flows are measured at the region boundaries, the losses when the interconnector flow is zero will not be zero due to the system loads at the time. Thus the MLF obtained by calculating the additional generation for I MW load injection will give the correct marginal loss for an interconnector between two RRNs, but the resulting equation obtained by integrating the MLF equation will not give the losses on the notional interconnector but rather the total system loss which includes the interconnector loss.

The losses for the notional interconnector between two RRNs can be approximated by integrating the MLF equation and applying the initial condition of zero loss at zero interconnector flow. This is illustrated below for the NSW – Victoria interconnector.

5. Victoria – NSW interconnector

The inter-regional loss factor equation for the **Victoria - NSW** link is provided in Appendix A. The average loss equation for the notional link, obtained by integrating the loss factor equation is included in Appendix B.

The equation describing the variation in "**region boundary referred to Victoria RRN and to NSW RRN**" loss factor with significant system conditions, and the resultant average loss equation are also provided in the Appendices.

Figure 1 is a plot of the MLFs for Sydney West 330 kV (RRN of NSW) referred to Thomas Town 66 (RRN of Vic) against the Vic-NSW transfers. Integrating this MLF equation and applying the appropriate initial condition resulted in the average loss between the Vic RRN and the NSW RRN as shown in figure 2, which is simply the average loss of the Vic and NSW regions. The effect of the interconnector on losses can be seen in figures 1 and 2. During low Vic to NSW transfers, the losses reduce as the transfer increases up to about 300 MW at which point the losses begin to increase again. This is due to the interconnector flow at these levels flowing against the resultant net flows from the system loads. This is also clearly shown by the less than 1.0 MLF values for these transfers.

It can be seen that the marginal loss factors for a notional interconnector linking adjacent RRNs can be obtained readily. The average loss for this link cannot, however, be obtained as simply, because a two node equivalent with each and every systems loads in the regions transfer to the RRNs is difficult, if not impossible to determine. As discussed in the introduction above, the losses for the regions are required for determining the regional settlement surplus. It is proposed to approximate the losses between the RRNs by integrating the MLF equation with the integration constant set to zero by setting the losses to zero for zero interconnector flow. This is shown in figure 3. It can be seen that the effect of having zero loss at zero interconnector flow is that the losses are negative over a small part on the right hand side. The effect of the counter net flow at these levels is also captured by this approximate loss equation, though negative losses have no meaning in practice. Fortunately, the amount of negative losses is small in general, and experience so far has shown that their impact on regional settlement surpluses is insignificant.

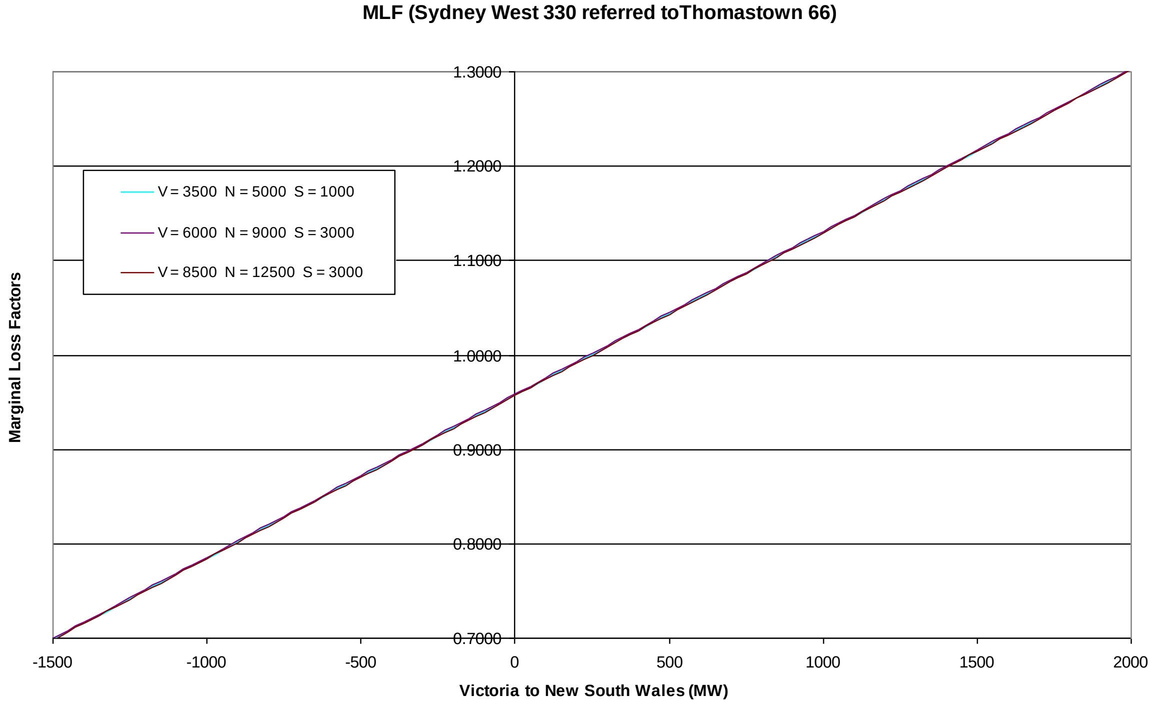


FIGURE 1: MARGINAL LOSS FACTOR VS TRANSFER FOR VIC-NSW NOTIONAL INTERCONNECTOR

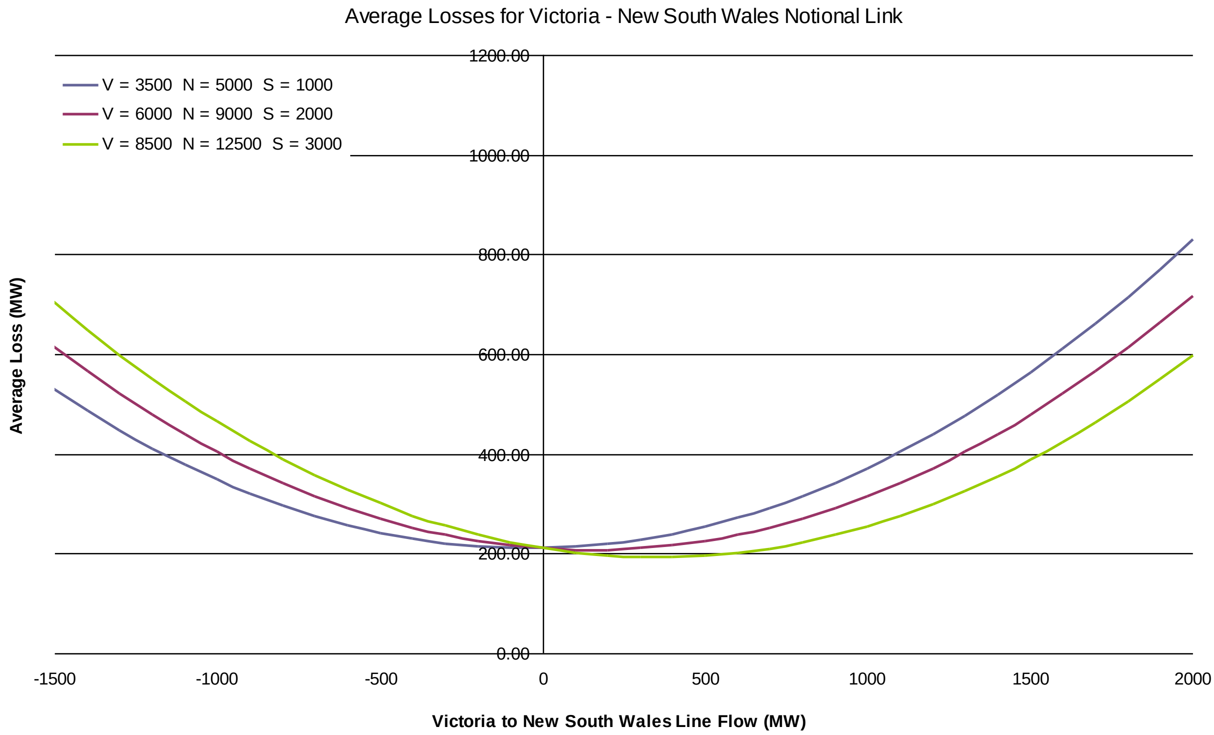


FIGURE 2: AVERAGE LOSS VS TRANSFERS BETWEEN THOMASTOWN 66 & SYDNEY WEST 330

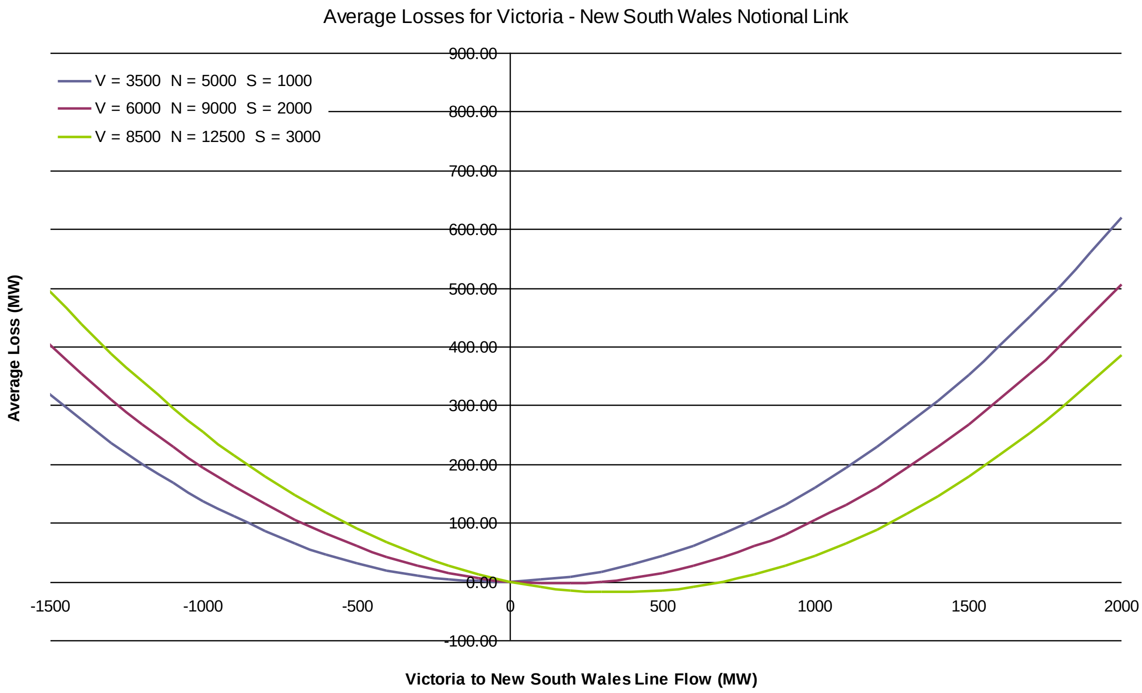


FIGURE 3: AVERAGE LOSS VS TRANSFERS FOR VIC-NSW NOTIONAL INTERCONNECTOR

In determining the losses in each region, the negative losses from the notional interconnector loss equation would result in incorrect proportioning of the losses between the regions. However, as the notional interconnector loss in figure 3 is a subset of the average region loss in figure 2, it is proposed to allocate losses between the regions using the average region loss.

Table 1 shows the losses for a number of Vic-NSW transfers from the MLF calculations for the Vic-NSW notional interconnector. The losses for the Vic and NSW regions were determined using the corresponding "region boundary referred to RRN" equation and the total interconnector losses using the average loss equation shown in figure 2. It can be seen that for each interval the sum of the region losses equal the total losses. Averaging these losses for the year will then give the proportion of losses for each region as shown in table 2.

		VIC	NSW		Total
VIC to NSW		***Losses***	***Losses***		***Losses***
-894.067		75.46199	232.6284		319.5439
-765.389		70.07108	213.4106		294.0557
-752.996		68.97139	211.2977		290.6532
-693.177		66.4922	202.5632		278.9433
-650.69		65.35729	196.5474		271.4789
-597.266		64.14509	189.8741		263.3111
-501.368		62.52997	178.8941		250.2786
-554.321		63.24983	184.6132		256.9115
-492.124		62.80971	177.6835		249.3065
-463.811		62.46154	175.0409		246.255
-494.235		62.25657	178.7743		249.946
-532.412		60.76871	184.4125		254.3308
-447.883		59.15458	176.1247		244.157
-298.07		59.02397	161.5331		228.8517
-162.217		61.08817	149.4961		218.3471
-38.964		64.64849	139.8785		211.8478
19.916		66.80219	135.8738		209.8147
7.976		66.35391	136.6425		210.1694
136.096		72.3178	128.4599		207.5427
328.902		83.86254	119.5314		209.7062
496.534		96.87197	114.1569		216.9936
669.246		112.0084	112.3987		230.2013
718.874		117.4251	111.7251		234.8482
404.431		89.8303	115.5362		211.3432
405.673		91.03282	114.5332		211.4733
399.69		91.87363	113.7401		211.4777
361.716		90.14161	114.3744		210.4385
-121.158		60.12841	148.2277		216.1447
-183.004		56.8532	155.0079		220.007
-275.092		52.28542	165.73		226.6839
-243.706		53.1488	162.3648		224.0134
-219.592		53.96085	159.7068		222.0252
-122.226		58.85186	149.1277		215.8038
132.079		74.88724	126.0336		207.4909
331.622		90.29212	112.5249		208.5087
515.257		106.3333	104.2109		215.5694

TABLE 1: SYSTEM LOSSES VS VIC-NSW NOTIONAL INTERCONNECTOR FLOW

Notional interconnector	Proportioning factor	Region applied to
Queensland – New South Wales (QNI)	0.57	New South Wales
Queensland – New South Wales (Terranora Interconnector)	0.65	New South Wales
Victoria – New South Wales	0.61	New South Wales
Victoria – South Australia (Heywood)	0.70	Victoria
Victoria – South Australia (Murraylink)	0.72	Victoria

TABLE 2: PROPORTIONING OF INTER-REGIONAL LOSSES TO REGIONS

Appendix A:

Inter-Regional Loss Factor Equations

Notional Link Loss Factor Equations

1. **Sydney West 330 - Thomastown 66 notional link**

   Inter-regional loss Factor = 0.9649 + 1.7257E-04*VNt – 1.4631E-05*Vd + 5.7202E-06*Nd + 1.4938E-05*Sd

2. **South Pine 275 - Sydney West 330 notional link**

   QNI:

   Inter-regional loss Factor = 0.9751 + 1.8839E-04*NQt –7.9144E-07*Nd + 1.1623E-05*Qd

   Terranora:

   Inter-regional loss Factor = 1.0726 + 1.5930E-03*$Flow_t$

3. **Torrens Island 66 - Thomastown 66 notional link**

   Heywood:

   Inter-regional loss Factor = 1.0235 + 3.5816E-04*VSAt – 4.6640E-06*Vd + 5.9808E-06*Sd

   Murraylink:

   Inter-regional loss Factor = 1.0596 + 2.9540E-03*$Flow_t$

Proportional Loss Factor Equations

1.

a) Vic/NSW boundary - Thomastown 66 notional link

Vic Loss Factor = 1.1265 + 6.4407E-05*VNt - 7.1282E-06*Vd - 2.9712E-06*Nd - 1.6496E-05*Sd

b) Sydney West 330 - Vic/NSW boundary notional link

NSW Loss Factor = 0.8483 + 1.0490E-4*VNt - 5.6866E-06*Vd + 7.8271E-06*Nd + 2.63897E-05*Sd

2.

QNI

a) NSW/Qld boundary – Sydney West 330 notional link

NSW Loss Factor = 0.9830 + 1.3597E-4*NQt + 1.6945E-06*Nd - 3.1352E-07*Qd

b) South Pine 275 - NSW/Qld boundary notional link

Qld Loss Factor = 0.9886 + 5.5599E-05*NQt - 2.6840E-06*Nd + 1.3059E-05*Qd

Terranorra

a) NSW/Qld boundary – Sydney West 330 notional link

NSW Loss Factor = 1.0384 + 1.6676E-03*Flow

b) South Pine 275 - NSW/Qld boundary notional link

Qld Loss Factor = 1.0343 - 1.4491E-04*Flow

3.

Heywood Link

a) Vic/SA boundary - Thomastown 66 notional link

Vic Loss Factor = 1.0250 + 2.0880E-05*VSAt - 4.4514E-06*Vd + 5.9479E-06*Sd

b) Torrens Island 66 - Vic/SA boundary notional link

SA Loss Factor = 0.9984 + 3.3284E-04*VSAt - 2.1117E-07*Vd - 1.4558E-07*Sd

Murraylink

a) Vic/SA boundary - Thomastown 66 notional link

Vic Loss Factor = 1.1078 + 1.1918E-03*Flow

b) Torrens Island 66 - Vic/SA boundary notional link

SA Loss Factor = 0.9533 + 1.4673E-03*Flow

Where,

Qd = Queensland demand

Vd = Victorian demand

Nd = New South Wales demand

Sd = South Australia demand

NQt = transfer from New South Wales to Queensland

VNt = transfer from Victoria to New South Wales

VSAt = transfer from Victoria to South Australia

Appendix B:

Inter-Regional Loss Equations

Notional Link Loss Equations

1. **Sydney West 330 - Thomastown 66 notional link**

   Inter-regional loss = (-0.0351 – 1.4631E-05*Vd + 5.7202E-06*Nd + 1.4938E-05*Sd)*VNt + 0.8629E-04*VNt^2 + 210.4232

2. **South Pine 275 - Sydney West 330 notional link**

   QNI:

   Inter-regional loss = (-0.0249 –7.9144E-07*Nd + 1.1623E-05*Qd)*NQt + 0.9420E-04*NQt^2 + 183.0929

   Terranora:

   Inter-regional loss = 0.0726*$Flow_t$ + 0.7965E-03*$Flow_t^2$ + 33.2756

3. **Torrens Island 66 - Thomastown 66 notional link**

   Heywood:

   Inter-regional loss =(0.0235 – 4.6640E-06*Vd + 5.9808E-06*Sd)*VSAt + 1.7908E-04*VSAt2 + 47.6288

   Murraylink:

   Inter-regional loss = 0.0596*$Flow_t$ + 1.4770E-03*$Flow_t^2$ + 44.4581

Proportional Loss Equations

1.

a) **Vic/NSW boundary - Thomastown 66 notional link**

   Vic Loss = (0.1265 - 7.1282E-06*Vd - 2.9712E-06*Nd - 1.6496E-05*Sd)*VNt +

   3.2204E-05*VNt^2 + 66.0394

b) **Sydney West 330 - Vic/NSW boundary notional link**

   NSW Loss = (-0.8483 - 5.6866E-06*Vd + 7.8271E-06*Nd)*VNt + 2.63897E-05*Sd

   + 0.5245E-4*VNt^2 + 137.1857

2.

QNI

a) NSW/Qld boundary – Sydney West 330 notional link

NSW Loss = (-0.0170 + 1.6945E-06*Nd - 3.1352E-07*Qd)*NQt + 0.6799E-4*NQt^2 + 76.2441

b) South Pine 275 - NSW/Qld boundary notional link

Qld Loss = (-0.0114 - 2.6840E-06*Nd + 1.3059E-05*Qd)*NQt + 2.7800E-05*NQt^2 + 106.0970.......

Terranorra

a) NSW/Qld boundary – Sydney West 330 notional link

NSW Loss = 0.0384*Flow + 0.8338E-03*$Flow^2$ + 15.8556

b) South Pine 275 - NSW/Qld boundary notional link

Qld Loss = 0.0343*Flow - 0.7246E-04*$Flow^2$ + 15.6728

3. Heywood Link

a) Vic/SA boundary - Thomastown 66 notional link

Vic Loss = (0.0250 - 4.4514E-06*Vd + 5.9479E-06*Sd)*VSAt + 1.0440E-05*$VSAt^2$ + 39.5520

b) Torrens Island 66 - Vic/SA boundary notional link

SA Loss = (-0.0016 - 2.1117E-07*Vd - 1.4558E-07*Sd)*VSAt + 1.6642E-04*$VSAt^2$ + 8.1278

Murraylink

a) Vic/SA boundary - Thomastown 66 notional link

Vic Loss = 0.1078*Flow + 0.5959E-03*$Flow^2$ + 38.1978

b) Torrens Island 66 - Vic/SA boundary notional link

SA Loss = -0.0467*Flow + 0.7337E-03*$Flow^2$ + 6.2859

Where,

Qd = Queensland demand

Vd = Victorian demand

Nd = New South Wales demand

Sd = South Australia demand

NQt = transfer from New South Wales to Queensland

VNt = transfer from Victoria to New South Wales

VSAt = transfer from Victoria to South Australia