Calculation of Losses for Scheduled Network Service Providers

A Report for the Australian Energy Market Commission

Final Report

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Executive Summary

The Australian Energy Market Commission (AEMC) commissioned this report on how losses are calculated for scheduled network service providers (SNSPs) in the NEM as input to a rule change proposal by International Power – GDF Suez (IPRA) and the Loy Yang Marketing Management Company (LYMMCo). The rule change proposal was submitted to the Australian Energy Market Commission (AEMC) on 5 December 2011 and would impose a price floor constraint on scheduled network service providers (SNSP) of $0/MWh.

The rationale for the IPRA/LYMMCo proposal is to overcome their concern that negative offers from SNSPs can cause some generators to have an effective offer below the price floor of -$1,000/MWh, thus undercutting other generators and producing inefficient outcomes. While the rule change is expressed generically, as Basslink is the only SNSP, practically the rule change applies to Basslink.

Losses in the NEM are treated differently within regions (intra-regional) and between regions (inter-regional). Further, inter-regional losses are treated differently depending on whether the interconnection is regulated or an SNSP.

The loss models used in the NEM vary as follows:

- The losses associated with intra-regional generators are indirectly modelled by marginal loss factors (MLF) which are used as price multipliers. Within the dispatch process when dispatching generators to meet the regional demand, generator outputs are treated as lossless.
- Regulated interconnectors use predefined quadratic loss functions to estimate the losses for power transfers from the regional reference node in the sending region to the regional reference node in the receiving region. For regulated interconnectors losses are explicitly modelled in the dispatch process.
- SNSPs use a hybrid model for losses which is a combination of linear loss models based on the MLFs of the connecting terminals for within region flows and a quadratic loss model for flows over the physical SNSP. For SNSPs the losses are explicitly modelled in the dispatch process.

The NEM dispatch model uses an approximate form of a full nodal or locational marginal pricing model in that the transmission constraints are modelled and transmission losses are approximately modelled. In a full nodal model the losses for all power transfers would be dynamically modelled, effectively giving rise to dynamic transmission loss factors in every dispatch interval. In the case of the NEM, loss functions are established on an annual basis. Static marginal loss factors are used for flows within each region and inter-regional loss equations which do not change as network configurations change are used for flows between regions.

Since the NEM does not use an explicit network model, transmission limits and system security are managed by controlling the dispatch of generators, dispatchable loads and interconnector and SNSP flows using 'generic constraints' in the NEM Dispatch Engine. Generic constraints consist of linear functions of dispatchable terms, such as generator outputs and interconnector flows, on the left hand side of the constraint and a constant which could be calculated from a complicated function of input data on the right hand side of the constraint.

The methods for the treatment of losses in the NEM as applied to intra-regional generators, SNSP and interconnectors are summarised in Table 1 below.

Table 1 Treatment of Losses in the NEM

	Generator	SNSP	Interconnector
Price multiplier	Yes	No	No
Losses modelled in regional energy balance	No	Yes	Yes
Static loss model	Yes (via fixed MLF used to adjust offer prices)	Partially (via fixed MLFs at connection points)	No
Dynamic loss model using pre-computed loss equations	No	Partially (dynamic for SNSP between terminals)	Yes
Full dynamic loss model based on state of the physical network at the time	No	No	No

The NEM dispatch is a linear programming optimisation which seeks to maximise the value of spot trade (implemented as a minimisation of generator and dispatchable load costs). NEM prices are set at the margin: i.e. the regional reference price can be thought of as being determined by the cost of a supplying an incremental MWh in a region.

The different treatment of losses results in a bias in favour of intra-regional generation in the NEM dispatch when there are constraints affecting both intra-regional generation and a regulated interconnector or an SNSP. This is because intra-regional generators are treated as lossless from a dispatch perspective whereas the dispatch of generators across regions includes losses (regardless of whether the region is connected by a regulated interconnector or an SNSP). Hence, when there is network congestion, the incremental supply of a MWh at the regional reference node of the importing region from another region is penalised by an additional congestion cost due to losses whereas the intra-regional generators face no congestion penalties due to intra-regional losses.

This bias is generally amplified in the presence of significant intra-regional transmission constraints where the shadow price of the constraint can be large (say $10,000 to $12,000/MWh) and even the imposition of a small loss factor on inter-regional generation (say 2%) would result in a price penalty of between $200 and $240/MWh on the inter-regional generators. This price penalty should be considered in the context of the marginal costs of most generators of being no more than $100/MWh

The result of this bias in favour of intra-regional generation is that the NEM's dispatch may be significantly suboptimal in the presence of transmission constraints when compared to an optimisation which properly models transmission losses and constraints. There are two main alternative approaches to improve the efficiency of dispatch and remove the bias in favour of intra-regional generation:

- The first approach would be to model generator transmission losses using their MLFs just as is done for SNSPs between each of their terminals and the corresponding regional reference node;
- Alternatively, and by far the best option in terms of overall market efficiency would be to properly model losses using a full network (branch and bound) model

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1 Introduction

The AEMC contracted SW Advisory and ACIL Tasman (ACIL) to prepare a report on how losses are calculated for SNSPs in the NEM. This work will be an input into the broader analysis being undertaken by the AEMC on the proposed rule change submitted by IPRA and LYMMCo on 5 December 2011.

The rule change that IPRA and LYMMCo have proposed is that scheduled network service providers (SNSPs) should be subject to a price floor of zero. IPRA and LYMMCo are concerned that negative offers from SNSPs can cause some generators to have an effective offer below the price floor of -$1,000/MWh, undercutting other generators and producing inefficient outcomes.

While IPRA and LYMMCo expressed the identified problem generically in respect of SNSPs, currently there is only one SNSP operating in the NEM: Basslink. Consequently the directly affected generators are those in the Latrobe Valley, and Hydro Tasmania is purported to be the “undercutting” generator.

AEMC staff published a consultation paper on 29 March 2012 to facilitate stakeholder comments on the rule change proposal. The AEMC has delayed the publication of a draft determination to allow time to undertake more detailed analysis of the efficiency effects of the issues identified in the rule change request.

1.1 Transmission Losses

One of the issues that has arisen in the AEMC’s deliberations over the proposed rule change is the impact of transmission losses on the dispatch of intra-regional generation compared to inter-regional generation, in particular when an SNSP is involved. Losses influence the dispatch order of generators at either end of an SNSP and are therefore an important factor in the AEMC’s analysis of the proposed rule change. The AEMC considers that there is currently a lack of clarity around the way in which losses for Basslink are calculated and consequently how they impact the relative dispatch of Tasmanian and Latrobe Valley generation. The AEMC’s understanding of this, based on information provided by the Australian Energy Market Operator (AEMO), was challenged by both IPRA and Hydro Tasmania.[1]

1.2 Objectives

The objective of this report is to explain how losses are calculated for SNSPs as compared to generators and interconnectors and how the calculation and modelling of losses in the dispatch process affects the relative dispatch of intra-regional generators compared to inter-regional generation connected by interconnectors or SNSPs.

[1] See AEMC (2012), *Negative offers from scheduled network service providers*, Consultation Paper, March 2012, pp. 18-20 and IPRA and Hydro Tasmania’s submissions.

1.3 Scope of the Report

The report endeavours to:

1. set out how losses for SNSPs are calculated under the National Electricity Rules and Procedures;
2. detail how AEMO practically applies the National Electricity Rules and Procedures to calculate losses over Basslink and whether there have been any changes to the way losses have been calculated for SNSPs over time (with reference to Basslink, Murraylink and Directlink);
3. explain how the different methods of modelling losses for generators, SNSPs and interconnectors affect the dispatch of generators, particularly when there are constraints that affect both intra-regional generation and inter-regional power flows; and
4. discuss the most effective way to calculate losses over SNSPs in the context of the marginal losses approach applied in the NEM (incorporating SW Advisory and ACILs' experience and approaches in other countries,), while having regard to the National Electricity Objective and the fundamental principle of providing efficient price signals.

In order to meet the report's objective and address the scope, of the report considers:

1. the current methods for calculating marginal loss factors and loss equations for generators, interconnectors and SNSPs; and
2. the current approach for incorporating marginal loss factors into the NEM dispatch process – in particular the methods through which the marginal loss factors and marginal loss equations are included in the NEM dispatch engine's (NEMDE) constraints and objective function including:
   - generator offer prices and the NEMDE objective function,
   - regional demand forecast,
   - regional energy balance equations, and
   - the dispatch of generators and SNSPs in the presence of joint constraints.

2 Calculation of Marginal Losses Factors in the NEM

2.1 Modelling Losses in the NEM

The NEM market model is a substantially simplified model of the transmission network, particularly in the area of modelling transmission losses. These simplifications mean that transmission network characteristics and limits are in many cases approximated (usually with a conservative bias). Thus the actual NEM dispatch may be sub optimal when compared to an optimisation which more accurately models losses. This is not a reflection of AEMO’s implementation of the dispatch optimisation but rather is a reflection of the degree to which the National Electricity Rules simplify modelling the actual physical network in general and the modelling of losses in particular.

2.2 Calculation of Loss Equations and Marginal Loss Factors

The National Electricity Rules set out the general principles by which losses are calculated for inter-connectors, SNSPs and intra-regional transmission networks. Clauses 3.6.1, 3.6.2 and 3.6.2(A) specify the principles and requirements for calculating the inter-regional and intra-regional loss factors, and the data to be used in the calculations. Clauses 3.8 sets out how central dispatch and spot market operations are meant to operate and account for losses. The implementation of the Rules with respect to losses is managed via:

- AEMO’s market operations procedures regarding loss factors[2] and
- the NEM dispatch engine NEMDE[3].

The NEM dispatch model is an approximate form of a full nodal or locational marginal pricing model in that the transmission constraints are modelled and transmission losses are approximately modelled. In a full nodal model the losses for all power transfers would be dynamically modelled, effectively giving rise to dynamic transmission loss factors every dispatch interval. In the case of the NEM, static marginal loss factors are used for flows within each region and inter-regional loss equations are used for flows between regions.

2.3 Generators, Loads and Intra-regional Losses

Intra-regional losses are electrical energy losses that occur due to the transfer of electricity between a regional reference node and transmission network connection points in the same region (NER Clause 3.6.2).

[2] AEMO (1 April 2010), Methodology for The Averaging of Transmission Loss Factors v4.0 (AEMO filename: 0172-0004.pdf)
AEMO (29 June 2011), Methodology for Calculating Forward-Looking Transmission Loss Factors: Final Methodology v4.0 (AEMO filename: 0172-0008.pdf)
AEMO (13 June 2012), List of Regional Boundaries and Marginal Loss Factors for the 2012-13 Financial Year (AEMO filename: 0172-0015.pdf)
AEMO (28 March 2013), List of Regional Boundaries and Marginal Loss Factors for the 2013-14 Financial Year (AEMO filename: filename: MLF_2013_14_Final)

[3] AEMO / Cegelec ESCA Corporation (24 November 2011), Mathematical Modeling of the Wholesale Electricity Market Bid-Clearing System - SPD: Scheduling, Pricing and Dispatch, Version 1.36.2

The NEM uses intra-regional loss factors, generally called MLFs, to model intra-regional transfers. These MLFs are estimates of the marginal electrical energy required for electricity to be transmitted between a regional reference node and a transmission network connection point in the same region.

The regional reference node is in effect the reference point for intra-regional loss calculations with a loss factor by definition of unity (electricity generated or consumed at the regional reference node has no losses when referred to the regional reference node).

Connection points that generally export electricity to the regional reference node would be expected to have loss factors less than one reflecting losses consumed in transmitting to the reference node (one MWh injected at an exporting connection point provides a MWh less the losses at the regional reference node).

Connection points that generally import electricity from the regional reference node would be expected to have loss factors greater than one reflecting losses consumed in transmitting from the regional reference node (one MWh withdrawn at an importing connection point requires a MWh plus the losses to be injected at the regional reference node).

As generators are generally located at connection points that export electricity to the regional reference node, they will generally have MLFs which are less than one because the supply of one MWh of additional energy at the generator's connection point would result in one MWh less the losses at the regional reference node.

Connection points for loads will generally have MLFs greater than one. This reflects that in general, to supply one MWh extra energy at a load's connection point will require more than 1 MWh of additional power to be supplied at the regional reference node to cover the marginal losses of transmitting the power from the regional reference node to the load's connection point.

If the flow is always in one direction there will generally be just one MLF calculated for a connection point. Where the flows at a connection point may flow in either direction (tidal flows) or there are other circumstances which make the approximation of a single MLF too inaccurate, two MLFs may be calculated and used by AEMO. MLFs are updated annually – the same MLF(s) apply for a whole year.

2.4 Calculation of MLFs

MLFs are calculated on a forward looking basis, for the year ahead, using a full network model of the NEM based on a system snapshot[4]. AEMO uses the TPRICE software package to calculate the loss factors. TPRICE solves the power flow problem for each half hour based on projected half hourly load and generator

[4] The system snapshot network model used by AEMO reflects all normally connected equipment and any network augmentations due to be in operation in the following year.

data. For each half hour, TPRICE essentially calculates nodal prices ignoring network constraints.

For each half hour, a connection points half hourly MLF is just the ratio of its nodal price to the regional reference node's nodal price. For connection points with just one fixed MLF, its value is just the weighted average over the modelled year of the half hourly MLFs. Generation loss factors are weighted by generator output and load loss factors by load consumption. These MLFs are simply weighted averages (single point approximations) to these MLF distributions.

As an example, Figure 1 shows a histogram for a year of half hourly MLFs for a NSW coal generator calculated from AEMO's 2013-14 TPRICE modelling. For this modelling the generation weighted average MLF was 0.97. Figure 2, Figure 3 and Figure 4 show the MLF histograms for a range of other generators. It is interesting to note that the central and northern QLD generators have histograms with some MLF values greater than 1.0 and some values less than 1.0. This indicates that they are in network locations where there can be flows towards or away from the QLD regional reference node. None the less they still have single MLFs.

Figure 1 Histogram of Half Hourly MLFs for a NSW Coal Generator for 2013-14

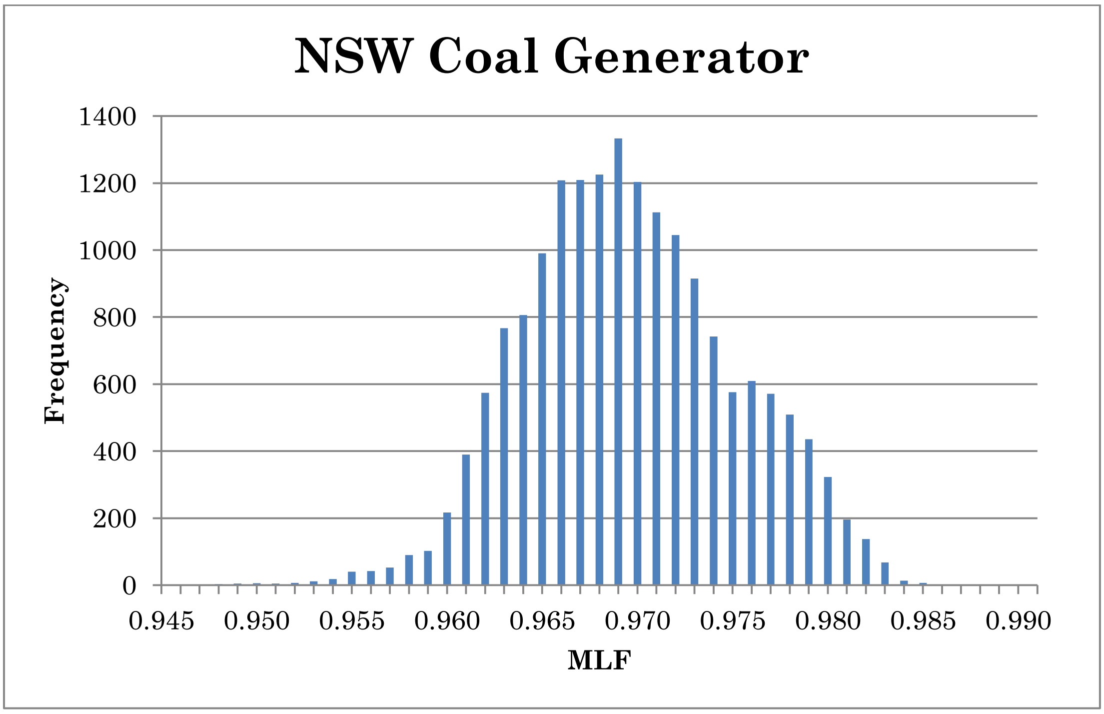


Figure 2 Histogram of Half Hourly MLFs for a Latrobe Valley Brown Coal Generator for 2013-14

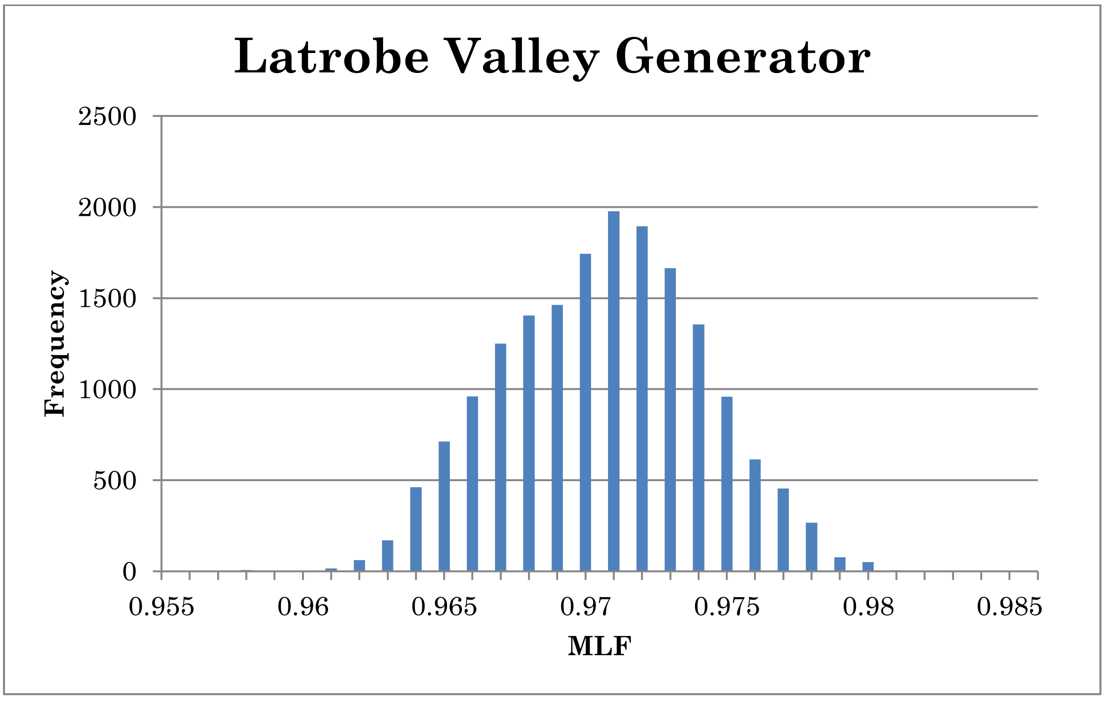


Figure 3 Histogram of Half Hourly MLFs for a Central QLD Coal Generator for 2013-14

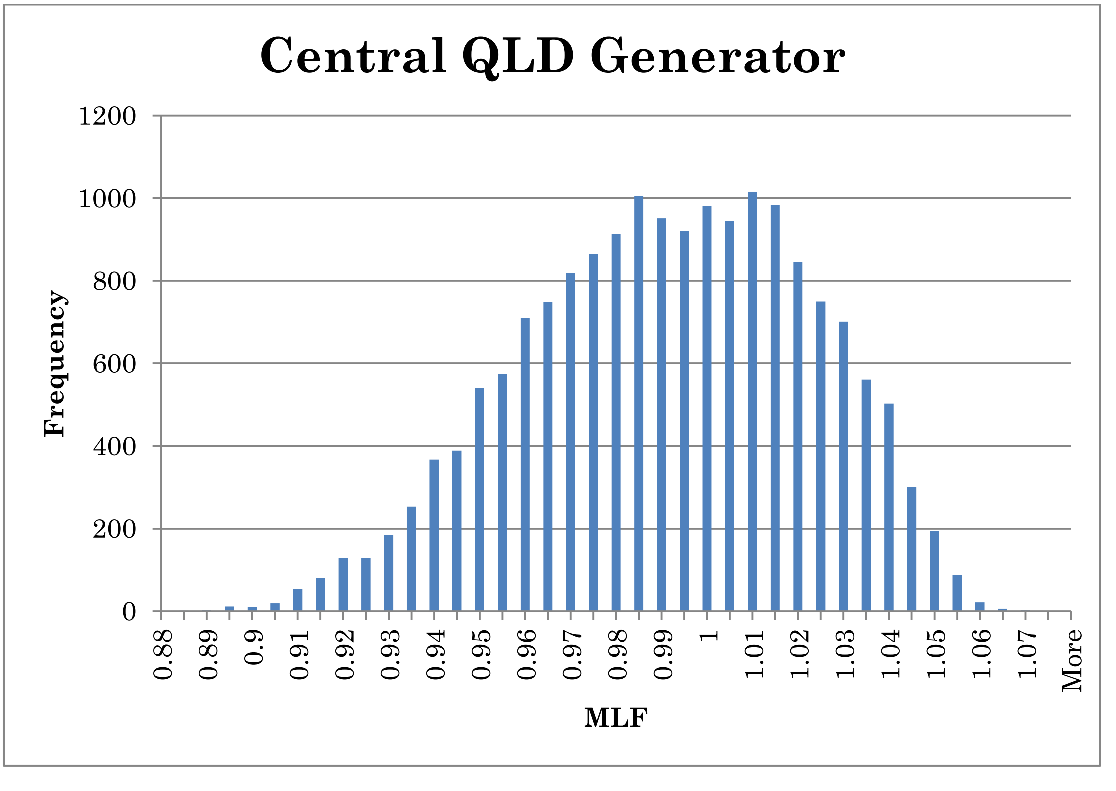
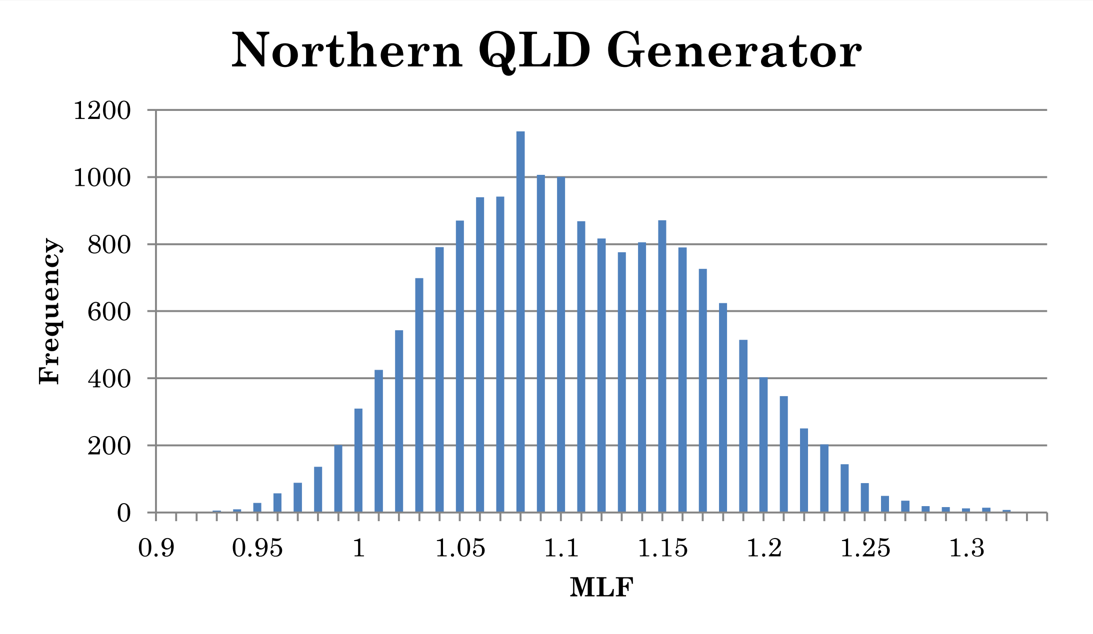


Figure 4 Histogram of Half Hourly MLFs for Northern QLD Generator for 2013-14



2.5 Use of MLFs

It is an important distinction that while MLFs are calculated based on expected losses referenced to the regional reference node, the MLFs are not used to explicitly model intra-regional losses in the NEM dispatch process. Instead they are used as:

- price multipliers that can be applied to the regional reference price to determine the local spot price at each transmission network connection point and virtual transmission node; and
- price adjustments to generator offer prices and to load bid prices to reflect a generator's effective offer price or a load's effective bid price when referred to the regional reference node to which that connection point is assigned[5].

2.6 Inter-connector Losses

Introduction

Inter-regional losses are electrical energy losses due to a notional transfer of electricity through regulated interconnectors from the regional reference node in one region to the regional reference node in an adjacent region (NER Clause 3.6.1).

Under NER Clause 3.6.1, AEMO is required to determine inter-regional loss factor equations which are to be used in the dispatch as a notional adjustment to relate

[5] See NER Clause 3.8.6 (h) (3)

the prices of electricity at regional reference nodes in adjacent regions so as to reflect the cost of inter-regional losses. This is done by developing an inter-regional loss equation that calculates the average or expected losses as a function of the power flows on an interconnector. The loss equation is generally a quadratic function of power flows. These equations are updated annually.

Inter-regional loss equations and marginal loss factors

There are some simple relationships which connect each inter-regional loss equation with its associated marginal losses and inter-regional loss factor equation.

- The marginal inter-regional losses for a known inter-regional power flow can be determined from the slope or derivative of the inter-regional loss equation.
- The inter-regional loss factor equation (marginal loss factor) is just equal to 1 + the slope of the inter-regional loss equation.

In NEMDE, piecewise linear approximations of the inter-regional loss equations are used and the dispatch optimisation automatically trades off the incremental costs of greater interconnector flows versus greater use of intra-regional generation.

Inter-regional loss equations

Inter-regional loss equations are not dynamically calculated (i.e. based on the actual configuration of the transmission network at each point in time) but are based on linear regression equations which fit a model to inter-regional losses in terms of interconnector flows and any other explanatory variables that AEMO regards as necessary, such as regional demands[6].

Since these equations are to be used in the NEMDE linear programming optimisation, generator terms, which are to be optimised, cannot be included as explanatory variables[7].

As an example, the 2013-14 inter-regional loss equation for the NSW to QLD notional link is[8]:

$$\text{average losses} = (0.0012 - 0.0000041356 \cdot Nd + .000013764 \cdot Qd) \cdot NQt + 0.00010539 \cdot NQt^2$$

where

Nd = New South Wales demand

Qd = Queensland demand

[6] This is actually done for an inter-connector by fitting a linear regression model to the observed marginal loss factors and flows to get a model for the inter-regional marginal loss factor equation and then deriving the inter-regional loss equation by subtracting 1 and integrating the inter-regional marginal loss factor equation.

[7] Dispatchable generator terms cannot be used but actual generator dispatches at the start of the dispatch interval could be used. The reason why dispatchable generator terms can't be included is that it would change the NEM dispatch from being a linear programming optimization to being a non-linear programming optimization. The NEM has stuck with a linear programming approach as this is a highly reliable optimization approach suited to real time or mission critical systems.

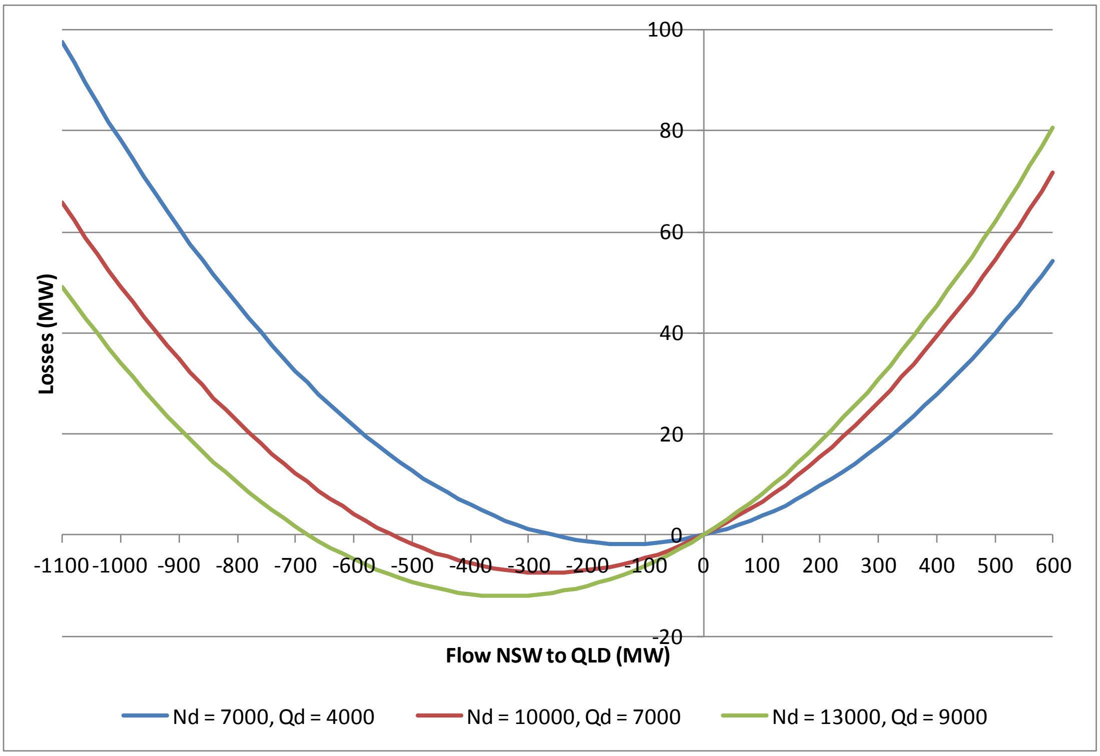
[8] AEMO (30 May 2013), Appendix B: Inter-regional loss factor equations for 2013/14, List of Regional Boundaries and Marginal Loss Factors for the 2013-14 Financial Year (AEMO filename: MLF_2013_14_Final)

NQt = transfer from New South Wales to Queensland

Figure 5 shows this equation for a few combinations of NSW and QLD demands. As expected the equation has zero losses for zero flow. However, a more interesting matter to note is that the minimum losses are negative and that this is for the case when there is a negative flow from NSW to QLD. This is because the total system losses are reduced when the northern NSW loads are partially satisfied from power flows from QLD.

Even though inter-regional loss equations are predetermined, the losses calculated from these equations are referred to as the 'dynamic losses' since they change with interconnector power flows.

Figure 5 Inter-regional Loss Equations for Power Transfers from NSW to QLD



2.7 Estimating Flows at the Start and End of Interconnectors

Because NEMDE uses a regional model of NEM demands, not only do the inter-connector flows need to be modelled but the interconnector losses need to be modelled as well. Further, the transmission losses on each interconnector need to be apportioned between the sending and receiving regions. This is equivalent to the NEM regional model requiring estimates of the flows of a notional interconnector at the exporting region's regional reference node and the importing region's regional reference node. That is, estimates of the flows at the start and end of the notional interconnector are required.

The flows at the exporting and importing regional reference nodes can be estimated based on the flows at the regional boundary and the inter-regional loss equations as follows.

flow at start	=	flow at boundary + p x losses
flow at end	=	flow at boundary – (1-p) x losses
losses	=	*fn*(flow at boundary)

where p is the proportion of losses allocated to the exporting region and *fn*(flow at boundary) is the inter-regional loss equation. If the boundary where the flows are measured is approximately in the middle of the notional interconnector then p will be around 0.5. If the boundary or measurement point is near one of the ends (one of the regional reference nodes) then p will be near zero or one.

2.8 Proportioning Inter-regional Losses to Regions

Calculation of the proportioning factor, p, is done in a similar way to how inter-regional losses are calculated except the interconnector is split into two at the boundary between the two connected regions. The modelled splits of losses are then used to determine an approximate proportioning factor.

A detailed description of the process used to determine the factors used to proportion inter-regional losses between regions is outlined in the AEMO document "Proportioning Inter-Regional Losses to Regions"[9].

2.9 Use of Inter-regional Loss Equations

The inter-regional loss equations and inter-regional loss proportions are used:

- to explicitly model inter-regional losses in the NEMDE optimisation; and
- indirectly, as an input to the calculation or regional demands and demand forecasts (for further discussion see section 3.3).

2.10 SNSP Losses

Introduction

The model for losses for an SNSP is essentially a hybrid of the dynamic loss model used for regulated interconnectors and fixed marginal loss model used for generators and loads. In particular, losses for SNSPs are modelled as follows:

- a dynamic loss equation for power transfers between the SNSP's connection points in each region (this loss equation is similar to the inter-regional loss equations that are used for regulated interconnectors); and
- fixed MLFs for the power transfers from each connection point to its regional reference node.

[9] AEMO (3 September 2009), Proportioning of Inter-Regional Losses to Regions (AEMO filename: 0170-0003.pdf)

Basslink

To illustrate these points, the loss model for Basslink is as follows:

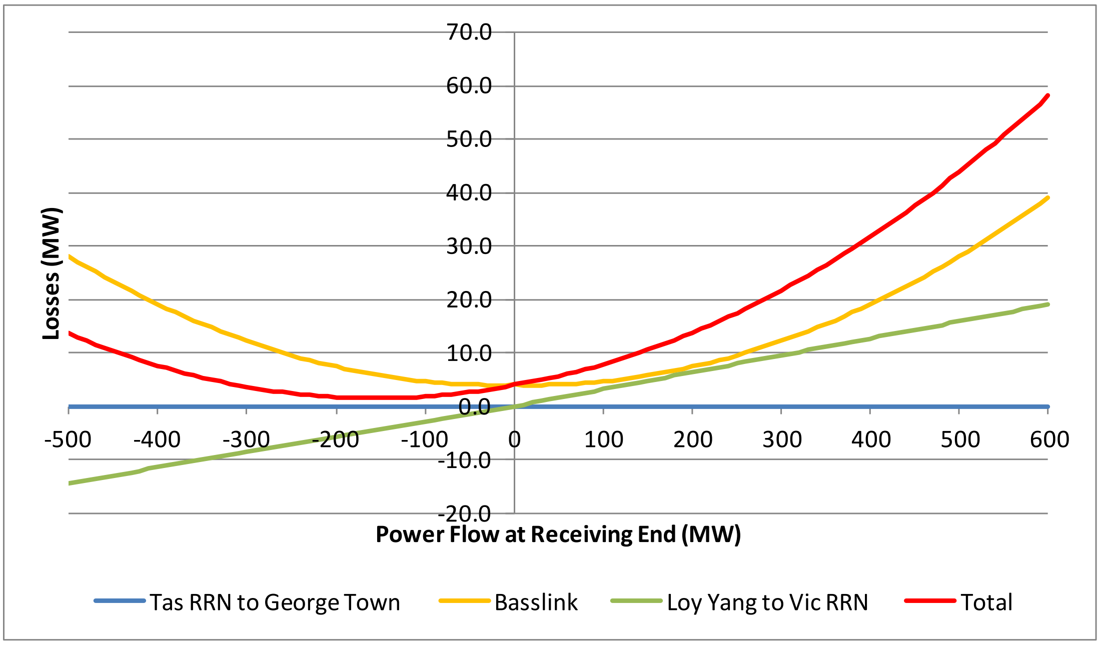
- The fixed marginal loss factor (intra-regional loss factor) for the George Town terminal of Basslink is 1.00 as George Town 220 KV substation is also the Tasmanian regional reference node;
- The dynamic loss equation, based on the Basslink power flow measured at the receiving end, is

  $$\text{Losses} = 4 - 0.00392 \times Q(\text{receive}) + 0.00010393 \times Q(\text{receive})^2$$

  where Q(receive) is the Basslink flow measured at the receiving end.
- Basslink (Loy Yang Power Station Switchyard) intra-regional loss factor is 0.9683 when importing power from Tasmania into Victoria and 0.9726 when exporting power to Tasmania.

Figure 6 shows the calculated losses for power transfers from Tasmanian regional reference node (RRN) to Victorian regional reference node (RRN) based on the NEM's loss model for SNSPs. There are no losses for transfers between the Tasmanian RRN and the George Town terminal of Basslink. There are quadratic losses for power transfers over Basslink. The computed losses for transfers between the Loy Yang terminal and the Victorian RRN are power flows at Loy Yang terminal x (1-MLF). Thus when the Basslink is exporting from Victoria into Tasmania the estimated losses for a power transfer from the Victorian RRN to the Loy Yang terminal are negative.

Figure 6 Losses for Power Transfers from Tasmanian RRN to Victorian RRN



When Basslink is exporting 600 MW from Tasmania to Victoria, as measured at the receiving end at Loy Yang, the average losses based on the SNSP loss model are 58MW and the marginal losses are about 15% for the transfer from the Tasmanian RRN to the Victorian RRN.

NEMDE

In NEMDE a physical SNSP is actually modelled by two notional SNSPs, one in each direction. Consequently, the dispatch offers must be such that both directions don't get dispatched at once. Also, NEMDE dispatches the flow at the importing (receiving) end rather than some point representing the boundary between regions. Hence all the losses are allocated to the exporting region.

Based on the SNSP model, the effective price of 1 MW of supply at the regional reference node in region A used to meet demand in Region B, would be computed as:

> Price at RRN B =
> Price at RRN A x (MLF to the sending node in region A)
> x the dynamic marginal loss factor[10] on the SNSP for the particular power flow
> x 1/(MLF to the sending node in region B).

Table 2 provides some examples of the relationships between the RRN prices and the connection point prices for a couple of export and import flows. For example, if the Tasmanian price is -$1000/MWh then a MW arriving in the La Trobe Valley is priced at approximately -$1121/MWh at Loy Yang terminal and -$1157/MWh at the Victorian RRN.

Table 2 Examples of the Relationship Between Prices ($/MWh)

Flow (MW)	Tas RRN	George Town	Loy Yang	Vic RRN
600	100	100	112	116
600	-1,000	-1,000	-1,121	-1,157
-500	107	107	97	100
-500	-1070	-1070	-973	-1000

2.11 Proportioning of an SNSP's Inter-regional Losses to Regions

As discussed earlier, NEMDE dispatches the flow of an SNSP at the importing (receiving) end rather than some point representing the boundary between regions. Consequently, for SNSPs the total losses calculated from the loss model equation are allocated to the sending region's node based on the initial flow at the start of the dispatch interval[11]. That is, if in the previous dispatch interval, the SNSP was exporting from node A in region 1 to node B in region 2, then all the losses over the physical SNSP will be allocated to node A. This is quite different to interconnector losses which are apportioned to both regions with constant

[10] 1 + the slope of the dynamic loss equation for the particular power flow
[11] AEMO / Cegelec ESCA Corporation (24 November 2011), Mathematical Modeling of the Wholesale Electricity Market Bid-Clearing System - SPD: Scheduling, Pricing and Dispatch, Version 1.36.2, Section 4.1.1 Calculation of Loss Share for MNSPs

factors. In the case of an SNSP the apportioning factor is either 1 or 0 depending on the direction of flow.

2.12 Use of an SNSP's Inter-regional Loss Model

The SNSP's loss model is used to:

- calculate the power flows at the sending and receiving nodes (connection points), with the convention that all losses are allocated to the sending node; and
- for the power transfers within each region the respective connection MLFs are used to adjust the power transfer quantities.

2.13 Summary of Loss Models

The key points to note about the loss models used in the NEM are as follows:

- The losses associated with intra-regional generators are indirectly modelled by MLFs which are used as price multipliers. Within the dispatch process when dispatching generators to meet the regional demand, generator outputs are treated as lossless.
- Regulated interconnectors use predefined quadratic loss functions to estimate the losses for power transfers from the regional reference node in the sending region to the regional reference node in the receiving region. For regulated interconnectors losses are explicitly modelled in the dispatch process.
- SNSPs use a hybrid model for losses which is a combination of linear loss models based on the MLFs of the connecting terminals for within region flows and a quadratic loss model for flows over the physical SNSP. For SNSPs the losses are explicitly modelled in the dispatch process.

3 NEM Dispatch

3.1 Introduction

The actual dispatch of generators, loads and SNSPs is determined by the NEM dispatch engine, NEMDE. NEMDE is based on a linear programming optimisation. The aim of this optimisation is to maximise the value of spot market trade, which is equivalent to minimising costs if dispatch bids are treated as negative costs. The formulation of the NEMDE optimisation is based on the NER, various AEMO procedures and historical decisions based on the original NEMDE[12] formulation and decisions made by the Dispatch and Pricing Reference Group. The NEMDE formulation and software are updated on a periodic basis. The latest version of the formulation is 1.36.2[13].

NEMDE is a linear programming optimisation. A rough outline of its formulation is as follows:

- The objective function is to minimise the costs of dispatched energy bids and offers, offers for power transfers by SNSPs and dispatched ancillary service offers;
- Subject to the following constraints:
  - Meeting the forecast regional demands:
    - Using a forecast of regional demands and managed via regional energy balance constraints;
  - Meeting frequency control ancillary service (FCAS) requirements:
    - Managed via “generic constraints”;
  - Generation plant capacity, ramp rate and FCAS limits;
  - Interconnector limits and loss equations;
  - SNSP limits and loss equations;
  - Transmission and security constraints:
    - Managed via “generic constraints”, which may affect the dispatch of generators, interconnectors and SNSPs.

As discussed earlier, the NEM models losses differently for intra-regional transmission and generation, interconnectors and SNSPs. The different models of losses in turn affect the NEM dispatch processes in the areas of:

- generator offer prices and the NEMDE objective function,
- regional demand forecasts,
- regional energy balance equations, and

[12] The original NEMDE mathematical programming formulation was called the SPD: Scheduling, Pricing and Dispatch formulation.
[13] AEMO / Cegelec ESCA Corporation (24 November 2011), Mathematical Modeling of the Wholesale Electricity Market Bid-Clearing System - SPD: Scheduling, Pricing and Dispatch, Version 1.36.2

- the dispatch of generators and SNSPs when a “generic constraint” affects the dispatch of both generators and an interconnector or an SNSP.

The interaction of the different models for losses in NEMDE when there are constraints affecting intra-regional generation and inter-regional generation can result in subtle and surprising results which sometimes substantially advantage intra-regional generation.

3.2 Offer Prices and the Objective Function

As discussed above, the NEMDE objective function is to minimise costs based on the energy offers and bids and the offers for ancillary services and the offers for power transfers by SNSPs. Since intra-regional power transfer losses are not modelled in NEMDE, the prices for generator offers and bids are adjusted by the MLFs at their connection points. In particular, for a generator each of its 10 offer prices are adjusted as follows:

Adjusted offer price = original offer price / MLF

Thus the total cost, in the objective function, of dispatching Y MWs of a generator’s offer is

Y x adjusted offer price = Y x original offer price / MLF

= original offer price x Y / MLF

Thus, as far as the objective function is concerned, the adjustment of prices by the MLFs is equivalent to the adjustment of generation quantities by MLFs. This was the justification for treating generators and intra-regional transmission as lossless. This in turn was done because historically regional demand forecasts were based on the sum of regional generation adjusted for any inter-regional transfers.

3.3 Demand Forecasts

The regional demands and their forecasts used in the NEM dispatch correspond to the nodal loads plus intra-regional losses. These demand forecasts are called the fixed demand in the NEMDE formulation and do not include dispatchable loads. For each region and each dispatch interval, the forecast fixed demand is determined as follows:

- total region generation in the region at the start of the interval;
- plus sum of imported flows from other regions as measured at the regional reference node (the same as interconnector flows at the border minus losses allocated to the region);
- less sum of exported flows to other regions as measured at the regional reference node (the same as interconnector flows at the border plus losses allocated to the region);
- less the total demand from dispatchable loads in the region at the start of the interval,
- plus the projected region demand change five minutes into the future.

The total region generation is measured at each generator's terminal therefore intra-regional losses are included in the supply from generators when the forecast demand is calculated.

Finally, the total demand from dispatchable load units in the region is also measured at each unit's terminal.

When the actual dispatch of generators in a region differs from the implied projected dispatch in that one or more generators with low intra-regional transmission losses is displaced by those with high intra-regional losses or vice versa, the total amount of intra losses in the region will change. When this change occurs the regional demand forecast will be too low or too high since the demand forecasts do not explicitly include intra-regional losses but do so indirectly via the measured dispatch of generators from the previous dispatch interval.

Within the dispatch interval any forecast error is managed through the use the regulation FCAS. Once the dispatch interval is over, a new five minute regional demand forecast is made and this forecast will be based on the sum of the regional generator outputs which include any regulation provided by generators within the region with any regulation provided by generators outside the region picked up by changes in power flows into or from the region. Thus any forecast errors are incrementally (every five minutes) being corrected based on the actual dispatch of generation.

3.4 Regional Demands and Regional Boundaries

Because regional demands include intra-regional losses associated with intra-regional generation, the sum of demands of all regions will change depending on the regional structure. A single region would have the highest total demand as all losses are included in the intra-regional losses. At the other extreme a regional model consisting of one region for each node would have a much lower total regional demand as all the intra-regional losses would be picked up as inter-regional losses associated with interconnectors or SNSPs.

Appendix A.2 provides a simple example that shows that the dispatch process can result in quite different regional demands and nodal or connection point prices for exactly the same dispatch of generator offers on the same physical network, depending on the regional model used and whether an interconnection is regulated or is an SNSP.

3.5 Regional Energy Balance Equations

The NEM market design essentially envisages demand and supply balancing on a regional basis. This is done in NEMDE via the regional energy balance equations. Essentially for each region the equation states that:

- the sum of the three components:
  - fixed (or inflexible) regional demand,

  - dispatched demand, and
  - exports from the region to other regions as measured at the regional reference node (the same as interconnector flows at the border plus losses allocated to the region);
- must equal the sum of
  - dispatched generation and
  - imports into the region from other regions as measured at the regional reference node (the same as interconnector flows at the border minus losses allocated to the region).

What is important to note about the energy balance equation is that losses are modelled for interconnector and SNSP power flows but not for intra-regional power flows associated with generators. This difference in treatment of losses in the energy balance equation combined with binding constraints that may affect the dispatch of intra-regional generation and interconnector or SNSP flows can create a bias in favour of intra-regional generation. This is discussed further in subsequent sections.

3.6 Model of Interconnectors

Regulated interconnectors are modelled by a single notional transmission line linking the RRNs of the two regions they connect. Electrical losses over this notional transmission line are modelled as a function of the flow on the interconnector. Since transmission losses are generally quadratic functions of flows these losses are approximated by a piecewise linear function of the flow on the interconnector. As noted earlier in the report, these losses are generally referred to as the 'dynamic losses'.

Figure 7 below shows the dispatch model's representation of a regulated interconnector between regions *a* and *b*. Electrical losses over the interconnector are proportioned between regions *a* and *b* using a predefined fraction called the loss share constant.

Figure 7 Model for Regulated Interconnectors

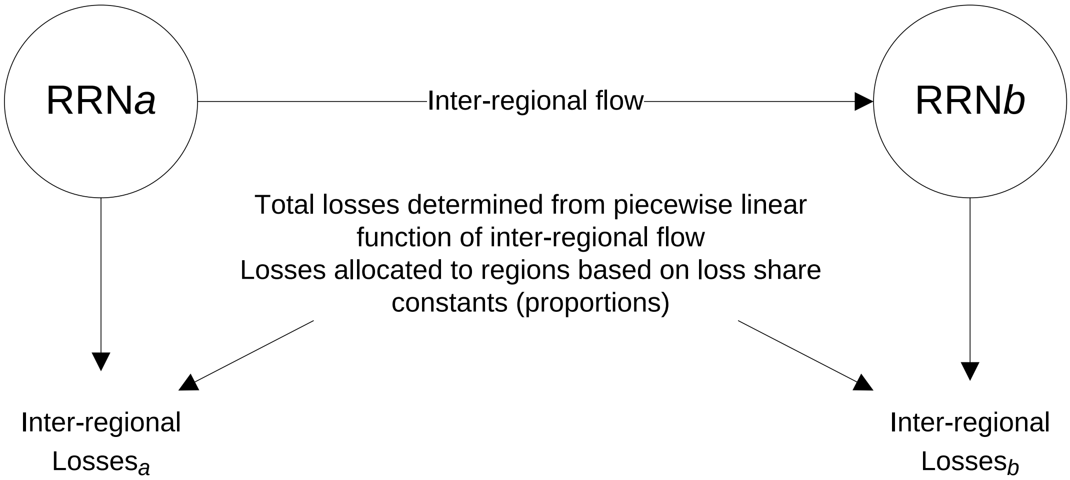
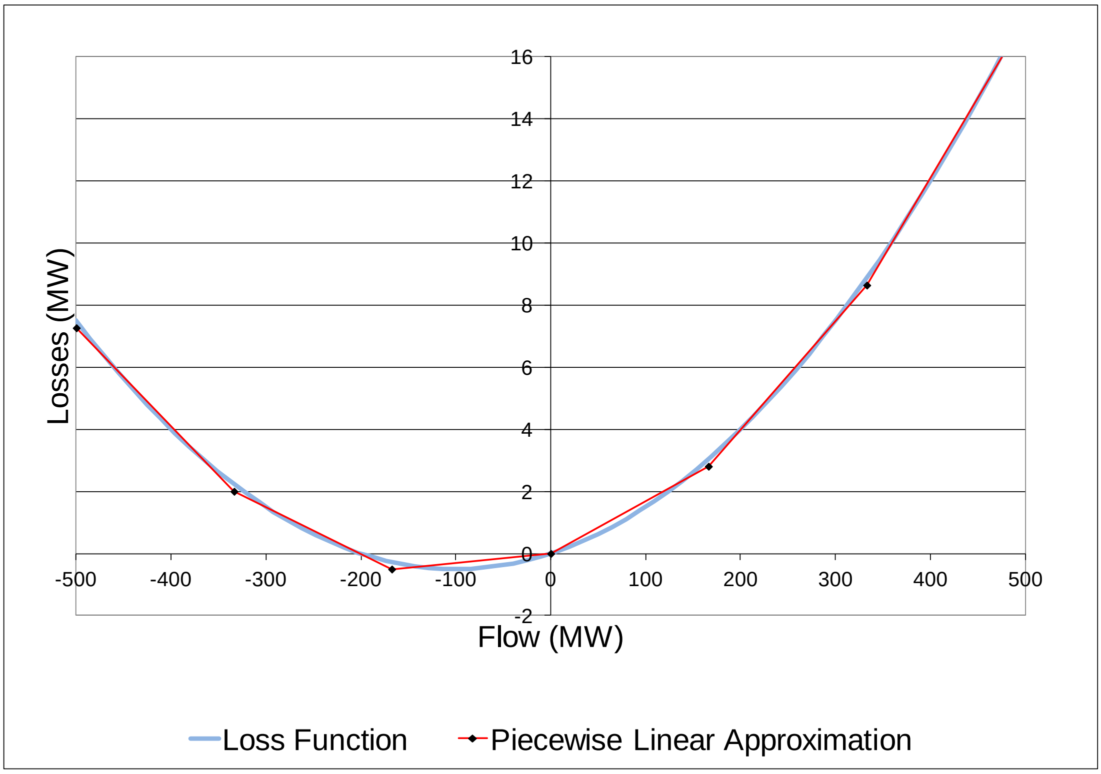


Figure 8 shows an example of a piecewise linear approximation of a quadratic function. Given enough linear segments these approximation can be quite accurate.

Figure 8 Example of Piecewise Linear Approximation of Quadratic Function



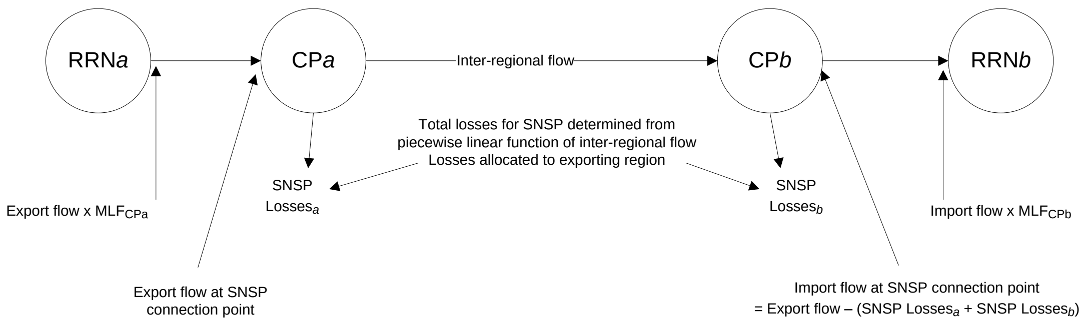
3.7 Model of SNSPs

SNSPs are modelled with a series of three transmission segments. The middle segment represents the physical network element which connects the regions at the SNSPs connection points (the line's terminals). The model used to represent electrical losses on this middle segment is identical to the model used for regulated interconnectors, that is losses over this middle segment are modelled as a function of the flow on the SNSP and approximated by a piecewise linear function.

The first and third segments represent notional flows between the points of connection and the RRN in each region connected by the SNSP. On these segments, electrical losses are simply represented by linear functions of the flows and are referred to as static marginal losses or MLFs. Losses on the middle segments can be seen as the inter-regional part of the transmission losses between two RRNs while the losses on the other two segments represent the intra-regional parts.

Figure 9 shows the modelling for an MNSP between regions *a* and *b* assuming the power transfer is from region *a* to region *b*. Similar to the regulated interconnector model, losses between the points of connections (CP_a and CP_b) are allocated using the loss share constant, which is 1 at the sending end and 0 at the receiving end.

Figure 9 Model for Market Network Service Provider



3.8 Non Physical Losses

The dispatch engine NEMDE uses a piecewise linear approximations of the interconnector and SNSP loss functions. If there are negative regional prices or locally negative nodal prices that affect the flows on an interconnector then a situation known as non-physical losses can occur. In this situation, NEMDE tries to get rid of "surplus" negatively priced power by using the highest loss linear segments in the piecewise linear approximations first and the lowest loss segments last. This is clearly physically impossible, hence the name "non-physical losses". NEMDE has some workarounds to address this problem. These generally involve just using the current loss segment slope and some clamping of flows. In the longer term we understand that AEMO plans to use an integer programming approach to this problem using special binary variables called special ordered sets. When this is done the problem of non-physical losses will disappear. Hence the discussion in this document does not focus at all on the issue of non-physical losses.

3.9 Regional Energy Balance Equations and Interconnectors

For both SNSPs and regulated interconnectors their contribution to balancing the regional supply and demand equations is based on their notional flows at the regional reference nodes. That is their dispatched flows at the regional boundaries in the case of an interconnector or the receiving node in the case of an SNSP are adjusted for losses. Whereas as noted earlier, these adjustments are not made for generators. As far as NEMDE is concerned, generators are treated as lossless sources of power when meeting intra-regional demands. This difference treatment of losses can have a substantial impact on the dispatch of intra-regional generators versus inter-regional generators in the presence of binding network constraints.

3.10 Generic Constraints

Since the NEM does not use an explicit network model, transmission limits and system security are managed by controlling the dispatch of generators, dispatchable loads and interconnector and SNSP flows using 'generic constraints' in NEMDE. Generic constraints consist of linear functions of dispatchable terms, such as generator outputs and interconnector flows, on the left hand side of the constraint and a constant which could be calculated from a complicated function of input data on the right hand side of the constraint.

For a generator, the quantity used in generic constraints is measured at its terminal, for a regulated interconnector it is measured at the regional boundary (a predefined point between the two connected regional reference nodes), and for an SNSPs it is measured at the line's terminal corresponding to the receiving end.

Generator outputs and interconnector flows on the left hand sides of a network constraint are multiplied by fixed factors that generally reflect their respective impact on the constraint. When generators and SNSPs, which are connected to the same connection point, are included in a network constraint, they often have the same left hand side coefficient, particularly for constraints which are used to manage thermal transmission limits.

3.11 Summary of Treatment of Different Loss Models in Dispatch

Table 3 provides a summary of the treatment and modelling of losses in the NEM for generators, SNSPs and interconnectors.

Table 3 Treatment of Losses in the NEM

	Generator	SNSP	Interconnector
Price multiplier	Yes	No	No
Losses modelled in regional energy balance	No	Yes	Yes
Static loss model	Yes (via fixed MLF used to adjust offer prices)	Partially (via fixed MLFs at connection points)	No
Dynamic loss model using pre-computed loss equations	No	Partially (dynamic for SNSP between terminals)	Yes
Full dynamic loss model based on state of the physical network at the time	No	No	No

3.12 Interaction of Loss Models and Constraints

As mentioned earlier, the combination of constraints and the different treatment of losses for SNSPs and interconnectors compared to intra-regional generation can produced some unexpected dispatch results with a bias towards intra-regional generation. To understand how this could happen it is worthwhile illustrating it with an example.

Initially we will assume that

- the price in Tasmania is $10/MWh
- the marginal loss factors for the Latrobe Valley generators and Basslink are around 0.97; and
- there is no disorderly bidding and the Latrobe Valley marginal price is $100/MWh.

In this case the effective price of the Tasmanian generation at the Victorian regional reference node is:

Price at Vic RRN =

Price at Tas RRN x (MLF of the sending node in Tasmania)
x the dynamic marginal loss factor on the Basslink for 600MW power flow
x 1/(MLF of the receiving node in Victoria).

Since the MLF for the Tasmanian terminal of Basslink is 1 and the dynamic marginal loss factor for a power flow of 600MW is 1.121 this gives:

Price at Vic RRN = $10/MWh x 1.121 / 0.97 = $11.57/MWh

The effective price of the Tasmanian generation at the Loy Yang terminal is $11.21/MWh.

Now if we also make the following additional assumptions:

- Latrobe Valley generators and Basslink are all affected by a thermal limit and they all have left hand side coefficient values of 1 for the corresponding constraint;
- there is a very high Victorian regional reference node price of say $10,100/MWh; and
- there is no disorderly bidding and the Latrobe Valley marginal price is $100/MWh following the adjustment of the generator offer prices for their MLFs.

we can consider the costs of providing additional power from Latrobe Valley generators versus Basslink.

- The cost of providing 1 MWh of additional energy to the Victorian RRN from the Latrobe Valley generators, as determined by NEMDE, is $100/MWh plus the opportunity cost of using the congested line from the Latrobe Valley to Melbourne. This opportunity cost can be determined from the marginal cost or shadow price of the generic constraint limiting the flow. In this case the shadow price will be $10,100/MWh - $100/MWh = $10,000/MWh. Thus, as far as NEMDE sees the situation, the cost of providing an extra 1 MWh to the Victorian RRN from Latrobe Valley generators is $10,100/MWh.
- As NEMDE sees it, If 1 MWh of extra energy is to be supplied at the Victorian RRN from Basslink then 1/0.97 MWh (1.031 MWh) of extra energy would be required to be supplied at the Basslink Loy Yang terminal. Based on the previous calculation the cost of this energy supplied to the Loy Yang terminal is $11.21/MWh. Now, as NEMDE sees it, to provide 1 MWh extra energy at the Victorian RRN would require 1.031 MWh energy transmitted from the Loy Yang terminal. The opportunity cost of using the congested transmission line and providing 1 MWh of extra energy at the Victorian RRN would be 1.031 x $10,000/MWh = $10,309/MWh. Thus, as NEMDE sees it, the total cost of providing an extra MWh to the Victorian RRN via Basslink is $11.57/MWh + $10,309/MWh = $10,321/MWh.

Hence the Latrobe Valley generation will be favoured over the use of Basslink even though in this instance it is much more expensive.

3.13 Bias in Favour of Intra-regional Generation

In the example above it was shown that intra-regional generation in Victoria would be favoured compared to inter-regional Tasmanian generation when there is significant congestion affecting both. The reason why this is occurring is because losses are modelled for Basslink but not for intra-regional generators and consequently the opportunity cost of a transmission constraint appears to be larger for Basslink than the intra-regional generators, $10,309/MWh versus $10,000/MWh, a bias of 309/MWh. This does not reflect physical reality but rather the artificial simplifications used in the NEM's underlying network model and dispatch process. The same issue of bias applies to interconnectors as it does to SNSPs.

For SNSPs and interconnectors, the level of bias resulting from the combination of how losses are modelled and a binding constraint is as follows:

Bias = constraint coefficient x shadow price x (1/MLF -1)

In the case of Basslink, if we assumed a fixed MLF at the Loy Yang terminal of 0.9683 and a coefficient of 1 in the binding generic constraint, then this would be

Bias = shadow price x 0.0327

If the shadow price of the constraint is high then this bias is large enough to cause counter price flows.

In the case of interconnectors the bias is much the same except the fixed MLF is replaced by the dynamic MLF for the losses between the regional boundary and the regional reference node.

The result of this bias in favour of intra-regional generation is that the NEM's dispatch may be significantly suboptimal in the presence of transmission constraints when compared to an optimisation which properly models transmission losses and constraints. The appendix A3 provides a simple example which illustrates how much the outcomes from the NEM's regional dispatch model can differ from a truly optimal dispatch.

4 Alternative Approaches to Calculation and Modelling of Losses

The main two alternative approaches to the current NEM dispatch which could improve the efficiency of dispatches and reduce the bias in favour of intra-regional generation are as follows.

4.1 Model generator transmission losses

Instead of adjusting generator prices and treating them as lossless, model generator transmission losses using their MLFs just as is done for SNSPs between each of their terminals and the corresponding regional reference node. This is equivalent to clearing the market and managing the energy balances at the regional reference node rather than on a regional basis. Such a change would require changes to the systems for producing load forecasts and formulation and implementation of NEMDE. This approach would remove the obvious bias between generators and SNSPs and interconnectors but could still lead to quite suboptimal dispatches.

4.2 Full network model

Alternatively, and by far the best option in terms of overall market efficiency would be to properly model losses using a full network (branch and bound) model. A full network model would replace the single static MLF for generators with a dynamic MLF which would reflect the current power flows and state of the network at any time. Sometimes this would increase a generator's dispatch and at other times it might decrease the dispatch. How this might occur can be seen in Figure 10 which shows a histogram of 2013-14 MLFs for a Snowy generator; even though the average MLF is near one (0.99), the actual MLF in any period could be 10%-15% higher or lower.

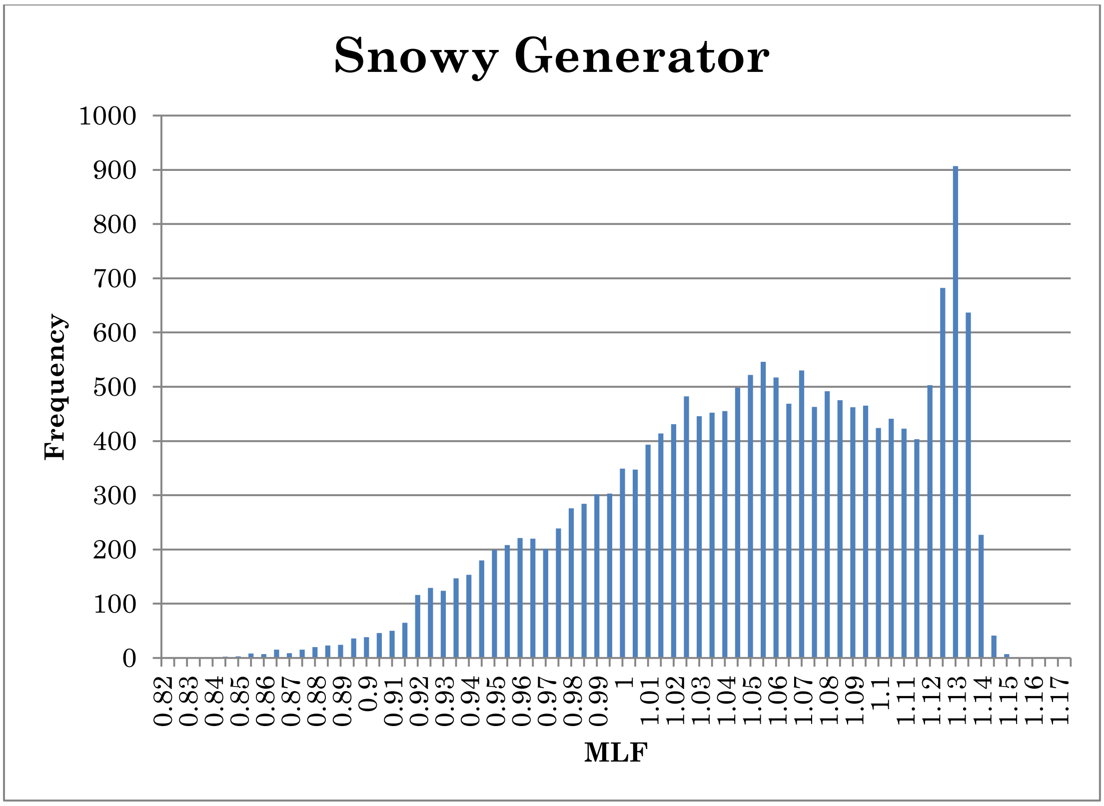
A full network model would be expected to improve the efficiencies of dispatches in large regions such as QLD quite materially and would also facilitate improvements in managing constraints and ancillary services[14]. Most electricity markets which have any degree of locational pricing use much more explicit network models than the NEM. In our view the NEM might achieve something like a 1% efficiency gain with a full network model that incorporates a dynamic model for losses, security constraints, FCAS and possibly NCAS.

The introduction of a full network model does not mean nodal pricing for generators. All that it means is a more efficient dispatch. Just as the modelling of network constraints in the NEM has not changed the NEM pricing model for generators, a full network model using a dynamic loss model does not require any changes in the regional pricing of generators.

[14] A full network model would provide an opportunity to greatly reduce the use of generic constraints and have these replaced by explicit models of thermal limits, frequency control ancillary services and network control ancillary service in the NEMDE formulation. Further this would facilitate continuous improvement of the dispatch optimisation process.

Conceptually generators could still be paid the regional reference price adjusted for their fixed MLFs but there would be a more efficient dispatch which may marginally affect the amount of energy provided by each generator. The details of any such arrangement would have to be reviewed to ensure that the use of the fixed MLFs for payments to generators balanced out with the actual underlying dynamic marginal losses used for dispatch.

Figure 10 Histogram of Half Hourly MLFs for a Snowy Generator for 2013-14



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Appendix A Examples

A.1 Introduction

This appendix considers how the different modelling of inter-regional losses for generators, interconnectors and SNSPs within NEMDE can produce subtly different dispatch outcomes which can result in somewhat different price outcomes . The first example is based on a simple linear network and the second example is a similar network but with a binding transmission constraint.

A.2 Simple Transmission Network

A.2.1 Introduction

This example is based on a simple transmission network consisting of four nodes: A, B, C and D; four generators at A; and the demand at D (see Figure 11). The demand at D is set at 65 MW for the example. There are also an assumed set of MLFs as though they had been calculated by TPRICE in Table 4. To calculate MLFs for any regional allocation of nodes the relative MLFs are used. A node's MLF is its relative MLF divided by its regional reference node's MLF.

The purpose of this example is to illustrate what happens to regional demands and prices when:

- a set of generators is contained within a region;
- a set of generators is connected to a region via a regulated interconnector; and
- a set of generators is connected to a region via an SNSP.

Figure 11 Simple Linear Transmission Example

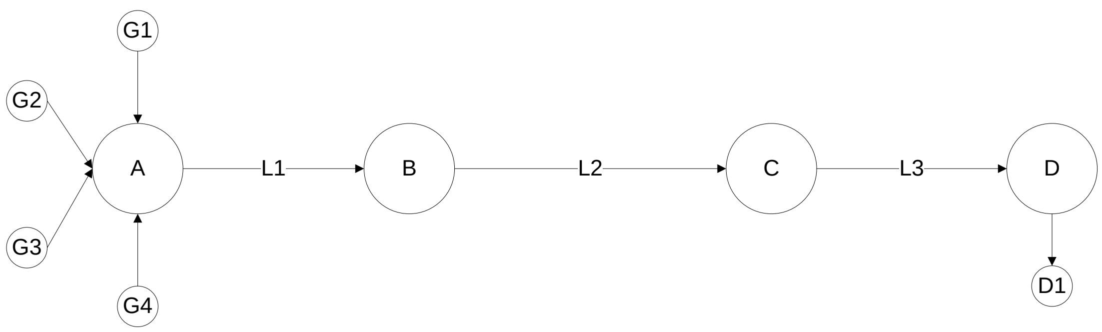

Table 4 Nodal Characteristics of the "Physical Model"

Node	A	B	C	D
Nodal demand	0	0	0	65
Relative MLFs "calculated from TPRICE" referenced to node B	0.95	1	0.97[15]	1.05

The transmission system consists of three lines: L1, L2 and L3. Each line is assumed to have a flow limit of +/- 100 MW. The transmission losses on each line are assumed to be a function of flow as follows:

transmission loss = loss parameter x flow^2

The associated assumed loss share proportion defines how much of the losses are allocated to the sending end of the transmission line (for regulated interconnector cases). Alternatively, the loss share proportion can also be thought of as the relative distance along the line where the power flow is measured.

Table 5 Network Characteristics of the "Physical Model"

Transmission Line	Start	End	loss parameter	flow lower limit	flow upper limit	loss split
L1	A	B	0.001	-100	100	0.5
L2	B	C	0.001	-100	100	0.5
L3	C	D	0.001	-100	100	0.5
Notional interconnector	B	D	0.002	-100	100	0.25

The assumed generator capacities and offers are presented in Table 6.

Table 6 Generator Offers

Generators	Node	Capacity	Price
G1	A	30	20
G2	A	30	50
G3	A	30	100
G4	A	30	1000

A.2.2 Scenarios

This physical model is used to compare the following situations or scenarios:

- Scenario 1: A, B, C, D are all in one region, say region 2, and the regional reference node is at D;

[15] The MLF of 0.97 at C represents the hypothetical situation that there is generation at this location (not shown on the diagram) which under some scenarios causes power to flow from C to both B and D.

- Scenario 2: A and B are in region 1, C and D are in region 2, L2 is a regulated interconnector, B is the regional reference node for region 1 and D is the regional reference node for region 2; and
- Scenario 3: A and B are in region 1, C and D are in region 2, L2 is an SNSP, B is the regional reference node for region 1 and D is the regional reference node for region 2.

Even though each of the scenarios will have the same physical dispatch, they will have different regional demands and prices at each node.

A.2.3 Dispatch and physical losses

For this model the demand at D is met by the least cost merit order of generation at A. This merit order is constant for all the scenarios. The actual amounts of generation required to meet the demand at D are calculated from a physical model that reflects the actual transmission losses and is the equivalent to an actual physical NEM dispatch.

Table 7 shows the generator dispatch and the cost of dispatch as calculated for the objective function. Table 8 shows the physical line losses which are also constant for all scenarios. Table 9 shows the nodal demands and nodal prices (locational marginal prices) reflecting the actual physical dispatch. The nodal prices correspond to the marginal generator offer dispatched in node A and the marginal losses for transfers from A to B to C to D.

Table 7 Generator Dispatches

Generators	Capacity	Price	Dispatch	Dispatch Cost
G1	30	20	30.00	600.00
G2	30	50	30.00	1,500.00
G3	30	100	20.77	2,077.11
G4	30	1000	0.00	0.00
			Total Dispatch Cost	4,177.11

Table 8 Line Flows and Losses

Transmission Line	loss share	flow start	flow middle	flow end	line loss	marginal loss based on flow at middle	Marginal losses based on flow at start	price multiplier (1 + ML)**
L1	0.5	80.77	77.75	74.73	6.04	15.5%	16.9%	1.169
L2	0.5	74.73	72.13	69.52	5.20	14.4%	15.5%	1.155
L3	0.5	69.52	67.26	65.00	4.52	13.5%	14.4%	1.144
Notional	0.25	74.73	72.13	64.32	10.40	28.9%	36.8%	1.368

interconnector								

Table 9 Nodal Demands and Nodal Prices (locational marginal prices)

Node	A	B	C	D
Nodal demand	0	0	0	65
Nodal prices (locational marginal prices)	100.00	116.86	135.03	154.50

A.2.4 Scenario 1: A, B, C, D Are All in One Region

Table 10 presents the results for scenario 1. For this scenario, the regional demand is 80.77 MW and the regional reference price is 110.53 $/MWh.

Table 10 Regional Demands, Losses and Prices for Scenario 1

Node	A	B	C	D
Nodal demand	0.00	0.00	0.00	65.00
Relative MLF	0.95	1.00	0.97	1.05
Region	2	2	2	2
RRN	D	D	D	D
MLF	0.90	0.95	0.92	1.00
Regional demand				80.77
Intra-regional losses				15.77
Nodal prices	100.00	105.26	102.11	110.53
Total regional demands less intra-regional losses	65.00			

A.2.5 Scenario 2: A and B in region 1, C and D in region 2 and L1 regulated interconnector

Table 11 presents the results for scenario 2. For this scenario, the regional demands are 6.04 MW for region 1 and 64.32 MW for region 2 and the regional reference price is 144.02 $/MWh. The regional demand of 6.04 MW for region 1 corresponds to intra-regional losses for the generation at node A. The notional intra-regional losses for region 2 are negative. This is due to the interconnector model underestimating the power transfer to the regional reference node, D.

Table 11 Regional Demands, Losses and Prices for Scenario 2

Node	A	B	C	D
Nodal demand	0.00	0.00	0.00	65.00
Relative MLF	0.95	1.00	0.97	1.05
Region	1	1	2	2
RRN	B	B	D	D
MLF	0.95	1.00	0.92	1.00
Regional demand		6.04		64.32
Intra-regional losses		6.04		-0.68
Nodal prices	100.00	105.26	133.04	144.02

Total regional demands less intra-regional losses	65.00			

A.2.6 Scenario 3

Table 12 presents the results for scenario 3. For this scenario, the regional demands are 6.04 MW for region 1 and 63.79 MW for region 2 and the regional reference price is 131.66 $/MWh. The regional demand of 6.04 MW for region 1 corresponds to intra-regional losses for the generation at node A. The notional intra-regional losses for region 2 are negative. This is due to the SNSP loss model (SNSP component and within region MLF) underestimating the power transfer to the regional reference node, D.

Table 12 Regional Demands, Losses and Prices for Scenario 3

Node	A	B	C	D
Nodal demand	0.00	0.00	0.00	65.00
Relative MLF	0.95	1.00	0.97	1.05
Region	1	1	2	2
RRN	B	B	D	D
MLF	0.95	1.00	0.92	1.00
Regional demand		6.04		63.79
Intra-regional losses		6.04		-1.21
Nodal prices	100.00	105.26	121.63	131.66
Total regional demands less intra-regional losses	65.00			

A.2.7 Conclusions

Depending on the regional model used and whether an interconnection is regulated or an SNSP, then the dispatch process can result in quite different regional demands and nodal or connection point prices for exactly the same dispatch of generator offers on the same physical network.

A.3 Two Regions with and without Transmission Congestion

A.3.1 Introduction

This next example illustrates how the NEM's current dispatch model can result in a bias against inter-regional generators when there are constraints which affect both intra-regional generators and inter-regional power flows.

A.3.2 Physical Network and Regional Structure

This example is based on a simple transmission network consisting of four nodes: A, B, C and D each with one generator, see Figure 12. There are assumed demands of 20 MW at node A and 90 MW at node D and assumed regional MLFs for each node (see Table 13).

Figure 12 Simple Regional Example

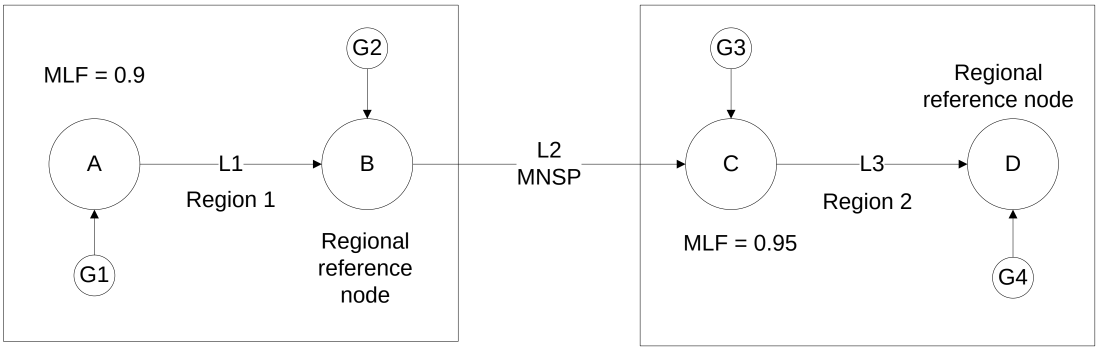

Table 13 Nodal Characteristics

Node	A	B	C	D
Region	1	1	2	2
Nodal demand	20	0	0	90
MLFs	0.9	1	0.95	1

The transmission system consists of three lines: L1, L2 and L3. Each line has a flow limit. The transmission losses on each line are assumed to be a function of flow:

transmission loss = loss parameter x flow^2

The associated assumed loss share proportion defines how much of the losses are allocated to the sending end of the transmission line(for regulated interconnector cases). This information is presented in Table 14.

Table 14 Physical Network Characteristics

Transmission Line	Start	End	loss parameter	flow lower limit	flow upper limit	loss split
L1	A	B	0.001	-100	100	0.5
L2	B	C	0.001	-100	100	0.5
L3	C	D	0.001	-80	80	0.5

The assumed generator capacities and offers are shown in Table 15.

Table 15 Generator Offers

Generators	Node	Capacity	Price
G1	A	70	30
G2	A	100	60
G3	A	100	80
G4	A	100	1000

A.3.3 Least Cost Dispatch Based on Physical Network

The least cost physical dispatch was determined by a non-linear programming optimisation which modelled the transmission limits and network constraints. The generator outputs and costs for this dispatch are shown in Table 16.

Table 16 Generator Dispatches for Least Cost Dispatch

Generators	Node	MLF	Capacity	Offer Price	Dispatch	Dispatch Cost
G1	A	0.9	70	30	70.00	2,100
G2	B	1	100	60	43.15	2,589
G3	C	0.95	100	300	0.00	0
G4	D	1	100	10000	13.20	13,200
					Total Dispatch Cost	17,888

The resulting power flows over the network are shown in Table 17.

Table 17 Line Flows for Least Cost Dispatch

Line	From	To	lower limit	upper limit	loss split	flow start	flow middle / border	flow end	line loss
L1	A	B	-100	100	0.5	50.00	48.81	47.62	2.38
L2	B	C	-100	100	0.5	90.77	86.98	83.20	7.57
L3	C	D	-80	80	0.5	83.20	80.00	76.80	6.40

The demands and nodal prices are shown in Table 18.

Table 18 Nodal Prices from Least Cost Dispatch

Node	A	B	C	D
Region	1	1	2	2
Nodal demand	20	0	0	90
MLFs	0.9	1	0.95	1
Nodal price	54.42	60.00	71.43	1000.00

A.3.4 NEM Dispatch

A NEM dispatch was emulated for the same physical network, demands, generators and generator offer prices as outlined earlier in section A.3.2. With transmission line L2 being a SNSP.

To emulate the NEM regional model, generic constraints needed to be set up to manage the power flow limits on lines L1 and L3. The limits for the SNSP, line L2, are managed explicitly in the NEM dispatch.

The generic constraints to manage the power flow limits on line L1 are:

lower line flow limit for L1 <= G1 – D1 <= upper line flow limit for L1

The generic constraints to manage the power flow limits on line L3 are:

lower limit for L3 <= Power flow at C from L2 + G3 – D3 <= upper limit for L3

As well, the regional demands needed to be adjusted until the generation met the nodal loads. This was done in an iterative process, whereby the was an initial NEM dispatch and any regional demand which was not met from the dispatch was assumed to be met by regulation FCAS. This regulation was then added back on to the regional demands and the process repeated until no regulation was required. This process approximately emulates how demand and supply are balanced in the NEM and regional demand forecasts are updated based on actual generation.

A.3.5 NEM Dispatch Results

The generator dispatches from the NEM model are presented in Table 19, the line flows in Table 20 and the connection point prices in Table 21.

Table 19 Generator Dispatches for NEM Dispatch

Generators	Node	MLF	Capacity	Offer Price	Dispatch	Dispatch Cost
G1	A	0.9	70	30	33.24	997
G2	B	1	100	60	0.00	0
G3	C	0.95	100	80	70.30	5,624
G4	D	1	100	1000	13.20	13,200
					Total Dispatch Cost	19,821

Table 20 Line Flows for NEM Dispatch

Line	From	To	lower limit	upper limit	loss split	flow start	flow middle / border	flow end	line loss	marginal losses
L1	A	B	-100	100	0.5	13.24	13.16	13.07	0.17	2.63%
L2	B	C	-100	100	0.5	13.07	12.99	12.90	0.17	2.60%
L3	C	D	-80	80	0.5	83.20	80.00	76.80	6.40	16.00%

Table 21 Connection Point Prices from NEM Dispatch

Node	A	B	C	D
Region	1	1	2	2
Nodal demand	20	0	0	90
MLFs	0.9	1	0.95	1
NEM connection point prices	30.00	33.33	950.00	1000.00

Some interesting points to note about the simulated NEM dispatch are as follows:

- the offer by generator G2 is not dispatched and G1's dispatch is reduced considerably; and
- the dispatch costs for the NEM dispatch are much higher than for the least cost dispatch ($19,821 vs. $17,888).

A.3.6 Understanding the NEM Dispatch Results

At first glance the NEM dispatch results don't appear sensible. Why would the more expensive G3 generation at node C be dispatched instead of cheaper G1 and G2 generation, even when MLFs and marginal losses over the SNSP (line 2) are taken into account? The reason for this is to do with how losses are modelled differently in NEMDE for generators, interconnectors and SNSPs and how this subtly interacts when there are inter-regional constraints that affect inter-regional flows and intra-regional generation.

To understand what is happening it is worth looking at the costs of supplying 1 MW more power at D based on the NEM dispatch model.

If the power is provided from the generator G3 it will cost $84.21/MWh plus the opportunity cost of using the congested line L3. This opportunity cost can be determined from the marginal cost or shadow price for the generic constraint which limits flows on line L3. It is $915.79/MWh. Thus the cost of providing 1 MWh of extra power from G3 would be $84.21/MWh + $915.79/MWh = $1000.00/MWh.

In the case of providing additional power from G2 the cost would be the cost of the power when losses are accounted for plus the opportunity cost of using the congested line L3. This is:

$60/MWh x (1+the marginal losses on L2) x 1/MLFc = $64.82/MWh

plus

1/MLFc x $915.79/MWh = $963.99/MWh

which equals

$1028.81/MWh

This explains why G2 was not dispatched in the NEM model. What is happening is that because the intra-regional generators are treated as lossless while inter-regional generators have the losses of any inter-regional flow included there is an inherent bias in favour of intra-regional generators when there is a binding constraint. As a consequence, similar results would have occurred for the situation where L2 was a regulated interconnector.