TREATMENT OF LOSS FACTORS IN THE NATIONAL ELECTRICITY MARKET

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Contents

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Executive Summary

The National Electricity Market (**NEM**) comprises both transmission (high voltage) and distribution (low voltage) networks that transport power from generating units to loads. The equipment making up these networks are not perfect conductors and a percentage of the power generated is therefore lost before it reaches the loads. This network loss contributes to the cost of supplying power to consumers, and must be considered if the most efficient dispatch and location of generation and loads is to be achieved.

Economic efficiency requires that the price for a good or service reflect the full cost of producing and delivering to the point of consumption the next unit of that good or service (in the electricity industry, this process is also called “economic dispatch”). This principle has been adopted for the NEM through the use of marginal pricing and an approximate form of nodal pricing.

Marginal pricing is implemented by defining the spot price for electricity to be the incremental cost of additional generation (or demand reduction) for each spot market trading interval.

Marginal pricing is extended to an approximate form of nodal pricing by taking account of network losses to derive a set of nodal prices for each node at which a Market Participant is located. An accurate implementation of full nodal pricing would require marginal network losses to be calculated and updated every dispatch interval. All network flow constraints would also have to be taken into account.

The NEM adopted an approximate version of nodal pricing was adopted. This approximate method involves the calculation of marginal loss factors to reflect the marginal cost of network losses. Regions have been defined between which flow constraints are modelled and the inter-regional loss factors vary from one dispatch interval to the next, as would be the case if full nodal pricing were employed. These dynamic loss factors are defined between specific connection points in each region referred to as “regional reference nodes” (**RRNs**). In the absence of inter-regional flow constraints, the dynamic loss factor for an interconnector equals the ratio between the spot prices at the respective RRNs.

Within each region static marginal loss factors are calculated that approximately represent the impact of marginal network losses on nodal prices at the transmission network connection points at which generation and loads are located. These static marginal loss factors are average values calculated from historical network flow data from the previous financial year.

At the distribution level a further approximation to marginal pricing is adopted in that the loss factors are generally calculated based on the average, rather than marginal losses that occurred over the previous financial year, however, in the case of Scheduled Generators AEMO may request that a marginal distribution loss factor be calculated if, in AEMO’s opinion, the calculation of an average distribution loss factor would significantly impact on the central dispatch of generation (and thus on market price signals)

The nodal spot price at a particular location within a region is calculated by multiplying the spot price at the RRN for that region by the appropriate transmission loss factor and (if relevant) the appropriate distribution loss factor.

This document details the theory supporting the adoption of marginal pricing in the NEM. The benefits provided, including the efficient dispatch of generation and scheduled loads, and the provision of efficient locational signals, are discussed.

The approximations adopted for the NEM, including the processes AEMO has used to calculate the dynamic inter-regional and static intra-regional marginal loss factors, are considered consistent with the requirements of the National Electricity Rules (Rules). The document also discusses the impact of loss factors on central dispatch and settlements.

1 Purpose of Document

The purpose of this document is to provide some assistance and guidance on how loss factors have been treated in the NEM.

2 General

Generating units supply power to customer loads through the electrical network, which comprises the transmission network and the distribution network.

Transmission networks are generally very high voltage (220kV or higher) networks capable of efficiently conveying large flows of electricity over long distances. Distribution networks are generally lower voltage networks that carry electricity within a more localised geographic area. There may be particular exceptions to the general concepts distinguishing transmission networks from distribution networks in the NEM because the positions at which transmission networks end and distribution networks begin is, for the time being at least, determined on a State by State basis by the particular jurisdictional regulator for each State, rather than on a national basis by AEMO or the AER.

The point at which a distribution network connects to a transmission network is known as the transmission network connection point.

No transmission element is a perfect conductor of electricity. Because of resistance within the element, a small amount of electricity is “lost” when being transported from one point to another. For example in the radial network shown in Figure 1 the generating unit must produce 103 MW of power to supply the 100 MW of load plus 3 MW of losses in the transmission line.

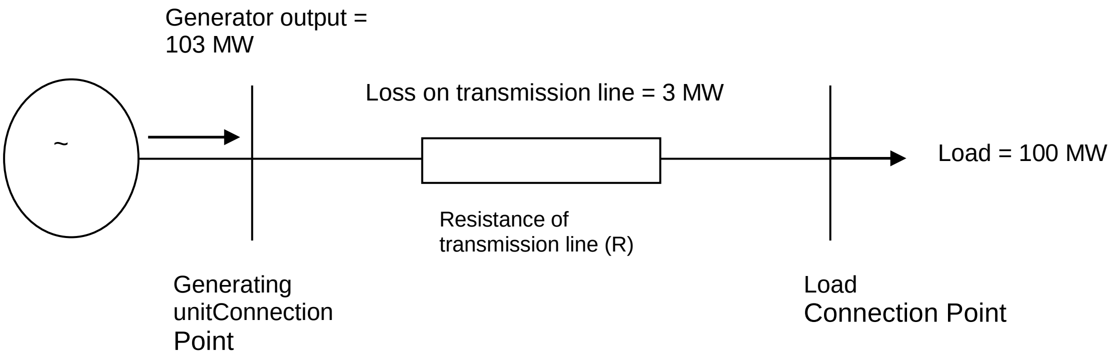


Figure 1: Generating unit supplying load in a radial network

Because of the very high voltages involved, transmission networks have the capacity to convey very large flows of electricity efficiently over long distances with relatively small losses. Losses also occur within distribution networks. In the NEM, losses in the transmission network are typically around 2.5 – 4.5% of the power transmitted, while losses in the distribution networks may be much higher, particularly when supplying rural customers.

The proportion of power generated that is lost depends on the location of generation and load connection points. Generally, transporting power to or from more remote connection points incurs higher losses.

It is important to minimise the losses in the transmission and distribution networks (to the extent that it is cost effective to do so).

The signal for loss minimisation in the NEM is provided by using "marginal loss factors" (**MLFs**) for load and generation transmission network connection points and average "distribution loss factors" (**DLFs**) for load connection points embedded within the distribution network. Generation in a distribution network may be allocated either a MLF at the generator terminal or a MLF at the connection point of the distribution network where the generator is embedded supplemented by a DLF depending on whether the generator is transmission connected or embedded.

MLFs represent the increase (or decrease) in loss that would occur in response to an incremental change in generation output or load demand from its current value. The basic theory of marginal pricing is described in Section 3.

MLFs have been introduced into the NEM to:

- Provide for the dispatch of generation that is as economically efficient as possible. The use of MLFs ensures that the network loss impacts on economic efficiency associated with loading alternative generation are properly incorporated into dispatch decisions.
- Provide efficient spot pricing signals for loads. This is important in allowing loads to participate in decisions about whether they are prepared to have their demand reduced rather than paying the occasionally high prices that may arise in the spot market.
- Provide appropriate signals for network investment decisions, i.e., allowing benefits of loss reduction to be incorporated into the network investment decision making process.
- Provide what is often referred to as "locational signalling" to existing Market Participants and new entrants.
- Ensure market neutrality between locations and participants.

The manner in which MLFs provide these signals is discussed in more detail in Section 5.

DLFs are also used by Distribution Network Service Providers (**DNSPs**) to allocate a portion of the average losses occurring within their distribution network to individual loads and generating units (when applicable). This can be achieved by dividing the losses that are allocated to these individual loads and generating units over a defined period (normally 12 months) by their load demand or generation output over the same time span.

The relationship between transmission and distribution networks and MLFs and DLFs is illustrated in Figure 2. All transmission network MLFs are referred to the RRN[1], which is described in more detail in Section 7

1 The RRN is used as a basis for implementing the pre-determined nodal price ratios derived from static network loss factors. The RRN may be thought of as the location at which trading in electricity is defined to occur.

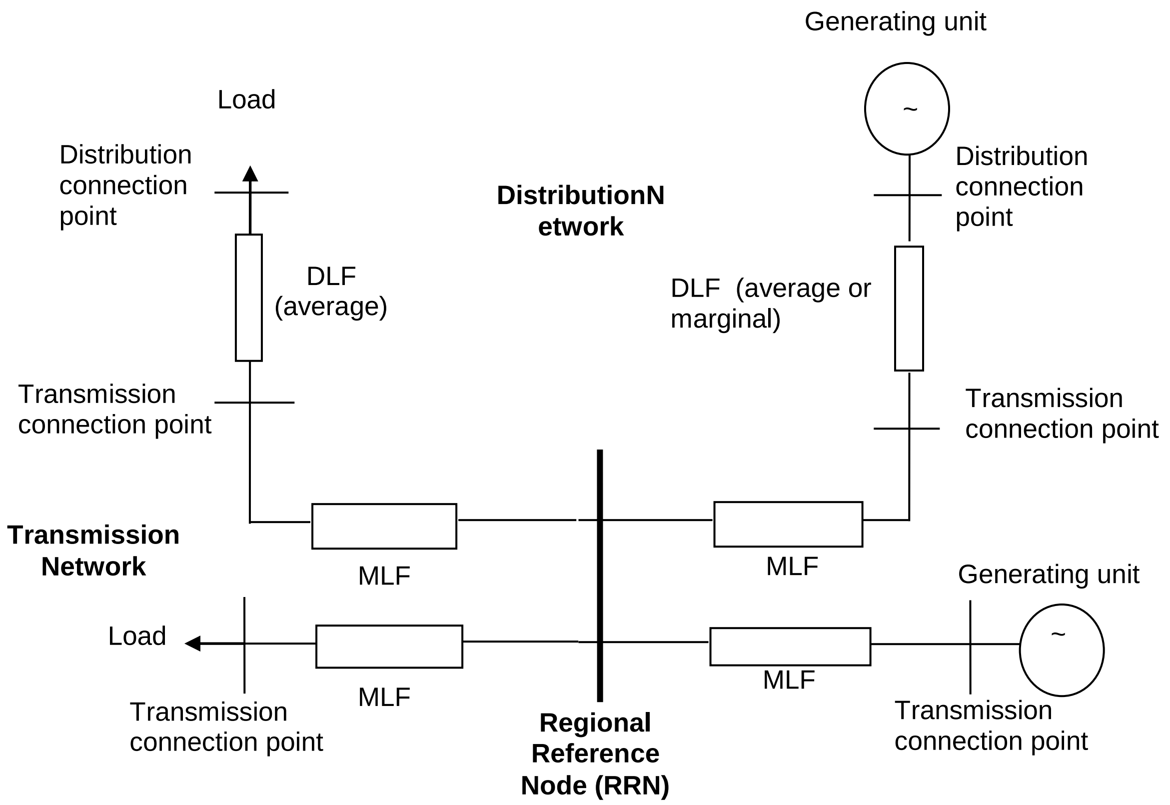


Figure 2: Relationship between connection points and loss factors

Most Generators participating in the NEM are connected to transmission networks. A small but growing number are connected to distribution networks. These are sometimes known as “embedded generators” (in the sense that they are embedded within a distribution network).

Loads may be connected to distribution networks or transmission networks.

AEMO is responsible for calculating the MLFs for transmission connection points, which are updated annually. DLFs are calculated each year by the DNSPs and must be approved by the AER, before being published by AEMO.

3 Spot Pricing

3.1 Basic Theory – Generation only

For a simple power system supplying customers neglecting transmission and distribution costs, the hourly spot price for supplying electrical energy is the total increased in cost of providing an additional MWh of electrical energy.

$\rho(t) = {}^{\rho(\text{Total cost of providing electrical energy to customers})}/\rho_{d(t)}$

= Marginal cost ($/MWh) of providing electrical energy to customers during hour t wit capital and operating costs taken into consideration.
For more detailed information on marginal pricing, refer to **Error! Bookmark not defined.**,**Error! Bookmark not defined.**,**Error! Bookmark not defined.** below

Economic theory derives the fact that marginal cost pricing is optimum in a social welfare sense. This can be viewed as a way to introduce spot prices $\rho(t)$ which causes the customer to choose a value for demand which satisfies the social optimality conditions for the demand at the time. Thus spot prices based on marginal pricing satisfy the basic objectives of the National Electricity Market by:

- Providing customers with the cost of supply so they can choose how to use electrical energy.
- Motivating customers to adjust their own electrical energy usage patterns to match supply marginal costs, thus improving economic efficiency.

3.2 Basic Theory – Generation with Network included

Electrcal energy from power stations is delivered to customers via the the transmission network. When the transmission network is included in above analysis, the following network properties have to be included in the marginal based spot price.

- Transport capacity – physical constraints in the transport system may interfere with the transfer of power through a particular part of the transport network.
- *Transport losses* – some power is lost during transmission so more power than is required by customers has to be injected.

Even though the transmission network properties can be shown in separate physical components in the spot price, they are not totally independent of each other. It is important to note that the coat of transmission losses and constraints cannot be calculated and minimised separately from the cost of generation. The reason is that transmission losses are dependent on the generation dispatch, which is dependent on generation cost. In other words, the value of transmission losses and constraints is derived from the generation configuration, and this in turn has an impact on the the generation pattern. Thus, the whole system is optimised by minimising the cost of generation subject to the the network constraints and taking into account the losses between nodes/locations.

The result of the optimisation gives the spot price at a node/location (k) as shown below:

$\rho_k(t)$ = (Marginal cost of the generator that is on the margin) * (Marginal loss factor between this generator and location k)

As is the case above with only generation being considered, this spot price is optimum in a social welfare sense; this is the rate charged to customers which minimises the social cost assuming optimum customer behaviour.

In addition to satisfying the economic efficiency objective, it can be shown that the derived generation and network spot price satisfies two further required objectives:

- Locational pricing.
- Some form of capital costs recovery.

The spot price equation derives an optimum value of electricity in the market place, but the value of electricity differs by location, due to the marginal cost of losses in the transmitting the electricity to the location.

The dispatch of generation always results in marginal costs exceeding average variable operating costs. Thus, charging customers at marginal costs collects reveneues in excess of total variable operating costs. This difference can be applied towards the capital costs of the transmission network.

3.3 Decision-making

Centralised *decision-making* pre-empts the commercial discretion of market participants and distorts market outcomes. Therefore, the NEM is designed as a 'simple' spot market, in which the spot market for each trading interval is solved independently of all other spot market trading intervals.

Centralised day-ahead forecasts of future prices are made by AEMO, however, most responsibility for decision-making rests with participants. For example, decisions to start or stop generation (commitment or de-commitment decisions) are left to Market Participants. As a result of this design choice, there are now active markets in financial instruments linked to future spot prices to assist Market Participants in decision-making and risk management.

3.4 Nodal spot market

The concept of a *nodal spot market*is to have a set of locational spot prices for an electricity network computed simultaneously by use of a computer algorithm that contains a model of the electricity network.

For a market where Generators submit bids but loads do not, the computed locational prices represent the marginal cost of supplying a very small increment in demand at each location while demands at all other locations are held constant.

The structure and parameters of the network model, together with the pattern of network flows, determine the relationship between the locational electricity prices. This is the electricity industry equivalent to finding the most economically efficient solution to the "transport problem" outlined earlier.

For various reasons, it may not be worthwhile to calculate a nodal spot price for every location in an electricity network, and approximations may be used in practice. See Outhred and Kaye[2] for a discussion of the concepts of nodal (locational) pricing and the reasoning behind the adoption of an approximate design.

3.5 NEM Approximation to Full Nodal Pricing

The NEM under the Rules approximates locational pricing by introducing the concept of 'loss factors' that involve certain assumptions:

- Regions are defined and within each region there is a RRN, which is the point at which a spot price is calculated.
- Prices for all other nodes (locations) within the region at which there are Market Participants are calculated according to a pre-determined static ratio with respect to the price at the RRN. That ratio is called "*a transmission loss factor*".

[2] H. R. Outhred and R. J. Kaye, "Incorporating Network Effects in a Competitive Electricity Industry: An Australian Perspective", Chapter 9 in M Einhorn and R Siddiqi (eds), *Electricity Transmission Pricing and Technology*, Kluwer Academic Publishers, 1996, pp 207-228.

- Loss factors *within* regions are marginal, calculated as a static figure of volume-weighted averages through time (temporal averages).
- Price differences *between* regions are calculated according to inter-regional loss factor equations. That is, the loss factors between regions are updated at each five-minute dispatch interval.

4 Basic Theory of Loss Factors

In mathematical terms, marginal losses are determined by the first derivative of the network loss function at a particular level of network flows. The first derivative equals the ratio of the (infinitely small) change in overall network losses divided by the infinitely small change in generation or load that produced the change in overall network losses.

Consistent with this definition, MLFs are calculated based on the incremental network losses incurred when a very small increment of load is injected into the network at a generation or load connection point rather than at the RRN. Transmission network loss factors are always calculated as MLFs.

Marginal network losses are always a more appropriate basis for computing loss factors than average network losses from the point of view of market design, because they reflect the underlying ideal relationship between locational marginal prices better (remembering that a key principle of the NEM is the adoption of marginal pricing).

Distribution loss factors are used for calculating losses in distribution networks and the Rules requires them to be determined as volume weighted averages of the average electrical energy losses between transmission network connection points and distribution network connection points.

5 Marginal Loss Factors

MLFs are used to represent the change in network losses that occur due to a small increase in load at connection points across the NEM, compared to the change that would occur if the loads were located at the RRN. Conceptually, this can be achieved by modelling a small increase in load at each generation and load connection point in each region in turn, and determining the resultant increase in generation required to meet that load increase assuming it is supplied from a generating unit located at the RRN.

The MLF is defined in terms of this small increase in load as:

MLF = (change in generation at the RRN)/(change in load at the connection point)

= (change in network losses + change in load)/(change in load)

That is:

$$\text{MLF} = 1 + \Delta_{\text{loss}} / \Delta_{\text{load increment}}$$

Where

Δ_{loss} = change in network

$\Delta_{\text{load increment}}$ = incremental increase in load at connection point

By definition the MLF at the RRN = 1.

5.1 Simplified approach to calculating marginal loss factors for radial lines

Losses in a particular network element are given by:

Transmission loss = $I^2 * R$ ………………………………. (i)

Where,

I = current flowing through the network element;

R = resistance of the network element.

The magnitude of current is dependent on both the active and reactive power flowing through the network element and the voltage magnitude:

$$I = \frac{\sqrt{(P^2 + Q^2)}}{\sqrt{3} * V} \quad \text{………………………………. (ii)}$$

Where,

P = three phase active power flowing at sending (or receiving) end of network element;

Q = three phase reactive power flowing at sending (or receiving) end of network element;

V = line-line voltage magnitude at sending (or receiving) end of network element.

(Loss factors are calculated at the end of the network element that is electrically remote from the RRN. This may be either the sending or receiving end depending on the direction of flow.)

As a simplifying approximation it can be assumed that Q is zero and V is nominal. In this case

$I \, \alpha \, P$

Substituting into equation (i) above:

Transmission loss $\alpha \, P^2 * R$ ………………………………. (iii)

$= k' * P^2$ ………………………………. (iv)

For example, considering figure 1, the power flowing across the transmission line to supply the load is 100 MW and, assuming k’ = 0.0003, then:

Transmission loss = k’ * power flow^2

= $0.0003 * 100^2$

= 3 MW

Now, the MLF can be calculated from:

MLF = 1 + Δ_{loss} / $\Delta_{load\ increment}$

In mathematical terms marginal loss factors are determined by the first derivative of the loss function at a particular level of network flow. Therefore:

MLF = 1 + $\partial_{\ loss}$ / $\partial_{\ load\ increment}$

Differentiating equation (iv) above yields:

MLF = 1 + 2 * P * k'

5.2 Where P is positive when flowing through the network element towards the connection point at which the loss factor is to be determined.MLF Calculation for load connection point

Consider Figure 1 with the generation connection point defined as the RRN. If a small (1 MW) increment of load is added to the load connection point, the loss on the transmission line increases to 3.06 MW and 104.06 MW must be generated at the RRN to supply the load.

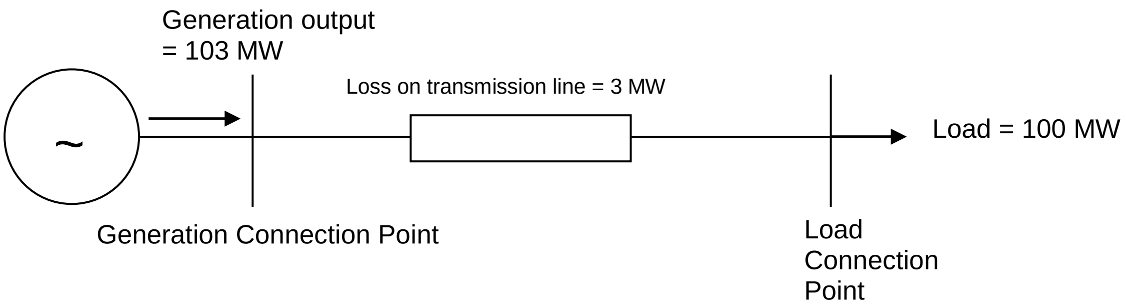


Figure 3: Radial network prior to 1 MW load injection at load connection point

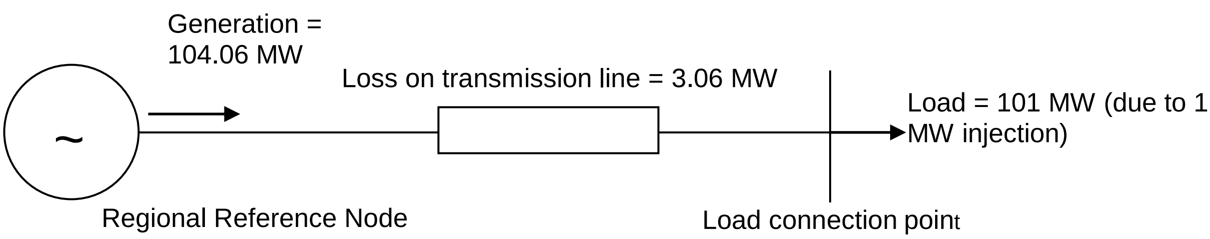


Figure 4: Radial network after 1 MW load injection at load connection point

In this case the transmission loss has increased by 0.06 MW (3.06 – 3) due to the 1 MW load injection at the connection point. The MLF is therefore equal to:

MLF = (change in generation at the RRN)/(change in load at the connection point)

= 1 + (change in loss / change in load at the connection point)

= 1 + 0.06 / 1

= 1.060

Or MLF = 1 + 2 * P * k'

= 1 + 2 * 100 * 0.0003

= 1.060

5.3 MLF Calculation for generator connection point

Consider Figure 5, which is the same as Figure 3 except that a generating unit replaces the load. If it is assumed that the loss on the transmission line is again 3 MW, then the RRN must now act as a net load of 97 MW.

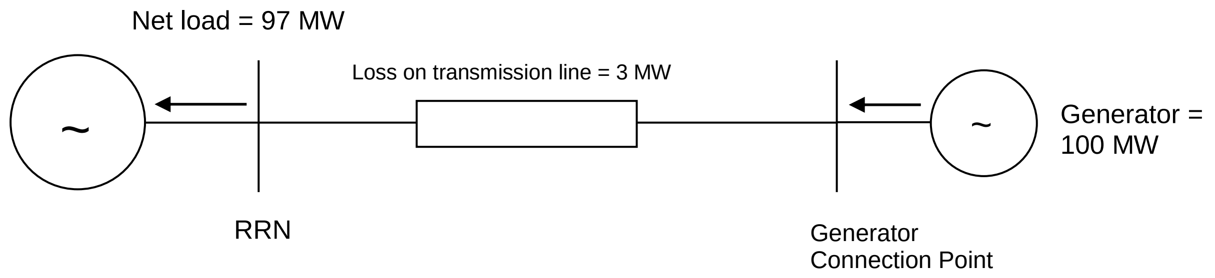


Figure 5: Radial network prior to 1 MW load injection at generation connection point

If a small (1 MW) increment of load is added to the generation connection point, the flow from the generating unit towards the RRN will reduce. Since the transmission loss is proportional to the square of the flow, this also decreases:

Transmission loss = R * power flow^2

= 0.0003 * 99^2

= 2.94 MW

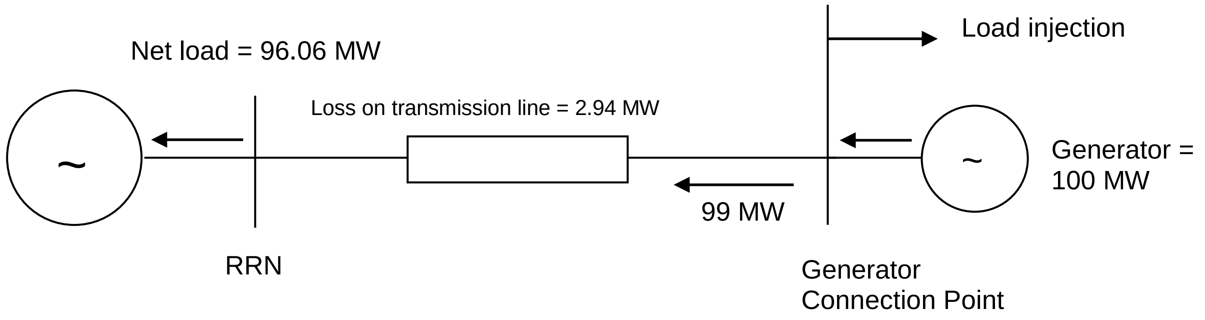


Figure 6: Radial network after 1 MW load injection at generation connection point

In this case the transmission loss has decreased by 0.06 MW (3 – 2.94) due to the 1 MW load injection at the connection point. The MLF is therefore equal to:

MLF = (change in generation at the RRN)/(change in load at the connection point)
= 1 + (change in loss / change in load at the connection point)
= 1 + (-0.06) / 1
= 0.94

Or MLF = 1 + 2 * P * k'
= 1 + 2 * -100 * 0.0003
= 0.940

5.4 General Considerations

Commercially available loss factor calculation programs typically use an infinitely small load increase at the connection points to determine loss factors, however, a 1 MW increase is generally accepted as being a robust approximation for connection points in large power systems. As one moves further into a distribution network, where load and generation increments may be smaller, there is an argument to reduce the increment size accordingly.

The examples in Sections 5.2 and 5.3 considered flow across a single transmission line supplying either load or generation. In complex power systems there may be a large number of intervening loads and generating units between the connection point and RRN. In such cases, while the loss across each transmission element may be a simple square law characteristic, the effect of a small increment of load at the connection point on overall network losses may be quite different.

5.5 Locational Signals

5.5.1 MLFs less than 1

Connection points in areas where there is an overall net injection into the network will tend to have MLFs less than 1. This would normally be expected to apply to generators. However, this will also apply to loads situated in areas where the local level of generation is greater than the local load.

MLFs less than 1 at connection points indicate that network losses will increase as more generation is dispatched at that node and decrease as more load is taken. The smaller the MLF when it is below 1, the greater the increase (or decrease) in network losses for the same magnitude of change.

This is also reflected as an increase in the generator bid price when it is referred to the RRN, and therefore a reduced likelihood of the generator being dispatched. Similarly the price paid for output from generators (as determined at the generator connection point) reduces. Conversely, loads located in areas where MLFs are less than 1 pay less for the energy consumed than if they were at the RRN.

There is therefore a signal for increased load and decreased generation in areas of net generation until local load and generation is in balance and network losses are minimised.

5.5.2 MLFs greater than 1

Connection points in areas where there is an overall net load tend to have MLFs greater than 1. This would normally be expected to apply to loads, however, this will also apply to generation situated in areas where the local load is greater than the local level of generation.

MLFs greater than 1 at connection points indicate that losses will increase as more load is consumed and decrease as more generation is dispatched. The higher the loss factor is above 1 the greater the increase (or decrease) in losses for the same magnitude of change.

This is reflected in a higher price being paid by the load for the energy it takes from the NEM than if it were located at the RRN. Conversely, generating units located in the same area receive a reduced bid price when it is referred to the RRN, and are, therefore, more likely to be dispatched. The price paid to the Generator for its output is higher than the price at the RRN.

There is, therefore, a signal for increased generation and decreased load in these areas until local load and generation is in balance and transmission losses are minimised.

6 Average Loss Factors

Figure 7 represents the transmission loss versus power flow characteristic for the radial network example shown in Figure 3.

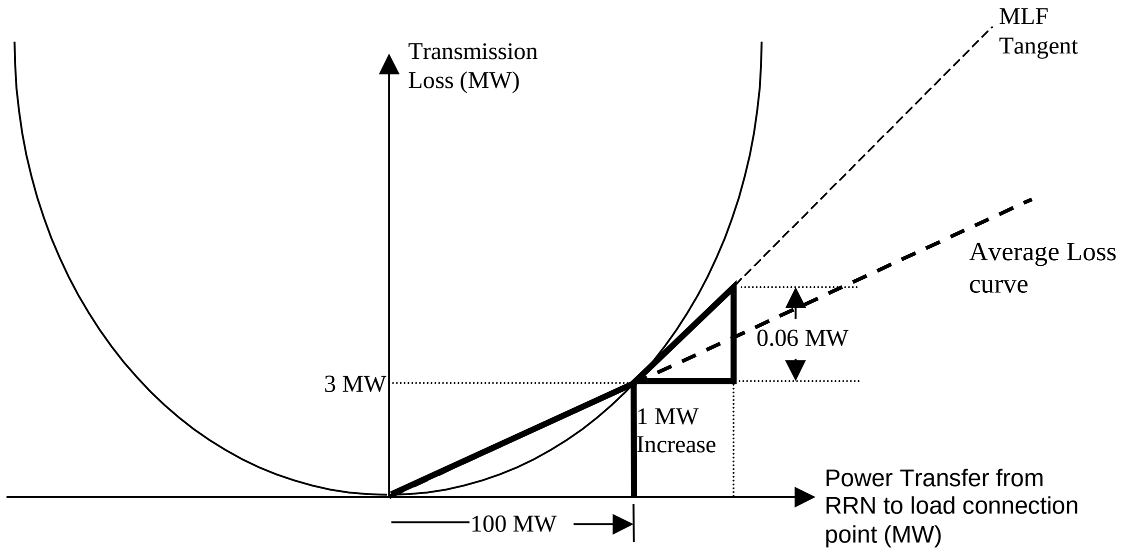


Figure 7: Transmission loss versus power flow for radial network

The horizontal axis represents the power flow from the RRN towards the load connection point. (Note exaggerated scales.) Negative flows would occur if instead of a load, a generating unit was located at the connection point. The point at 100 MW corresponds to the load in the example.

Consistent with the calculation provided in Section 5.2, the MLF in the above diagram is 1+ 0.06 = 1.06.

The average loss factor (**ALF**) can be determined by dividing the average loss by the load at the operating point and adding 1. For example, if it is assumed that over a period of time the average loss is 3 MW and the average load is 100 MW, then

ALF = 1 + (Average loss over period) / (average load over period)

ALF = 1 + 3.0/100

= 1.03

as represented by the heavy dashed line in Figure 7.

From Figure 7 it can be seen that the slope of the MLF tangent is always steeper than the slope of the ALF curve, and the MLF will always be greater than the ALF for any operating condition where flow is from the RRN to the connection point. (If the flow is in the opposite direction – generation located at the connection point – the MLF will be less than 1, and always less than the ALF.)

6.1 The application of an average distribution loss factor

The NEM consists of the transmission network with MLFs applied to connection point generators and loads. The Rules also provide for DLFs, calculated as volume weighted average of average losses, to be generally applied to loads within distribution networks.

Clauses 3.6.3(b)(2)(i) and 3.6.3(h)(4) of the Rules provide for DLFs, calculated using average electrical energy loss between distribution network connection points and transmission network connection points, to be applied to connection points within distribution networks. DLFs are also to be applied to embedded generating units under 3.6.3(b)(2)(i)(A).

7 Loss Model for National Electricity Market

The NEM is currently divided into five regions for market pricing purposes. They are:

- Queensland;
- New South Wales;
- Victoria;
- South Australia; and
- Tasmania

There is a transmission network extending across each region.

Each region has a single RRN, which is located at or close to a large load centre in each region. The RRNs are currently located at:

- South Pine 275 kV node for the Queensland region;
- Sydney West 330 kV node for the New South Wales region;
- Thomastown 66 kV node for the Victorian region;
- Torrens Island 66 kV node for the South Australian region; and
- George Town 220 kV node for the Tasmania region

A market (not physical network) representation of the regions of the NEM is provided in Figure 8.

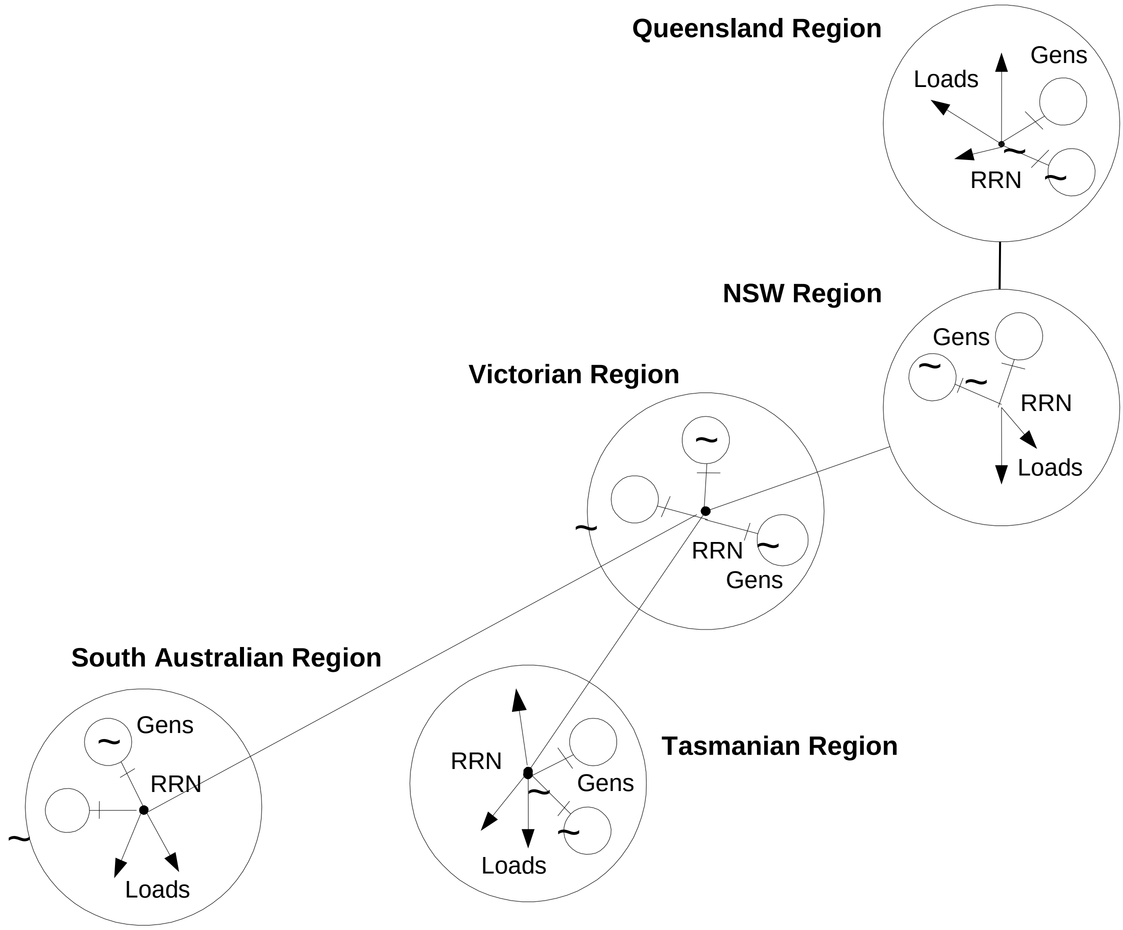


Figure 8: Regions of the NEM

The transmission network in each region is linked to the transmission network in the adjacent region by notional inter-regional interconnectors.

Intra-regional loss factors are MLFs that apply between a RRN and transmission network connection point within the same region. They are pre-determined as a single static loss factor to apply at each connection point for a financial year. As previously discussed, this is achieved by calculating an MLF at each transmission network connection point for each half-hour during the year. The intra-regional loss factor is set equal to the average of these 17,520 half-hourly loss factors.

Because of the large variability of flows between regions, a single static loss factor is not appropriate to apply between RRNs. In this case, an equation is determined to allow the MLF between adjacent RRNs to be calculated for each dispatch interval using a number of parameters that have a significant impact on inter-regional losses. These parameters include power flow on the interconnector between the adjacent regions and total demand in each region. This equation is referred to as an inter-regional loss factor equation.

Regions are constructed so that they are separated by interconnectors that may, at times, become "constrained"; that is, the potential power flow across the interconnector (arising from the dispatch conditions) exceeds its technical capability.

When there are no constraints between regions the spot price at each RRN will be linked to the other RRNs by inter-regional loss factors. In the absence of intra-regional constraints, the spot price at each RRN is also linked to the bid price of the marginal generating unit (the last one dispatched to meet demand) referred via its own intra-regional loss factor to its RRN, and to the other RRNs by inter-regional loss factors. More generally, there may be several marginal generating units in a region, with output being adjusted between them to meet a load increment at the RRN without violating any intra-regional constraints.

Where a constraint is reached for power transfer between regions, a separate regional reference price is determined at the RRNs on either side of the constraint as though they were separate pools.

8 Calculation of Marginal Loss Factors for the NEM

8.1 Rules requirements

The requirements for determining MLFs for the NEM are specified in clauses 3.6.1 and 3.6.2 Rules. In particular clauses 3.6.1(c) and 3.6.2(d) state that AEMO must determine, publish and maintain, in accordance with Rules consultation procedures, a methodology for the determination of inter-regional and intra-regional loss factors to apply for a financial year.

8.2 Process for calculating loss factors

In 2002, following a lengthy consultation, NEMMCO determined and published a forward-looking methodology for calculating loss factors (FLLF) for the transmission network. This consists of:

- the methodology for determining the inter-regional loss factor equations (clause 3.6.1(c));
- the methodology for determining intra-regional loss factors (clause 3.6.2(d)); and
- the methodology for forecasting and modelling the load and generation data used to calculate the inter-regional loss factor equations and intra-regional loss factors (clause 3.6.2A)

The FLLF methodology can be found on AEMO's website at http://www.aemo.com.au/electricityops/172-0032.html

8.2.1 Network Data

The FLLF methodology requires future augmentations to be identified.

AEMO will consult with the TNSPs to develop a list of transmission augmentations that are committed to be commissioned during the financial year for which the loss factors are to apply.

The TNSPs must confirm that the transmission augmentations have satisfied the commitment criterion in the Electricity Statement of Opportunities.

The TNSP must supply AEMO with sufficient network data for the augmentation to be represented in the network model.

8.2.2 Calculation of Forward-Looking Loss Factors

NEMMCO prepared and published a FLLF Issues Paper in April 2002, followed by a public forum in July 2002. The Final Methodology (V-02) was published on 12 August 2003. An algorithm for the calculation of FLLFs was then developed and implemented in the TPRICE program. This was followed by the publication of a set of forward-looking loss factors to give an indication to participants of the likely impact of changing to a forward-looking loss factor methodology.

An audit was then carried out on the implementation of these forward-looking loss factors. This confirmed that the FLLF methodology and the TPRICE algorithm complied with the Rules.

8.2.3 Static intra-regional loss factors

Intra-regional losses are electrical energy losses that occur due to the transfer of electricity between a RRN and transmission network connection points in the same region.

Clause 3.6.2 of the Rules requires AEMO to determine and publish volume-weighted average marginal loss factors to apply for each financial year for each transmission network connection point.

The Rules also provide for average loss factors to be determined for virtual transmission nodes. With the agreement of the AER, an adjacent group of transmission network connection points within a single region can be collectively defined as a virtual transmission node. Its loss factor is then calculated as the volume-weighted average of the transmission loss factors of the constituent transmission network connection points.

The method for determining intra-regional loss factors can be found in section 5.6 of the FLLF methodology document, which can be found on AEMO's website. The method and loss factors have been audited and confirmed to comply with the Rules.

8.2.4 Inter-Regional Marginal Loss Factor Equations

Inter-regional losses are electrical energy losses due to a notional transfer of electricity through regulated interconnectors from the RRN in one region to the RRN in an adjacent region.

Clause 3.6.1(c) requires AEMO to determine and publish inter-regional loss factor equations for a financial year, describing inter-regional loss factors between each pair of adjacent RRNs in terms of significant variables.

The adjacent RRNs for which loss factor equations must be produced are currently:

Qld – NSW	Qld	South Pine 275 kV	NSW	Sydney West 330 kV
Victoria – NSW	Victoria	Thomastown 66 kV	NSW	Sydney West 330 kV
Victoria – SA Victoria - Tasmania	Victoria Victoria	Thomastown 66 kV Thomastown 66 kV	SA Tasmania	Torrens Island 66 kV George Town 220 kV

1. The method for determining intra-regional loss factors can be found in section 5.7 of the FLLF methodology document, which can be found on AEMO's website. The method and loss factor equations have been audited and confirmed to comply with the Rules.

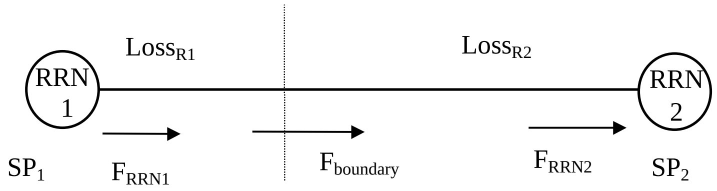
8.2.5 Inter-regional losses

Inter-regional losses must be estimated so that the settlement surplus for each notional interconnector can be calculated. (Notional interconnectors 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 NEM.

Inter-regional loss factor equations describe the variation in MLFs across the notional links. Integration of the (inter-regional loss factor-1) equation is used to determine the average losses on each notional interconnector:

Inter-regional loss = ∫ (inter-regional MLF – 1) dflow

The inter-regional loss must be separated into the amount belonging to each of the two regions connected by the notional link. This separation of losses allows 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 example 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 RRN 1
	$= F_{boundary} + Loss_{R1}$
F_{RRN2}	= Inter-regional flow at RRN 2
	$= F_{boundary} - Loss_{R2}$

If SP_1 is the spot price at the RRN in region 1 and SP_2 is the spot price at the RRN in region 2, the Inter-regional Settlement Surplus (IRSS) can be calculated from:

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

The process for proportioning inter-regional losses is detailed in the document “Proportioning Inter-Regional Losses to Regions” which is located on AEMO’s website using the link below:

http://www.aemo.com.au/electricityops/701.html.

The proportion of inter-regional losses in each region will vary as notional link flow and region demands vary, however, the current version of the ESCA SPD system is only capable of modelling a static ratio between adjacent regions. These losses are published each year with MLFs.

9 Relationship between Loss Factors and Spot Price

AEMO must determine and publish, in accordance with clause 3.9 of the Rules, a spot price for energy to apply at each RRN in each trading interval. Thus, inter-regional loss factors are to be used in the central dispatch process as a notional adjustment to relate the prices of electricity at RRNs in adjacent regions so as to reflect the cost of inter-regional losses. An intra-regional loss factor is to be used as a price multiplier 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.

In addition, distribution loss factors (DLFs) are to be used in the settlement process as a notional adjustment to the electrical energy, expressed in MWh, flowing at a distribution network connection point in a trading interval to determine the adjusted gross energy amount for that connection point in that trading interval, in accordance with clause 3.15.4.

The equations describing the price relationships are listed below:

Connection Point Price referred to RRN

- Generator bid price at RRN = Generator bid price at connection point / (MLF * DLF)
- Load offer price at RRN = Load offer price at connection point / (MLF * DLF)

RRN Price referred to Connection Point

- Price at generation connection point = RRN spot price * (MLF * DLF)
- Price at load connection point = RRN Spot Price * (MLF * DLF)

10 Settlements Residue due to Network Losses

AEMO must provide settles the billing and payment of amounts due in respect of Chapter 3 transactions in accordance with clause 3.15 of the Rules.

Since generation in the NEM is dispatched optimally based on marginal costing, marginal network losses, not average losses, are charged for the transmission of power. Charging customers at marginal costs yields excess revenues, as marginal costs generally exceed average costs. This excess revenue is known as “settlements residue” and there are provisions in the Rules dealing with its distribution.

Under clause 3.6.5(2), settlements residue attributable to regulated interconnectors (as adjusted to take into account the effect of any applicable jurisdictional derogations referred to in Clause 3.6.5(a)(1)) will be distributed or recovered in accordance with clause 3.18.

Clause 3.6.5(3) provides for settlements residue due to intra-regional loss factors, to be distributed to or recovered from the appropriate Transmission Network Service Providers (does not include Market Network Service Providers)

It is important to note that the fact that there exists a settlements residue is not an accident, oversight or afterthought. It is an inherent feature of a market designed on the basis of marginal pricing principles.

11 Impact of loss factors on Pool Prices and Settlements

The following sections illustrate the impact of applying:

- No loss factors;
- Average loss factors; and
- Marginal loss factors.

to prices paid in the pool and ultimately to the ability of the pool to clear[3].

11.1.1 No Loss Factor applied

If loss factors were not used and the same spot price applied across the entire NEM the pool would operate in deficit. This is because generating unit must produce more energy than is consumed by customers due to network losses, and this difference would result in a shortfall in revenue in each trading interval.

For example, consider the following single region consisting of two nodes with no allowance for loss factors:

[3] That is to receive sufficient payments from energy consumers to pay Generators for the energy produced.

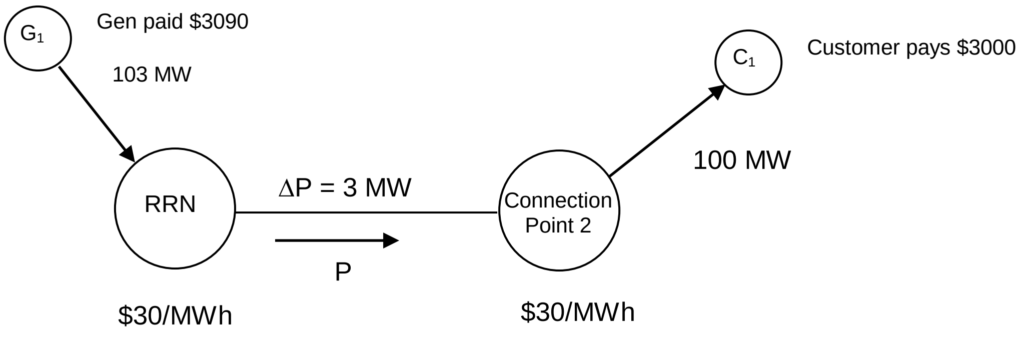


Figure 9: Pool clearance (No loss factor applied)

Trade through the pool is equal to:

Generator G1 is paid 103 MW * $30 = $3090 per hour

Customer C1 pays 100 MW * $30 = $3000 per hour

And the pool has a shortfall of $90 per hour (equal to □P * $30).

The absence of loss factors and, therefore, locational signals will also result in the unfair treatment of a local versus remote generating unit, and the inability to achieve economically efficient dispatch.

11.1.2 Average Loss Factor Applied

Consider the application of an ALF of 1.03 to the single region model (this is equal to the ALF calculated in Section 6). The price at connection point 2 is now equal to:

SP_2 = $30 * 1.03 = $30.90.

And pool clearance for the single region model is as shown in Figure 10.

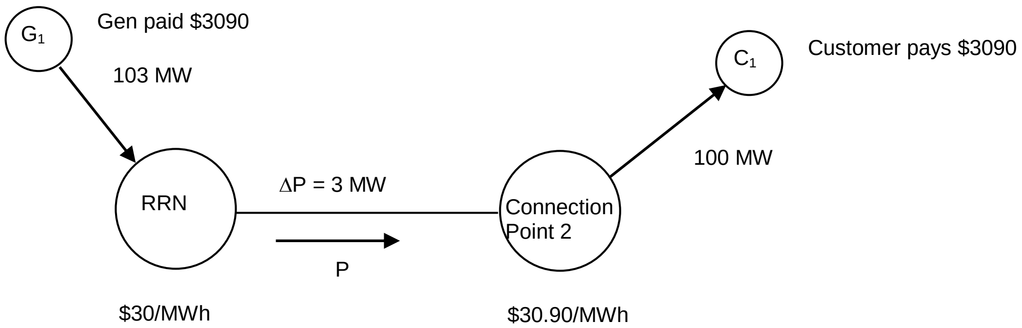


Figure 10: Pool clearance (Average loss factor applied)

Trade through the pool is equal to:

Generator G_1 is paid 103 MW * $30 = $3,090 per hour

Customer C_1 pays 100 MW * $30.90 = $3,090 per hour

And the pool clears.

ALFs are not consistent with the marginal pricing approach adopted for the NEM and are, therefore, not used at transmission network connection points, however, in the distribution network average DLFs have been adopted as a pragmatic approximation to MLFs.

11.1.3 Marginal Loss Factor Applied

Consider the application of an MLF of 1.06 to the single region model (this is equal to the MLF calculated in Section 5.2). The price at connection point 2 is equal to:

SP_2 = 1.06 * $30

= $31.80

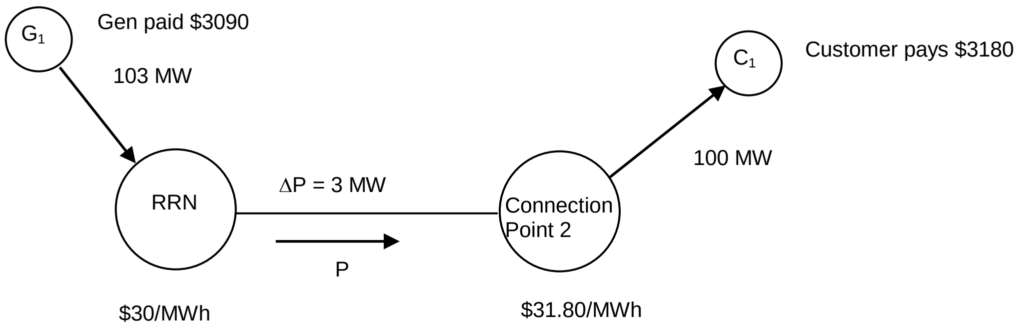


Figure 11: Pool clearance (Marginal loss factor applied)

Trade through the pool is now equal to:

Generator G_1 is paid 103 MW * $30 = $3,090 per hour

Customer C_1 pays 100 MW * $31.80 = $3,180 per hour

And the pool has a surplus of $3180 - $3,090 = $90 per hour.

MLFs provide the most appropriate economic signals for the NEM and are, therefore, calculated for all transmission network connection points. The surplus arising from the Pool is passed back to customers via the TNSPs.

12 Impact of Loss Factors on Merit Order of Generators

Conceptually, the spot market solution process may be described as follows: Generators submit bid prices for blocks of generation (up to 10 blocks for each generator) to AEMO that apply at the generation connection point. These prices are then divided by the MLF (and DLF if required) so that they can be referred to the RRN for comparison with other generating unit. This process involves building up a merit order list (from lowest price to highest price) of all generating unit MW blocks and bid prices (as equivalent generating unit at the RRN).

The equivalent generating unit are then dispatched starting from the lowest price in the merit order until sufficient generation has been dispatched to meet the load plus losses in the NEM. A generating unit with a higher loss factor has an advantage in this process because its bid price when referred to the RRN is reduced relative to other generating unit with lower loss factors.

Consider the example below with three generating unit supplying 3 loads. It is assumed for simplicity that the Generators submit bids for three MW blocks only.

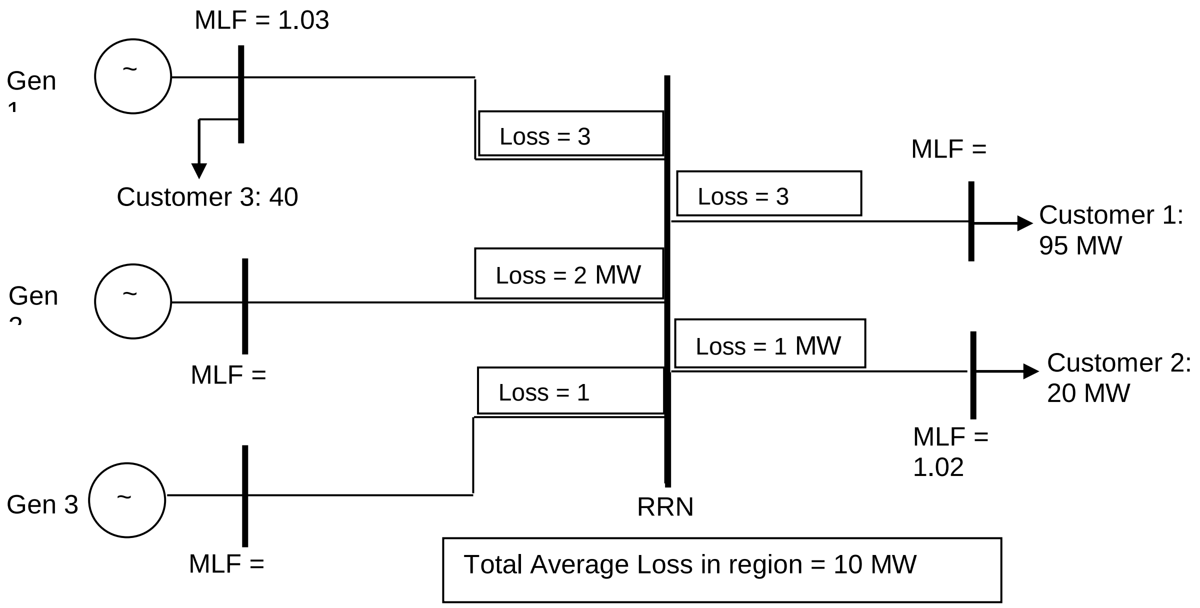


Figure 12: Dispatch of generation to meet load in simple network with 6 connection points

Generator	Capacity	Block 1		Block 2		Block 3	
		MW	Price at Gen	MW	Price at Gen	MW	Price at Gen
1	20 MW	-	-	15	$20	5	$50
2	200 MW	120	$0	50	$25	30	$30
3	30 MW	-	-	30	$25	-	-

Table 1: Generator bids at generator connection points

Generator	Capacity	Block 1		Block 2		Block 3	
		MW	Price at RRN	MW	Price at RRN	MW	Price at RRN
1	20 MW	-	-	15	$19.42	5	$48.54
2	200 MW	120	$0	50	$26.04	30	$31.25
3	30 MW	-	-	30	$25.77	-	-

Table 2: Equivalent Generator bids at RRN

The merit order for the Generator bids is obtained by arranging the bid prices in Table 2 in order from cheapest to most expensive:

Price at RRN	Generator	Block	MW	Cumulative MW
$0	2	1	120	120
$19.42	1	2	15	135
$25.77	3	2	30	165
$26.04	2	2	50	215
$31.25	2	3	30	245
$48.54	1	3	5	250

Table 3: Merit order of equivalent Generator bids

Sufficient generation must be dispatched to meet the load (155 MW) plus region losses (10 MW). From the merit order table this can be achieved by dispatching the first three blocks of generation. The highest priced block dispatched is block 2 of Generating Unit 3. Generating Unit 3 is therefore the marginal generating unit setting a spot price at the RRN of $25.77. Even though the price bid for block 2 of Generating Unit 2 is the same as for block 2 of Generating Unit 3, it hasn't been dispatched due to the impact of its lower loss factor.

The payments made by Market Customers and to Generators for the above example are tabulated below:

Market Customer	Spot Price$_{RRN}$ * MLF	LOAD	Payment by Market Customer
1	$27.06	95 MW	$2,571
2	$26.29	20 MW	$526
3	$26.54	40 MW	$1,062
Total			$4,159

Table 4: Payments from Customers to Pool

Generator	Spot Price$_{RRN}$ * MLF	Output Dispatched	Payment to Generator
1	$26.54	15 MW	$398
2	$24.74	120 MW	$2,969
3	$25	30 MW	$750
Total			$4,117

Table 5: Payments from Pool to generators

For this example the loads pay slightly more to the pool for their energy demand than the Generators are paid for energy produced ($4,159 - $4,117 = $42). In the NEM this settlement surplus would be returned to Market Customers via the relevant TNSPs through reduced network charges.

13 Relationship between Generator Bids, Dispatch and Settlements

A Generator may set its bids to maximise revenue while taking into account the need to at least recover short run (operating) costs. If the spot price in the market is below the Generator's short run cost, it is more efficient for the Generator to purchase power from the market than to produce it itself, however, once the spot price exceeds this threshold, the Generator will bid to maximum both its output and the spot price.

The process through which Generators earn revenue may be described conceptually as follows:

- The generator submits bid prices to AEMO referenced to its connection point,
- These bid prices are divided by the generating unit loss factor to refer the price to the RRN.
- The bid prices of the equivalent generating unit at the RRN are entered into a bid stack of bid prices submitted by all generating unit (all referred to the RRN).
- The bid stack is arranged into a merit order of bids offered, ranging from cheapest to most expensive.
- The equivalent generating unit are dispatched according to this merit order until sufficient generation is available to meet demand.
- The most expensive generating unit dispatched sets the marginal price.

- Each Generator is paid for its generation through the AEMO settlements system. The price paid is equal to the marginal (spot) price multiplied by the relevant loss factor.

In order to optimise its revenue each Generator will review its bidding strategy taking into account how often it is dispatched and the revenue it earns through the settlements system. The relationship between these considerations and loss factors is illustrated below:

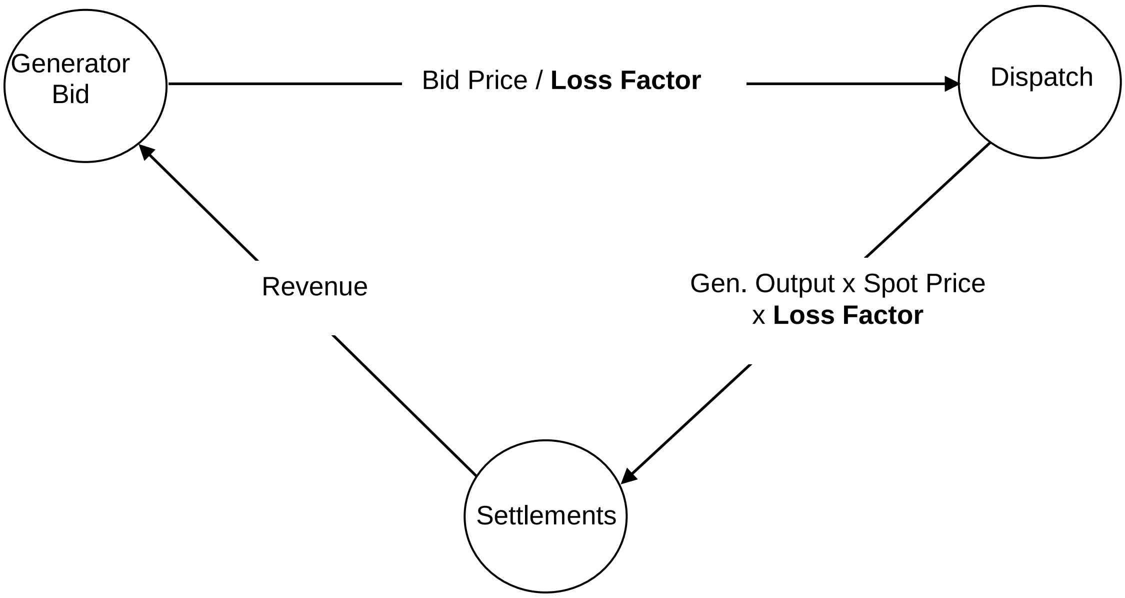


Figure 13: Relationship between bidding, dispatch and settlements

Through the process illustrated above the loss factor fulfills the role of providing both a locational price signal and a mechanism for loss optimisation in the NEM.

14 Application of Dual Marginal Loss Factors to Dispatch and Spot Market Transactions

Clause 3.6.2 of the NER permits AEMO to determine two marginal loss factors (MLFs) for a transmission network connection point in accordance with AEMO's forward looking loss factor methodology. Where AEMO has determined two MLFs, they are applied as follows.

In central dispatch:

- Where AEMO has calculated and published dual MLFs for a transmission network connection point, the MLFs applicable for generation and load will be applied to bid prices for the generation dispatchable unit and load dispatchable unit as appropriate. Registered Participants will continue to be responsible for managing their bids and offers so that the generation and load are not concurrently dispatched.
- Where there is a market network service (such as Basslink) to be dispatched, the MLFs applicable to each direction of flow will be applied to the market network service model as appropriate. AEMO is responsible for managing the potential for dispatching circulating flows on the market network service. From 1 July 2012, AEMO has implemented mixed integer program modelling in NEMDE to ensure the dual MLFs are correctly modelled, optimised and priced in the market.

In spot market transactions:

Where AEMO has calculated and published dual MLFs for a transmission network connection point, the relevant intra-regional loss factor to be applied in the calculation of spot market transactions in NER clause 3.15.6(a) is determined as follows:

- For a transmission network connection point where generation and load occurs:
  1. If the adjusted gross energy for the trading interval is positive (i.e. energy generated into the grid), then the MLF applicable to the generator is used.
  2. If the adjusted gross energy for the trading interval is negative (i.e. energy consumed from the grid), then the MLF applicable to the load is used.
- For a transmission network connection point related to a market network service:
  1. If the adjusted gross energy for the trading interval is positive (i.e. energy imported to the connection point), then the MLF applicable to imports is used.
  2. If the adjusted gross energy for the trading interval is negative (i.e. energy exported from the connection point), then the MLF applicable to exports is used