March 2008

Transmission Rentals
(Losses and Constraints Excess Payments)

An information booklet from
Transpower New Zealand Limited
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1 INTRODUCTION

This booklet describes the methodology used by Transpower to allocate transmission rentals to grid users from 1 April 2008. Part D of the Benchmark Agreement that forms Schedule F2 of Section II of Part F of the Electricity Governance Rules 2003 refers to transmission rentals as "losses and constraint excess payments". These terms have identical meanings for the purposes of this allocation methodology.

Transmission rentals are the surplus[1] created in the wholesale electricity market as a result of nodal pricing of energy, which prices transmission losses and constraints at each pricing node. The booklet starts by explaining how transmission rentals arise. It then outlines the difference between transmission rentals and the 'Rentals Received' that Transpower receives each month and then allocates to grid users. The method used to allocate the 'Rentals Received' to grid users is then described, together with a worked allocation example.

[1] There may be negative transmission rentals due to fixed losses on transformers. See Appendix 1 for more detail.

2 WHAT ARE TRANSMISSION RENTALS?

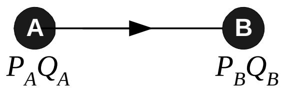
Efficient short run pricing of energy sets prices such that the amount a consumer will pay for an additional unit of demand (or that a generator will be paid for an additional unit supplied) will equal the full cost of providing that unit. This requires that:

- energy prices at a particular grid location, or node, are set by the marginal cost of generation required to meet the demand at that node; and
- the price difference between nodes reflects the marginal costs of losses and of transmission constraints.

Energy prices set on this basis are often referred to as nodal prices or spot prices. They signal the short-run marginal costs of system operation. The remainder of this section explains how nodal prices result in transmission rentals being generated. Transmission rentals are composed of two interrelated types of costs: the cost of marginal losses (i.e. loss rentals) and the marginal costs of any power system constraints (i.e. constraint rentals).

2.1 Loss Rentals

Loss rentals are generated on a line-by-line basis when nodal prices are calculated using marginal transmission losses. To illustrate how loss rentals arise, consider the example shown below where power is flowing from node A to node B along a transmission line (or equivalently through a transformer):



The price at node A is P_A and is P_B at node B. The quantity of power going into the line at node A is Q_A. Q_B is the power taken off at node B.

The prices, in the absence of constraints, are set by the marginal loss rate ML so that:

$$P_B = P_A(1 + \mathrm{ML})$$

The quantities are related by the average loss rate AL:

$$Q_A = Q_B(1 + \mathrm{AL})$$

The loss rental is the difference between purchasing power at node B and purchasing power at node A:

$$\begin{aligned}\text{Rental} &= P_B Q_B - P_A Q_A \\ &= P_A Q_A\left(\frac{1+\mathrm{ML}}{1+\mathrm{AL}} - 1\right)\end{aligned}$$

For transmission lines, the dependence of losses on the square of the current flow means that ML is greater than AL (ML is approximately twice AL). The result is a positive surplus (or rental) between nodes A and B. However, transformers that have fixed losses can generate negative rentals, for reasons explained in the Appendix.

For a buyer at node B, paying the loss rental component has the same effect as if they had purchased the quantity Q_A at node A (at the lower price P_A), and incurred the actual losses on the line AB. Similarly, for a producer at node A, receiving the loss rental has the same effect as if they had sold the quantity Q_B at node B (at the higher price P_B) and injected sufficient energy to make up for actual losses on the line AB.

2.2 Constraint Rentals

Rentals are influenced by the marginal costs of any constraints in the power system. Consider again the example of a transmission line between nodes A and B. Assume now that there is a generator situated at each node and that there is a load of 100 MW at node B. Furthermore, assume that line AB has zero losses (i.e. ML = AL = 0).

Consider first the scenario where the line is not constrained. If Generator A offers its power into the market at 2c/kWh and Generator B offers its power into the market at 3c/kWh, a load at node B will buy all its power from Generator A. This is because the price of buying and transporting power from node A to node B is less than the offer price of Generator B, clearly so in this example because losses are ignored.

Assume now that line AB has a transmission constraint of 50MW forcing the load to buy some of its power from Generator B[2]. A surplus now arises because all power purchased at node B is purchased at the new marginal price of node B, which is 3c/kWh because the next unit of power must come from Generator B. However, there is 50MW of power flowing from A to B. This has been generated at the lower node A price of 2c/kWh, but is paid for at the higher node B price of 3c/kWh. Therefore, the total amount paid by the load exceeds the total amount paid to the two generators.

The difference (surplus) in the amounts paid is the constraint rental component on the line connecting A and B. Thus, the surplus is the quantity transferred times the price difference. Assuming that the constraint exists for only 1 hour, the constraint rental component across line AB is:

$$\text{Constraint rental component} = 50\text{MW} \times (3 - 2)\ \text{c/kWh} \times 1\text{hour} = \$500$$

It follows that a line that is not constrained will have a constraint rental of zero. In practice, whenever a constraint occurs in the system it will affect losses, and in many cases losses can cause constraints. Thus the distinction between loss and constraint rentals is blurred when constraints occur.

2 Note that this example is specific to transmission thermal constraints. Different types of constraints (e.g. reserve constraints, etc.) can affect rentals in different ways.

3 ‘RENTALS RECEIVED’

The sum that Transpower receives from M-co, the Clearing Manager, each month and then allocates to grid users is called the ‘Rentals Received’. It includes the settlement of NZEM and Load Following Generator (LFG) losses, wash-ups and a (very small) settlement of local service receipts. Over time, the cumulative sum of ‘Rentals Received’[3] equals the actual rentals generated in the market. In any one month, however, the ‘Rentals Received’ may not equal the transmission rentals calculated as finally cleared by the market due to the effects of amounts such as wash-ups.

The remainder of this section presents the methodology used by Transpower to allocate to grid users the ‘Rentals Received’ from M-co.

3.1 Method for Allocating ‘Rentals Received’

The allocation of ‘Rentals Received’ to customers is determined by the class of assets that generates the rentals – connection assets, interconnection assets or HVDC assets. Injection customers (i.e. generators) receive the portion of ‘Rentals Received’ allocated to their connection assets. South Island generators also receive a portion of the rentals produced by the HVDC link in proportion to their contribution to total South Island Historical Anytime Maximum Injection (HAMI). Similarly, offtake customers receive the portion of the ‘Rentals Received’ produced by their connection assets and the portion of rentals produced by interconnection assets corresponding to their contribution to the payment of interconnection charges as determined by the transmission pricing methodology (TPM).

The ‘Rentals Received’ is a dollar amount derived from physical dispatch over the transmission grid. The problem is to allocate this amount amongst Transpower’s customers, whose charges are based on the value and configuration of the physical grid. This is done, firstly, by calculating the proportion of the ‘Rentals Received’ attributable to the connection and HVDC assets. These proportions are allocated to the customers paying those charges. The remainder is the proportion attributable to the interconnection assets, and, as such, is allocated to the offtake customers paying interconnection charges. Figure 1 illustrates the process. Actual monthly allocations are based on information from the corresponding April year, adjustments made pursuant to section 7 of the TPM and new investment, notional embedding/prudent discount, input connection contracts and other related contracts.

It has been noted that customers can receive negative connection allocations of ‘Rentals Received’. In general though, the total ‘Rentals Received’ allocation for most customers has remained positive due to the magnitudes of their interconnection charges and/or their HVDC allocations. Negative allocations are the result of any negative transmission rentals used to calculate the scaled rental guides referred to in Figure 1. See the appendix for details of negative transmission rentals.

[3] That is, minus the ‘Settlement of local service receipts’ amount.

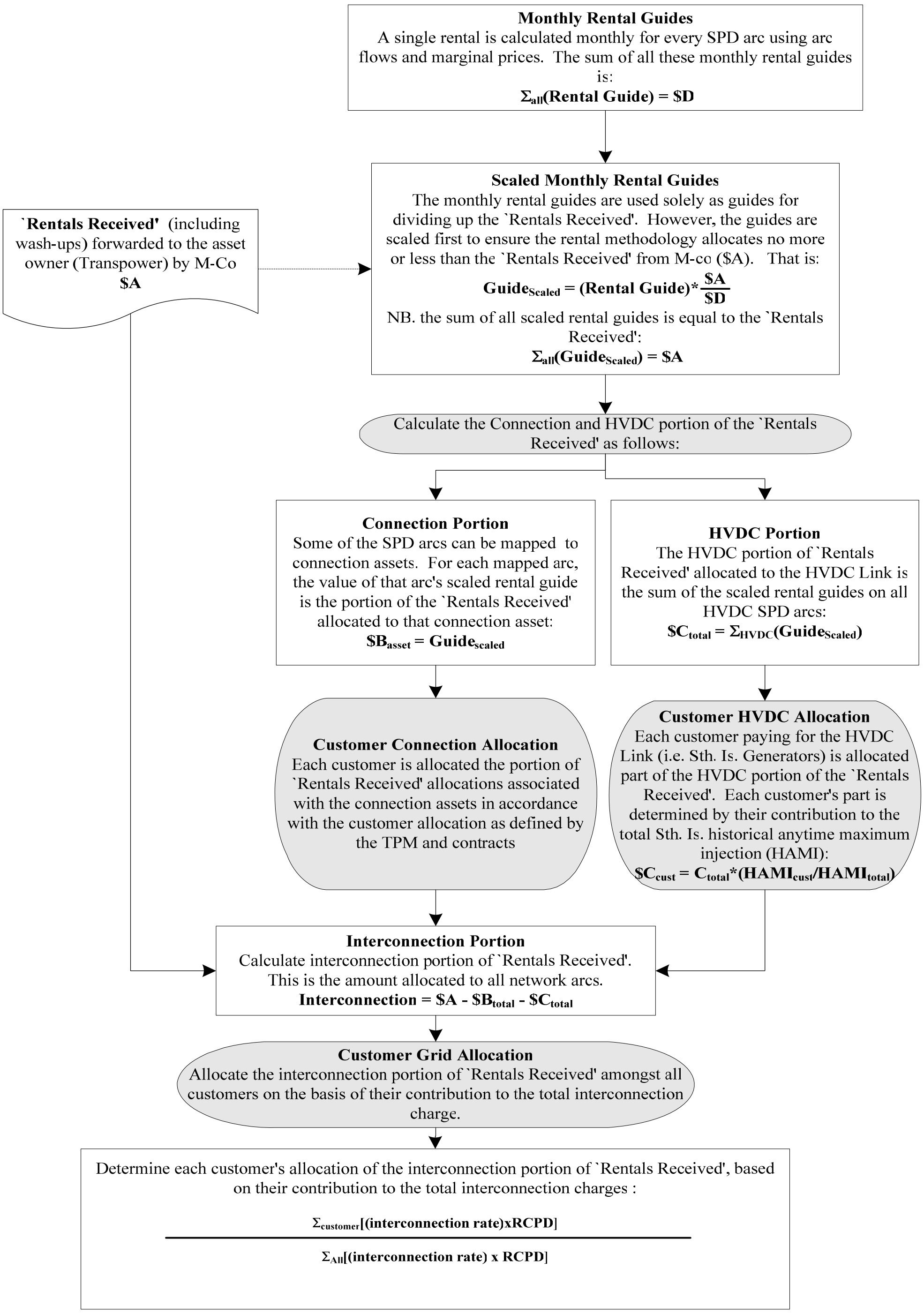


Figure 1 – Transmission rental allocation methodology flow diagram

3.2 A Worked Example

Tables 2 and 3 present a worked example of the transmission rental allocation methodology that is illustrated in Figure 1. Each box in the worked example corresponds to a box in Figure 1. The numbers in the example are purely illustrative. They illustrate the process of allocating a portion of the 'Rentals Received' to two imaginary customers who pay charges based on the TPM effective from 1 April 2008

Customer 1 is an off-take customer, paying charges for two connection assets. Customer 2 is a South Island generator, paying for two connection assets and for a portion of the HVDC assets. Figure 2 illustrates the configuration of the connection assets for these two customers. The customer connection charge allocations for these assets (as defined by the TPM) are stated in Table 1.

The transmission rental allocation methodology also requires two totals: the total of the interconnection charges paid by customers, and the total Historical Anytime Maximum Injections (HAMIs) of South Island generators. These totals are also stated in Table 1.

In Table 2, portions of the 'Rentals Received' are allocated to grid assets using scaled rental guides. Then, each customer's allocation of the connection rental portion is calculated. In Table 3, the HVDC and interconnection portions of the 'Rentals Received' are calculated. The customers' allocations of these HVDC and interconnection portions are then calculated. Finally, these three allocations are summed to produce total 'Rentals Received' allocations for the two customers.

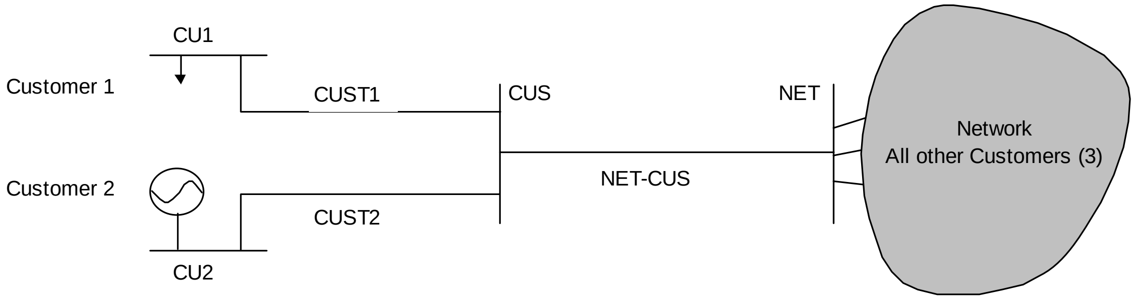


Figure 2 – Illustrative connection assets

Customer Details		Customer 1	Customer 2
Customer Allocations of Assets:	CUST1	100.00%	0.00%
	CUST2	0.00%	100.00%
	NET-CUS	25.00%	75.00%
Historical Anytime Maximum Injections (HAMIs) (kW)		0	200,997
Interconnection Charge		$ 12,500.00	$ 0.00
Details of all Customers			
Total of all customer interconnection charges			$ 300,000,000.00
Total of all South Island generator HAMIs (kW)			3,000,000

Table 1 – Illustrative pricing methodology data

Illustrative Settlement of Losses Plus Wash-ups:	$ 1,500,000.00
Illustrative Settlement of Local Service Receipts:	$ 200.00
Rentals Received ($A)	$ 1,500,200.00

$A to Table 3

Scaled Monthly Rental Guides (Illustrative)			
Illustrative SPD Arc	**Illustrative Arc Rental (Guide)**	**x Scaler (ie $A/$D)**	**= $Guide_{scaled}$**
CUS_T1.T1	($ 199.97)	0.7501	($ 150.00)
CUS_T2.T2	($ 466.60)	0.7501	($ 350.00)
NET_CUS.1	$ 1,066.52	0.7501	$ 800.00
ALL_HVDC_ARCS	$ 399,813.36	0.7501	$ 299,900.00
Other SPD Arcs	$ 1,599,786.70	0.7501	$ 1,200,000.00
Sum of Rental Guides ($D):	$ 2,000,000.00	**Sum of Scaled Guides:**	$ 1,500,200.00

$Guide_{Scaled}$

Connection Portion		
Mappable Arcs	**Mapping to Illustrative Real Connection Assets**	**Connection Asset Allocation $\$B_{asset}$ (=$Guide_{scaled}$)**
CUS_T1.T1	CUST1	($ 150.00)
CUS_T2.T2	CUST2	($ 350.00)
NET_CUS.1	NET-CUS	$ 800.00
	Connection Total $\$B_{Total}$	$ 300.00

$\$B_{asset}$

Customer Connection Allocation:		**Customer 1**	**Customer 2**	
Asset: CUS_T1.T1	$\$B_{asset}$	($ 150.00)	($ 150.00)	
	x Customer Allocation:	100.00%	0.00%	
	= $\$B_{Cust:}$	($ 150.00)	$ 0.00	
Asset: CUS_T2.T2	$\$B_{asset}$	($ 350.00)	($ 350.00)	
	x Customer Allocation:	0.00%	100.00%	
	= $\$B_{Cust:}$	$ 0.00	($ 350.00)	
Asset: NET_CUS.1	$\$B_{asset}$	$ 800.00	$ 800.00	
	x Customer Allocation:	25.00%	75.00%	
	= $\$B_{Cust:}$	$ 200.00	$ 600.00	**$\$B_{Total}$**
	Customer Totals:	$ 50.00	$ 250.00	$ 300.00

$\$B_{Total}$ to Table 3

Table 2 – Illustrative calculations of scaled rental guides, connection asset allocations and customer connection allocations

Scaled Monthly Rental Guides
(HVDC Guides - From Table 2)

HVDC Portion	
Aggregate of all HVDC Arcs	**Allocation to HVDC Link $\$C_{total}$ (=$Guide_{Scaled}$)**
ALL_HVDC_ARCS	$ 299,900.00

$\$C_{total}$

Customer HVDC Allocation				
Customer	**$\$C_{Total}$**	**x (Customer HAMI**	**/ Illustrative Total HAMI)**	**= $\$C_{Cust}$**
Customer 1	$ 299,900.00	0	3,000,000	$ 0.00
Customer 2	$ 299,900.00	200,997	3,000,000	$ 20,093.00
All Other Customers	$ 299,900.00	2,799,003	3,000,000	$ 279,807.00
			$\$C_{total}$	$ 299,900.00

$\$C_{total}$

$A and **$\B_{total}** (From Table 2)

Interconnection Portion			
$A	**- $\$B_{Total}$**	**- $\$C_{Total}$**	**= $Inter_{Total}$**
$ 1,500,200.00	$ 300.00	$ 299,900.00	$ 1,200,000.00

$Grid_{total}$

Customer Interconnection Allocation				
Customer	**$Inter_{Total}$**	**x ($Charge_{Customer}$**	**/ Illustrative $Charge_{Total}$)**	**= $Inter_{Cust}$**
Customer 1	$ 1,200,000.00	$ 12,500.00	$ 300,000,000.00	$ 50.00
Customer 2	$ 1,200,000.00	$ 0.00	$ 300,000,000.00	$ 0.00

Total of Customer Allocations		
Portion	**Customer 1**	**Customer 2**
$\$B_{cust}$	$ 50.00	$ 250.00
$\$C_{cust}$	$ 0.00	$ 20,093.00
$\$Grid_{cust}$	$ 50.00	$ 0.00
Total Allocation:	$ 100.00	$ 20,343.00

Table 3 – Illustrative calculations of customer HVDC and interconnection allocations

4 APPENDIX – RENTALS IN A DC POWER SYSTEM

This appendix demonstrates how marginal power losses are twice the average power losses in a DC[4] power system and how negative rentals arise.

Negative transmission rentals are, on occasion, generated across some of the arcs in the scheduling, pricing and dispatch model (SPD). Specifically, negative rentals are caused by the way losses are modelled for transformers in SPD. Fixed or standing losses for transformers are included to improve the accuracy of the calculation of losses. This causes the actual loss rate in any transformer to be greater than the marginal loss rate when the flow of power through the transformer is low. The following demonstrates how low power flows can generate negative rentals across transformers.

4.1 Calculating Transmission Rentals

As shown in Section 2.1, rentals are calculated as:

$$\begin{aligned} \text{Rental} &= P_B Q_B - P_A Q_A \\ &= P_A Q_A \left(\frac{1 + \text{ML}}{1 + \text{AL}} - 1 \right) \end{aligned}$$

It can be seen from this equation that the rental will be positive if the marginal loss rate is larger than the average loss rate. However, if the marginal loss rate is less than the average loss rate, the rental will be negative.

4.2 Calculating Marginal and Average Losses

Losses on a transformer or line are given by the following quadratic loss function:

$$L = k + I^2 R$$

where L is the power loss, k is a constant level of fixed losses, I is the current flow through the transformer and R is the resistance.

Marginal losses are determined by differentiating the loss function with respect to the power flow (Q_B):

$$ML_B = \frac{dL}{dQ_B} = \frac{d(k + I^2 R)}{d(IV_B)} = \frac{2IR}{V_B}$$

where Q_B is the power flow at B and V_B is the voltage at B. Note that $Q_B = IV_B$

4 DC in this context refers to the fact that the scheduling, pricing and dispatch model SPD is a DC rather than AC model of the power system. Thus, the DC power system described here is a model of New Zealand's integrated HVAC and HVDC power system.

The average loss rate (losses per MW arriving at B) is:

$$AL_B = \frac{L}{Q_B} = \frac{k}{Q_B} + \frac{I^2 R}{Q_B} = \frac{k}{IV_B} + \frac{I^2 R}{IV_B} = \frac{k}{IV_B} + \frac{IR}{V_B}$$

4.3 No Fixed Losses – Transmission Lines

The following analysis applies to lines only. In the case of lines, fixed losses are not modelled, i.e. $k=0$. Hence:

$$L = k + I^2 R = I^2 R$$

Therefore, the average loss rate becomes:

$$AL_B = \frac{IR}{V_B} = \frac{1}{2} ML_B$$

Thus, marginal losses are twice the average loss when $k=0$. This can be seen in Figure 3.

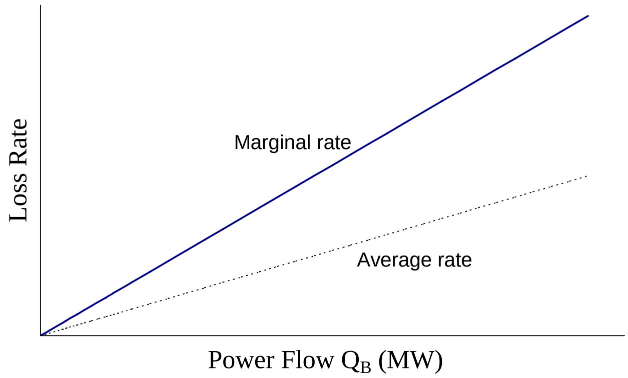


Figure 3 – Marginal and average losses in absence of fixed losses

When $k=0$, marginal losses are always greater than average losses. This means that loss rentals are always positive in the absence of fixed losses[5].

4.4 Including Fixed Losses – Transformers

The following analysis applies only to transformers. A fixed loss component (i.e. $k \neq 0$) is included in the quadratic loss equation:

$$L = k + I^2 R$$

When $k \neq 0$ the average loss rate becomes infinite (i.e. $AL_B \to \infty$) as Q_B drops to zero (i.e. $Q_B \to 0$), but the marginal loss rate does not change. This gives the graph in Figure 4.

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5 In certain circumstances constraints may cause negative rentals due to the 'spring-washer' effect. See *An Introduction to Nodal Pricing*, Transpower, 1995, for further details. Negative rentals have been observed across unconstrained transmission lines. However, unconstrained negative rentals are rare, being caused by very specific loop flow conditions.

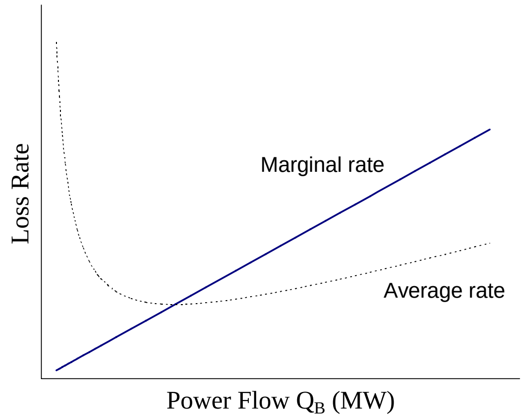

Figure 4 – Marginal and average losses with fixed loss component

The point where the average loss rate drops below the marginal loss rate depends on the parameters used to model the losses in the transformer.

As shown earlier, transmission rentals are calculated using the following equation

$$Rental = P_A Q_A \left(\frac{1 + ML_B}{1 + AL_B} - 1 \right)$$

If the energy price is held constant the rental generated by a transformer varies as indicated in Figure 5.

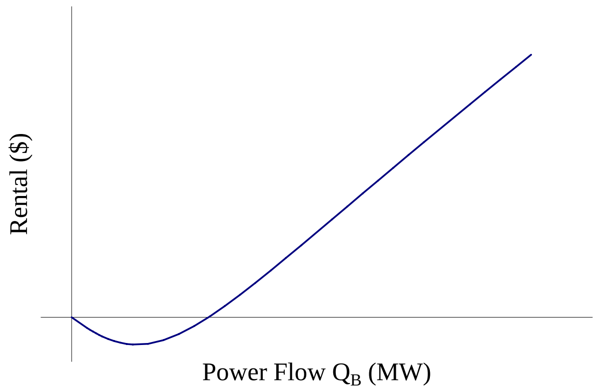

Figure 5 – Variation in rentals with fixed losses where energy price is held constant

Since February 1998 the fixed or standing losses for transformers have been included in the SPD model to improve the accuracy of the calculation of losses. The modelling of losses in SPD approximates the quadratic loss function with a three step piecewise linear function. The marginal and average loss rates for a typical transformer using this approximation to the quadratic loss function are shown in Figure 6.

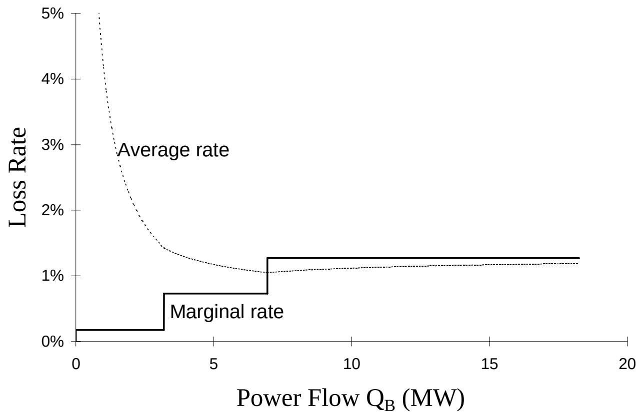

Figure 6 – Marginal and average loss rates for a transformer

For losses approximated in this way, the average loss rate is always greater than the marginal losses for the first step and as $AL_B \to ML$ as $Q_B \to \infty$. That is, the rentals are constant as the flow increases.

If the price at point A is assumed to be $40/MWh, as the energy taken at B varies, the magnitude of the rentals generated varies as shown in Figure 7.

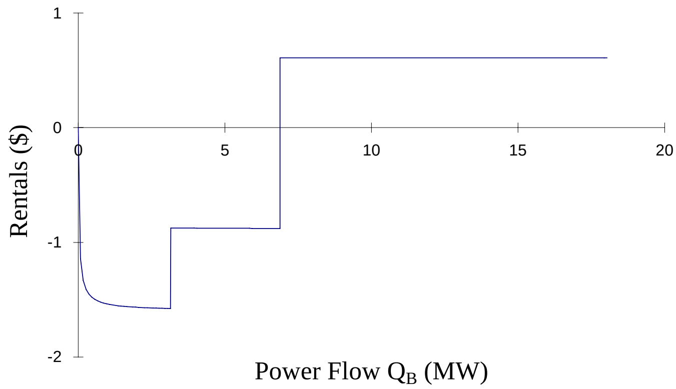

Figure 7 – Rentals on a transformer with fixed losses

This shows it is possible to have negative transmission rentals for low power flows through transformers, whether losses are represented accurately as a quadratic function or by a piece-wise linear approximation.

4.5 Summary

Transmission rentals are generated on a line or transformer when nodal prices are calculated using marginal transmission losses. It has been shown that negative rentals are valid and should be expected on transformers that have a small load. However, negative rentals are uncommon on transmission lines[6], and the lines rentals are typically much larger than any negative rentals caused by transformers.

[6] See footnote 5.