Net Benefit Test for continuing Arapuni grid reconfiguration

Executive Summary
On 29 September 2011, we implemented a bus split at Arapuni to relieve the constraints on generation at Arapuni, increase power transfer capacity into the Upper North Island on the 220 kV network and reduce system losses. At that time, we published a summary of the Net Benefit Test carried out to confirm that this was the most economic system configuration until the new 400 kV-capable line to Auckland is commissioned (https://www.transpower.co.nz/sites/default/files/news-articles/attachments/Arapuni-Grid-Reconfiguration.pdf).

The new 400 kV-capable transmission line is expected to be commissioned in the last quarter of 2012. We have reviewed the Net Benefit Test for the Arapuni bus split post-commissioning of the new line and this document summarises the Net Benefit Test for continuing that split.

We have reviewed the net benefit split test for the period following the commissioning of the new line. There are three general options:

- Close the split immediately following the commissioning of the 400 kV-capable line into Auckland.
- Keep the split for a defined time (i.e. until other developments on the grid are completed).
- Reconfigure the bus at Arapuni to allow the split to remain indefinitely.

Previously, the net benefit analysis indicated there were clear benefits even using conservative assumptions in implementing the split. With the commissioning of the new 400 kV-capable line into Auckland, the Wairakei–Whakamaru C double circuit line and the upgraded Tarukenga interconnecting transformers, the benefits of the split are diminished to the point where it is less certain there is a positive net benefit in retaining the split in the longer term.

Reconfiguring the bus at Arapuni to allow the split to remain indefinitely will require around $560k of expenditure on the Arapuni bus. This expenditure can be deferred until after the Wairakei–Whakamaru C line and the new Tarukenga interconnecting transformers are commissioned.

We consider, based on the Net Benefit Test, the bus split at Arapuni should be continued until the new Wairakei–Whakamaru C line and the new Tarukenga interconnecting transformers are commissioned (currently expected in late 2013). At that time, the net benefit of the Arapuni bus split should be reviewed.

Background
In 2011 we reconfigured the 110 kV bus at Arapuni. This enabled us to easily implement a system split at Arapuni and close that split when required. The split has three Arapuni generating units connected to the circuits to Kinleith and five generating units connected to the circuits going to Ongarue, Hangatiki, Hamilton and Bombay.
The system split was implemented by bypassing the bus side disconnectors on three 110 kV circuits. We consider this configuration is acceptable to remain in place for 2013 (after which time the split will be removed). The split will be normally in place but may be removed during some planned outages or during certain grid emergencies.

The bus split relieves constraints on Arapuni generation. The installed capacity at Arapuni is 180 MW. The power station could be constrained back to 110 MW at times of very low generation in the Upper North Island. It should be noted that the bus split will not completely relieve constraints at Arapuni.

The split reduced the number of grid emergencies declared by the System Operator to manage loading on the 110 kV circuits between Tarukenga, Kinleith, Arapuni and Hamilton.

The split does require a minimum amount of generation at Arapuni from the generating units connected to Kinleith. This is to maintain security of supply to Kinleith and Lichfield and to manage voltages.

**Net Benefit Test**
Section 12.117 of the Electricity Industry Participation Code requires Transpower to demonstrate a net benefit for any permanent reconfiguration of the grid. The following benefits and costs should be estimated where applicable:

- Changes in fuel costs incurred by a generator
- Direct labour and material costs incurred by Transpower and the designated transmission customers
- Changes in estimated maintenance costs including Transpower’s and any designated transmission customer’s costs
- Any change in the estimation of expected unserved energy
- Changes in fuel costs of existing assets, committed projects and modelled projects
- Changes in the value of involuntary demand curtailment
- Changes in the costs of demand-side management changes in costs resulting from deferral of capital expenditure on modelled projects
- Changes in costs resulting from differences in the amount of capital expenditure on modelled projects
- Changes in costs resulting from differences in operations and maintenance expenditure on existing assets, committed projects, and modelled projects
- Changes in costs for ancillary services
- Changes in losses, including local losses
- Changes in subsidies or other benefits provided under or arising pursuant to all applicable laws, regulations and administrative determinations

**Upcoming committed projects**
Two upcoming projects that have a major effect on the Arapuni bus split are:
• replacing the Wairakei–Whakamaru B line with a new double circuit 220 kV Wairakei–Whakamaru C line
• replacing the Tarukenga interconnecting transformers with 2x150 MVA 15% impedance transformers.

These two projects are due for commissioning in late 2013. Although not their primary purpose, they will reduce the power flows in the 110 kV network between Tarukenga and Hamilton. This will consequently reduce the constraints on Arapuni generation with the Arapuni bus split closed.

Methodology for analysis
Options considered
Three options are compared in this analysis:

• Base Case: Reconfigure Arapuni to disable the bus split. This option requires expenditure of $26k to restore the bus to its previous condition.
• Option 1: Reconfigure Arapuni to permanently operate the bus split open. This option requires capital expenditure ($560k) at Arapuni power station to allow maintenance of the bus section breaker.
• Option 2: Continue with temporary configuration at Arapuni until 2014. This option avoids the capital expenditure ($560k) required to allow maintenance of the bus section breaker.

Option 2 is a variation on the bus with the closing of the split deferred until 2014. There is considerable net benefit in retaining the bus split until 2014. Hence we will focus the analysis on the differences between options 1 and 2.

Losses and generation fuel costs
We used historic load, generation and voltage set-point information for 2010 to estimate the reduction in losses and generation fuel costs through implementing the split. Loads were scaled to reflect the 2013-2017 forecast load.

A slack bus was placed at Bunnythorpe to supply the additional load. Constraints on Arapuni generation were met by additional thermal generation at Huntly.

Arapuni generation was varied to determine the maximum generation that would allow a five minute off-load time on the Arapuni–Hamilton circuits during a Hamilton–Whakamaru or Arapuni–Hamilton contingency.

The Arapuni split was then opened and Arapuni generation was varied to determine the maximum generation that would allow a five minute off-load time on the Arapuni–Hamilton circuit during an Arapuni–Hamilton contingency. The constrained-off generation has conservatively been valued at $20/MWh1.

1 The value of the constrained-off generation will vary between $0/MWh and the marginal cost of thermal generation depending on generation offers at the time in question. An average figure of $20/MWh is used to reflect this variation.
The following table shows the relative fuel benefits of having the bus split ‘permanently’ open (option 1) compared to option 2 (the bus being closed from 2014).

Table 1: Relative fuel benefits between options 1 and 2

<table>
<thead>
<tr>
<th>Year</th>
<th>Benefit of split ($m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>0.529</td>
</tr>
<tr>
<td>2014</td>
<td>0.105</td>
</tr>
<tr>
<td>2015</td>
<td>0.107</td>
</tr>
<tr>
<td>2016</td>
<td>0.081</td>
</tr>
<tr>
<td>2017</td>
<td>0.108</td>
</tr>
</tbody>
</table>

The table shows that the benefit reduces substantially in 2013. This is due to the replacement of the Tarukenga interconnecting transformers and the Wairakei–Whakamaru C line. These projects will reduce power flows through the 110 kV network.

The reduction in benefit between 2015 and 2016 is due to the new grid exit point at Papamoa.

We expect the benefits in reducing generation constraints at Arapuni will range between around $70-100k per year in the longer term.

Losses were calculated for every hour, using the 2010 Arapuni dispatch, with the Arapuni split both open and closed. Losses have also been valued at $20/MWh².

The following table shows the relative loss benefits of having the bus split ‘permanently’ open (option 1) compared to option 2 (the bus being closed from 2014).

Table 2: Relative reduction in losses benefits between options 1 and 2

<table>
<thead>
<tr>
<th>Year</th>
<th>Benefit of split ($m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>0.027</td>
</tr>
<tr>
<td>2014</td>
<td>0.025</td>
</tr>
<tr>
<td>2015</td>
<td>0.023</td>
</tr>
<tr>
<td>2016</td>
<td>0.022</td>
</tr>
<tr>
<td>2017</td>
<td>0.020</td>
</tr>
</tbody>
</table>

We expect the benefits in reduced losses will be around $30k per year in the longer term.

**Unserved energy**

The probabilities of forced outages on the circuits from Tarukenga to Arapuni were calculated from historic fault records.

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² The value of the losses depends on the value of the marginal generation at the time in question. Marginal generation costs can vary between $0/MWh (e.g. from wind or must run generation) and the marginal cost of the most expensive thermal generation. An average figure of $20/MWh is used to reflect this variation.
Auto-reclose functionality has been installed on the line protection relays at Arapuni and Kinleith to block auto-reclose attempts where there is a risk of an out of synchronism switching for Arapuni generation.

The auto-reclose functionality of the protections on the Kinleith–Tarukenga circuits is currently disabled to avoid the risk of an auto reclose attempt when Arapuni generation on the south bus is out of synchronism with the power system.

**Loss of both Arapuni–Kinleith circuits**
The Arapuni–Kinleith circuits do not seem to have any history of double circuit faults in the last twenty years. The Arapuni–Kinleith circuits do have a history of sequential outages where one circuit is forced out of service followed by the remaining circuit being forced out of service a few minutes later during lightning storms. This occurs about once every five years on average. The auto-reclose functionality on the Arapuni–Kinleith circuits will restore the faulted circuit within seconds most of the time.

The consequence of both Arapuni–Kinleith circuits being out of service at the same time the Arapuni split is in place is the loss of Arapuni ‘south’ bus generation which would need to be made up from generation elsewhere. It is likely some load at Kinleith will be lost following the tripping of both Arapuni–Kinleith circuits due to a drop in voltage but this loss would occur regardless of whether the Arapuni bus split is in place.

**Arapuni bus fault with split in place**
A bus fault at Arapuni on the south bus (with the split in place) will result in the loss of all south bus generation. This generation will need to be made up from elsewhere. It is likely some load at Kinleith will be lost following the tripping of both Arapuni–Kinleith circuits due to a drop in voltage but this loss would occur regardless of whether the Arapuni bus split is in place.

The probability of a bus fault occurring in a year is around 0.02\(^3\) (50 year return period).

Assuming maximum Arapuni ‘south’ bus generation at the time of the bus fault, additional generation fuel cost to replace the lost generation is $20/MWh and 4 hours to restore connection, the expected costs per year are 0.02 bus trippings per year x 68 MW x 4 hours x $20/MWh = $109 per year. This has a NPV of $446 for the five years.

A bus fault at Arapuni on the north bus (with the split in place) will result in the loss of all north bus generation, and voltage collapse on the Central North Island 110 kV circuit. This collapse can be contained to a loss of supply at Hangatiki.

Assuming maximum Arapuni ‘north’ bus generation at the time of the bus fault, additional generation fuel cost to replace the lost generation is $20/MWh and 4 hours to restore connection, the expected costs per year are 0.02 bus trippings per year x 112 MW x 4 hours x $20/MWh = $179 per year This corresponds to a NPV of $735 for the five years.

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1 October 2012
The following table shows the unserved energy cost at Hangatiki. The table shows the NPV of the lost load is $100,000 over five years.

Table 3: Unserved energy cost at Hangatiki with Arapuni bus split in place.

<table>
<thead>
<tr>
<th>Year</th>
<th>Peak load (MW)</th>
<th>Total Annual load (GWh)</th>
<th>Expected lost load (MWh)</th>
<th>Value of lost load PV 2012 ($m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>30.6</td>
<td>128.1</td>
<td>1.17</td>
<td>0.022</td>
</tr>
<tr>
<td>2014</td>
<td>31.2</td>
<td>130.6</td>
<td>1.19</td>
<td>0.021</td>
</tr>
<tr>
<td>2015</td>
<td>31.8</td>
<td>133.1</td>
<td>1.22</td>
<td>0.020</td>
</tr>
<tr>
<td>2016</td>
<td>32.5</td>
<td>136.0</td>
<td>1.24</td>
<td>0.019</td>
</tr>
<tr>
<td>2017</td>
<td>33.1</td>
<td>138.5</td>
<td>1.27</td>
<td>0.018</td>
</tr>
</tbody>
</table>

We expect the cost of energy not served at Hangatiki to be around $20k per year in the longer term.

**Kinleith–Lichfield–Tarukenga circuits**

The Kinleith–Lichfield–Tarukenga circuits do not seem to have any history of double-circuit faults in the last twenty years. The circuits average 2.3 trips per year. If we assume that a line patrol takes three hours on average then the risk of the second circuit tripping before the first circuit has been restored is 2.3 faults per year x 3 hours of risk/24 hours per day/365 days per year = 0.0008 per year – which corresponds to a return period of around 1250 years.

The Kinleith–Lichfield–Tarukenga circuits do have a history of sequential outages where one circuit is forced out of service followed by the remaining circuit a few minutes later. This occurs about once every twenty years on average.

The consequence of both Kinleith–Lichfield–Tarukenga circuits being out of service at the same time the Arapuni split is in place is:

- loss of Arapuni ‘south’ bus generation
- loss of all load at Kinleith and Lichfield.

The loss of load and generation may be smaller if the Arapuni and Kinleith generation and Kinleith load can successfully form an island.

The cost of both Kinleith–Lichfield–Tarukenga circuits tripping when the split is in place is:

- the loss of generation at Arapuni on the south bus which would need to be made up from generation elsewhere
- energy not served at Kinleith and Lichfield.

It is assumed that following the tripping of both circuits, supply to Kinleith and the Arapuni south bus can be restored quickly by closing the Arapuni bus split.
Assuming maximum Arapuni ‘south’ bus generation at the time when the Arapuni-Kinleith circuits are tripped, additional generation fuel cost to replace the lost generation is $20/MWh and 0.5 hours to restore connection, the costs per year are 0.05 consecutive trippings per year x 68 MW x 0.5 hours x $20/MWh = $34 per year. This has an NPV of $139 for the five years.

Assuming load reduction of 80 MW at Kinleith following the loss of the Arapuni ‘south’ bus generation, 0.5 hours to restore connection, a VOLL of $20,000/MWh, the energy not served costs are 0.05 consecutive faults per year x 80 MW x 0.5 hours x $20,000/MWh = $40,000 per year. This has an NPV of $164,000 for the five years.

The load reduction at Lichfield is not considered as this load will be lost regardless of whether the 110 kV bus at Arapuni is split if both Kinleith–Lichfield–Tarukenga circuits are tripped.

We expect the cost of energy not served at Kinleith to be around $40k per year in the longer term.

**Table of costs and benefits**

The following tables show the forecast costs and benefits for the two options compared to the base case of returning the Arapuni 110 kV bus to its pre-split configuration immediately. The PV values are calculated using a discount factor of 7%.

**Table 4: Option 1: Reconfigure Arapuni in summer 12/13 to enable long term split**

<table>
<thead>
<tr>
<th>Year</th>
<th>Capital Work</th>
<th>Increased unserved energy</th>
<th>Increased fuel costs</th>
<th>Reduction in fuel costs</th>
<th>Reduction in losses</th>
<th>Total (PV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>-0.532</td>
<td>-0.063</td>
<td>-0.001</td>
<td>0.567</td>
<td>0.029</td>
<td>0.000</td>
</tr>
<tr>
<td>2014</td>
<td>-</td>
<td>-0.064</td>
<td>-0.001</td>
<td>0.12</td>
<td>0.029</td>
<td>0.073</td>
</tr>
<tr>
<td>2015</td>
<td>-</td>
<td>-0.064</td>
<td>-0.001</td>
<td>0.132</td>
<td>0.029</td>
<td>0.078</td>
</tr>
<tr>
<td>2016</td>
<td>-</td>
<td>-0.065</td>
<td>-0.001</td>
<td>0.106</td>
<td>0.029</td>
<td>0.064</td>
</tr>
<tr>
<td>2017</td>
<td>-</td>
<td>-0.065</td>
<td>-0.001</td>
<td>0.152</td>
<td>0.029</td>
<td>0.082</td>
</tr>
<tr>
<td>Total (NPV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.298</strong></td>
</tr>
</tbody>
</table>

**Table 5: Option 2: Reconfigure Arapuni to remove the split in summer 13/14**

<table>
<thead>
<tr>
<th>Year</th>
<th>Capital Work</th>
<th>Increased unserved energy</th>
<th>Lost generation</th>
<th>Reduction in generation constraints</th>
<th>Losses</th>
<th>Total (PV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>0.026</td>
<td>-0.089</td>
<td>-0.001</td>
<td>0.567</td>
<td>0.029</td>
<td>0.497</td>
</tr>
<tr>
<td>2014</td>
<td>-0.026</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-0.023</td>
</tr>
<tr>
<td>2015</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.000</td>
</tr>
<tr>
<td>2016</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.000</td>
</tr>
<tr>
<td>2017</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.000</td>
</tr>
<tr>
<td>Total (NPV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.474</strong></td>
</tr>
</tbody>
</table>
Option 2 has a higher NPV (over the 5 year period) as this option avoids capital expenditure of $560k required to enable maintenance of the bus section breaker.

If the benefits of the Arapuni bus split persisted indefinitely then option 1 would be preferred overall.

The conclusion is that we should proceed with option 2 (retain the bus split until 2014) and then make a decision whether to continue with the split after that time.

**Market implications**

Two to three generating units are required to be generating on the south bus at Arapuni when the bus split is in place. They are required to manage loading of Kinleith–Tarukenga circuit 1, maintain voltages at Kinleith within an acceptable range following the outage of one of the Kinleith–Tarukenga circuits and to ensure that there is sufficient fault current for protection relays at Arapuni to operate correctly. Around 60 MW of generation on the south bus is required at peak times.

Concern has been expressed at the need for this south bus generation. It is perceived that the bus split has required this generation to be “constrained-on” and that competition in the area has been reduced.

The Arapuni bus split increases the capacity of the 220 kV network to transfer power into the Upper North Island. At peak times following the commissioning of the 400 kV-capable transmission line into Auckland, the bus split can reduce reliance on regional generation by up to 240 MW.

While 60 MW of generation is “constrained-on” at Arapuni, the bus split reduces the amount of generation “constrained-on” to prevent thermal constraints in the Upper North Island by 240 MW. However, it should be noted that the absolute generation constraints in the upper North Island are small compared to the total generation in the region. In reality, this generation is likely to be required for load balance at peak time.

In terms of competition, the bus split is fairly neutral to competition in New Zealand.

**Discussion and Conclusions**

The net benefit test shows that the Arapuni bus split should remain open for the period between the commissioning of the 400 kV-capable line into Auckland and the commissioning of the Wairakei–Whakamaru C line and new Tarukenga interconnecting transformers. There are two possible options to achieve that:

- reconfigure the 110 kV bus to allow the Arapuni split to be used indefinitely
- delay reconfiguration of the 110 kV bus until constraints on Arapuni reduce, then return to the pre-split configuration.
The second option gives the benefits of deferring the decision on whether to commit $560k to reconfigure the 110 kV bus at Arapuni for a permanent split and the benefits of reduced generation constraints at Arapuni over that period.

Beyond 2013 (following the commissioning of the Wairakei–Whakamaru C line and Tarukenga interconnecting transformers), it is not so clear that there is benefit in keeping the split open.

We will need to spend $560k to allow for the on-going maintenance of the Arapuni bus section breaker. These costs are balanced against the net benefit of the Arapuni split (around $70-120k per year from 2013).

The benefits are reducing generation constraints at Arapuni (around $100-150k per year) and reduced losses (around $30k per year) less the costs of energy not served at Kinleith and Hangatiki (around $60k per year). These benefits have assumed a fuel cost of $20 per MWh and losses cost of $20 per MWh. Using different assumptions around these costs affects whether there is a net benefit for retaining the Arapuni bus split indefinitely. Similarly, should there be any other change in the assumptions that leads to a reduction in generation constraints at Arapuni, then the bus split at Arapuni may not be able to be justified on reduction of losses alone.