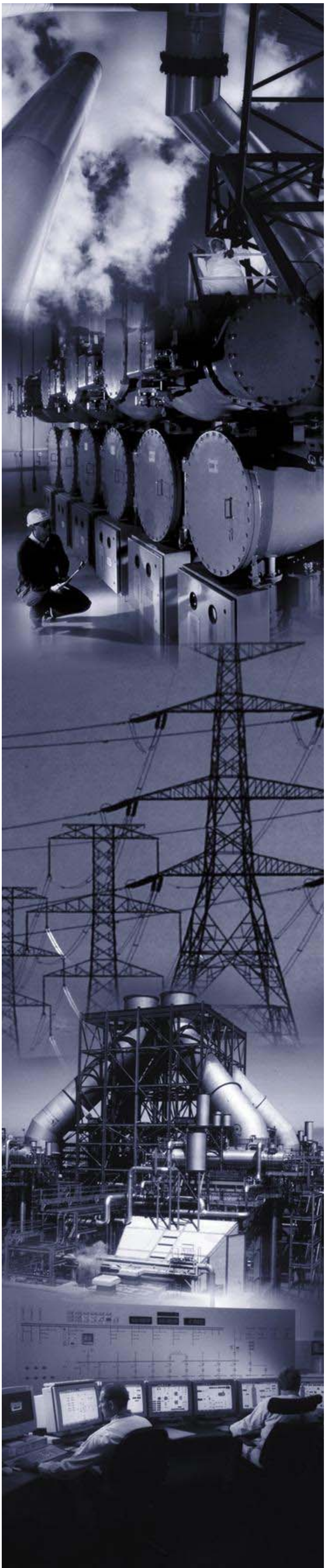

PB POWER

# PEER REVIEW OF CHOICE OF VOLTAGE FOR DEVELOPMENT OF THE NEW ZEALAND GRID

**CONFIDENTIAL**

**Prepared for**

**TRANSPOWER**

**In association with Beca Simons Ltd**

***PB Power*** *Quality System:*

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# TABLE OF CONTENTS

## SECTIONS



## APPENDICES:

# EXECUTIVE SUMMARY

PB Power was employed by Transpower to undertake a high level review of the Transpower long term proposals for developing the New Zealand Grid, and particularly whether the Grid should be developed at 400 kV or 500 kV. Using accepted demand forecasts and various future generation scenarios, Transpower had identified an initial need to enhance transmission infrastructure initially in the corridors between Whakamaru and Otahuhu in the North Island, and between Livingstone and Islington in the South Island using a combination of load related and aging asset drivers. Transpower identified voltage elevation to 400 kV as the best option in both cases.

PB Power undertook a review of technical and economic issues, and Beca Simons a review of Resource Consenting issues. Our conclusions and recommendations are summarised below.

**Technical Review**

Our review found that, based on technical considerations, the upgrade to 400 kV is the most appropriate choice for the Whakamaru-Otahuhu circuit, consistent with the long term requirements for the development of the grid. In the case of the Livingston-Islington circuit, both 220 kV and 400 kV options provide technically feasible means of enhancing the transmission capacity.

In either case, there is no clear advantage in adopting 500 kV over 400 kV.

**Economic Review**

The transmission line and substation unit costs used by Transpower to assess economic viability are consistent with our international experience.

Stringent audible noise limits rather than thermal ratings govern the conductor size used as a basis for the 400 and 500 kV designs. Overhead line costs could be reduced by between 10-15% by aligning audible noise limits with international best practice. A review should be undertaken to establish an acceptable degree of noise for the design of the future overhead lines in New Zealand.

For the North Island, we consider there to be a robust economic case for elevating the voltage to 400 kV, whether considering a 10-15 or 40 year planning period. There is no economic case for choosing 500 kV over 400 kV, even taking into account the reduced losses.

For the South Island, the economic studies carried out to date indicate that there is no case for upgrade to 500 kV and that the Net Present Value difference between 220 kV and 400 kV options is marginal. The benefits of the 400 kV option are realised only in the longer term when there is greater uncertainty, whilst continued development at 220 kV is capitally efficient in the short term and still provides an economically comparable solution to the 400kV in the longer term. It is recommended that supplementary economic analysis, using alternative methods to Net Present Value analysis are undertaken to provide a clearer differentiation between 220 and 400 kV options.

Recognising the uncertainty in the longer term and the present difficulty in obtaining land easements and Resource Consents, Transpower should consider developing 400 kV construction overhead lines to be operated initially at 220 kV, thus deferring substation and transformation costs and securing the route until such time as demand and generation forecasts provide a more robust economic justification for the upgrade.

**Resource Management Act**

Consentability of any grid enhancement option will be increased with a robust evaluation of the ‘need’ and benefits of the project relative to a do-nothing or do-minimum option or one based largely on the existing or an expanded 220 kV grid. Transpower will need to counter arguments promoting embedded generation increases over grid enhancement.

It is not possible to undertake a detailed comparison of 400 kV and 500 kV solutions on environmental grounds at this stage. However at a strategic level, it is likely that 400 kV would have less impact whilst offering the same long-term benefits.

**Conclusion**

The Transpower proposal for the introduction of 400 kV on certain transmission corridors, with continued development on other transmission corridors at 220 kV is considered to be appropriate. There is no advantage in adopting higher transmission voltages than 400 kV.

# 1. INTRODUCTION

## 1.1 BACKGROUND

Transpower has undertaken an investigation into New Zealand's future electricity supply needs. As part of the investigation it has made forecasts of (or sourced from other published data) the growth in electrical demand over the next 40 years. The peak demand of about 6,200 MW in 2003 is expected to double by 2040. This corresponds to a load growth of about 2 per cent / annum.

To supply this demand additional generation has been projected. Recognising the uncertainty associated with the type and location of future generation a number of alternative generation scenarios have been postulated.

Transpower has taken the forecasts of electricity demands and generation scenarios and modelled them against the existing capabilities of New Zealand Grid. From this Transpower has identified parts of New Zealand Grid that require enhancement, technically feasible options for facilitating the enhancement, and when they are required. These options were assessed against a number of criteria and Transpower's conclusion was that introducing 400 kV is the optimal development option for New Zealand.

## 1.2 SCOPE OF REVIEW

This Report presents a high level review of the Transpower proposals for developing the New Zealand Grid, particularly that aspect associated with whether the Grid should be developed at 400 kV or 500 kV.

In undertaking the review PB Power has focused on the techno-economic justifications behind the Transpower proposals for developing the New Zealand Grid. As such, the load forecast and background generation scenarios have been taken as read. The focus of the review has been on the methodology employed, the assumptions made and the overall conclusions, not on the presentation quality of previous reports.

The documents that were reviewed are listed in Appendix A.

## 1.3 STRUCTURE OF REPORT

This Report is structured as follows:

- The Executive Summary provides a summary of our conclusions and recommendations
- Section 1 comprises this brief introduction, including an appreciation of the background to the work.
- Sections 2, 3 and 4 present the findings of our review, categorised into Technical, Economic and Resource Management Act aspects.

# 2. TECHNICAL REVIEW

## 2.1 GENERAL

There is an immediate need to consider options for enhancing transmission infrastructure in the corridors between Whakamaru and Otahuhu in the North Island, and between Livingstone and Islington in the South Island, particularly recognising the lead times associated with transmission projects. However, there are other parts of the New Zealand Grid which will need reinforcement to meet demand from generation sources over the next 10-40 years.

The transmission infrastructure in the Whakamaru-Otahuhu corridor transfers power generated in central and southern part of North Island combined with transfers from South Island to the major load centre of Auckland accounting for about one third of the country's demand.

The Livingstone-Islington corridor transfers power generated largely by hydro-electric plant in central and southern part of South Island to the load centre of Christchurch accounting for about one sixth of the country's demand.

In assessing options for upgrading the supplies to Auckland and Christchurch Transpower has sought to review the voltage of electrical transmission to ensure optimised development of the New Zealand Grid.

Experience shows that, if there is a need to migrate to another system voltage, the next system voltage level should be about twice the existing voltage level. With the current principal transmission voltage in New Zealand being 220 kV, this suggests voltages of either 400 kV or 500 kV, the ultimate choice being a function of a number of factors including:

- The distance over which power transfers are required.
- The load density.

These are discussed in relation to the New Zealand system in the following sections.

## 2.2 THE NEW ZEALAND SYSTEM

The North Island accounts for two thirds of the demand of New Zealand and, as indicated previously about one third is consumed in Auckland alone. The remaining one third of the demand is associated with the South Island with a large proportion consumed in Christchurch.

Over the 40 year planning period transfers on a number of corridors will require reinforcement depending on the assumed generation although a number of reinforcements would be required irrespective of the generation background. Transpower have considered options for meeting these transfer needs, from which individual circuit transfers may be derived. The forecast corridor transfers and expected worst case circuit loads for affected circuits under n-1 contingency conditions are shown in Figure 1 and Figure 2 for the North Island and South Island respectively. Figure 1 and Figure 2 also show typical transfer capabilities of circuits at 220 kV, 400 kV and 500 kV although these may vary slightly depending on the choice of conductor and overhead line configuration.

**Figure 1 North Island - transfer capability at various voltage levels compared to expected corridor and circuit transfers.**

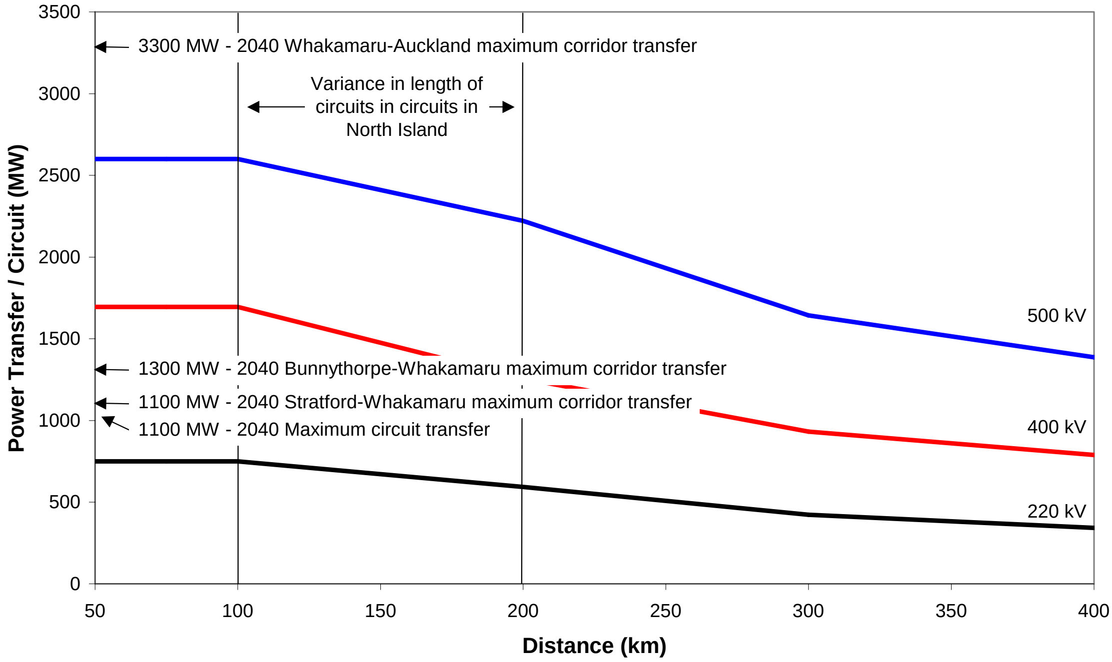
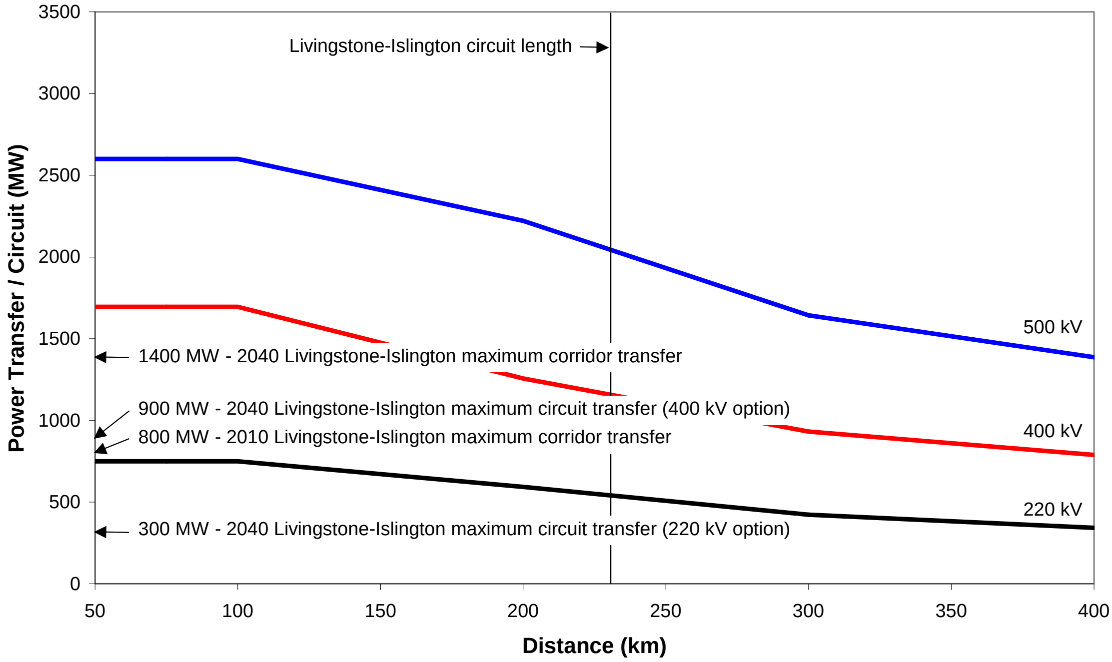



**Figure 2 South Island - transfer capability at various voltage levels compared to expected corridor and circuit transfers.**




In the North Island, the Whakamaru-Otahuhu, Bunnythorpe-Whakamaru and Stratford-Whakamaru corridor transfers are forecast to increase to about 3,300 MW, 1,300 MW and 1,100 MW respectively over the planning period. The number of additional circuits required to secure these transfers under contingency conditions is shown in Table 1.

**Table 1 Requirements for additional circuits to secure corridor transfers by 2040**

| Corridor | 220 kV | 400 kV | 500 kV |
|---|---|---|---|
| Whakamaru-Otahuhu | 8/2 | 4 | 3 |
| Bunnythorpe-Whakamaru | 4[1] | 2 | 2 |
| Stratford-Whakamaru | 4[2] | 2 | 2 |

1. Comprises 2 x Bunnythorpe-Whakamaru circuits and 2 x Bunnythorpe-Rangipo circuits
2. Comprises 1 new double circuit and 1 rebuilt double circuit with heavier construction

Therefore whilst there may be an argument for the introduction of 500 kV to accommodate transfers in the Whakamaru-Otahuhu, the capacity would be overly high for transfers required in the Bunnythorpe-Whakamaru and Stratford-Whakamaru corridor.

***400 kV is therefore considered to be an appropriate technical solution for the North Island.***

In the South Island, with the exception of the Livingstone-Islington transmission corridor, the magnitude of power transfers on the Grid is such that there is no clear case for considering the elevation of voltage to either 400 kV or 500 kV.

***Therefore, for the majority of South Island it is considered that development of the Grid should continue at 220 kV.*** Transpower reached the same conclusion.

In the case of the Livingstone-Islington transmission corridor, the argument is whether there is a need at all to elevate the voltage from the existing level of 220 kV. This is particularly the case as whilst the Livingstone-Islington corridor transfer can be as high as 1,400 MW, the maximum circuit loading is about 300 MW and 900 MW under contingency conditions for the 220 kV and 400 kV options respectively.

A review of the proposals indicates the following alternatives:

Continued 220 kV development:

- By 2010 construct a 220 kV double circuit overhead line from Livingstone-Islington.
- By 2030 construct a 220 kV double circuit overhead line from Twizel-Islington
- Refurbish existing 220 kV existing single circuit overhead lines.

400 kV development:

- By 2010 construct a 400 kV double circuit overhead line from Livingstone-Islington.
- Decommission existing 220 kV existing single circuit overhead line from Livingstone-Islington.

As can be seen, the next reinforcement is required by 2010 but in the case of continued 220 kV development refurbishment or rebuild works on the existing infrastructure is also required, with further reinforcement required a further 20 years into the planning horizon.

***In summary both 220 kV and 400 kV options can be shown to provide technically feasible means of enhancing the transmission capacity between Livingstone and Islington.***

## 2.3 OVERHEAD LINE DESIGN

The design of the overhead line has been largely dictated by audible noise and electro-magnetic fields requirements. The audible noise limits used as a basis for the design are demanding in comparison to international best practice whilst those for the electro-magnetic fields increase the height of the tower. The levels of audible noise calculated by Transpower have been verified by PB Power independently. This is commented on further in Section 4 but recognising the impact of meeting audible noise requirements on the overhead line design, a review should be undertaken to establish acceptable degrees of noise for the design of the future overhead lines of New Zealand.

The overhead line has been designed for a 50°C operating temperature. For a modern design 75°C or 85°C is the usual criteria. However, in the case of Transpower's proposals, it is the audible noise criteria rather than the thermal limit requirements that are constraining. Should the audible noise criteria be relaxed such that, say, a 3 x Goat bundle as opposed to the currently proposed 4 x Goat bundle is required for 400 kV construction overhead lines, the 50°C operating temperature would require review. This will also affect the cost of the overhead line.

## 2.4 REACTIVE COMPENSATION

In the case of 400 kV and 500 kV development options it is of note that switched reactive compensation has been incorporated at 220 kV. It is understood that this has largely been incorporated to ensure voltages are maintained within ±10 per cent limits and reactive capabilities of generation plant are not exceeded, particularly under light load conditions.

However, it is unclear if this compensation will provide appropriate overvoltage control at either 400 kV or 500 kV during line energisation, particularly recognising that certain of these circuits are of the order of 250 km in length. This should be confirmed as part of the detailed design. It is however recognised that this would make the case for 500 kV even less attractive when compared to 400 kV.

# 3. ECONOMIC REVIEW

## 3.1 UNIT COSTS

Transpower has determined unit costs of equipment to be used as building blocks in the consideration of alternative options for developing the New Zealand Grid. The unit costs include design, installation and commissioning costs but exclude on-costs associated with Transpower's inputs to the projects.

These unit costs may be broadly categorised into overhead line and substation costs:

### 3.1.1 Overhead Line Costs

Transpower have produced preliminary designs of overhead lines to determine unit costs. The costs have been based on assumed line routings and terrain; the requirements to ensure appropriate insulation and statutory clearances whilst accommodating bare hand live line work; operate at 50°C, ensure adherence to audible noise and electro-magnetic fields; and are based on the provision of an optical ground wire.

These costs are consistent within budgetary tolerances of costs on international projects that PB Power has been involved with. Transpower also indicates that the overhead line costs have been found comparable to CIGRE benchmarks and as expected the costs are biased to reflect the requirements imposed by certain councils on levels of permitted audible noise. However, it is of note that the audible noise limits used as a basis for the design are demanding in comparison to international best practice. Overhead line costs could be reduced by between 10-15% by aligning audible noise limits with international best practice.

It is also of note that technical studies associated with the 500 kV development analysis have assumed that the 400 and 500 kV overhead lines will have the same conductor configuration. From a load flow perspective this is a valid assumption. However to meet environmental requirements a larger conductor size will be needed for the 500 kV option. This would have the effect of approximately halving the transmission losses attributed to the 500 kV circuits compared to the 400 kV option and improving its economic Net Present Value. That does not however alter the overall conclusions drawn from the economic analysis.

### 3.1.2 Substation Costs

These costs are consistent, within budgetary tolerances, with costs on international projects that PB Power has been involved with.

## 3.2 ECONOMIC ANALYSIS METHODOLOGY

Economic analysis has been undertaken using traditional cost-benefit analysis techniques for alternative options for developing the Grid, known in New Zealand as National Benefit Test. The National Benefit Test is largely the same as the Australian Consumer and Competition Commission (ACCC) Market Benefit Test and therefore may be considered to have been tried and tested. In summary, for the alternative options the national benefit is calculated from:

National Benefit = Present Value [local generation cost – grid generation cost]

+ loss savings compared to 220 kV

- Present Value [ project capital cost + operating/maintenance costs]

Economic as opposed to financial analysis has been undertaken for comparing options which in our opinion is the appropriate mechanism for undertaking the assessment.

The overall economics of the proposals for developing the New Zealand Grid have been assessed over a 40 year period consistent with depreciation of these assets over their lives. Whilst assessments over such a period are the norm for state owned utilities, a period of 10-15 years can be more appropriate, particularly where the company is privately owned. The choice depends on the way in which transmission investments are financed, the degree of certainty with respect to demand and generation, and the lead times associated with satisfaction of environmental and consenting issues.

## 3.3 NORTH ISLAND ANALYSIS

The analysis undertaken by Transpower concludes that developing the interconnection between Whakamaru and Otahuhu at 400 kV is the most economic compared to 500 kV (or 220 kV and 330 kV) based on a 40 year planning period. In the case of a 10-15 year planning period in which there is more certainty associated with the investment, combined with the need to address current constraints on the network, supplementary analysis carried out by Transpower at our request confirms that 400 kV is still the optimum choice.

***For the North Island, therefore, it is considered that there is a robust economic case for elevating the voltage to 400 kV, whether considering a 10-15 or 40 year planning period.***

There is no economic case for choosing 500 kV over 400 kV.

## 3.4 SOUTH ISLAND ANALYSIS

Developing the interconnection between Livingstone and Islington at 400 kV is more economic compared to 500 kV based on a 40 year planning period. However the Net Present Value analysis shows 220 kV and 330 kV to be even more economic, albeit within tolerances that do not permit distinction of alternatives.

In the case of a 10-15 year planning period in which there is more certainty associated with the investment, development at 220 kV is sufficient to address current constraints on the network. There may be an argument for introducing 400 kV construction overhead lines that would initially be operated at 220 kV, thus deferring substation and transformation costs, until such time as there is more certainty in the development of demand and generation. This would also provide environmental and operational benefits through the decommissioning of existing 220 kV single circuit overhead lines.

However, the 40 year Net Present Value analysis also makes no clear case for 400 kV over 220 kV. Both 220 kV and 400 kV alternatives are similar in that they trigger capital spend in 2010 but different in that the 220 kV option requires rebuilding and/or refurbishment of existing 220 kV infrastructure and a further reinforcement in 2030. The benefits of 400 kV are only realised in the longer term when there is greater uncertainty (and therefore risk of stranded assets). Continued development at 220 kV is capitally efficient in the short term and still provides an economically comparable solution to the 400 kV given the uncertainty of planning 25 years into the future.

***In summary, for the South Island, the economic studies carried out to date indicate that there is no case for upgrade to 500 kV and that the Net Present Value difference between 220 kV and 400 kV options is marginal. It is recommended that supplementary economic analysis, using alternative methods to Net Present Value analysis are undertaken to provide a clearer differentiation between 220 and 400 kV options.***

Recognising the uncertainty in the longer term and the present difficulty in obtaining land easements and Resource Consents, Transpower should consider developing 400 kV construction overhead lines to be operated initially at 220 kV, thus deferring substation and transformation costs and securing the route until such time as demand and generation forecasts provide a more robust economic justification for the upgrade.

## 3.5 SUPPLEMENTARY ANALYSES

For completeness, a sensitivity analysis (in which the economic case is tested at tolerance limits of projected demand, costs, etc) would be useful, particularly between 400 kV and 500 kV development scenarios. Further, the use of Net Present Value analysis as a means for discriminating on economic grounds between South Island 220 kV, 330 kV and 400 kV options has not yet identified a clear choice. It would be helpful if supplementary analysis was undertaken to draw out the differential between these options.

# 4. RESOURCE MANAGEMENT ACT IMPLICATIONS

## 4.1 APPROACH

Within the limited scope of this review it has not been possible, nor is it appropriate to evaluate in detail all work being progressed by Transpower's in house Environmental Team. Further, it is understood from discussions with Transpower that in house work is currently focussed on a 400 kV option. Evaluation of a 500 kV option is limited to extrapolating the likely environmental effects from a 400 kV option based on the significant differences in design and construction between options.

By necessity then, this peer review is limited to a high level evaluation of the key differences between the two options and the relative consenting challenges which might (to a greater or lesser extent) impact upon the feasibility of either option.

## 4.2 CONSENTING A GRID ENHANCEMENT PROJECT

The general approach to consenting any of the grid enhancement options will be similar regardless of voltage selection. This is because the consenting regime under RMA is essentially the same for all projects, and secondly, because the range of effects (though not the scale or extent) to be considered are common to all options. These effects can be summarized as land use and property impacts, visual and landscape impacts, noise and EMF effects, construction, social and cultural effects, and positive social and economic effects due to security of supply.

Our understanding is that the above effects are all subject to assessment by Transpower and there is nothing to suggest that any significant effects have been ignored in work to date.

A key 'test' will be to establish a robust case to demonstrate that it is necessary to move from 'do nothing' and secondly that a 'do minimum' scenario is not sustainable in the medium to long term. This will address challenges to the validity of a grid enhancement option (regardless of voltage selected) and will primarily need to address two key issues:

- Whether additional grid capacity is necessary given the potential for an increase in local generation (i.e. what is the case for strong national grid)

- Why is the existing 220 kV system near capacity and/or the end of its useful life.

The material reviewed suggests there is strong evidence on both these points. It is recommended that this be presented in lay terms for the consenting process including an evaluation on the timing or staging options.

## 4.3 CHOICE OF 400 KV OR 500 KV

The RMA does not require Transpower to select the best practicable option from an environmental perspective, rather Transpower must demonstrate that it has considered alternatives, and that in doing so, it has taken reasonable steps to avoid, remedy and mitigate significant adverse effects for the preferred option. The preferred option will be identified on a variety of criteria, environmental factors being only one of these.

As indicated earlier, it is not possible to make a detailed comparison of the options. A further complication arises, as all options will cross a multitude of district and regional boundaries with a variety of district and regional plans and a diverse environment/ community through which the grid passes. This complication can be arrested by use of the designation powers of the RMA to achieve consistency on a national basis, however some regard must still be had to local conditions in the design and consenting process.

At a high level it is possible, on the basis of the limited peer review undertaken, to identify some broad distinctions between the environmental effects of 400 kV and 500 kV options:

- Land Use/Property Impacts – The material reviewed shows circuit length will be similar for both options (and offer some benefits over an enhanced 220 kV solution). A 500 kV option is likely to require a wider easement and have greater property impacts than 400 kV, however it is not simply a matter of assuming that, say a 10% increase in easement width (on average) will result in a 10% increase in either impacts or land costs. This can only be assessed in detail based on an indicative corridor alignment, as even a small easement increase may on some properties mean that it is better to purchase a property outright than secure a wider easement. In this regard land cost estimates (which are a big ticket item) must be viewed with real caution. In an urban context wider easements could be a significant constraint and cost differential.

  In summary the analysis suggests 400 kV is a better option from a land use and property perspective. However Transpower must ensure that it demonstrates that 400 kV has adequate long-term capacity and avoids the need for further circuits later, which might otherwise be avoided if 500 kV were selected as the design standard.

- Visual and Landscape Effects – 500 kV requires taller towers which in general will have greater impact than 400 kV provided circuit length stays the same. In general 400 kV should be less intrusive, provided that it has long-term capacity to avoid additional circuits later.

- Noise and EMF Effects – It is understood that noise generation and EMF are both greater for a 500 kV network. In general a 400 kV network will be preferred especially in urban areas and will be more compatible with New Zealand's generally low ambient noise environment.

  A night time (most restrictive) noise limit between 37dBA(leq) to 42dBA(leq) at the notional boundary of a dwelling (say 5-25m from the façade) would be typical in most districts however Transpower will need to select a suitable criteria on a national basis. In an urban context easement boundaries may be close to dwellings, whereas in rural areas dwellings would be more distant. It is understood that Transpower has used the easement boundary to assess noise. This may be appropriate in urban areas, but on average, perhaps too onerous in rural areas.

- Construction Impacts – Based on a similar circuit length there is little difference between options, though access for larger 500 kV infrastructure will present some additional challenges.

- Social and cultural impacts – These are related to property impacts. It is also possible that a 500 kV network will exacerbate feelings of intrusion and severance especially in urban areas.

- Economic Benefits – Both options give NZ security of supply which is a significant benefit. Whilst not directly relevant to RMA, there may be criticism about wastage and over design if the capacity from a 500 kV solution is grossly above forecast demand over say the next 25 years.

## 4.4 CONCLUSIONS

Consentability of any grid enhancement option will be increased with a robust evaluation of the 'need' and benefits of the project relative to a do-nothing or do-minimum option or one based largely on the existing or an expanded 220 kV grid. Transpower will need to counter arguments around local generation increases making a national grid less relevant.

It is not possible to undertake a detailed comparison of a 400 kV and 500 kV solution on environmental grounds at this stage. However at a strategic level, it is likely that 400 kV has less impact, whilst offering the same long term benefits, provided the capacity of a 400 kV solution is adequate without the need for additional circuits in the foreseeable future.

# APPENDIX A
# References

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