



ELECTRICITY COMMISSION

Frequency Regulation Market Development

**Discussion Paper
September 2008**

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Glossary of Abbreviations and Terms

AGC	Automatic Generation Control. A system which monitors system frequency and time error and issues on-line MW raise and MW lower signals to enabled generators or groups of generators and potentially controllable loads.
Block dispatch	Flexibility provided under the Rules for the operator of a hydro scheme, with hydraulically coupled power stations, to allocate System Operator dispatch instructions across the scheme's stations. This flexibility is subject to there being no transmission constraints, in which case a block dispatch group is split into subgroups. It enables the hydro scheme operator to efficiently manage flows and storage within the scheme.
Constrained-on, -off	Generation offered at a higher price than the market price which was dispatched by the System Operator is <i>constrained-on</i> . Available generation offered at a lower price than the market price but not dispatched by the System Operator is <i>constrained-off</i> . There can be various reasons for this, including intra-half hour demand variations. Constrained-on generation receives an additional payment to compensate for the difference between its offered price and the wholesale market price for that half hour. Constrained-off calculations are made but no compensation is paid under the market Rules. However, the System Operator currently pays constrained-off payments to frequency keeping providers.
CQAG	The Electricity Commission's <i>Common Quality Advisory Group</i> . (http://www.electricitycommission.govt.nz/advisorygroups/comqual).
CQDP	The Electricity Commission's <i>Common Quality Development Plan</i> [1], developed in conjunction with the Common Quality Advisory Group (CQAG).
Effectiveness factor	A means of representing the 'quality' of contribution to frequency regulation that a particular provider can make. For example, under the straw person design, an offered frequency regulation band implies the maximum MW response of a unit or station over a 5 minute period. SPD would interpret this as a linear response. Plant that in practice does not respond uniformly (for example, has a delay of several seconds) could, through an effectiveness factor, be de-rated relative to other providers.
EMS	Energy Management System – the collection of computer-aided tools used by the System Operator to monitor and control the power system.
Free governor action	The unrestrained automatic response of generator governors to changes in system frequency. Generators are required under the Rules (Part C) to provide support frequency.

Glossary of Abbreviations and Terms

Frequency keeping	In this paper, the ancillary service procured under current arrangements by the System Operator to assist in maintaining normal system frequency. i.e. to compensate for mismatches in supply and demand in the (typically) 5 minute market dispatch process.
Frequency regulation	Term used to describe frequency keeping under the proposed market arrangements.
HVDC	High voltage direct current link between the North Island and South Islands.
MILP	Mixed integer linear programming.
NCC	The National Control Centre from which the System Operator dispatches the system.
NEM	The “National Electricity Market” operating across the interconnected Australian eastern states (NSW, Queensland, South Australia, Tasmania and Victoria).
Participation factor	The relative response requested from each frequency regulation provider when raise/ lower requests are issued by AGC to cleared providers.
PDS	The market <i>pre-dispatch schedule</i> produced by the System Operator.
PLSR	<i>Partly loaded spinning reserve</i> (instantaneous reserves that can be provided by generating units that are operating at partial output).
RTGEN	The software module in the System Operator’s Energy Management System which would perform the AGC function.
SCADA	<i>Supervisory Control and Data Acquisition</i> . A system used to transmit plant control signals and transmit/ receive plant status/ data around the power system.
SDPQ	The market <i>Schedule of Dispatch Prices and Quantities</i> prepared by the System Operator.
SPD	Scheduling, dispatch and pricing (the market clearing engine).
WMAG	The Electricity Commission’s <i>Wholesale Market Advisory Group</i> . http://www.electricitycommission.govt.nz/advisorygroups/wmag

1. Introduction

- 1.1 The cost of frequency keeping services has increased significantly in recent years. While efforts are being made to reduce these costs, there is an underlying concern that the number of providers able to meet current frequency keeping requirements is limited, with only one company in each island being selected in each half hour. Frequency keeping requirements may also increase in future as more intermittent generation is added to the system (including the possibility that availability of generation free governor action on the system could reduce). Increasing the level of participation and competition in the frequency keeping market is therefore a strategic initiative in the common quality development plan (CQDP)¹ [1].
- 1.2 The Electricity Commission (Commission) has been investigating in more detail a conceptual frequency keeping market design outlined in the CQDP. This discussion paper presents the Commission's findings, including a preliminary assessment of cost-benefits and invites stakeholder comment to assist the Commission in considering its next steps.
- 1.3 In this paper, the term frequency regulation market is used to distinguish proposed market arrangements from the current frequency keeping arrangements².

2. Structure of Discussion Paper

- 2.1 This paper is structured as follows:
- Section 3 provides a summary of the proposals in this discussion paper.
 - Section 4 provides a set of questions as a suggested for submissions.
 - Section 5 provides a brief summary of frequency keeping arrangements and the background to the proposals in this paper.
 - Section 6 discusses the Commission's investigations to date, including preliminary cost benefits.
- 2.2 The following appendices are attached to this report:
- Appendix A: Straw Man Frequency Regulation Market
 - Appendix B: NZ Electricity Market Overview
 - Appendix C: Regulation Market Issues
 - Appendix D: Adaptations to NZ Market Formulation

¹ Developed in conjunction with the Common Quality Advisory Group (CQAG).

² The term *frequency regulation* is commonly used in electricity markets.

- Appendix E: Preliminary Cost-Benefit Assessment
- Appendix F: List of References

3. Summary

Ultimate aim

- 3.1 An ultimate frequency regulation market would include:
- (a) An optimal normal frequency standard that minimises overall costs (direct frequency keeping procurement and indirect frequency quality impacts).
 - (b) The System Operator setting frequency regulation requirements in each island to meet the optimum standard.
 - (c) Participants submitting multi-band frequency regulation offers (along the lines of instantaneous reserves offers).
 - (d) The market clearing software (SPD) selecting the least cost combination of frequency regulation, instantaneous reserves and energy offers. i.e. co-optimisation (of energy and instantaneous reserves) would be extended to include frequency regulation.
 - (e) Multiple cleared frequency regulation providers being co-ordinated centrally (via AGC³) and, where cheaper, transferred via the HVDC to contribute to regulation requirements in the other island. More and smaller providers/ sites could participate.
 - (f) 'Enablement' prices being set in each island for frequency regulation, recognising interdependencies with energy and instantaneous reserves.
 - (g) Participants accepted for frequency regulation duty receiving the relevant island price.
 - (h) Frequency regulation costs being recovered from causers of the need for frequency regulation.

Nature of benefits

- 3.2 The Commission has developed a straw man frequency regulation market which would directly address items b to g above. Items a and h are part of separate Commission work streams⁴. The straw man design would have a number of benefits including:

³ Automatic Generation Control (AGC) facilities used to simultaneously coordinate multiple generators. In this instance, to control frequency quality.

⁴ CQDP tasks.

- (a) Multiple, and smaller, providers could compete to simultaneously share frequency regulation requirements in each island.
 - (b) Regulation of the HVDC would take advantage of frequency diversity between the islands, reducing overall frequency regulation requirements.
 - (c) The transfer of frequency regulation from one island via the HVDC to the other would facilitate competition between providers on a national basis.
 - (d) The amount of frequency regulation required could be more easily adjusted according to system needs. For example, varying requirements at different times of the day.
 - (e) More frequency regulation could be procured in future if necessary. For example, due to increased system intermittency associated with short term wind variability and/or displacement of generation with free governor action.
 - (f) The market clearing software (SPD) would select frequency regulation providers taking account of interactions between energy, instantaneous reserves and regulation offers. i.e. just as energy and instantaneous reserves are co-optimised at present.
- 3.3 The net present value of these benefits is estimated to be between \$60 and \$180 M. More detail is contained below in the section on cost-benefit assessment (beginning in paragraph 6.9) and also in Appendix E.

Straw man context

- 3.4 AGC and co-optimisation are key features of the straw man design. In a sense, co-optimisation is not a large leap in the New Zealand market context, with energy and instantaneous reserves being co-optimised since the market's inception. Under the straw man design, the co-optimisation paradigm would be extended by adding frequency regulation as another category of reserves. As for the instantaneous reserves market, and as in overseas frequency regulation markets, participation would be voluntary. Frequency regulation arrangements would accommodate block dispatch, as in the instantaneous reserves and energy markets.
- 3.5 The co-optimisation concept was first developed in the New Zealand electricity market and has since been applied in a number of overseas markets to frequency reserve products including frequency regulation. The straw man frequency regulation market design developed and evaluated in this paper draws on experience in these markets.
- 3.6 Unlike New Zealand though, these jurisdictions generally had legacy AGC systems in place when their frequency regulation markets were developed. The necessary interfaces with market clearing software and co-optimisation of frequency regulation services were also built into their market systems when developed.

Proposed approach

- 3.7 Implementing the full straw man market design in New Zealand would take some time and a number of related issues would need to be addressed. Subject to stakeholder feedback, the Commission therefore proposes to take a staged approach to developing a frequency regulation market in New Zealand, as depicted in Figure 1. At each stage the Commission will need to be satisfied that there will be additional cost-benefits.

Figure 1: Overview of staged approach



- 3.8 The first stage involves developing the capability to coordinate a single provider in each island and the HVDC so as to transfer frequency regulation from one island to the other. Frequency regulation requirements would be set by island, taking advantage of any diversity between islands to reduce overall regulation requirements. Providers would compete to supply the service in their island, as now, and, via the HVDC, a share of the requirement in the other island.
- 3.9 From a technical perspective, this would involve:
- The System Operator developing the capabilities to calculate frequency control error for each island and to communicate real time MW regulation requests to the HVDC and the selected provider in each island.
 - The Grid Owner enabling HVDC MW set point regulation, within agreed limits.
 - Generators selected for the service receiving and implementing MW regulation requirements.
- 3.10 The System Operator would need to modify its selection process but minimal, if any, changes to the Rules would be required.
- 3.11 Subject to the HVDC being available for regulation transfer, stage one benefits in the range of \$38m to \$75m NPV have been estimated.
- 3.12 This arrangement could be extended to more than one provider in each island. This would make the selection process and commercial arrangements more complex. Co-optimising frequency regulation services with energy and instantaneous reserves offers along the lines of the straw man proposal in this paper would also be desirable.
- 3.13 Potential benefits of implementing the full straw man frequency regulation market design are estimated to lie between approximately \$60 and \$180m NPV. Stage 1 would achieve some of these benefits as indicated above.

Next steps

- 3.14 Subject to stakeholder feedback on this discussion paper (see next section for specific questions), the Commission intends to:
- (a) Confirm arrangements with the System Operator to complete a full investigation of the technical requirements and associated costs to implement the first stage, with a view to implementation. This will also involve discussion with the Grid Owner with respect to the role of the HVDC.
 - (b) Develop fully the straw man design in this report and, in conjunction with the System Operator, investigate detailed design and implementation requirements and cost estimates. This would involve discussions with frequency regulation providers (including potential providers) and further consultation before settling on a final proposal.
 - (c) Review the dispatch process, including interpretation of offers/ formulation of dispatch instructions and delays, to ensure an appropriate foundation on which to develop a full frequency regulation market.

4. Suggested form for submissions

- 4.1 The Commission appreciates that this paper contains a lot of material and much of it is quite technical in nature. It is interested in receiving submissions on any aspect of the paper but it is particularly interested in receiving feedback on the following set of questions:

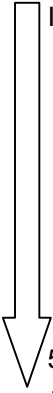
Suggested questions for submitters to consider

1. Do you agree with the goal and design of the ultimate frequency regulation market outlined in Appendix A?
 - a. Which details do you agree with (why?) and which do you not (why not) – eg symmetrical vs asymmetrical?
 - b. Are there any other features you believe should be included (why?)?
2. Do you agree with the transitional arrangements outlined in section 6 of Appendix A?
 - a. Which details do you agree with (why?) and which do you not (why not)?
 - b. Are there any other features you would like to suggest?
3. Do you agree that there are significant net benefits, of the magnitude suggested in Appendix D, that justify both the transitional and ultimate frequency regulation market?
4. Are there any other issues you wish to bring to the Commission's attention?

5. Background

Role of frequency keeping

5.1 Under normal circumstances⁵, supply and demand and system frequency are maintained through a combination of:

Timeframe	How	Mechanism
 5 minutes +	Continuous generator free governor action in response to changes in system frequency.	Mandated generator performance obligations (Part C of the Rules).
	A selected generator “keeping frequency” in its island, restoring generators to their dispatch set points following free governor action.	Ancillary service contracts procured by the System Operator (Part C of the Rules, Procurement Plan).
	Generation dispatched in accordance with energy offers, typically at 5 minute intervals, enabling frequency keepers to remain within their control range.	Dispatch of generators by the System Operator (Part G of the Rules).

Current frequency keeping arrangements

5.2 Under the current arrangements, the System Operator is expected to maintain the frequency in each island within a *normal band* between 49.8 Hz and 50.2 Hz, except for momentary fluctuations⁶, and to maintain system time error⁷. In order to achieve these objectives, the System Operator contracts annually with generation companies that can maintain frequency and time error by regulating their production over a +/- 50MW range and respond at a rate of at least 10 MW/ minute. Currently only Meridian Energy and Contact Energy in the South Island and Genesis Energy and Mighty River Power in the North Island are able to meet these requirements.

5.3 Contracted providers submit half hourly offers to the System Operator. In each island, the provider offering the lowest price in each half hour⁸ is selected to keep frequency. In addition to the price offered, which represents an enablement fee, the selected

⁵ i.e. except for contingency situations for which additional measures are employed.

⁶ i.e. under normal system conditions, in the absence of contingent events.

⁷ i.e. maintain time error to within five seconds and eliminate time error at least once every day.

⁸ Note that since 4 June 2008 the System Operator's selection of frequency keepers has taken account of the constrained on payable to a frequency keeper should it need to be scheduled up to meet its minimum control limit.

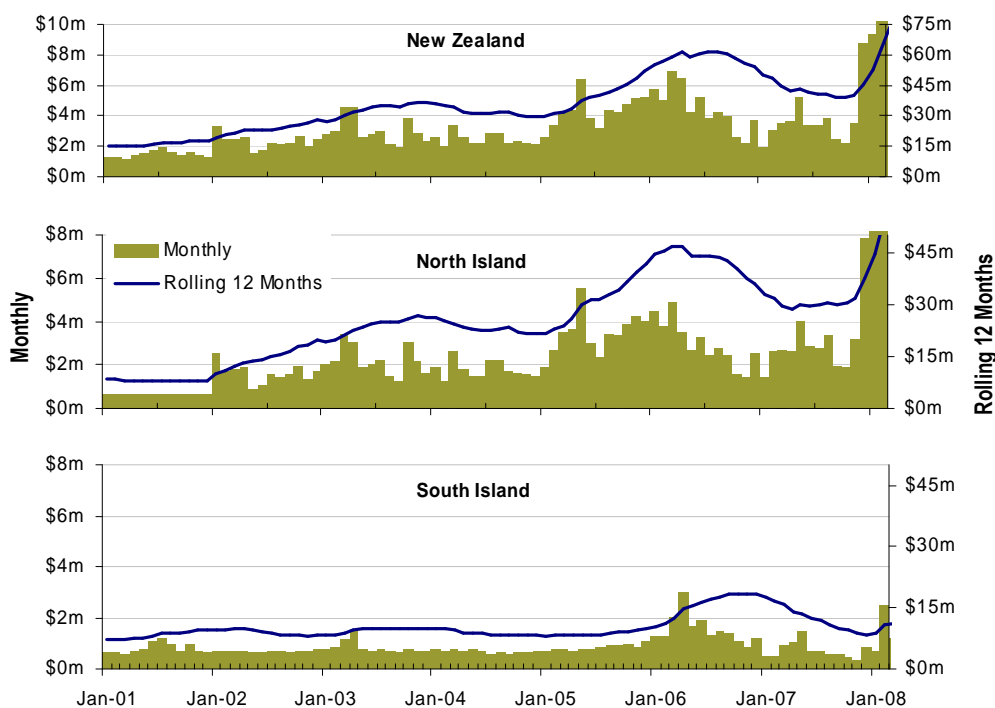
provider receives constrained-on or constrained-off payments relative to its energy dispatch⁹.

- 5.4 National half-hourly frequency keeping procurement costs (including frequency keeping constrained on and off payments) are allocated to wholesale market purchasers in proportion to the amount of electricity purchased. Settlement is monthly.
- 5.5 A more detailed description of current frequency keeping arrangements can be found in Appendix B.

Frequency keeping costs

- 5.6 Frequency keeping procurement costs have risen significantly in recent years, as shown in Figure 2. It shows that North Island procurement costs are higher and have increased proportionately more than in the South Island.

Figure 2: Frequency Keeping Procurement Costs (Jan 2001 to Jun 2008)



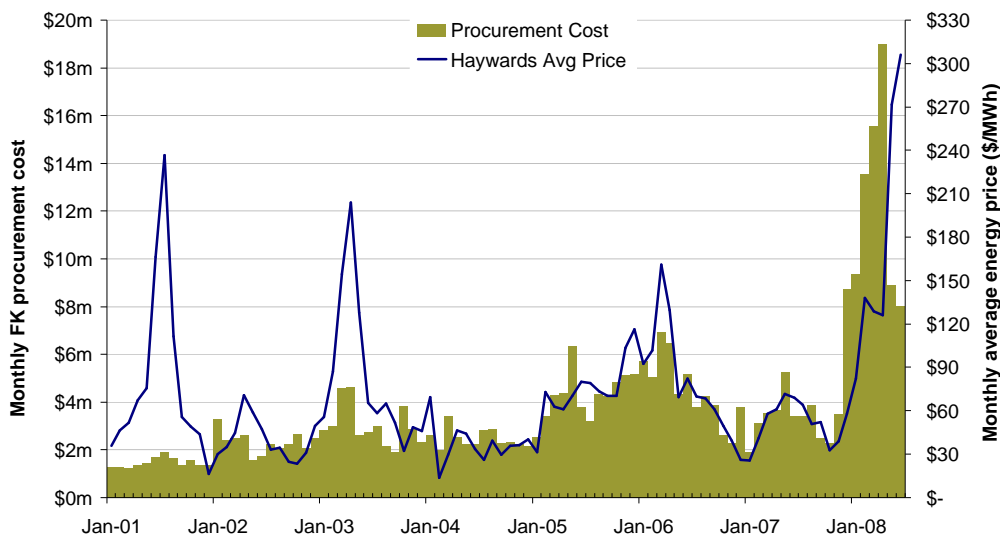
- 5.7 As illustrated in Figure 3, there appears to be some relationship between frequency keeping procurement costs and wholesale electricity market prices, except in 2001 when contract fees were largely fixed a year in advance¹⁰. Given the same generating

⁹ This is intended to keep the provider whole in terms of energy provided above its regulation mid-point (energy dispatch level) or opportunity costs foregone below its regulation mid-point.

¹⁰ Subsequently, some providers would not submit fixed fee tenders.

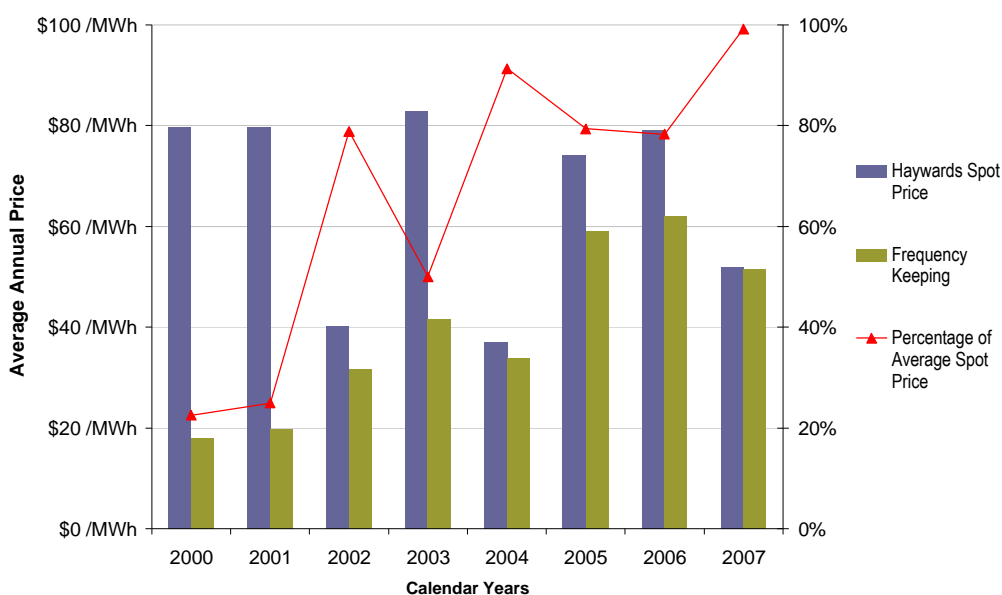
capacity can be used to produce electricity, instantaneous reserves or frequency keeping, this trend is not unexpected.

Figure 1: FK Costs and Wholesale Electricity Prices (Jan 2001 to Jun 2008)



5.8 However, the cost of procuring frequency keeping on a per MWh basis has increased proportionately more than electricity spot prices as shown in Figure 4¹¹. There may be a number of factors behind this trend but the limited number of providers that can meet the current technical performance requirements and the level of competition between providers are of concern.

¹¹ For simplicity, the chart assumes a fixed quantity of frequency keeping is always procured. In practice, the quantity in the South Island is sometimes as low as +/-25 MW and as high as +/-75 MW. The impact of this simplification on the chart, which is intended to be indicative only, is not material.

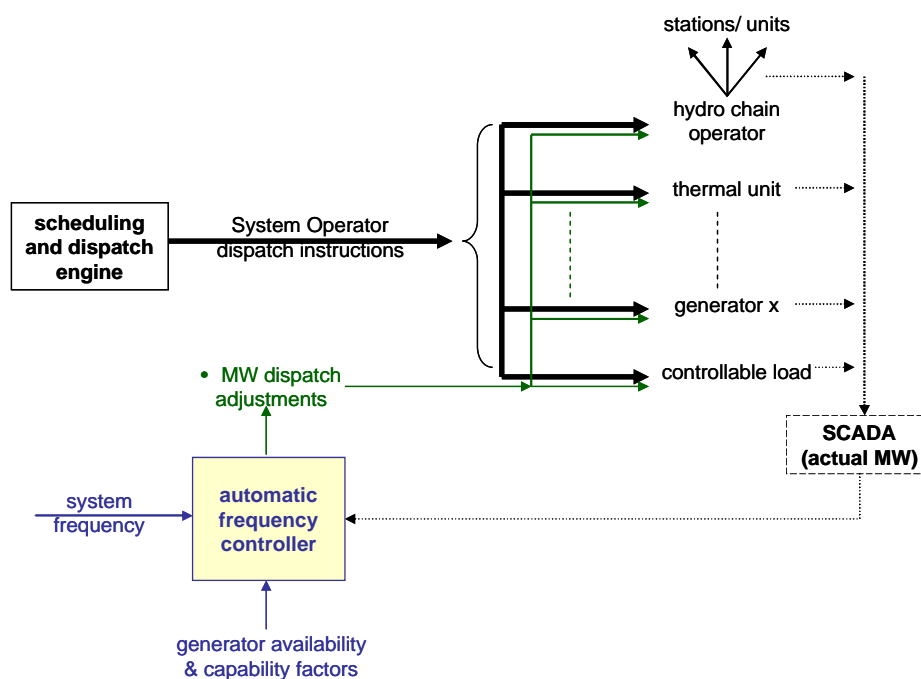
Figure 2: Annual Average FK and Wholesale Energy Prices (2000 to 2007)

- 5.9 The System Operator has recently modified its selection process to take account of potential constrained-on costs in the North Island [2]. It is also considering whether there is scope to adjust frequency keeping requirements. On the other hand, if significant levels of wind generation are connected to the system, this could increase short term system variability and displace some generation with free governor action, increasing frequency keeping requirements.

CQDP proposal

- 5.10 These factors prompted the Commission, in conjunction with the Common Quality Advisory Group (CQAG), to consider ways to reduce frequency keeping procurement costs and to increase procurement options. Distributing frequency keeping duty across multiple providers in each island along the lines depicted in Figure 5, was identified as a higher priority CQDP option [1]. An arrangement that would operate alongside existing dispatch arrangements, including block dispatch of hydro chains, was envisaged. i.e. the System Operator would continue to issue dispatch instructions based on SPD dispatch schedules but instead of selecting a single provider in each island to keep frequency, multiple providers would compete to supply the service simultaneously. A central engine would calculate and issue MW raise and lower requests to selected providers, in accordance with their offered capabilities and the frequency control error in each island. Coordination of multiple providers in this manner is typically provided by an automatic generation control (AGC) system.
- 5.11 More background to the CQDP proposal can be found in [1]. The CQDP also envisaged that the HVDC would play a greater role in frequency keeping.

Figure 5: CQDP conceptual frequency regulation design



6. Commission Investigations

- 6.1 The Board endorsed the CQDP proposal to investigate the conceptual design more fully. As a first step, the Commission engaged KEMA to review technical options for extending frequency keeping service to multiple providers, including considering the possible role of the HVDC. Following analysis of New Zealand arrangements, including discussions with generators and Transpower, KEMA confirmed that from a technical perspective an AGC style regime was practical, although it noted concerns about possible delays and latency in existing dispatch processes [4].
- 6.2 Building on the KEMA study, the Commission then developed a straw man frequency regulation market to assess overall feasibility and identify key design and implementation requirements to integrate an arrangement like the CQDP conceptual design into the market.
- 6.3 A high level summary of the straw man design is shown in Table 1. It assumes that frequency regulation offers would be co-optimised in SPD with energy and instantaneous reserves offers. This would automate the selection of providers and minimise the overall cost of dispatching energy, instantaneous reserves and regulation recognising interdependencies between each.

Table 1: High level outline of straw man design of frequency regulation market

<i>Participation</i>	Participation would be voluntary. Providers holding contracts with the System Operator would be eligible to submit offers (as for IR).
<i>Offers</i>	Participants would submit half hourly frequency regulation offers subject to the same provisions as for energy and instantaneous reserves offers.
<i>Setting regulation requirements</i>	The System Operator would determine, and set in SPD, the amount of frequency regulation required in each half hour in each island. This would take into account generator free governor action and HVDC capabilities.
<i>Pre-dispatch schedule</i>	SPD would co-optimize frequency regulation with energy and IR requirements to maximise overall economic benefits in each trading period of the schedule, accounting for interdependencies/ cost-trade-offs between products.
<i>Dispatch schedule</i>	<p>The System Operator would re-run SPD (with frequency regulation co-optimised as above) and re-dispatch the system at 5 minute intervals, or more frequently if necessary, as it does now.</p> <p>In addition to calculating instantaneous reserves and energy dispatch, as now, SPD would pass cleared frequency regulation offers from each real time dispatch schedule to an AGC system. The cleared offers would be used by the AGC to calculate participation factors¹² for cleared frequency regulation providers.</p>
<i>Real time dispatch/ operations</i>	<p>Frequency error in each island would be monitored and regulation response requirements for North Island & South Island frequency regulation providers and for the HVDC would be calculated every few seconds. The AGC system would apportion these between generators according to participation factors and simultaneously issue raise / lower signals to participants which had frequency regulation offers cleared in the most recent dispatch schedule.</p> <p>Energy and instantaneous reserves dispatch instructions would continue to be issued to generators via the GENCO system. Generators would pass GENCO dispatch instructions directly to MW set point controllers.</p> <p>For block dispatch groups, AGC would issue raise/ lower signals for individual stations and local participant systems could distribute or, subject to meeting the aggregate regulation instruction, redistribute instructions to individual stations/ units.</p>
<i>Pricing</i>	<p>Indicative prices from each dispatch schedule (currently published at 5 minute intervals) would reflect co-optimisation of energy, instantaneous reserves and frequency regulation.</p> <p>The clearing price for supply of frequency regulation would be set ex post in each island (each half hour as for, and co-optimised with, energy and instantaneous reserves prices).</p>
<i>Settlements</i>	In addition to payments for energy dispatch and cleared instantaneous reserves, frequency regulation providers in each region would receive half hourly market (enablement) prices for any cleared frequency regulation capacity. Constrained-off payments would not be necessary and dependence on constrained-on payments would reduce ¹³ .
<i>Compliance</i>	As for instantaneous reserves, non-performance of a frequency regulation provider would be a contractual or compliance issue.

¹² The proportion of frequency regulation allocated to a particular provider.

¹³ Constrained-on payments, where dispatch instructions were issued by the System Operator for security related reasons, would continue.

- 6.4 The straw man design developed by the Commission is presented in Appendix A. It includes:
- (a) The basis for the overall design.
 - (b) A summary of reference frequency regulation markets.
 - (c) Discussion, with illustrative examples, of the co-optimisation concept.
 - (d) Detailed discussion of key design features, design issues/ implications/ choices and associated issues (for example, integration with dispatch).
 - (e) Draft adaptations to the SPD formulation to identify changes needed to implement the straw man design.
 - (f) Transitional measures.
- 6.5 In developing the straw man design presented in Appendix A, a minimalist approach was adopted given the intent was to confirm feasibility and identify key design requirements rather than a fully fleshed out design.
- 6.6 The straw man design has been discussed with the CQAG and the Wholesale Market Advisory Group (WMAG). Both support the proposal in principle, subject to cost-benefits, but with a preference for a staged approach. As outlined in section 3, the Commission proposes to adopt a staged approach.
- 6.7 Since developing the straw man design, the Commission has been exploring technical and market implementation requirements with Transpower. Taking into account feedback on this discussion paper, the Commission will be requesting the System Operator to fully investigate its implementation requirements, including firmer cost estimates and timeframes, taking into account the proposed staged approach. The Commission will also be discussing the role of the HVDC with the Transpower. Discussions to date have confirmed that the proposal is technically feasible although Transpower is concerned that regulation transfer as proposed could increase wear and tear on the link and that therefore this proposal should only be considered when pole 1 is replaced.
- 6.8 In the meantime, the System Operator has indicated broad-brush estimates of likely costs to implement stage 1 of the proposal. The Commission wants to make it clear that the purpose of these estimates is to assist it in assessing likely cost-benefits before committing to the next phase of the project. A focus of the next stage of investigation will be to assess budget requirements.

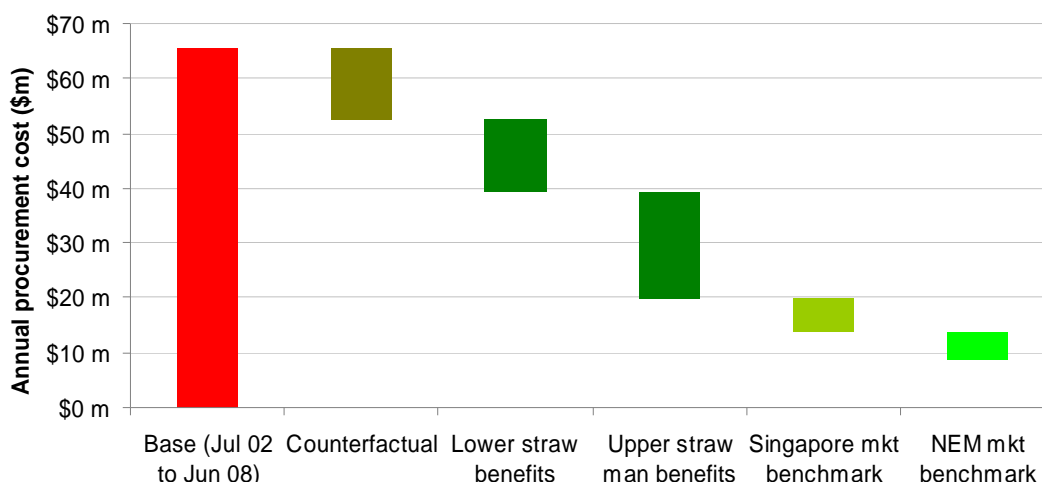
Cost-benefit Assessments

- 6.9 The Commission has undertaken preliminary assessments of potential straw man regulation market benefits and, separately, the stage one benefits.
- 6.10 As frequency keeping costs fluctuate widely from one month to the next the Commission has used the average ratio of frequency keeping to wholesale energy

procurement costs over the period July 2002 to Jun 2008 (approximately 100%) to estimate base procurement costs going forward.

- 6.11 It is possible that the recent change to the System Operator’s selection methodology could result in ongoing procurement cost savings. However, there is insufficient data to know how effective that change will be. It is possible for example, that offer prices may change to reflect the risk constrained on costs. It is also possible that other measures could reduce procurement costs. For example, reducing procurement requirements at off peak times. Given the uncertainties involved, the Commission has therefore assessed potential benefits going forward relative to a counterfactual assuming a procurement cost ratio of 80% (instead of 100% as above).
- 6.12 Straw man benefits have been estimated with reference to observed experience in the Australian and Singapore electricity markets. Assumed straw man frequency regulation procurement costs are shown in Figure 6 relative to historical costs, a counterfactual assuming other benefits relative to the status quo, and Singapore and Australian market benchmarks.

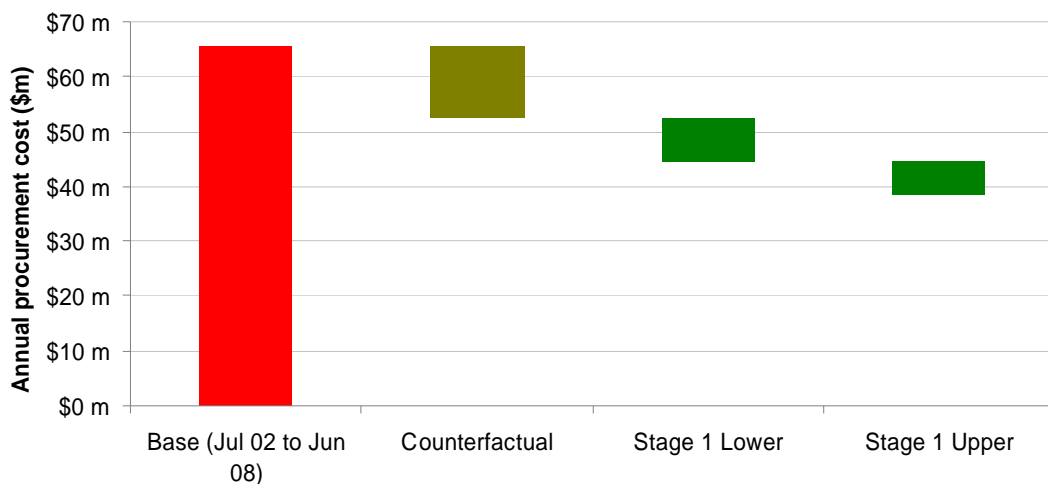
Figure 3: Assumed straw man procurement costs pa



- 6.13 The Commission’s analysis ignores other potential straw man benefits. For example, the ability to more readily adjust regulation requirements over time to trade-off procurement costs and frequency quality, including sculpting, as system requirements vary. Regulation requirements could also be increased more readily, if necessary, if system intermittency increases over time given increased renewable generation and the possibility of generation with conventional free governor being displaced.
- 6.14 The Commission’s assessment of potential stage one procurement costs under the stage one proposal are summarised in Figure 7, relative to the same base and counterfactual as for the straw man design. This analysis assumes that approximately 25MW of regulation can be transferred over the HVDC to reduce overall procurement

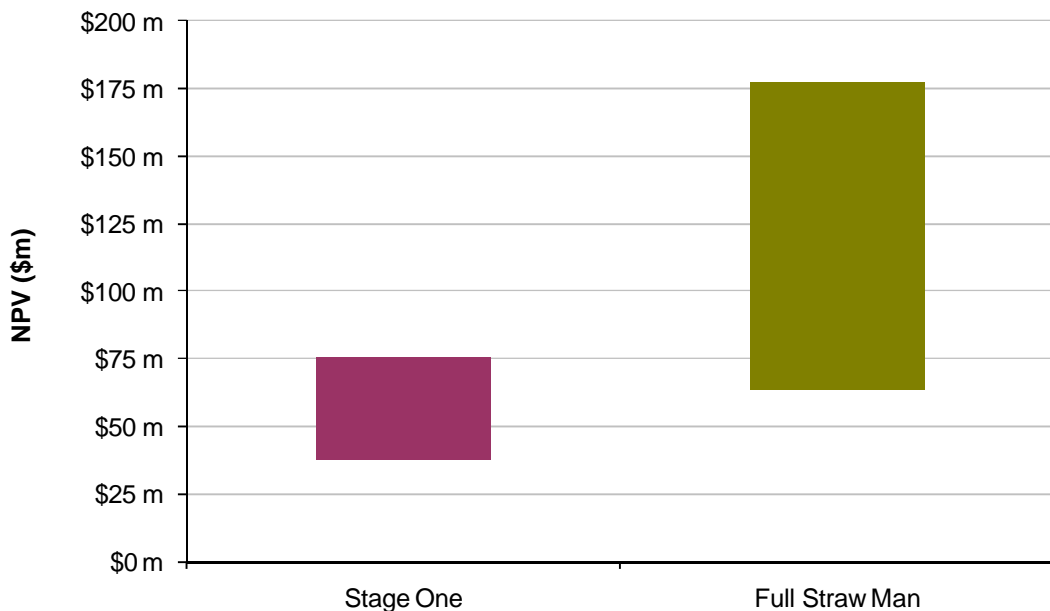
costs based. Estimates are based on historical HVDC flows and frequency keeping costs in each island.

Figure 4: Assumed stage one procurement costs



6.15 Figure 8 shows the estimated range of net benefits for stage one and the full straw man proposal. Stage one benefits would fall within the overall straw man benefits.

Figure 5: Estimated range of net benefits for straw man and stage one proposals



6.16 The Commission’s preliminary cost-benefit assessments are described more fully in Appendix E.