Wholesale Advisory Group

National Frequency Keeping Market

A WAG Briefing Paper

17 October 2013

Note: This paper has been prepared for briefing the WAG.

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1 Purpose

1.1.1 In October 2013 the Electricity Authority (Authority) requested that the Wholesale Advisory Group (WAG) consider a number of new items including the development of a national frequency keeping market for inclusion in the advisory group's work programme.

1.1.2 The WAG agreed that national frequency keeping should be added to its work programme.

1.1.3 This initial briefing paper is intended to provide an overview of key parameters associated with this project. It also sets out a proposed approach and timeline for consideration by WAG.

2 Context

2.1 Existing arrangements

2.1.1 In accordance with the frequency principal performance objective (PPO) in part 7 of the Code[1], the system operator is required to act as a reasonable and prudent system operator with the objective to maintain system frequency in each island between 49.8 Hz and 50.2 Hz - the normal band.

2.1.2 Maintaining frequency in the normal band is a quality objective intended to achieve the optimum trade-off between quality and the cost.

2.1.3 The system operator meets this quality objective by procuring frequency keeping services in a half hour market in each island from frequency keeping providers. Providers are currently generating companies that have sufficiently responsive plant and adequate spare capacity to be able to vary their output to maintain frequency in an island within the normal band, for normal demand/supply imbalances.

2.1.4 The two island power systems presently operate as independent a.c. systems loosely coupled in frequency by the stabilising influence of the HVDC link. The link effectively transfers a degree of system inertia between the islands, but this benefit is neither recognised nor paid for under the current procurement arrangements for frequency keeping and instantaneous reserves.

2.1.5 Procurement arrangements in the North and South Islands differ while a transition is in progress from single frequency keeping (FK) to multiple frequency keeping (MFK). MFK commenced in the North Island on 1 July 2013 and is planned to be introduced in the South Island in August 2014.

2.1.6 In summary, the respective arrangements in the two islands can summarised as follows:

North Island – MFK

- providers offer up to 5 frequency keeping bands, each between 4 MW and 50 MW in size
- the system operator selects the lowest cost combination of offers to make up a

[1] Clause 7.2(b) covering normal band, momentary fluctuations, return to the normal band after fluctuations and time error.

cumulative band of 50 MW and dispatches the providers
- the system operator controls frequency using a central frequency controller which issues raise/lower set point controls to dispatched providers every 2 s

South Island – FK

- providers offer up to 5 frequency keeping bands of at least 25 MW
- the system operator selects the lowest cost offer of 25 MW or more and dispatches a single provider
- the dispatched single provider controls frequency using its own local station or area based frequency control system
- responsibility for frequency control moves from one provider to another whenever there is a dispatch change.

2.1.7 At present, only four generating companies meet the system operator's technical requirements for MFK and FK:

- Mighty River Power Limited using the Waikato hydro block (North Island)
- Genesis Energy Limited from four Huntly thermal units, the Tokaanu hydro station, and the Waikaremoana hydro block (North Island)
- Contact Energy using two Stratford thermal units and the Clutha hydro block (North Island and South Island)
- Meridian Energy Limited using the Waitaki hydro block and the Manapouri hydro stations (South island).

2.1.8 The system operator has a second frequency related PPO under part 7 of the Code to manage frequency time error (time error). Time error is the cumulative number of cycles (expressed in seconds) by which frequency is running slow or fast due to frequency varying in the normal band. This measure is of importance in regard to low cost mains powered digital clocks found in a wide range of domestic and commercial appliances and other equipment. The PPO requirement is to maintain frequency time error within +/- 5 seconds and to return it to zero at least once a day.

2.1.9 The System Operator manages time error continuously in the North Island using its MFK controller and frequency keeping providers manage time error independently in the South Island.

2.2 Frequency keeping payments and cost allocation

2.2.1 A frequency keeping provider dispatched by the system operator is currently paid the following:

- the provider’s offer price, also referred to as the availability fee
- to-the-band constrained on or off compensation, if required, to move the frequency keeper from its natural dispatch point so that its control maximum or control minimum operating points are not exceeded within the dispatched frequency keeping band
- in-band constrained on or off compensation, if required, to compensate the provider for any difference between actual and dispatched quantities of output, for example:
  - if a generator produces a lower energy output than its dispatched quantity (to

compensate for an increase in system frequency) when the energy price is above its energy offer price, it receives a constrained off payment
    - if a generator produces a greater energy output than its dispatched quantity (to compensate for a decline in system frequency) when the energy price is below its energy offer price, it receives a constrained on payment
- in addition, providers are paid in the energy market for any generation produced at the final price, although this is not treated or reported as part of the frequency keeping costs.

2.2.2 Frequency keeping ancillary service costs are allocated monthly to purchasers. The total cost of frequency keeping for each trading period of the previous month is pro-rated to purchasers according to the quantity of electricity purchased in each trading period. The allocation is carried out on a national basis even though the service is procured separately in each island. A degree of cross-subsidisation occurs as North Island prices are generally higher than South Island prices.

2.3 Operation of MFK with HVDC controls

2.3.1 When MFK is commissioned in both islands by August 2014, it could be used in conjunction with the new HVDC bipole control system to facilitate the transfer of frequency keeping between islands. This would allow the service to be procured from available providers nationally, rather than at an island level.

3 Key drivers for a national frequency keeping market

3.1 Price diversity between islands

3.1.1 Limited competition in the island-based frequency keeping markets and certain shortcomings in the offer selection tool algorithm have resulted in periods of price volatility, when significant differences have arisen between island prices, as shown in Figure 1 and Figure 2 below. The constrained on and off costs shown in blue and red in these graphs are summed to-the-band and in-band constrained on and off costs (as described in paragraph 2.2.1 above).

Figure 1 - North Island frequency keeping prices

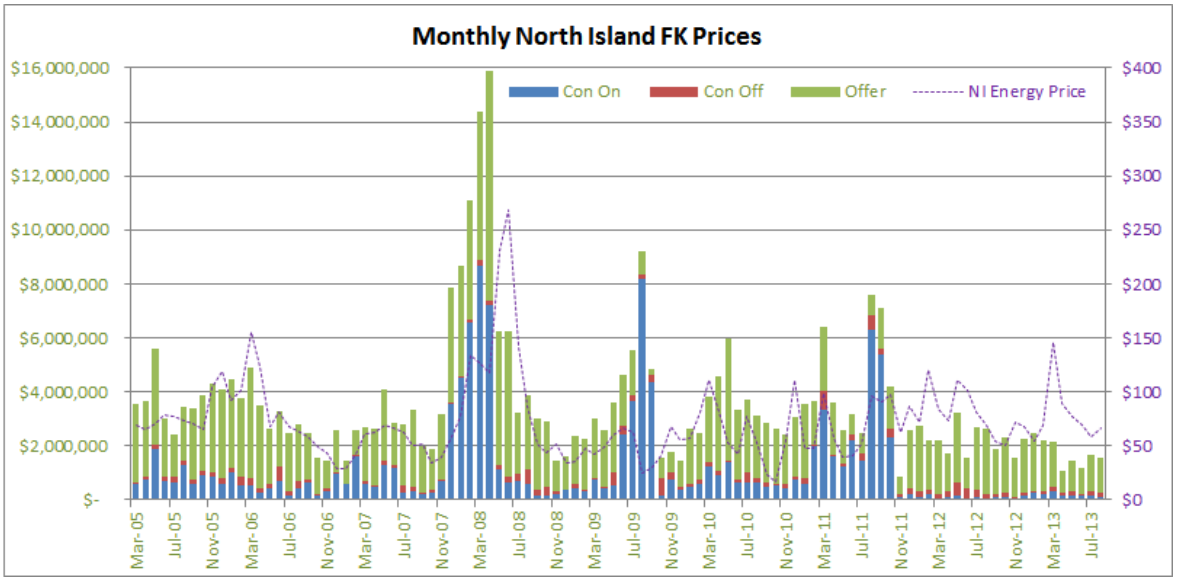
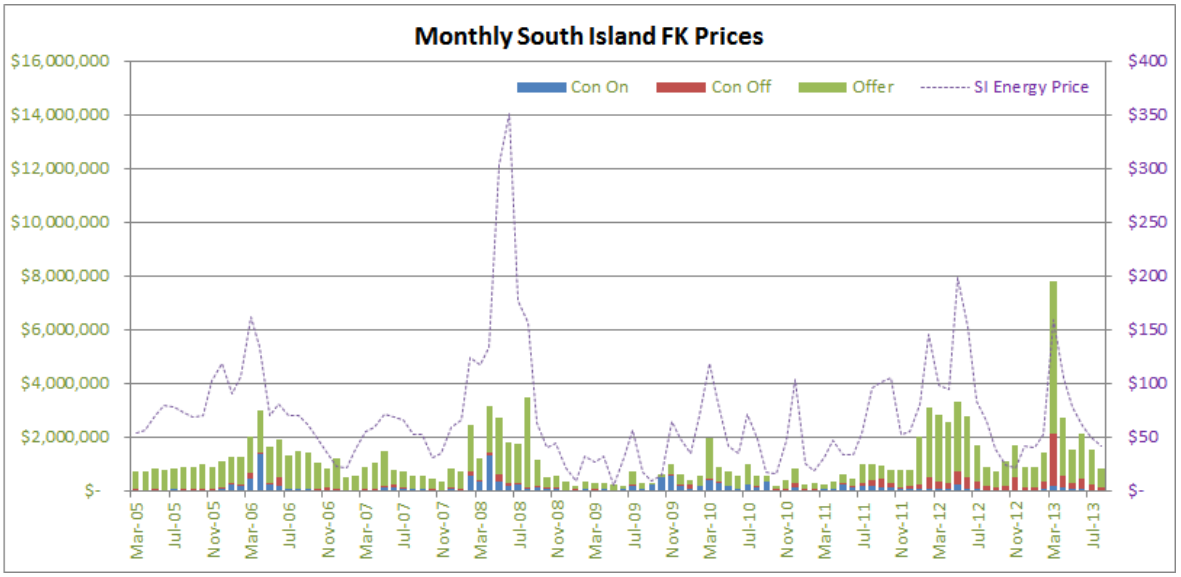


Figure 2 - South Island frequency keeping prices



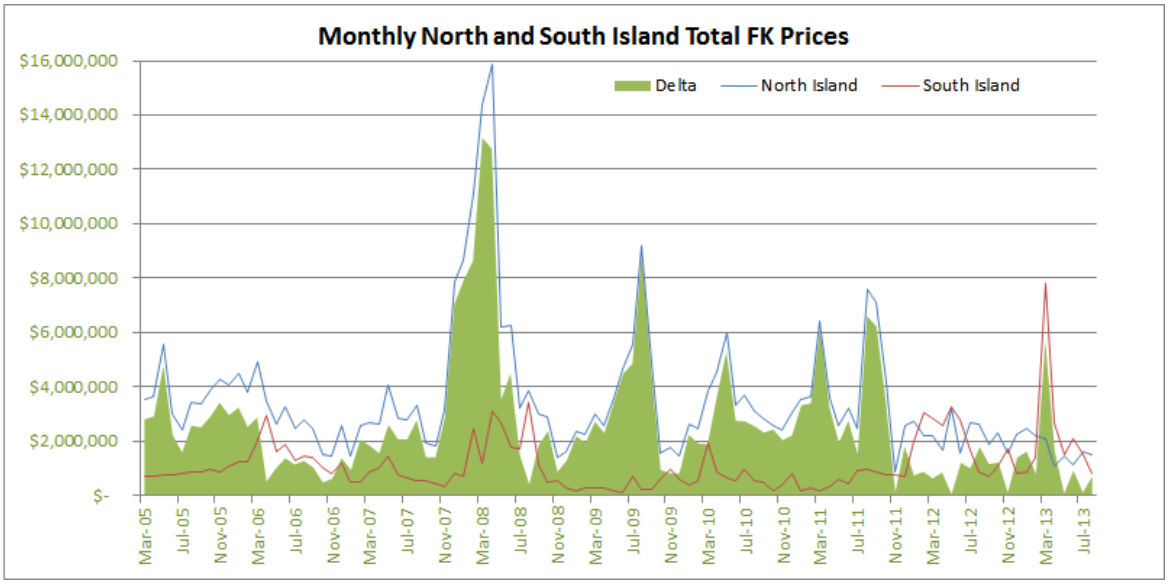
3.1.2 Although frequency keeping providers are paid separately in the energy market for any generation produced, offer prices show an underlying energy price component. This results in a reasonable level of correlation between energy and frequency keeping prices in both islands, but there is reasonable diversity between the two islands.

3.1.3 There have been periods of unusually high prices in the North Island in 2008, 2009 and 2011, as evident in Figure 1, when one generator was able to exploit constrained on payments. Because the generator concerned is dispatched at station level, it could structure its energy offers at a frequency keeping station to maximise constrained on payments which were not fully taken into account in the offer selection algorithm. The Electricity Commission and the Authority have subsequently initiated changes to the system operator's selection algorithm to address this problem by better accounting for constrained on payments. The last change made in November 2011 appears to have effectively eliminated the problem as no pattern of

high constrained on costs has re-emerged.

3.1.4 Ignoring these excess constrained on payments, there is still considerable price diversity between North Island and South Islands. Since 2005, South Island prices having averaged about 44% of North island prices (not including constrained on prices). The inter-island price difference shown in the area graph in Figure 3 indicates there are significant opportunities to purchase frequency keeping from lower cost providers under a national market arrangement.

Figure 3 - Price differences between North and South Islands



3.2 Quantity diversity between islands and total quantity required

3.2.1 The system operator's current practice is to purchase frequency keeping bands of +/- 25 MW in the South Island and +/- 50 MW in the North Island. The bands are sized to cover:

- the impact of non-dispatchable generation
- the intra-trading period variability of load
- errors in forecast load
- generation not exactly meeting its dispatch targets.

3.2.2 Under a national market, the two island a.c. systems would be closely coupled together using the HVDC link, effectively increasing inertia in both islands. It is possible that a +/- 50 MW band may be adequate to control frequency in both islands. This is not something that can be easily simulated by modelling, but the system operator plans to carry out tests during the HVDC bipole control system commissioning to try to observe the effect of coupling the two island a.c. systems together.

4 Design and implementation issues

4.1 Selection of providers

4.1.1 Frequency keeping selection under the current market arrangements is very processor intensive. Providers are paid as offered and frequency keeping is cleared in discrete bands. Even though the number of offers is relatively small (20-30), the number of combinations to

be assessed is large and increases factorially with each additional offer. Constrained on and off costs must also be estimated and added to offer prices to determine total offer costs.

4.1.2 The system operator's selection tool runs as an application in the market systems database and is not a dedicated stand-alone solver. The tool has limited solving capability and is only just capable of supporting the extra selection load of MFK. The system operator has already advised the Authority that the tool is inadequate to support a national frequency keeping market and will need to be replaced with a more capable solver.

4.2 Co-optimisation with energy and reserves

4.2.1 Frequency keeping selection can influence energy market prices. For example, if a generator dispatched for frequency keeping is constrained on or off to provide the dispatched frequency keeping band, the cleared price of energy may change. This effect is not currently taken into account in the frequency keeping selection or the energy and reserves dispatch because frequency keeping is not co-optimised in the market clearing software (SPD).

4.2.2 Energy and reserves have been co-optimised in the New Zealand electricity market since its inception and it would not be a large step to extend the co-optimisation to frequency keeping, treated as another category of reserves. A number of overseas markets have taken the co-optimisation concept first developed in New Zealand and applied it to frequency regulation products. The feasibility of co-optimising energy, reserves and frequency keeping in SPD has been investigated and verified by the Electricity Commission.

4.2.3 Full co-optimisation inherently offers efficiency gains and would provide a solution to the system operator's selection tool problem as the selection would become fully integrated in SPD with energy and reserves.

4.2.4 The frequency keeping band is currently fixed but the band requirement could be made variable depending on dispatched generation and load. SPD would allow a scheduled quantity of frequency keeping to be dispatched in the same way that the reserve products are scheduled and dispatched.

4.3 Pay-as-offered vs uniform price

4.3.1 Frequency keeping is a pay-as-offered market under both the SFK and MFK arrangements. In addition, providers also receive constrained on or off payments in accordance with the arrangements described above in paragraph 2.2.1.

4.3.2 SPD solves a linear programming problem to schedule and price both energy and reserves. In its present form, SPD could not readily solve the mixed integer programming problem that arises if pay-as-offered frequency keeping in discrete bands is to be co-optimised with energy and reserves. A workable arrangement would involve changing the frequency keeping market to include a single national $/MW enablement price, and to permit part bands to be cleared. This would be similar to the market for reserves (accepting that there are currently separate island prices for reserves).

4.3.3 The Authority is in the process of amending the Code to remove the in-band constrained on and off payments to generators in order to improve the efficiency of the current selection

tool. A national market would be compatible with this approach but would necessarily introduce further changes to frequency keeping payments and the structure of the offer. A number of issues would need to be worked though with generating companies to agree on the exact offer structure, control limits and form of payment.

4.4 HVDC controls

4.4.1 Transpower plans to complete commissioning of its new HVDC bipole controls on Pole 2 and Pole 3 by the end of 2013. Besides standard HVDC controls such as the converter control and the transformer tap-changer control, a number of non-standard power modulation control function are included in the new bipole control system. These functions are mainly responsible for maintaining stability after severe disturbances in the power system, but a new form of control is included referred to as frequency keeping control (FKC).

4.4.2 FKC is a fast responding controller designed to minimise the absolute frequency difference between the North and South Islands. It allows both frequency keeping and fast instantaneous reserves (FIR) to be sourced in either a.c. island by controlling the HVDC link to perform as if it was an a.c. link.

4.4.3 FKC if enabled, will transfer both frequency keeping and instantaneous reserves between the a.c. islands, irrespective of whether island-based or national markets are introduced for these ancillary services. In the absence of national markets, 'free' reserves and frequency keeping would be transferred across the link.

4.4.4 Operation of a national frequency keeping market is dependent on the ability to transfer a frequency keeping market product between the a.c. islands using the HVDC link. While FKC is not the only control option for a national frequency keeping market, it is emerging as the preferred option because it is a requirement for the separate national reserves market initiative.

4.5 HVDC round power

4.5.1 The HVDC link has a minimum transfer level in either direction on the HVDC which would constrain the link's ability to transfer frequency keeping (and instantaneous reserves) between the islands whenever the link is scheduled at low power transfer levels.

4.5.2 It is possible to reduce this constraint by using round power, where power is transferred in opposite directions on the two poles. At this point, it is unclear whether Transpower will be prepared to offer round power capability to the market when Pole 3 is commissioned, and if so, under what conditions. This is a common issue with the national reserves market project and may have a material impact on the extent to which frequency keeping can be transferred between the islands.

4.6 Frequency quality

4.6.1 The aspects of frequency quality managed by the system operator are:

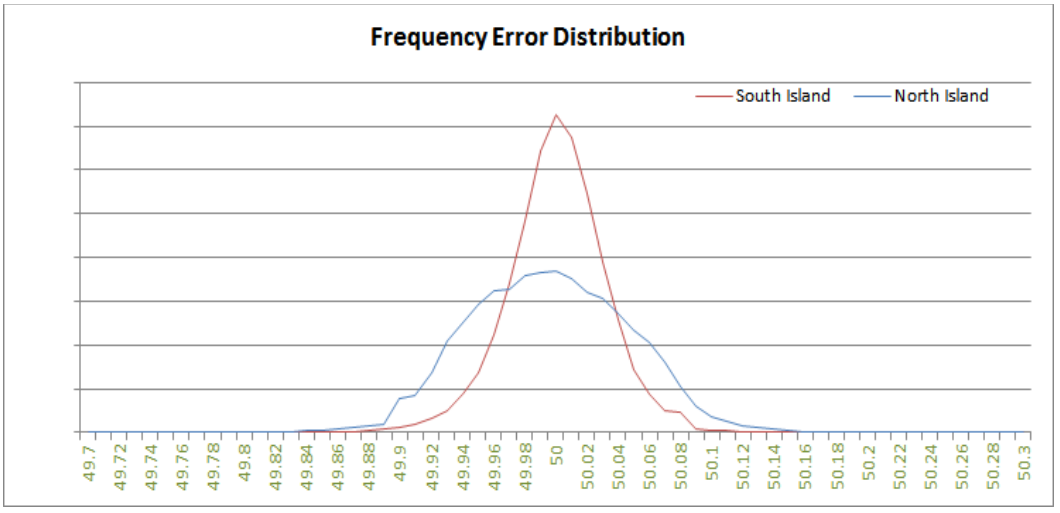
- frequency error in the normal band
- the rate of occurrence of momentary fluctuations outside of the normal band

- frequency time error.

4.6.2 Figure 4 shows the distribution of frequency error in the two a.c. systems taken from 10 s frequency data recorded over a typical month. The quality of frequency is characteristically lower in the North Island than it is in the South Island – the respective standard deviations are 0.05 Hz and 0.03 Hz approximately. The difference is attributable to a greater proportion of industrial motor load in the North Island, and a surplus of generation over load in the South Island.

4.6.3 There are no specific PPO targets for frequency error quality in the normal band but complaints relating to frequency quality are rare. While load does not appear to be particularly sensitive to frequency error, the error distribution would change in both islands in a national market due to strong coupling of the a.c. systems by the HVDC link.

Figure 4 - Frequency quality



4.6.4 The Code includes PPO target limits for occurrence of momentary fluctuations outside of the normal band. As the targets are set nationally, a national market is unlikely to have any impact on these measures. Any increase in one island is expected to be offset by a decrease in the other island.

4.6.5 Frequency time error is controlled separately in each island. In accordance with a Code PPO, the system operator must limit time error to a maximum of 5 s and zero the error at least every 24 hr.

4.6.6 Frequency time error is managed on the power system to keep synchronous clocks running accurately - these low cost clocks maintain time within 5 s indefinitely, provided they remain energised by an a.c. power source. The Authority recently carried out a survey to check whether the frequency based time error service is still of general use given that much more precise universal time references are now commonly available. The survey found that synchronous clocks, albeit now in digital form, remain widely in use as a time reference in a range of domestic appliances and industrial equipment, and it would be premature to consider relaxing or removing the time error PPO.

4.6.7 If the North and South Island a.c. systems are tightly coupled by the HVDC link, as is proposed in a national market, time error management in accordance with the existing PPO would become more difficult. The respective island time error time error could be different when the islands are locked together by the FKC controller and error may drift in opposite directions in the two islands. It may be necessary to update the PPO to better recognise the operation of a national frequency keeping market given that the PPO was intended to apply in separate a.c. systems.

4.7 Transition between national and island-based frequency keeping

4.7.1 A feature of a national frequency keeping market (and national reserves market) is that separation into island markets would occur at certain times. This must be allowed for in the design of a national frequency keeping market and the design of the frequency keeping control system which would have to be capable of managing two separate a.c. systems.

4.7.2 Separation would take place when power transfer on the HVDC link reduces below a control minimum or above a control maximum, taking into account both dispatched generation and the uncertainty of non-dispatched generation. If HVDC round power is enabled, the control minimum limit would not need to apply.

4.8 Effect on HVDC operating costs

4.8.1 Transpower has raised some concerns in the in the past that additional duty on the link imposed by national frequency keeping and/or instantaneous markets could increase maintenance costs and shorten the life of the HVDC. It will be important to understand the scale of this issue as such costs would be a detriment from an overall economic perspective. There may also be an impact on the scale of benefits that can be achieved, if operational constraints affect the level of instantaneous and frequency keeping transfers. It will be important to obtain quantitative analysis on these issues to understand their materiality.

Q1.	What (if any) other issues need to be considered in the context of the possible introduction of a national frequency keeping market?

5 Costs and benefits

5.1 Benefits

5.1.1 The following categories of potential efficiency benefit would be expected from a national frequency keeping market:

- reducing the cost of frequency keeping through increased competition in the frequency keeping market by allowing procurement of frequency keeping from the least cost source at a national rather than island level
- reducing the cost of frequency keeping through lowering the overall frequency keeping requirement as set out in section.

5.1.2 The magnitude of these effects would depend on a range of factors such as the operational limits affecting frequency keeping transfer capability on the HVDC, the level of frequency

keeping prices in each island etc.

5.1.3 A broad indicative estimate of net present benefits was published by the Electricity Commission (Commission) in 2006. An indicative NPV upper bound was calculated in the order of $75 m, based on annual savings of $10 m and implementation costs of $2 m.

5.1.4 The Commission's estimate is indicative only and it is proposed to refine this estimate by:

- designing a full co-optimisation model in vSPD, and analysing the feasibility and impact of co-optimisation of energy, reserves and frequency keeping using historical market data
- engaging the system operator to investigate and develop a proposal for implementing full co-optimisation in SPD, including a detailed estimate of costs.

Q2.	What other categories of benefits (if any) could arise from a national frequency keeping market, and how should benefits be estimated?

5.2 Potential costs

5.2.1 The following issues could give rise to costs from a national economic perspective:
5.2.2

- costs to modify SPD and any associated on going operational costs
- costs to implement frequency keeping offer structure and payment process changes in WITS
- costs to modify the system operator's frequency control systems
- increased operating costs for the HVDC such as increased maintenance
- costs for generators to implement offer format changes

5.2.3 It is proposed that cost estimates will be developed in conjunction with the system operator based on its proposal for implementation of full co-optimisation.

Q3.	What other categories of costs (if any) could arise from a national frequency keeping market, and how should costs be estimated?

6 Linkages to other projects

6.1 MFK Project

6.1.1 The MFK Project involves the system operator controlling and co-ordinating frequency in each island from its national control centre, as a replacement for station based frequency keeping. The North Island was cut over to the new system on 1 July 2013 and has operated satisfactorily since that time. The date for the South Island is planned to be 4 August 2014.

6.1.2 MFK was planned as an initial step towards a national market by allowing multiple providers to be dispatched in the same trading period in the island-based frequency keeping markets. The national market builds on this approach by combining the two markets to further increase

competition.

6.2 National instantaneous reserves market

6.2.1 The national frequency keeping and instantaneous reserves markets would be both reliant on the same HVDC modulation controller, compete for the same HVDC capacity resource and are similarly affected by the implementation of round power.

6.2.2 The two projects would place demands on the same system operator resources and the sequencing of market systems changes and commissioning work would need to be co-ordinated closely between the projects.

Q4.	What other linkages might need to be considered as part of scoping the introduction of a national frequency keeping market?

7 Proposed implementation process

7.1 Stage 1 – Investigations

7.1.1 Stage 1 would focus on the following:

- developing a vSPD model to analyse the market impacts of full co-optimisation of energy, reserves and frequency keeping
- engaging the system operator to investigate and develop a proposal for implementing full co-optimisation in SPD, including assessment of costs
- co-ordination with the national instantaneous reserves market project, particularly in regard to HVDC modulation controls and the use of round power
- assessment of any new or amended Code provisions required to enable a national frequency keeping market
- making recommendations to Authority on whether to proceed to a capital implementation project.

7.1.2 Assuming WAG agrees with the proposed process, this information would be prepared in the form of a WAG Discussion Paper .

7.2 Stage 2 – Detailed assessment and design

7.2.1 Stage 2 would be based on the outputs of Stage 1 and would include the following:

- committing to a capital project with the system operator to implement SPD and other market systems changes
- detailed design of system operator and NZX system changes
- detailed development of required Code and procurement plan amendments
- development of ancillary services contract changes
- planning for market cut-over to a national market
- liaising with stakeholders on offer arrangements

7.3 Stage 3 – Implementation

7.3.1 Stage 3 would include:

- **implementing SPD, WITS and other system changes**
- **commissioning the new market systems**
- **cut-over to a national market**

Q5.	What changes (if any) should be made to the proposed process for this project?