System Operator TASC Report

Future Solution Option Analysis

Normal Frequency Management Strategy Project

30/09/2015

SYSTEM OPERATOR

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PREPARED BY:

Name	Position
Julie Dyer	System Operations, Business Analyst

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CONTRIBUTORS

Name	Position
Marije Postma	Project Manager
Mike Phethean	Team Leader, Power System Modelling and Tools
Andrew Ward	Engineer, Power System Modelling and Tools
John Bartley	Market Systems Technical Specialist
Phil Yao	Senior Analyst, Market Capability
Charles Chrystall	Analyst, Market Operations
Scott Avery	Compliance Manager
Leigh Westley	Ancillary Services Manager

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Abbreviations

The abbreviations used in this document are provided below. Definitions for control response and governor response have been included, since these two concepts may be new to the document audience.

AGC	Automatic Generator Control
AOPO	Asset Owner Performance Obligation
Code	Electricity Industry Participation Code 2010
CR	Control Response This includes governor response (refer below) and any other energy storage technology that is constantly varied by a proportional integral controller e.g. batteries under proportional integral control.
CRE	Competition, Reliability, Efficiency
EA	Electricity Authority
FKC	HVDC Frequency Keeping Control
FS	Future Solution
FSC	HVDC Frequency Stabiliser Control
GR	Governor Response Generators responding to changes in frequency in the normal band.
HVDC	High Voltage Direct Current
MFK	Multiple Frequency Keeping
PPO	Principal Performance Obligations
RFM	Reserves and Frequency Management Programme
RIER	Regulation Instruction Error Ratio
RP	Round Power
SFK	Single Frequency Keeper
SO	System Operator
SOW	Statement of Work
TASC	Technical Advisory Services Contract

1 Executive Summary

HVDC operations with frequency keeping control (FKC) and multiple frequency keepers (MFK) represents a material change to normal frequency management. The change includes a shift of frequency keeping effort from contracted frequency keeping providers to inherent governor response.

Before progressing with the planned national market for frequency keeping project, the Electricity Authority (EA) wishes to revalidate the proposed solution and any impact FKC and MFK have had on the assumptions and benefits of the project.

The EA has established a normal frequency management strategy project which will deliver work from various third parties, including the System Operator (SO) to inform development of a future strategy for normal frequency management, intended to achieve an optimal mix and configuration of frequency keeping and governor response.

As part of this strategy work the EA requested the SO to develop options for future management of normal frequency, including consideration of options where no procurement of frequency keeping from providers occurs and where generators are compensated for governor response.

A set of workshops were held with representatives from the Engineering, Operations and Business groups within the SO. An initial long-list of 15 future solutions were identified and reduced to a short-list of five options.

1. **Control response with compensation.** No frequency keeping is procured. Frequency control in the normal frequency band is managed by governor response and energy storage response, collectively called control response. Generators and energy storage providers would be compensated for the control response.
2. **National market: national frequency keeping selection with co-optimisation.** Frequency keeping procured from a national market with the most economic providers selected across both islands. Frequency keeping would be co-optimised with energy and reserves. Compensation of generator governor response from generators other than those contracted to provide frequency keeping is not considered.
3. **National market: national frequency keeping selection without co-optimisation**. Frequency keeping procured from a national market with the most economic providers selected across both islands. Frequency keeping would not be co-optimised with energy and reserves. Compensation of generator governor response from generators other than those contracted to provide frequency keeping is not considered.
4. **National market: national frequency keeping selection with co-optimisation; compensation for control response.** As per option 2, but the response provided by generator governors and energy storage providers would be compensated.
5. **National market: national frequency keeping selection without co-optimisation; compensation for control response**. As per option 3, but the response provided by generator governors and energy storage providers would be compensated.

Detailed consideration of the short-list options against technical, operational and market criteria determined:

Option 1: Control response with compensation

- incentivises generators to continue providing the current level of governor response in the normal frequency band and minimises the risk of generators introducing deadbands and a material drop in the quality of frequency control in the normal frequency range
- has no MFK component, requiring an alternative to effectively manage time error
- has yet to determine a suitable frequency keeping back-up option for when FKC is disabled
- requires a new basis for managing frequency based on control response and a compensation scheme to deliver the required behavior
- has the potential to reduce frequency keeping costs, since no MFK is procured, but achieving this benefit is dependent on the compensation scheme implemented
- is expected to provide a reduction in frequency keeping costs (since no MFK is procured) but achieving this benefit is dependent on the cost of the compensation scheme

Option 2 and 3: National market: national frequency keeping selection with co-optimisation and **National market: national frequency keeping selection without co-optimisation**

- selects the most economic frequency keepers nationally and for the co-optimised option, co-optimises frequency keeping with energy and reserves
- controls time error through MFK, effectively minimising dispatch workload for system co-ordinators
- has an accepted frequency keeping back-up arrangement (SFK) though back-up may be sufficiently provided by governor response
- provides no compensation to generators for governor response, increasing the risk of generators introducing deadbands and a material drop in the quality of frequency control in the normal frequency range
- requires a new performance measure for frequency keeping compliance that may be difficult to develop
- is expected to deliver market benefits from national selection with co-optimisation providing additional benefit

Option 4 and 5: National market: national frequency keeping selection with co-optimisation; compensation for control response and **National market: national frequency keeping selection without co-optimisation; compensation for control response**

- incentivises generators to continue providing the current level of governor response in the normal frequency band and minimises the risk of generators introducing deadbands and a material drop in the quality of frequency control in the normal frequency range
- requires a new basis for managing frequency based on control response and a compensation scheme to deliver the required behavior
- selects the most economic frequency keepers nationally and for the co-optimised option, co-optimises frequency keeping with energy and reserves
- controls time error through MFK, effectively minimising dispatch workload for system co-ordinators
- has an accepted frequency keeping back-up arrangement (SFK) though back-up may be sufficiently provided by governor response
- requires a new performance measure for frequency keeping compliance that may be difficult to develop
- potentially reduces the total frequency keeping costs but this is dependent on the nature of the compensation scheme implemented and balancing this with MFK payments.

While all five options appear technically feasible, further work is required to understand certain technical aspects before determining a preferred future solution. As the option selection does not benefit from the balance of the strategy development, the profiled options do not constitute a recommendation for implementation.

Recommendations for future work include investigating:

- time error to determine if time error can be managed effectively using only control response and whether time error is the best solution for the quality of frequency
- compensation scheme design and the appropriate balance of efficiency, reward of contribution and recovery of costs for frequency management using control response
- the impact on system security of:
    - excessive governor response in the normal frequency band, under an incentivised governor response scheme
    - generator governor deadbands through limitation of frequency response
- frequency keeping operational back-up options
- performance measures for frequency keeping compliance quantity.

2 Introduction

2.1 Reserve and Frequency Management Programme

The Reserves and Frequency Management (RFM) programme is a joint programme of work between the System Operator (SO) and the Electricity Authority (EA) to improve frequency keeping and instantaneous reserve market arrangements given the recent enhancements provided by the upgrade of the HVDC control system.

These enhancements, which enable the transfer of frequency keeping and reserve between islands, has culminated in a number of proposed capital projects to reduce the costs of frequency keeping and reserves to the market.

The programme currently contains nine projects[1] to contribute to this objective, of which one is to develop a national market for frequency keeping.

Work was initiated on this project through Technical Advisory Services Contract (TASC) 041, National Market for Frequency Keeping. In that report Transpower recommended revalidation of the project given the work completed to date on MFK and FKC and the impacts this work may have on the previous benefits of a national market for frequency keeping.

2.2 Normal Frequency Management

HVDC operations with FKC and MFK represents a material change to normal frequency management. The change includes a shift of frequency keeping effort from contracted frequency keeping providers to inherent governor response.

Before progressing with the planned national market for frequency keeping project, the EA wishes to assess, as a whole, the appropriateness of:

- the current Asset Owner Performance Obligations (AOPOs)
- possible options for a national market for frequency keeping
- the current frequency keeping selection tool
- MFK operations
- the current frequency keeping ancillary service dispatch and associated cost allocation

To manage consideration of these matters the EA has established a normal frequency management strategy project.

This project will deliver work from various third parties, including the SO, to inform development of a future strategy for normal frequency management, intended to achieve an optimal mix and configuration of frequency keeping and governor response.

[1] Further information on these work streams can be found at: https://www.ea.govt.nz/operations/market-operation-service-providers/system-operator/joint-development-programme/reserves-and-frequency-management-programme/

2.3 Purpose of this Report

Under the normal frequency management strategy project the EA has developed a TASC Statement of Work (SOW) 049, requesting the SO to:

1) develop a normal frequency performance benchmark to be used for comparison of interim and future options for normal frequency management
2) develop options for future management of normal frequency, including consideration of options where no procurement of frequency keeping from providers occurs
3) develop options for the interim management of normal frequency until implementation of any mandated change from the current normal frequency model.

This report provides the SO's response to the SOW item (2). It presents an assessment of the technical validity of a number of options. As the option selection does not benefit from the balance of the strategy development, the profiled options do not constitute a recommendation for implementation.

The SOW required at least the following options to be considered:

- national market based on fixed bands with additional competition (existing national markets scope)
- national market based on providers with fast governor response
- a 0 MW MFK procured with normal frequency keeping being maintained through incentives to support fast governor response
- mandated governor response to ensure the normal frequency performance benchmark (as developed in the SOW item (1)).

The SOW specifically required incentivised governor response options to be investigated. Compensating generators for governor response has been raised by market participants both during the FKC trial period, as documented in the FKC trial report, and at the RFM Industry Forums and Engagement Group meetings.

Market participants have commented that increased generator governor action, arising from FKC operation, is undesirable for various reasons, including increased operational costs. Market participants have suggested they may install governor deadbands preventing governor response to frequency movement within the normal band if there is no market mechanism to directly reflect the costs of increased governor action. Consequently, the EA required the SO to consider options to compensate generators for governor action if the current practice is maintained or further developed for allowing inherent governor response to replace part or all of currently contracted frequency keeping provider response.

2.4 Terms of Reference

The terms of reference are described in detail within the TASC-49 SOW dated 26th February 2015. The SOW scope has been guided and supported by the Authority throughout the writing of this report.

2.5 Intended Audience

The primary audience for this document is intended to be the EA and SO personnel involved in the normal frequency management strategy project. Whilst some definition of terms is provided, this document assumes readers have a prior knowledge of the New Zealand wholesale electricity market and specifically frequency keeping services in the wholesale electricity market.

3 Future Solution Options

3.1 Long-list Options

The options in Table 1 were initially identified as possible future solutions for normal frequency management. All options assume FKC and Round Power (RP) are enabled.

Table 1: Long-List Future Solution Options

#	Option	Option Description
1	Multiple frequency keepers in each island (status quo)	Frequency keeping is procured from multiple generators to provide the frequency keeping bands of 20 MW North Island and 10 MW South Island. The response from generator governors is not compensated.
2	Multiple frequency keepers in each island with the frequency keeping bands swapped between islands	As per option 1 but the frequency keeping bands are swapped with the North Island providing 10 MW and the South Island 20 MW. The intent here is to recognise the higher response levels provided by the South Island generator governors.
3	Single frequency keeper in either the North or South Island	Frequency keeping is procured from a single generator in either the North or South island to provide the national frequency keeping band of 30 MW. The response from generator governors is not compensated.
4	Single frequency keeper in the South Island only	As per option 3 but the single frequency keeper is always selected from the South Island. The intent here is to recognise the higher response levels provided by the South Island generator governors.
5	Governor response with no compensation	No frequency keeping is procured. Frequency keeping is managed entirely by governor response. The response from generator governors is not compensated.
6	Governor response mandated	No frequency keeping is procured. Frequency keeping is managed entirely by governor response with generators mandated to provide governor response at an appropriate level to manage frequency in the normal band. Some form of compensation/penalisation would exist.
7	Governor response with estimate compensation	No frequency keeping is procured. Frequency keeping is managed entirely by governor response. The response from generator governors is compensated based on an estimate of response.
8	Governor response with actual compensation	No frequency keeping is procured. Frequency keeping is managed entirely by governor response. The response from generator governors is compensated based on actual response.
9	National market: governor response based on target frequency	A national market for governor response is established. Generators would have the ability to operate governors at a different target frequency, to manage frequency within the normal band. This option allows better control of time error and provides compensation for generators providing governor response.
10	Multiple frequency keepers in each island with variable	Frequency keeping is procured from multiple generators in each island. The frequency keeping band required in

#	Option	Option Description
	frequency keeping bands based on operating conditions	each island would vary per trading period depending on the current operating conditions. The response from generator governors is not compensated.
11	National market: national frequency keeping selection, without co-optimisation	Frequency keeping is procured using multiple frequency keepers from either or both islands depending on the most economic frequency keeping offers. All frequency keeping offers are pooled and the most economic frequency keeper(s) selected nationally for each trading period. There is no co-optimisation with energy and reserves. Generators providing governor response are not compensated.
12	National market: national frequency keeping selection with co-optimisation	As per option 11 but frequency keeping offers would be co-optimised with energy offers & bids and reserve offers. The lowest cost combination of generators across energy, reserves and frequency keeping would be selected to meet the frequency keeping band required nationally, for each trading period. The response from generators governors is not compensated.
13	National market: national frequency keeping selection with compensation for governor response (hybrid)	This option is a hybrid of national market, national frequency keeping selection, either with co-optimisation (option 12) or without co-optimisation (option 11) with compensation (actual or estimate) for governor response.
14	Automatic Generator Control (AGC)	AGC refers to a system where a single application coordinates the frequency keeping provided by one or more generators. With AGC the frequency control signal is sent directly into the governor control system as opposed to MFK when the signal is sent via the power controller which introduces a time delay.
15	Governor and energy storage response with compensation	Allow governor response and any energy storage technology that is constantly varied by a proportional integral controller e.g. batteries under proportional integral controller, to respond to frequency and be compensated based on their response/impact on frequency.

Note: For all market options we can change the offer structure so that partial bands can be cleared. This applies to options 9, 11, 12 and 13.

3.2 Long-List to Short-List Options

3.2.1 Initial Short-List Options

Criteria were developed to assess the long-list options, with the objective of creating a credible short-list.

The assessment criteria were based on the EA CRE objective. A set of questions around the CRE objective were developed as in Table 2.

Table 2 – Long-list to Short-list Assessment Criteria

Criteria	Questions Asked
Reliability	At what level does this option ensure reliability and resilience to the levels required in a cost-effective manner?
Efficiency	Are the benefits for this option greater than the benefits of the current baseline for the participants?
	Will this option simplify SO operations and easily facilitate changes long term?
	What is the time/effort/risk associated with implementing this option?
Competition	Will this option reduce the barriers to entry for participants? (Minimise the limitations to participation)
	Will this option incentivise participants to compete?

Representatives from the SO's Market, Operations, Business and Engineering groups individually rated the options against the assessment criteria, using a scale of 1 (does not meet the criteria) to 10 (fully meets the criteria). This assessment assumed that all questions were of equal importance.

The individual scores for each question were averaged with any scores outside a four point range omitted. The scores are provided in Appendix A.

Options 8, 12, 11 and 13 received the highest scores and were confirmed as credible short-list options. Options 3, 4, 5 and 6 scored the lowest scores and it was agreed that these options should be rejected. A sanity check was then performed on the remaining options to see which, if any, of these options should be considered for the short-list. It was agreed that options 9 and 14 offered diversity and could also be considered as credible short-list options.

A summary of the initial short-listed options is given in Table 3.

Table 3: Initial Short-listed Options

Option #	Description of long-list options considered	Shortlisted ✗ ✓	Comments
8	Governor response with actual compensation	✓	This option was included in the short-list because it rated high on competition, removing all barriers to entry and incentivising generators to compete.
12	National market: national frequency keeping selection, with co-optimisation	✓	This option was included in the short-list as it rated high on competition and efficiency compared to other options and utilises existing frequency keeping mechanisms reducing the risk and effort to implement.
11	National market: national frequency keeping selection, without co-optimisation	✓	This option was included in the short-list as it rated high on competition and efficiency compared to other options and utilises existing frequency keeping mechanisms reducing the cost, risk and effort to implement.
13	National market: national frequency keeping selection with compensation for governor response (hybrid)	✓	This option was included in the short-list as it rated high on competition and reliability and utilises existing frequency keeping mechanisms while compensating for governor response.
9	National market: governor response based on target frequency	**Possible** ✓	This option rated 8th out of the 15 options but was considered a possible to include in the short-list as an alternative to option 12.
14	Automatic Generator Control	**Possible** ✓	This option rated 9th out of the 15 options but was considered a possible to include in the short-list as it has been suggested by the industry as a potential option as it increases the response time of the frequency keeper.
1	Multiple frequency keepers in each island (status quo)	✗	This option was rejected because if multiple frequency keeping is to be the future solution it would, at a minimum, be implemented in the form of a national market without co-optimisation (option 11) or national market with co-optimisation (option 12) to maximise efficiency and competition.
2	Multiple frequency keepers in each island with frequency keeping bands swapped between islands	✗	This option was rejected because if multiple frequency keeping is to be the future solution it would, at a minimum, be implemented in the form of a national market without co-optimisation (option 11) or national market with co-optimisation (option 12) to maximise efficiency and competition.

Option #	Description of long-list options considered	Shortlisted ✗✓	Comments
10	Multiple frequency keepers in each island with variable frequency keeping bands based on operating conditions	✗	This option was rejected because if multiple frequency keeping is to be the future solution it would, at a minimum, be implemented in the form of a national market without co-optimisation (option 11) or national market with co-optimisation (option 12) to maximise efficiency and competition.
3	Single frequency keeper in either the North or South Island	✗	This option was rejected because single frequency keeping does not promote competition or efficiency which are requirements for a future solution.
4	Single frequency keeper in the South Island only	✗	This option was rejected because single frequency keeping does not promote competition or efficiency which are requirements for a future solution.
15	Governor and energy storage response with compensation	✗	This option was rejected because, though it allows other forms of energy storage technology to participate, it does not promote competition or efficiency above the other options.
7	Governor response with estimate compensation	✗	This option was rejected because if governor response is to be the future solution then actual compensation (option 8) provides higher efficiency and competition than this option.
5	Governor response with no compensation	✗	This option was rejected because if governor response is to be the future solution then actual compensation (option 8) provides higher efficiency and competition than this option.
6	Governor response mandated	✗	This option was rejected because mandating governor response is a ‘negative’ mechanism and would not promote competition.

3.2.2 Final Short-List Options

The initial short-list was presented to the EA and SO management for review and comment before proceeding to the detailed assessment.

As a result of this discussion the following was agreed:

a. Short-listed options 8, 12, 11 and 13 are feasible options for the detailed assessment.

b. Short-listed option 8 should be broadened to encompass any form of compensation rather than being specific to 'actual' compensation. It may be difficult to achieve actual compensation and therefore this option should be evaluated on the merit of providing compensation, be it actual or estimate. This option, as a result, now encompasses option 7.

c. Rejected options 9 and 14, suggested as possible short-listed options, remain rejected. These options rated low when compared to the other options and are not, realistically, feasible contenders.

    i. Option 14 was considered when MFK was selected. It was rejected at that point due to implementation cost; block dispatch in its current form being incompatible with AGC; and reluctance by participants to allow direct control of generator governors. These reasons are still valid.

    ii. Option 9 was rejected because generators would be required to change the physical control settings of governors to enable them to match target frequency every trading period. This would come at a significant cost.

d. Rejected option 15, governor response and energy storage response, may have merit as incorporating other energy storage technologies is a feasible future strategy. However, a separate option is not needed and the 'energy storage' consideration can be evaluated as part of option 8. The title 'governor response' should be changed to 'control response' to incorporate the use of governor response and/or any energy storage technology that is constantly varied by a proportional integral controller.

Based on the above the revised final short-listed options are given in Table 4.

Table 4: Final Short-listed Options

Option #	Description of long-list options considered	Shortlisted ✗ ✓	Comments
8, 7	Control response with compensation (changed - refer a, b, d in section 3.2.2)	✓	This option was included in the short-list because it rated high on competition, removing all barriers to entry and incentivising generators to compete.
12	National market: national frequency keeping selection with co-optimisation	✓	This option was included in the short-list as it rated high on competition and efficiency compared to other options and utilises existing frequency keeping mechanisms reducing the risk and effort to implement.
11	National market: national frequency keeping selection without co-optimisation	✓	This option was included in the short-list as it rated high on competition and efficiency compared to other options and utilises existing frequency keeping mechanisms reducing the risk and effort to implement.
13	National market: national frequency keeping selection with compensation for control response (hybrid) (changed - refer d in section 3.2.2)	✓	This option was included in the short-list as it rated high on competition and reliability and utilises existing frequency keeping mechanisms while compensating for control response.
9	National market: governor response based on target frequency	✗	This option was rejected because there is a restricted market for frequency due to the inability of a number of generators to adjust their governors to match target frequency every trading period.
14	Automatic Generator Control (AGC)	✗	This option was rejected as it was evaluated at the time MFK was implemented and it is not a cost feasible option.
Other Options	As per the details in table 3. No changes.	✗	As per the details in table 3. No changes.

4 Detailed Assessment Criteria

Based on the findings published in the FKC Technical Report issued 12 June 2015, a set of technical, operational and market criteria were established against which the short-listed future solution options were evaluated. The criteria and an objective for each criterion that a future solution should meet are detailed below. Acknowledgement is given to the FKC Technical Report for the majority of the information provided.

4.1 Technical Criteria

4.1.1 Normal Frequency Band

T1: The future solution maintains frequency in the normal band.

Part 7 of the Electricity Industry Participation Code 2010 (the Code) outlines the principal performance obligations (PPO's) the SO must meet with regard to frequency. The SO must maintain frequency in the normal band which is defined as a frequency band between 49.8 Hz and 50.2 Hz.

4.1.2 Time Error

T2: The future solution maintains time error within the required limits of +/- 5 seconds.

Part 7 of the Code outlines the PPO's the SO must meet with regards to frequency time error. The SO must ensure frequency time error is not greater than 5 seconds of New Zealand standard time and ensure that at least once every day the frequency time error is eliminated. It is noted that the SO interprets the time error to be +/- 5 seconds.

Currently to maintain time error within the limits of +/- 5 seconds, system co-ordinators use a combination of MFK and manual dispatch, as follows:

- adjust the target frequency in MFK controls. This is to reduce positive or negative time error over time as the MFK controller drives to a frequency slightly higher or lower than the standard frequency of 50 Hz for both islands
- manually dispatch to correct time error. System co-ordinators can use adjustments to the actual load forecast (pre-solve deviation) for the next real-time dispatch solution to reduce time error in both islands.

4.1.3 Frequency Keeping Back-Up

T3: The future solution has a suitable frequency keeping back-up.

The SO currently procures back-up single frequency keeping (SFK) ancillary service to maintain PPOs should MFK fail.

4.1.4 Quality of Frequency Control

T4: The future solution maintains the quality of frequency control in the normal frequency range.

In this criterion "quality" refers to the extent of variation within the normal frequency band. Based on this definition, an option that allows the frequency to vary within a range of 49.85 to 50.15 Hz would have a lower quality frequency than an option that maintained frequency within the range of 49.9 to 50.1 Hz. For each of the short-listed options this criterion has been evaluated in two ways:

1. Qualitatively, based on assumptions about the risk of more generators introducing deadbands. See the 'Criteria Evaluation' table for each option.
2. Quantitatively, using the three performance benchmark metrics that were defined in Phase 1 of this TASC and for which values were calculated using historical SFK data.[2] Refer to section 5.6 for this benchmark evaluation.

4.2 Operational Criteria

4.2.1 Augmented Dispatch Mode

O1: The future solution supports augmented dispatch[3] and minimises manual dispatch calculations.

Under the current operating conditions with FKC, co-ordinators are required to manually dispatch so as to take into account the input variables of:

- HVDC off dispatch. The difference between the actual HVDC transfer and its dispatched transfer.
- Responsive generators off dispatch. The sum of the differences between actual generator active power and generator dispatched active power.

This leads to extra work for system co-ordinators who must issue dispatches manually which erodes situational awareness.

This issue will be addressed by the Security Tools Project which will enable better control of input variables in the market system allowing automatic calculation of dispatch quantities. The effect of these new inputs on the dispatch quantity is not proportional and some tuning will be required. Until the market system is tested with these new inputs, it is uncertain whether the tuning will successfully enable augmented dispatch.

4.2.2 Activation and Deactivation of FKC

O2: The future solution does not complicate the business process and market system tools used to activate and deactivate FKC.

Under the current operating conditions there are temporary operational procedures to manage the enabling and disabling of FKC. These procedures are complicated and onerous with an ongoing risk for errors. The process has 15 manual steps and takes three system co-ordinators up to 20 minutes to complete.

Completion of the Security Tools project will bring some reduction in the time to complete the processes. The project will make transitions to and from FKC operations easier and less prone to manual errors. The improvements however, may not sufficiently reduce the time taken to stop and start FKC and the lengthy process is a risk to prudent operation of the electricity system.

Activation and deactivation of FKC will need to be reviewed to determine how the business process and tools can be simplified to reduce the manual workload.

[2] See report: 'TASC 49 – Normal Frequency Management Strategy, Phase 1: Performance Benchmarks – Benchmark Values for Evaluating Frequency Management Options', 31 July 2015.

[3] Augmented dispatch is a combination of co-ordinator dispatch actions using automated calculations of dispatch quantities and automatic sending of dispatch instructions.

4.2.3 FKC Exit Conditions

O3: The future solution does not introduce any new FKC exit conditions or increases the probability of an existing FKC exit condition occurring.

It is desirable for FKC to remain in operation and deactivation of FKC should be minimised. FKC is currently deactivated for the following conditions:

a. loss of communications between MFK controller and generator local control systems

b. high HVDC transfer north or south (HVDC power limit, less margin)

c. bipole outage or trip

d. monopole outage or trip

e. RP unavailable (reclose blocks)

f. system security issue identified or major system event occurs.

It is noted that exit conditions b, d and e will disappear when the Security Tools project is implemented. However, if RP is unavailable FKC will be disabled when the market system wants to dispatch the HVDC to below the bipole minimum.

4.2.4 Transition to Frequency Keeping Back Up

O4: The future solution supports a simple transition to the frequency keeping back-up when the primary frequency keeping service fails.

As noted in section 4.1.3, the SO currently procures back-up SFK to maintain PPOs should MFK fail. As the back-up frequency keeping service is required quickly when MFK fails, it is important to have a process that allows the transition to the back-up to happen quickly and easily.

4.2.5 Future Dispatch Strategy

O5: The future solution minimises manual dispatch work for the system co-ordinators.

The National Coordination Centre in the SO is currently defining a strategy and vision for the future of the dispatch function. This strategy will encapsulate the tools and processes used in the dispatch function with an aim to drive effectiveness and efficiency. The strategy will focus on efficiency gains through elimination of unnecessary tasks and optimising primary and back-up processes and tools. This objective, while similar to O1, is included to ensure any future solution aligns with the National Co-ordination Centre dispatch strategy.

4.3 Market Criteria

4.3.1 Frequency Keeping Payments & Barriers to Entry

M1: The future solution effectively compensates those providing frequency management in the normal frequency band.

M2: The future solution minimises barriers to entry for providing frequency management services in the normal frequency band.

FKC operation has allowed frequency keeping services purchased to be reduced from 75 MW to 30 MW. It is estimated that a saving of $25 million per annum may be realised through the reduced frequency keeping services procured. However, the current frequency keeping payments do not consider the additional cost to generators due to increased governor action.

As discussed in section 2.3, it is necessary, and prudent, to look at options that compensate generators for governor action with more of the frequency keeping effort moving from contracted frequency keeping providers to inherent governor response.

4.3.2 Market Information

M3: The future solution enables information to be provided to frequency keeping providers to inform frequency keeping decisions.

Frequency keeping information is currently published in forward looking schedules. Any option has to be able to ensure the right information can be provided to frequency keeping providers to inform frequency keeping decisions.

4.3.3 Compliance

M4: The future solution supports a simple process for measuring and assessing frequency keeping performance that can be translated easily into clear compliance metrics.

Frequency keeping compliance is currently managed through the Code, the Policy Statement, the Procurement Plan and ancillary service procurement contracts.

With MFK, the SO initially reported frequency keeping performance using the Regulation Instruction Error Ratio (RIER). The RIER is specified as one of the frequency keeping performance measures in the ancillary service procurement contracts. The lower the RIER figure the better the frequency keeping provider is judged to have performed.

However, the RIER does not take into account unit governor response to system frequency. When FKC is enabled the RIER results for many frequency keeping providers vary widely between months and variations are particularly pronounced in the South Island, due to the greater deviations from MFK regulation caused by the frequency response of generating units during FKC operation.

As a result, the SO no longer has confidence the RIER metric provides a meaningful indication of the quality of the frequency keeping service provided. RIER performance reporting has been suspended while the work progresses on future solutions for normal frequency management.

5 Detailed Assessment of Short-list Options

From section 3.2.2 there were four short-listed options – options 8, 12, 11 and 13. As option 13 had two variations (option 12 with compensation and option 11 with compensation) this was separated out to provide five options for assessment against the criteria objectives. The assessment for each option is given in sections 5.1 to 5.5.

For each option a qualitative assessment of how well the option meets each criteria objective was undertaken. Where the option did not align with the criteria objective, the work required to align was discussed and documented. A summary of the perceived benefits versus costs for each option was then documented along with any risks associated with the option.

5.1 Option 8 – Control response with Compensation

5.1.1 Option Conditions

- ✓ **FKC enabled –** Links the two island frequencies together, enabling governors in each island to respond to frequency changes in the other island. Currently, FKC trials have shown that the South Island governors are correcting frequency deviations in the North Island because the majority of fast-acting governors are in the South Island and the largest load changes are in the North Island. Note: the North Island and South Island frequencies are similar, but not precisely synchronised due to latency in the FKC control system with the North Island having more variation than the South Island.
- ✗ **MFK enabled** – No frequency keeping is procured. There is no frequency keeping market as frequency control is provided by governor response and energy storage response.
- ✗ **Frequency keeping procurement costs** – There is no frequency keeping market so frequency keeping procurement costs are not applicable.
- ✗ **Frequency keeping co-optimised with energy and reserves** – There is no frequency keeping market so frequency keeping co-optimised with energy and reserves is not applicable.
- ✓ **Control response** – Frequency control in the normal frequency band managed by governor response and energy storage response.
- ✓ **Control response compensation** – Governor response and energy storage response in the normal frequency band would be compensated.

5.1.2 Criteria Evaluation

Table 6 summarises the assessment of the **control response with compensation** option against the criterion objectives.

Table 6: Option 8, Control response with Compensation

Cat.	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
T1	The FS maintains frequency in the normal band.	Yes	Normal frequency would be maintained through control response.	No further work is required.
T2	The FS maintains time error within the required limits of +/- 5 seconds.	Maybe	During the FKC trial, time error deviation increased when tests were run with MFK = 0 MW. Though time error was still within the PPO limits, this was managed mainly through manual dispatch. Manual dispatch to manage time error is not a viable long-term option.	The Security Tools project is expected to deliver dispatch automation, supported by some fine tuning testing later in the year, which will allow time error to be managed effectively. Depending on the outcome from this project, increased dispatch support may be needed to allow automatic correction for time error in the formulation of dispatch instructions.
T3	The FS has a suitable frequency keeping back-up.	Maybe	A backup of MFK/SFK is likely to be required, at least in the South Island, if FKC is disabled. However, it is possible control response in each island could continue to be used to manage frequency, along with increased dispatch, at least for a short duration.	Further work is required to investigate frequency control when FKC is disabled using island control response compared with MFK compared with SFK.
T4	The FS maintains the quality of frequency control in the normal frequency band.	Partial	Quality of North Island frequency control will be maintained. Quality of South Island frequency control will marginally deteriorate due to FKC-enabled cross-HVDC governor response. All short-listed options are expected to produce similar quality of frequency control. Refer to section 5.6 for details of the benchmark analysis. Quality is primarily determined by factors such as load behaviour and type of frequency keeping generation, and secondarily affected by the frequency keeping solution.	No further work is required.
O1	The FS supports augmented dispatch and minimises manual dispatch calculations.	Maybe	During the FKC trial the HVDC was off dispatch more when tests were run with MFK = 0 MW than with MFK = 30 MW. However, as co-ordinators became more familiar with dispatching in this scenario results improved.	The Security Tools project is expected to allow a return to augmented dispatch calculations. Depending on the outcome from Security Tools, increased dispatch support may be needed as per T2.
O2	The FS does not complicate the business process and market system tools used to activate and deactivate	Maybe	Meeting this objective depends on the frequency keeping back-up implemented as per O4.	Dependent on O4.

Cat.	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
	FKC.			
O3	The FS does not introduce any new FKC exit conditions or increases the probability of an existing FKC exit condition occurring.	Yes	No new FKC exit conditions introduced.	No further work is required.
O4	The FS supports a simple transition to the frequency keeping back-up when the primary frequency keeping service fails.	Maybe	Meeting this objective depends on the frequency keeping back-up implemented. As discussed in T3, it may be possible to control frequency using the control response in each island. If this is the case no transition process is required. However, if MFK or SFK is required then the process will be more complex than current state.	Dependent on T3.
O5	The FS minimises manual dispatch work for the system co-ordinators.	Maybe	During the FKC trial a 6% increase in manual dispatches over a week were noted. This increased the workload for co-ordinators encroaching on the time co-ordinators have to spend on other system and market issues.	The Security Tools project is expected to deliver dispatch automation, supported by some fine tuning testing later in the year that will allow a return to augmented dispatch calculations. Depending on the outcome from this project, increased dispatch support may be needed as per T2.
M1	The FS effectively compensates those providing frequency management in the normal frequency band.	Maybe	Meeting this objective depends on the compensation scheme implemented and achieving the correct balance of efficiency, reward of contribution and recovery of costs.	Further work is required to investigate the compensation scheme that will ensure effective payment for frequency management using control response.
M2	The FS minimises barriers to entry for providing frequency management in the normal frequency band.	Maybe	While this option has no set-up barriers to entry, because it is based on control response, encouraging participants to use control response to enhance performance depends on the compensation scheme implemented. Compliance testing may be a barrier to entry and consideration needs to be given to testing requirements for new participants that will ensure compliance while encouraging participation. At the moment the set-up for control response is expected to be the same as reserves.	Dependent on M1.
M3	The FS enables information to be provided to frequency keeping providers to inform frequency keeping decisions.	Yes	This is not a market option so there is no information that needs to be published in the forward looking schedules. Information around how the compensation scheme works and testing conditions would be required. If a frequency keeping back-up of MFK/SFK is required, information would need to be published to the market. These mechanisms are already in place.	No further work is required.

Cat.	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
M4	The FS supports a simple process for measuring and assessing frequency keeping performance that can be translated easily into clear compliance metrics.	Maybe	Meeting this objective depends on the compensation scheme implemented. The frequency performance measure could be more complex as SO would have to assess all responses in the normal frequency band. However, the compensation scheme should be designed to allow performance information to be extracted from the compensation calculations.	Dependent on M1 and once the compensation scheme is known, designing the performance measure upfront.

5.1.3 Benefits/Costs

The key benefit of option 8 is that it incentivises generators to continue providing the current level of governor response in the normal frequency band. This minimises the risk of generators introducing deadbands and a material drop in the quality of frequency control in the normal frequency range. It is also expected that this option will provide a reduction in frequency keeping costs (since no MFK is procured) but achieving this benefit is dependent on the cost of the compensation scheme.

The costs for option 8 are as yet unknown. The requirements for implementing this option are:

- changes to the Code to accommodate the frequency keeping provisions. Once approved, the SO will need to redraft the Procurement Plan and the associated ancillary service procurement contracts to align with the Code changes
- changes to the ancillary service procurement contracts to introduce a new performance measure for control response
- new basis for managing frequency based on control response. This will involve changing all business processes to reflect the new state and implementing a compensation scheme and associated monitoring
- changes (if any) to market system to accommodate any changes required to support the final compensation scheme. A compensation scheme based on actual response versus estimated response seems likely to require market system changes
- depending on outcome from the Security Tools project, increased dispatch support may be needed to allow automatic correction for time error in the formulation of dispatch instructions.

Option 8 appears relatively simple in terms of system operation (i.e. no frequency keeping market) but has unknown complexity around the form and operation of the compensation scheme. A cost benefit analysis will be required to enable full merit assessment.

5.1.4 Risks

1. **Time Error –** Time error is currently difficult to manage when MFK is not operating. It is expected that the augmented dispatch provided by the Security Tools project will effectively manage time error. The expected improvements are:
    - including a proportion of the difference between the HVDC transfer and the HVDC dispatch set point and a time error factor in the dispatch algorithm
    - enhanced charts including generator governor response and HVDC off dispatch trending (improving situational awareness).

    However, there is a risk the new functionality will be insufficient to control time error within the current time error PPOs requirements and new functionality or a revision of time error PPO will be needed.

2. **Compensation scheme -** The compensation scheme would need to be discussed with industry to determine an amount that all parties believe adequately and reasonably compensates the 'costs' of providing control response for normal frequency management.

   Compensation based on actual generator response measurements would be preferred but is the most complex. There are also a number of operating variants that would need to be considered for a compensation scheme, including how to compensate plant in dry years.

   There is a risk that:

   - the time and effort required to conduct the consultation and agree a compensation scheme will be protracted and fail to reach industry agreement
   - a poorly designed scheme will not encourage compliance; if compensation is not regarded as sufficient generators may introduce governor deadbands, reducing frequency keeping quality
   - the scheme is more expensive than current frequency management arrangements.

   This option poses a new basis for managing frequency that is completely different to current state. Compensating generators to encourage them not to implement deadbands is a relevant consideration of this option. Achieving this behavior is dependent on the compensation scheme and there is a risk the nature of the scheme would not drive the required behavior.

   There is a risk that conceptually the control response option appears to deliver frequency keeping for least cost but may not actually achieve this, once the overall costs of a compensation scheme and ongoing management are taken into account. A proof of concept may need to be evaluated to test the feasibility of this option.

3. **System Stability** – To maintain stable governor action between different generators the system operator requires governors to set their governor control parameters to meet prescribed stability criteria.[4]

   This requirement successfully ensures stable governor interaction on the system for both large and small frequency fluctuations.

   If the stability criteria were relaxed in the future and there was an increase in the number of governors without deadbands due to compensation arrangements, then there may be a risk to system frequency stability. Full technical analysis of any such relaxation must be undertaken to avoid this outcome.

[4] Page 53 of the document https://www.systemoperator.co.nz/sites/default/files/bulk-upload/documents/GL-EA-010_Companion%20Guide%20for%20Testing%20of%20Assets.pdf

4. **Frequency Keeping Back-Up –** Under this option when FKC is enabled, control response is expected to be sufficient to control frequency in the normal band. However, when FKC is disabled it is unknown how frequency keeping will be managed. There is a risk that transition from control response to the frequency keeping back-up will be complex and time-consuming for system co-ordinators, increasing their manual workload (contrary to the NCC dispatch vision).
5. **No Frequency Keeping Market –** This option would end the frequency keeping market which may appear inconsistent with the CRE objective. There is a risk, depending on the compensation scheme agreed, that this option will fail to deliver an efficient economic outcome in the absence of a real market. It is also unknown how many generators would receive compensation as this would depend on the nature of the compensation scheme, though it is expected the scheme would see the larger players receive the majority of the compensation.
6. **Compliance –** This option is a new basis for managing frequency. There is a risk that the compliance measures for control response will be more complex to implement than expected, increasing the expected level of change required to the Code, Procurement Plan and ancillary service procurement contracts.

5.2 Option 12 - National Market: National Frequency Keeping Selection with Co-Optimisation

5.2.1 Option Conditions

- ✓ **FKC enabled** – FKC enabled allows frequency keepers to be selected on a national basis. When FKC is disabled, selection would revert to island-based.
- ✓ **MFK enabled** - Frequency keeping procured from a national market. A national market allows the lowest cost providers to be selected from across both islands.
- ✓ **Frequency keeping procurement costs** - Generators are paid the cleared offer price for all trading periods when selected as a frequency keeper. It is expected the offer structure would change under this option, to allow partial band clearance.
- ✓ **Frequency keeping co-optimised with energy and reserves** –Frequency keeping would be co-optimised with energy and reserves. This is the key difference between this option and option 11.
- ✓ **Governor response** – Generators would continue to provide governor response in the normal frequency band.
- ✗ **Governor response compensation** – There would be no compensation for generators providing governor response in the normal frequency band.

5.2.2 Criteria Evaluation

Table 7 summarises the assessment of the **national market: national frequency keeping selection with co-optimisation** option against the criterion objectives.

Table 7: Option 12, National Market: National Frequency Keeping Selection with Co-optimisation

Cat	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
T1	The FS maintains frequency in the normal band.	Maybe	As generators are not being compensated for governor response they may use deadbands to dampen frequency response and minimise plant wear and tear. Deadbands may proliferate over time (if not managed by AOPO requirements) reducing the frequency response in the normal band.	Further work is required to investigate the impact of deadbands on the normal frequency band and at what level deadbands would pose a security risk.
T2	The FS maintains time error within the required limits of +/- 5 seconds.	Yes	With FKC enabled, MFK is no longer being used to correct frequency but is solely being used to correct time error. MFK is therefore primarily about control of time error.	No further work is required.
T3	The FS has a suitable frequency keeping back-up.	Yes	The existing mechanism of back-up SFK can be used as now. However, the question was raised whether any back up is needed or whether governor response could be used for the periods when FKC and/or MFK is down. SFK was only ever intended to be a temporary back-up until the reliability of MFK was proven.	Further work is required to investigate frequency control when FKC is disabled using island governor response compared with MFK, compared with SFK.
T4	The FS maintains the quality of frequency control in the normal frequency band	Maybe	Generators may use deadbands to dampen frequency response and minimise plant wear and tear. Other generator units would therefore have to work harder to provide the required response. Quality of North Island frequency control will be maintained. Quality of South Island frequency control will marginally deteriorate due to FKC-enabled cross-HVDC governor response. All short-listed options are generally expected to produce similar quality of frequency control. However, the level of quality is unknown for the scenario when the national market sources frequency keeping from only one island. Refer to section 5.6 for details of the benchmark analysis. Quality is primarily determined by factors such as load behaviour and type of frequency keeping generation, and secondarily affected by the frequency keeping solution.	Depending on the outcome of T1, further work may be required to mandate some minimum governor response levels in the PPO's. Further work may be required to mandate some minimum frequency keeping performance levels in the PPO's

Cat	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
O1	The FS supports augmented dispatch and minimises manual dispatch calculations.	Maybe	The Security Tools project is expected to allow a return to augmented dispatch calculations.	Evaluate after the Security Tools project goes live. Depending on the outcome increased dispatch support may be needed but this will be less work than is required for the control response option.
O2	The FS does not complicate the business process and market system tools used to activate and deactivate FKC.	No	When FKC is activated, a national co-optimised market will operate. When FKC is deactivated the market would revert to co-optimised island selection. This would make activating and deactivating FKC more complex from a system perspective.	Further work is required to investigate how the transition from national co-optimised to island co-optimised would work with FKC.
O3	The FS does not introduce any new FKC exit conditions or increases the probability of an existing FKC exit condition occurring.	Yes	No new FKC exit conditions introduced. It is noted that loss of MFK communications, previously an exit condition, has been removed as an exit condition.	Update the procedures to remove MFK communications as an FKC exit condition. (This is planned to be done as part of the Security Tools Project procedure updates.)
O4	The FS supports a simple transition to the frequency keeping back-up when the primary frequency keeping service fails.	Maybe	Meeting this objective depends on the frequency keeping back-up implemented. As discussed in T3, it is possible to use SFK island but would require tool and business process changes to go from MFK national/island to SFK national/island. The process would be more complicated than the current state.	Dependent on T3 and O2.
O5	The FS minimises manual dispatch work for the system co-ordinators	Maybe	The Security Tools project is expected to allow a return to augmented dispatch calculations.	Dependent on O1 and O4.
M1	The FS effectively compensates those providing frequency management in the normal frequency band.	Maybe	The frequency keeping payments to MFK providers would be more efficient as frequency keeping is being co-optimised with energy and reserves. However, this option would not compensate generators for governor response.	Further work is required to determine the economic benefit of co-optimisation vs the risk of deadbands and a material drop in the quality of frequency control in the normal frequency range.
M2	The FS minimises barriers to entry for providing frequency management services in the normal frequency band.	Yes	Allows clearance of partial bands so increases participation, but participants would still require MFK systems. Co-optimisation would enable participants to better understand whole market impact including energy, reserves and frequency keeping as compared to current state.	No further work is required.
M3	The FS enables information to be provided to frequency keeping providers to inform frequency keeping decisions.	Yes	Information is published to the market now for MFK so these mechanisms are already in place. Some changes would be required to accommodate national information.	No further work is required.
M4	The FS supports a simple process for measuring and assessing frequency	No	Meeting this objective depends on the performance measure. RIER does not currently work so new	Further work is required to investigate options for measuring frequency keeping performance of individual

Cat	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
	keeping performance that can be translated easily into clear compliance metrics.		performance measurements for individual generators are needed.	generators when operating MFK.

5.2.3 Benefits/Costs

The key benefit of option 12 is that it co-optimises frequency keeping with energy and reserves to provide a more efficient economic outcome than the current state. It also controls time error, effectively minimising dispatch workload for system co-ordinators.

The costs of option 12 have previously been documented in TASC41: National Frequency Keeping Market. The requirements for implementing this option are:

- changes to the Code to accommodate the frequency keeping provisions. Once approved, the SO will need to redraft the Procurement Plan and the associated ancillary service procurement contracts to align with the Code changes
- changes to the frequency keeping offer form to allow part bands to be cleared. This will require changes across the generators, NZX and the SO to implement the new offer form
- changes to the market system to enable a national operating mode, allow frequency keeping offers to be selected nationally, allow frequency keeping constrained on/off calculations for clearing partial bands and co-optimise frequency keeping with energy and reserves
- changes to the ancillary service procurement contracts to introduce a new performance measure for frequency keeping and consider how the compliance standard accounts for governor action and deadbands.

Option 12 introduces a level of complexity into the market system that may not be warranted given MFK is largely providing a time error service. However, while the changes may be expensive there are market benefits from co-optimisation and a cost benefit analysis will be required to enable full merit assessment.

5.2.4 Risks

1. **Frequency Quality** – There is a risk that with no compensation for governor response, a high proportion of generators would increase their deadband range. Governor deadband prevents governor action unless the speed change of the governor exceeds the deadband range. Deadbands are installed to prevent governor actuators/control valves working for continuous small speed changes. Additional deadbands may lead to a material drop in the quality of frequency keeping in the normal frequency range. In turn this may require purchase of additional under- and over-frequency reserves and a return to a larger frequency keeping band.
2. **Frequency Keeping Back-Up** – There is a risk the currently accepted frequency keeping back-up arrangements (SFK) would, by default, be kept as a back-up when it is not needed. Back-up may be sufficiently provided by governor response. Depending on the frequency keeping back-up selected there is a risk that the process to transition to the back-up will be difficult and time-consuming for the system co-ordinators, increasing their manual workload.
3. **Compliance –** There is a risk that developing an efficient performance measure for frequency keeping compliance may be difficult and that the correct measure may be impractical to implement. This may lead to an

ineffective performance measure being implemented leading to an inability to accurately monitor frequency quality.

4. **Competitive Market –** There is a risk this option would not increase market competition. While co-optimising frequency with energy and reserves would achieve a more efficient economic outcome than current state it would not necessarily increase market competition as participants would require MFK-capable systems, which may be a barrier to entry.

5.3 Option 11 – National Market: National Frequency Keeping Selection without Co-optimisation

5.3.1 Option Conditions

- ✓ **FKC enabled** – FKC enabled allows frequency keepers to be selected on a national basis. When FKC is disabled, selection would revert to island-based.
- ✓ **MFK enabled** - Frequency keeping is procured from a national market. A national market allows the lowest cost providers to be selected from across both islands.
- ✓ **Frequency keeping procurement costs** - Generators are paid the cleared offer price for all trading periods when selected as a frequency keeper. It is expected the offer structure would change under this option to allow partial band clearance.
- ✗ **Frequency keeping co-optimised with energy and reserves** – While frequency keepers would be selected on a national basis, frequency keeping would not be co-optimised with energy and reserves. This is the key difference between this option and option 12.
- ✓ **Governor response –** Generators would continue to provide governor response in the normal frequency band.
- ✗ **Governor response compensation** – There would be no compensation for generators providing governor response in the normal frequency band

5.3.2 Criteria Evaluation

Table 8 summarises the assessment of the **national market: national frequency keeping selection without co-optimisation** option against the criterion objectives. As this option is similar to Option 12, responses that are the same as option 12 have been noted in the rationale as 'same', while the responses that are different to option 12 have been noted as 'different'.

Table 8: Option 11, National Market: National Frequency Keeping Selection without Co-optimisation

Cat	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
T1	The FS maintains frequency in the normal band.	Maybe	As generators are not being compensated for governor response they may use deadbands to dampen frequency response and minimise plant wear and tear. Deadbands may proliferate over time (if not managed by AOPO requirements) reducing the frequency response in the normal band. (Same)	Further work is required to investigate the impact of deadbands on the normal frequency band and at what level deadbands would pose a security risk.
T2	The FS maintains time error within the required limits of +/- 5 seconds.	Yes	With FKC enabled, MFK is no longer being used to correct frequency but is solely being used to correct time error. MFK is therefore primarily about control of time error. (Same)	No further work is required.
T3	The FS has a suitable frequency keeping back-up.	Yes	The existing mechanism of back-up SFK can be used as now. However, the question was raised whether any back up is needed or whether governor response could be used for the periods when FKC and/or MFK is down. SFK was only ever intended to be a temporary back-up until the reliability of MFK was proven. (Same)	Further work is required to investigate frequency control when FKC is disabled using island governor response compared with MFK, compared with SFK.
T4	The FS maintains the quality of frequency control in the normal frequency band	Maybe	Generators may use deadbands to dampen frequency response and minimise plant wear and tear. Other generator units would therefore have to work harder to provide the required response. Quality of North Island frequency control will be maintained. Quality of South Island frequency control will marginally deteriorate due to FKC-enabled cross-HVDC governor response. All short-listed options are generally expected to produce similar quality of frequency control. However, the level of quality is unknown for the scenario when the national market sources frequency keeping from only one island. Refer to section 5.6 for details of the benchmark analysis. Quality is primarily determined by factors such as load behaviour and type of frequency	Depending on the outcome of T1, further work may be required to mandate some minimum governor response levels in the PPO's. Further work may be required to mandate some minimum frequency keeping performance levels in the PPO's.

Cat	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
			keeping generation, and secondarily affected by the frequency keeping solution (Same)	
O1	The FS supports augmented dispatch and minimises manual dispatch calculations.	Maybe	The Security Tools project is expected to allow a return to augmented dispatch calculations. (Same)	Evaluate after the Security Tools project goes live. Depending on the outcome increased dispatch support may be needed but this will be less work than is required for the control response option.
O2	The FS does not complicate the business process and market system tools used to activate and deactivate FKC.	No	When FKC is activated, a national market would operate. When FKC is deactivated the market would revert to island selection. This will make activating and deactivating FKC more complex from a systems perspective. This option however is less complex than option 12 as there is no co-optimisation. (Different)	Further work is required to investigate how the transition from national to island would work with FKC.
O3	The FS does not introduce any new FKC exit conditions or increases the probability of an existing FKC exit condition occurring.	Yes	No new FKC exit conditions introduced. It is noted that loss of MFK communications, previously an exit condition, has been removed. (Same)	Update the procedures to remove MFK communications as an FKC exit condition. (This is planned to be done as part of the Security Tools Project procedure updates.)
O4	The FS supports a simple transition to the frequency keeping back-up when the primary frequency keeping service fails.	Maybe	Meeting this objective depends on the frequency keeping back-up implemented. As discussed in T3, it is possible to use SFK island but would require tool and business process changes to go from MFK national/island to SFK national/island. The process would be more complicated than the current state but less complex than option 12 as there is no co-optimisation. (Different)	Dependent on T3 and O2.
O5	The FS minimises manual dispatch work for the system co-ordinators	Maybe	The Security Tools project is expected to allow a return to augmented dispatch calculations. (Same)	Dependent on O1 and O4.
M1	The FS effectively compensates those providing frequency management in the normal frequency band.	Maybe	The frequency keeping payments to MFK providers would be more efficient as frequency keeping is being selected nationally. However, this option does not compensate generators for governor response. (Different)	Further work is required to determine the economic benefit of national selection vs the risk of deadbands and a material drop in the quality of frequency control in the normal frequency range.
M2	The FS minimises barriers to entry for providing frequency management services in the normal frequency band.	Yes	Allows clearance of partial bands so increases participation but participants would still require MFK systems. (Different)	No further work is required.
M3	The FS enables information to be provided to frequency keeping providers to inform frequency	Yes	Information is published to the market now for MFK so these mechanisms are already in place. Some changes would be required to accommodate national information. (Same)	No further work is required.

Cat	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
	keeping decisions.			
M4	The FS supports a simple process for measuring and assessing frequency keeping performance that can be translated easily into clear compliance metrics.	No	Meeting this objective depends on the performance measure. RIER does not currently work so new performance measurements for individual generators are needed. (Same)	Further work is required to investigate options for measuring frequency keeping performance of individual generators when operating MFK.

5.3.3 Benefits/Costs

The benefit of option 11 is that it selects the lowest cost frequency keeping providers from across both islands, reducing the overall cost of frequency keeping. It also controls time error, effectively minimising dispatch workload for system co-ordinators.

The costs for option 11 are not yet known. The requirements for implementing this option are:

- changes to the Code to accommodate the frequency keeping provisions. Once approved, the SO will need to redraft the Procurement Plan and the associated ancillary service procurement contracts to align with the Code changes
- changes to the frequency keeping offer form, to allow part bands to be cleared. This will require changes across the generators, NZX and the SO to implement the new offer form
- changes to the market system, to enable a national operating mode, allow frequency keeping offers to be selected nationally and allow frequency keeping constrained on/off calculations for clearing partial bands.
- changes to the ancillary service procurement contracts to introduce a new performance measure for frequency keeping and consider how the compliance standard accounts for governor action and deadbands.

Option 11 introduces less complexity into the market system than option 12, co-optimised, but is expected to achieve lesser benefit. A cost benefit analysis will be required to enable full merit assessment.

5.3.4 Risks

1. **Frequency Quality** – Refer section 5.2.4.
2. **Frequency Keeping Backup** - Refer section 5.2.4.
3. **Compliance –** Refer section 5.2.4.
4. **Competitive Market –** There is a risk this option does not do enough to increase market competition. This option is status quo, with the addition of national frequency keeper selection. However, it is not clear whether this in itself is enough to achieve the most efficient economic outcome. Participants have previously indicated that if a national market is implemented they would prefer a co-optimised solution. Whether this viewpoint has changed, now that MFK is effectively managing time error, would have to be tested.

5.4 Option 13a - National Market: National Frequency Keeping Selection with Co-optimisation; Compensation for Control Response (Hybrid -Options 12 and 8)

5.4.1 Option Conditions

- **FKC enabled** – FKC enabled allows frequency keepers to be selected on a national basis. When FKC is disabled, selection would revert to island-based.
- **MFK enabled** - Frequency keeping is procured from a national market. A national market allows the lowest cost providers to be selected from across both islands.
- **Frequency keeping procurement costs** - Generators are paid the cleared offer price for all trading periods when selected as a frequency keeper. It is expected the offer structure would change under this option to allow partial band clearance.
- **Frequency keeping co-optimised with energy and reserves** –Frequency keeping would be co-optimised with energy and reserves.
- **Control response** – Frequency control in the normal frequency band managed by governor response and/or energy storage response.
- **Control response compensation** – Governor response and/or energy storage response in the normal frequency band would be compensated.

5.4.2 Criteria Evaluation

Table 9 summarises the assessment of the **national market: national frequency keeping with co-optimisation; compensation for control response** option against the criterion objectives. This option is a hybrid of options 12 and 8, previously discussed.

Table 9: Option 13a, National Market: National Frequency Keeping Selection with Co-optimisation; Compensation for Control Response

Cat	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
T1	The FS maintains frequency in the normal band.	Yes	Normal frequency would be maintained through control response.	No further work is required.
T2	The FS maintains time error within the required limits of +/- 5 seconds.	Yes	With FKC enabled, MFK primarily about control of time error.	No further work is required.
T3	The FS has a suitable frequency keeping back-up.	Yes	The existing mechanism of back-up SFK can be used as now. However, the question was raised whether any back up is needed or whether control response could be used for the periods when FKC and/or MFK is down. SFK was only ever intended to be a temporary back-up until the reliability of MFK was proven.	Further work is required to investigate frequency control when FKC is disabled using island control response compared with MFK, compared with SFK.
T4	The FS maintains the quality of frequency control in the normal frequency band.	Maybe	Generators may use deadbands to dampen frequency response and minimise plant wear and tear. Other generator units would therefore have to work harder to provide the required response. Quality of North Island frequency control will be maintained. Quality of South Island frequency control will marginally deteriorate due to FKC-enabled cross-HVDC governor response. All short-listed options are generally expected to produce similar quality of frequency control. However, the level of quality is unknown for the scenario when the national market sources frequency keeping from only one island. Refer to section 5.6 for details of the benchmark work. Quality is primarily determined by factors such as load behaviour and type of frequency keeping generation, and secondarily affected by the frequency keeping solution.	Further work may be required to mandate some minimum frequency keeping performance levels in the PPO's.
O1	The FS supports augmented dispatch and minimises manual	Maybe	The Security Tools project is expected to allow a return to augmented dispatch calculations.	Evaluate after the Security Tools project goes live. Depending on the outcome increased dispatch support

Cat	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
	dispatch calculations.			may be needed.
O2	The FS does not complicate the business process and market system tools used to activate and deactivate FKC.	No	When FKC is activated, a national co-optimised market would operate. When FKC is deactivated the market would revert to co-optimised island selection. This would make activating and deactivating FKC more complex from a systems perspective.	Further work is required to investigate how the transition from national co-optimised to island co-optimised would work with FKC.
O3	The FS does not introduce any new FKC exit conditions or increases the probability of an existing FKC exit condition occurring.	Yes	No new FKC exit conditions introduced. It is noted that loss of MFK communications, previously an exit condition, has been removed. (Same)	Update the procedures to remove MFK communications as an FKC exit condition. (This is planned to be done as part of the Security Tools Project procedure updates.)
O4	The FS supports a simple transition to the frequency keeping back-up when the primary frequency keeping service fails.	Maybe	Meeting this objective depends on the frequency keeping back-up implemented. As discussed in T3, it is possible to use SFK island but would require tool and business process changes to go from MFK national/island to SFK national/island. The process would be more complicated than the current state.	Dependent on T3 and O2.
O5	The FS minimises manual dispatch work for the system co-ordinators	Maybe	The Security Tools project is expected to allow a return to augmented dispatch calculations.	Depending on the outcome from Security Tools, increased dispatch support may be needed as per T2.
M1	The FS effectively compensates those providing frequency management in the normal frequency band.	Maybe	The frequency keeping payments to MFK providers would be more efficient as frequency keeping is being co-optimised with energy and reserves. However, meeting this objective overall depends on the compensation scheme implemented and achieving the correct balance of efficiency, reward of contribution and recovery of costs.	Further work is required to investigate the compensation scheme that will ensure effective payment for frequency keeping service using control response, balanced with the payments to MFK providers.
M2	The FS minimises barriers to entry for providing frequency management services in the normal frequency band.	Maybe	Allows MFK providers, generators with governor response in the normal band, and energy storage technology providers to participate at the level they choose. Allows clearance of partial bands so increases participation, but participants would still require MFK systems. Co-optimisation would enable participants to better understand whole market impact including energy, reserves and frequency keeping as compared to current state. Compliance testing may be a barrier to entry and consideration needs to be given to testing requirements for new participants that would ensure compliance while encouraging participation.	Dependent on M1.
M3	The FS enables information to be	Yes	Information is published to the market now for MFK so these	No further work is required.

Cat	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
	provided to frequency keeping providers to inform frequency keeping decisions.		mechanisms are already in place. Some changes would be required to accommodate national information. Information around how the compensation scheme works and testing conditions would be required.	
M4	The FS supports a simple process for measuring and assessing frequency keeping performance that can be translated easily into clear compliance metrics.	No	This option is the most complex as two performance measures are required. For MFK, RIER does not currently work so new performance measurements for individual generators are needed. For control response, meeting this objective depends on the compensation scheme implemented. The frequency performance measure could be more complex as the SO would have to assess all responses in the normal frequency band. However, the compensation scheme should be designed to allow performance information to be extracted from the compensation calculations.	For MFK, further work is required to investigate options for measuring frequency keeping performance of individual generators when operating MFK. For control response, dependent on M1 and once the compensation scheme is known, designing the performance measure upfront.

5.4.3 Benefits/Costs

The key benefits of this option are:

- incentivises generators to continue providing the current level of governor response in the normal frequency band. This minimises the risk of deadbands and a material drop in the quality of frequency control in the normal frequency range
- co-optimises frequency keeping with energy and reserves assuming the most economic selection of MFK providers
- allows time error through MFK to be effectively controlled minimising the dispatch workload for co-ordinators
- potentially reduces the total frequency keeping costs but this is dependent on the nature of the compensation scheme implemented and balancing this with MFK payments. The frequency keeping MW requirement may need to reduce to ensure overall costs of frequency keeping do not increase.

The costs for this option are not yet known. The requirements for implementing this option are:

- changes to the Code to accommodate the frequency keeping provisions. Once approved, the SO will need to redraft the Procurement Plan and the associated ancillary service procurement contracts to align with the Code changes
- changes to the ancillary service procurement contracts to introduce a new performance measure for control response and frequency keeping
- new basis for managing frequency based on control response. This would involve changing all business processes to reflect the new state and implementing a compensation scheme and associated monitoring
- changes to the MFK offer form to allow part bands to be cleared. This would require changes across the generators, NZX and the SO to implement the new offer form
- changes to the market system to enable a national operating mode, allow frequency keeping offers to be selected nationally, allow frequency keeping constrained on/off calculations for clearing partial bands and co-optimise frequency keeping with energy and reserves
- changes to market system to accommodate any changes required to support the agreed compensation scheme. A compensation scheme based on actual response versus estimated response would require market system changes.

This option is the most difficult as it combines the more complex market option of frequency keeping co-optimised with energy and reserves, with compensation for control response.

This option introduces a level of complexity into the market system that may not be warranted given MFK would already be providing a time error service. However, while the change may be expensive there are market benefits expected from co-optimisation. A cost benefit analysis will be required to enable full merit assessment.

5.4.4 Risks

1. **Compensation scheme –** Refer section 5.1.4
2. **Frequency Keeping Back-Up –** Refer section 5.2.4
3. **Compliance -** Refer compliance description in section 5.1.4 and 5.2.4. In addition to what has already been discussed, there is a risk of payment conflict with generators able to receive payments for both MFK and control response. Compliance around performance and payment for both would need to be clearly defined.

It is noted hybrid option 13a mitigates the following risks associated with the national frequency keeping market option:

- **Frequency Quality** – This option mitigates the frequency quality risk as it compensates generators for governor response. This would be expected to encourage generators not to implement deadbands, maintaining the quality of frequency control in the normal frequency range.

It is noted hybrid option 13a mitigates the following risks associated with the control response option:

- **Time Error –** This option mitigates the time error risk as it utilises MFK which effectively controls time error.
- **Competitive Market –** This option mitigates the competitive market risk as it would provide the ability for generators to be paid for governor response and the possibility to earn more if generators were willing to be dispatched with MFK. A greater number of generators may be able to participate in the market which may increase competition and drive frequency keeping costs down.

5.5 Option 13b – National Market: National Frequency Keeping Selection without Co-optimisation; Compensation for Control Response (Hybrid option 11 and 8)

5.5.1 Option Conditions

- ✓ **FKC enabled** – FKC enabled allows frequency keepers to be selected on a national basis. When FKC is disabled, selection would revert to island-based.
- ✓ **MFK enabled** - Frequency keeping is procured from a national market. A national market allows the lowest cost providers to be selected from across both islands.
- ✓ **Frequency keeping procurement costs** - Generators are paid the cleared offer price for all trading periods when selected as a frequency keeper. It is expected the offer structure would change under this option to allow partial band clearance.
- ✗ **Frequency keeping co-optimised with energy and reserves** – While frequency keepers would be selected on a national basis, frequency keeping would not be not co-optimised with energy and reserves.
- ✓ **Control response** – Frequency control in the normal frequency band managed by governor response and/or energy storage response.
- ✓ **Control response compensation** – Governor response and/or energy storage response in the normal frequency band would be compensated.

5.5.2 Criteria Evaluation

Table 10 summarises the assessment of the **national market: national frequency keeping selection without co-optimisation; compensation for control response** option against the criterion objectives. This option is a hybrid of options 11 and 8, previously discussed. As this option is similar to Option 13a, responses that are the same as option 13a have been noted in the rationale as 'same', while the responses that are different to option 13b have been noted with 'different'.

Table 10: Option 13b, National Market: National Frequency Keeping Selection without Co-optimisation; Compensation for Control Response

Cat	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
T1	The FS maintains frequency in the normal band.	Yes	Normal frequency would be maintained through control response. (Same)	No further work is required.
T2	The FS maintains time error within the required limits of +/- 5 seconds.	Yes	With FKC enabled, MFK primarily about control of time error. (Same)	No further work is required.
T3	The FS has a suitable frequency keeping back-up.	Yes	The existing mechanism of back-up SFK can be used as now. However, the question was raised whether any back up is needed or whether control response could be used for the periods when FKC and/or MFK is down. SFK was only ever intended to be a temporary back-up until the reliability of MFK was proven. (Same)	Further work is required to investigate frequency control when FKC is disabled using island control response compared with MFK, compared with SFK.
T4	The FS maintains the quality of frequency control in the normal frequency band	Yes	Generators may use deadbands to dampen frequency response and minimise plant wear and tear. Other generator unit would therefore have to work harder to provide the required response. Quality of North Island frequency control will be maintained. Quality of South Island frequency control will marginally deteriorate due to FKC-enabled cross-HVDC governor response. All short-listed options are generally expected to produce similar quality of frequency control. However, the level of quality is unknown for the scenario when the national market sources frequency keeping from only one island. Refer to section 5.6 for details of the benchmark work. Quality is primarily determined by factors such as load behaviour and type of frequency keeping generation, and secondarily affected by the frequency keeping solution. (Same)	Further work may be required to mandate some minimum frequency keeping performance levels in the PPO's.

Cat	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
O1	The FS supports augmented dispatch and minimises manual dispatch calculations.	Maybe	The Security Tools project is expected to allow a return to augmented dispatch calculations. (Same)	Evaluate after Security Tools project goes live. Depending on the outcome increased dispatch support may be needed.
O2	The FS does not complicate the business process and market system tools used to activate and deactivate FKC.	No	When FKC is activated, a national market would operate. When FKC is deactivated the market would revert to island selection. This would make activating and deactivating FKC more complex from a systems perspective. This hybrid option however, is less complex than 13a as there is no co-optimisation. (Different)	Further work is required to investigate how the transition from national to island would work with FKC.
O3	The FS does not introduce any new FKC exit conditions or increases the probability of an existing FKC exit condition occurring.	Yes	No new FKC exit conditions introduced. It is noted that loss of MFK communications, previously an exit condition, has been removed as an exit condition. (Same)	Update the procedures to remove MFK communications as an FKC exit condition. (This is planned to be done as part of the Security Tools Project procedure updates.)
O4	The FS supports a simple transition to the frequency keeping back-up when the primary frequency keeping service fails.	Maybe	Meeting this objective depends on the frequency keeping back-up implemented. As discussed in T3, it is possible to use SFK island but would require tool and business process changes to go from MFK national/island to SFK national/island. The process would be more complicated than the current state. This hybrid option however, is less complex than 13a as there is no co-optimisation. (Different)	Dependent on T3 and O2.
O5	The FS minimises manual dispatch work for the system co-ordinators	Maybe	The Security Tools project is expected to allow a return to augmented dispatch calculations. (Same)	Depending on the outcome from Security Tools, increased dispatch support may be needed as per T2.
M1	The FS effectively compensates those providing frequency keeping in the normal frequency band.	Maybe	The frequency keeping payments to MFK providers will be more efficient as frequency keeping is being selected nationally. However, meeting this objective overall depends on the nature of the compensation scheme implemented and achieving the correct balance of efficiency, reward of contribution and recovery of costs. (Different)	Further work is required to investigate the compensation scheme that will ensure effective payment for frequency keeping service using control response, balanced with the frequency keeping payments to MFK providers.
M2	The FS minimises barriers to entry for providing frequency management services in the normal frequency band.	Maybe	Allows MFK providers, generators with governor response in the normal band, and energy storage technology providers to participate at the level they choose. Allows clearance of partial bands so increases participation, but participants would still require MFK systems. Compliance testing may be a barrier to entry and consideration needs to be given to testing requirements for new participants that would ensure compliance while not discouraging participation.	Dependent on M1.

Cat	Future Solution (FS) objectives	Option meets objective?	Rationale	Option requires work to align with objective?
M3	The FS enables information to be provided to frequency keeping providers to inform frequency keeping decisions.	Yes	Information is published to the market now for MFK so these mechanisms are already in place. Some changes may be required to accommodate national information. Information around how the compensation scheme works and testing conditions would be required.	No further work is required.
M4	The FS supports a simple process for measuring and assessing frequency keeping performance that can be translated easily into clear compliance metrics.	No	This option is the most complex as two performance measures are required. For MFK, RIER does not currently work so new performance measurements for individual generators are needed. For control response meeting this objective depends on the nature of the compensation scheme implemented. The frequency performance measure could be more complex as the SO would have to assess all responses in the normal frequency band. However, the compensation scheme should be designed to allow performance information to be extracted from the compensation calculations.	For MFK, further work is required to investigate options for measuring frequency keeping performance of individual generators when operating MFK. For control response, dependent on M1 and once the compensation scheme is known, designing the performance measure upfront.

5.5.3 Benefits/Costs

The key benefits of this option are:

- incentivises generators to continue providing the current level of governor response in the normal frequency band. This minimises the risk of deadbands and a material drop in the quality of frequency control in the normal frequency range.
- selects the most economic MFK providers from across both islands, reducing the overall cost of frequency keeping.
- allows time error through MFK to be effectively controlled minimising the dispatch workload for system co-ordinators
- potentially reduces the total frequency keeping costs but this is dependent on the nature of the compensation scheme implemented and balancing this with MFK payments. The frequency keeping MW requirement may need to reduce to ensure overall costs of frequency keeping do not increase.

The costs for hybrid option 13b are not yet known. The requirements for implementing this option are:

- changes to the Code to accommodate the frequency keeping provisions. Once approved, the SO will need to redraft the Procurement Plan and the associated ancillary service procurement contracts to align with the Code changes
- changes to the ancillary service procurement contracts to introduce a new performance measure for control response and frequency keeping
- new basis for managing frequency based on control response. This would involve changing all business processes to reflect the new state and implementing a compensation scheme and associated monitoring
- changes to the MFK offer form to allow part bands to be cleared. This would require changes across the generators, NZX and the SO to implement the new offer form
- changes to the market system to enable a national operating mode, allow frequency keeping offers to be selected nationally and allow frequency keeping constrained on/off calculations for clearing partial bands
- changes to market system to accommodate any changes required to support the agreed compensation scheme. A compensation scheme based on actual response versus estimated response would require market system changes.

Hybrid option 13b is less difficult than hybrid option 13a to implement as it does not involve co-optimisation. If all that is required of MFK is time error control then hybrid option 13b may be the better option since it achieves time error control without the costs of co-optimisation changes. A cost benefit analysis will be required to enable full merit assessment.

It is noted this option could be implemented without national selection, in effect making it 'status quo' with compensation for control response. This would save the cost of national selection changes while maintaining MFK but lacks the benefit of selecting the most economic providers nationally.

5.5.4 Risks

1. **Compensation scheme –** Refer section 5.1.4
2. **Frequency Keeping Back-Up –** Refer section 5.2.4
3. **Compliance -** Refer compliance description in section 5.1.4 and 5.2.4. In addition to what has already been discussed, there is a risk of payment conflict with generators able to receive payments for both MFK and control response. Compliance around performance and payment for both would need to be clearly defined.

It is noted hybrid option 13b mitigates the following risks associated with the national frequency keeping market option:

- **Frequency Quality** – This option mitigates the frequency quality risk as it compensates generators for governor response. This would be expected to encourage generators not to implement deadbands, maintaining the quality of frequency control in the normal frequency range.

It is noted hybrid option 13b mitigates the following risks associated with the control response option:

- **Time Error –** This option mitigates the time error risk as it utilises MFK which effectively controls time error.
- **Competitive Market –** This option mitigates the competitive market risk as it would provide the ability for generators to be paid for governor response and the possibility to earn more if generators were willing to be dispatched with MFK. A greater number of generators may be able to participate in the market which may increase competition and drive frequency keeping costs down.

5.6 Benchmark Evaluation of Short-Listed Options

As stated in Criteria T4 (refer section 4.1.4) the short-listed future options were also evaluated quantitatively. Three performance benchmark metrics were calculated in Phase 1 of this TASC[5] to provide a baseline for comparing the quality of frequency control delivered by various future options. Therefore, benchmark metric values have been calculated for each of the short-listed options and are compared with the Phase 1 SFK benchmarks below.

Figures 1 and 2 compare the standard deviations for the short-listed options against the 'Standard Deviation SFK benchmark' calculated in Phase 1. Appendix B2 compares those options using the other two benchmarks.

The 'box' illustrates the system frequency range in the South Island. The 'whisker' illustrates the system frequency range in the North Island. They illustrate the range over which the system frequency might vary 99.7% of the time (i.e. 3x Standard Deviation) if that option were to be implemented. Anything beyond 99.7% of the time is statistically an outlier; e.g. an event-based frequency measurement.

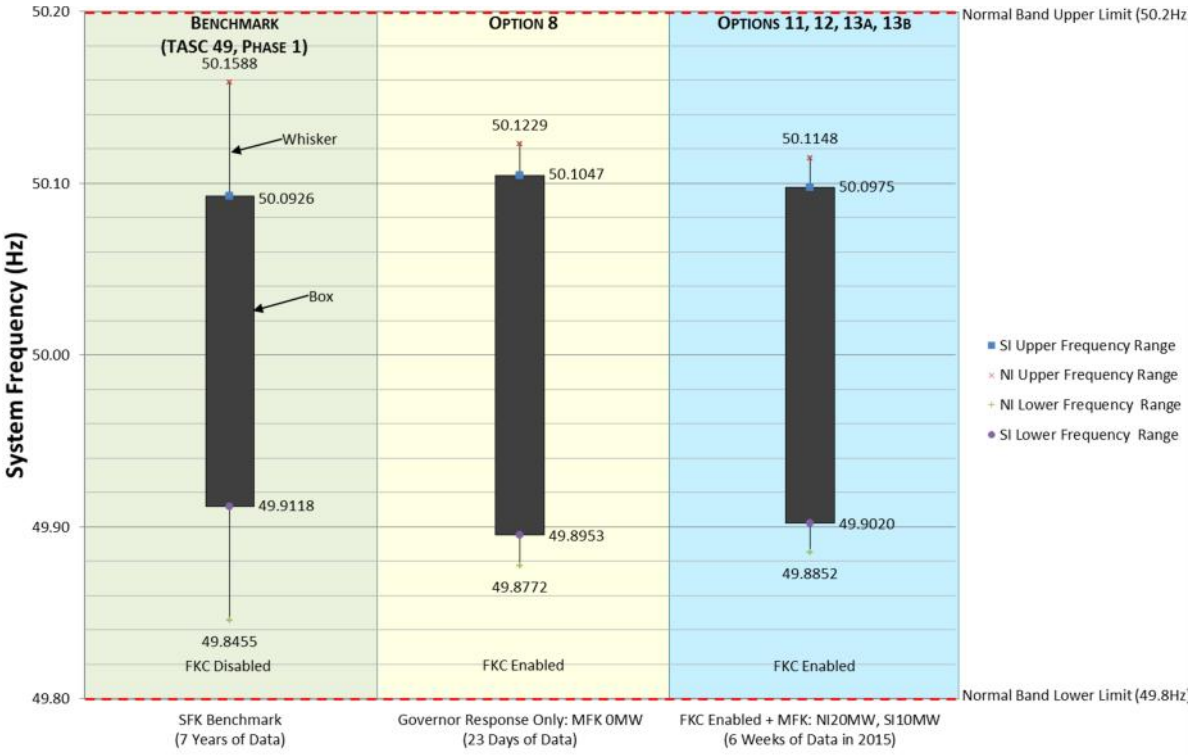

Figure 1 – Possible average variations in frequency for short-listed options during normal operation 99.7% of the time (i.e. 3x Standard Deviation).

[5] Refer Report "TASC 49 – Normal Frequency Management Strategy, Phase 1: Performance Benchmarks - Benchmark Values for Evaluating Frequency Management Options"

The quality of frequency control of Option 8 has been estimated using data from the trial with MFK set to 0MW (i.e. governor response only) and FKC was enabled.

Options 11, 12, 13a and 13b are equivalent with respect to their impact on quality of frequency control. Accordingly, their impact can be estimated using the same data sets (MFK with FKC-enabled) as the differences between these options are solely operational and commercial. Refer Appendix B1.

FKC-Disabled datasets were not used in this analysis because the 'conditions' for every short-listed option (refer sections 5.1-5.5) require FKC to be enabled.

Figure 2 includes the data for the MFK Band Swap trial (i.e. one week with North Island 10MW, South Island 20MW). It is not included in Figure 1 because the single week of data does not produce results of sufficient statistical significance.

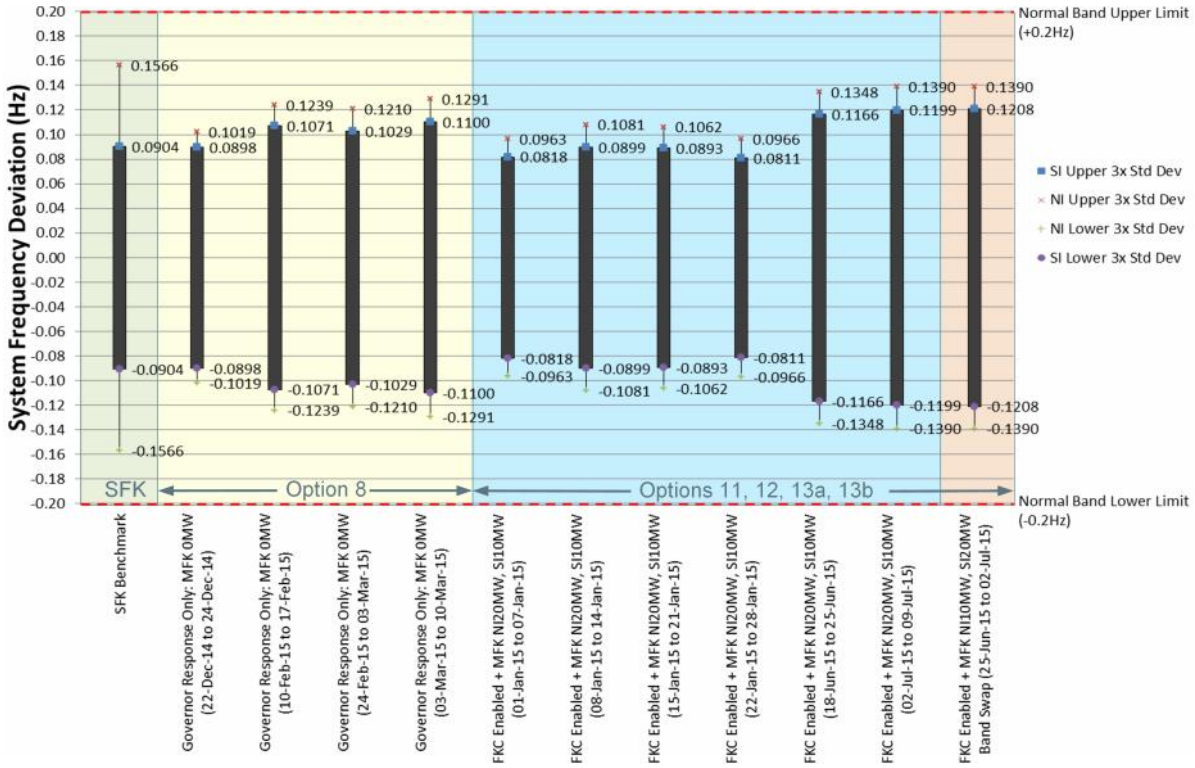

Figure 2 – Weekly variations in frequency for short-listed options during normal operation 99.7% of the time (i.e. 3x Standard Deviation).

5.6.1 Benchmark Observations

The following observations can be made from the averaged data in Figure 1:

- During normal operation the frequency is maintained comfortably within the normal band limits 99.7% of the time for all options.
- Moving from 'SFK with FSC' to FKC-based operation produces much tighter quality of frequency control in the North Island, but causes the South Island quality of control to deteriorate, though the South Island quality of control is still better than the North Island quality of control.
- While Figure 1 suggests that the MFK with FKC results in a slightly tighter overall average frequency range in both islands than for governor response only, the wide range of results shown in the weekly data of Figure 2

indicates that they have similar impact on frequency control. Although more testing could confirm the results of Figure 1, determining the degree of difference would not add any significant economic benefit to frequency keeping.

- Figure 2 indicates that swapping the MFK band from 'North Island 20MW – South Island 10MW' to 'North Island 10MW – South Island 20MW' had no impact on quality of frequency control.
- With respect to options 11, 12, 13a and 13b the data sets only represent one possible frequency keeping combination: multiple frequency keeping that is geographically spread across both islands. However, a national frequency keeping market has the potential to source all frequency keeping from only one island. But, there is currently insufficient data to draw any conclusions regarding the impact of 'single-island-only MFK' on quality of frequency control.

5.6.2 Benchmark Conclusions

The following conclusions and recommendations can be drawn from the above observations:

1. All the options have a similar level of quality of frequency control.
2. Before introducing any National Frequency Keeping Market further testing is recommended to determine the effects of sourcing frequency keeping from one island only.

Point of note:

- These conclusions are derived from historical results and not a guarantee of future quality of frequency control.
- The datasets used to perform this benchmark analysis are statistically small and do not capture seasonal variations in load and generation, variations in the types of generation and atypical load behaviour.

6 Recommendations

Table 11 summarises the assessment of the short-listed options against the future solution criteria.

Table 11: Assessment Summary of Short-Listed Options

		Option meets objective?				
Cat.	**Future Solution (FS) objectives**	Option 8 Control Response	**Option 12 National Market Co-optimised**	**Option 11 National Market Not Co-optimised**	**Option 13a Hybrid 8 & 12**	**Option 13b Hybrid 8 & 11**
T1	The FS maintains frequency in the normal band.	Yes	Maybe	Maybe	Yes	Yes
T2	The FS maintains time error within the required limits of +/- 5 seconds.	Maybe	Yes	Yes	Yes	Yes
T3	The FS has a suitable frequency keeping back-up.	Maybe	Yes	Yes	Yes	Yes
T4	The FS maintains the quality of frequency control in the normal frequency band.	Partial	Maybe	Maybe	Maybe	Maybe
O1	The FS supports augmented dispatch and minimises manual dispatch calculations.	Maybe	Maybe	Maybe	Maybe	Maybe
O2	The FS does not complicate the business process and market system tools used to activate and deactivate FKC.	Maybe	No	No	No	No
O3	The FS does not introduce any new FKC exit conditions or increases the probability of an existing FKC exit condition occurring.	Yes	Yes	Yes	Yes	Yes
O4	The FS supports a simple transition to the frequency keeping back-up when the primary frequency keeping service fails.	Maybe	Maybe	Maybe	Maybe	Maybe
O5	The FS minimises manual dispatch work for the system co-ordinators.	Maybe	Maybe	Maybe	Maybe	Maybe
M1	The FS effectively compensates those providing frequency management in the normal frequency band.	Maybe	Maybe	Maybe	Maybe	Maybe
M2	The FS minimises barriers to entry for providing frequency management services in the normal frequency band.	Maybe	Yes	Yes	Maybe	Maybe
M3	The FS enables information to be provided to frequency keeping providers to inform frequency keeping decisions.	Yes	Yes	Yes	Yes	Yes
M4	The FS supports a simple process for measuring and assessing frequency keeping performance that can be translated easily into clear compliance metrics.	Maybe	No	No	No	No

While all options appear technically feasible, further work is required to confirm specific technical aspects along with a cost benefit analysis to enable full merit assessment.

6.1 Control Response Option

Option 8, control response with compensation is the only option that will manage frequency without the use of MFK. Before this option can be confirmed, further work is recommended in the following areas:

6.1.1 Time Error

Recommendation 1: After the Security Tools project is deployed perform operational trials to determine if time error can be managed effectively using only control response.

Time error may be difficult to manage, as there is no MFK component which, when FKC is enabled, is currently responsible for managing time error.

The Security Tools project is expected to facilitate resumption of augmented dispatch, providing additional controls to effectively manage dispatch and time error. The effectiveness of these changes will not be known until operational experience is gained.

Recommendation 2: Review time error and determine the best solution for the quality of frequency noting the requirement to eliminate time error daily is likely to remain.

As the requirement to manage time error is based on the current PPO work should be undertaken to review the existing time error limits and determine the best solution for managing the quality of frequency and whether the current PPO stipulations should be changed.

A large time error indicates poor frequency control i.e. large deviations from 50 Hz, and results in generators being consistently under/over dispatched. Time error is therefore an important quality measure for frequency and arguably should be retained. However, the value of time error as a PPO, compared to other frequency quality measures should be reviewed. For example, is the current time error PPO of +/- 5 seconds too onerous[6] for the value it provides to industry and if so, can the PPO be expanded or even replaced with a non-PPO quality measure.

6.1.2 Compensation

Recommendation 3: Investigate compensation scheme design options and the appropriate balance of efficiency, reward of contribution and recovery of costs for frequency management using control response.

Generators and energy storage technology providers would be compensated based on response and impact on frequency quality. This is a new basis for managing frequency for the SO and the nature of the compensation scheme established is critical to the success of this option and the ability of the SO to meet the PPOs.

[6] It is noted that TASC11 – Normal Frequency Review, undertaken by the SO in 2011, recommended that the EA take steps to remove the 5-second time error obligation because it appeared the SO, in meeting the time error obligation, could affect system security without a corresponding benefit to participants. It was recommended that the EA undertake consultation with industry to determine if time error is still necessary.

A compensation scheme should effectively allocate frequency keeping payments to generators providing frequency keeping in the normal frequency band and in doing so should ideally:

1. sufficiently compensate generators for the wear and tear on governors. If compensation is not deemed sufficient there is a risk that generators would introduce deadbands, potentially defeating the purpose of this option
2. provide an efficient level of compensation frequency management to ensure overall market costs do not increase.

6.1.3 System Stability

Recommendation 4: Investigate the impact on system security of excessive governor response in the normal frequency band, under an incentivised governor response scheme.

There is a risk that if the stability criteria were relaxed in the future, and there was an increase in the number of governors without deadbands due to compensation arrangements, system frequency stability may be impacted.

Work is required to understand the impact of changing governor settings on system security and whether there is a need to restrict the number of generators that can participate in a chosen compensation scheme to a finite number to eliminate any oscillatory risk associated with an incentivised governor response compensation scheme.

6.1.4 Frequency Keeping Back-Up

Recommendation 5: Investigate frequency control when FKC is disabled using island control response, MFK and SFK to determine a suitable frequency back-up option.

When FKC is enabled, control response would be sufficient to control frequency in the normal band. However, when FKC is disabled how frequency keeping will be managed is unclear.

When FKC is disabled it may be possible to control frequency using the control response in each island, or at least in the South Island. However, if island control response is not sufficient then a backup of MFK or SFK may be required.

6.2 Multiple Frequency Keeping Options

Option 11, National market: National frequency keeping selection without co-optimisation, and Option 12, National market: National frequency keeping selection with co-optimisation, are the same except that option 12 co-optimises frequency keeping selection with energy and reserves.

As MFK is effectively managing time error, the selection of an MFK option is largely about control of time error and the value placed on such control. Generators participating in MFK will be indirectly compensated for their governor response, but most generators will not be compensated for their contribution to frequency management.

Before either of these options can be confirmed, further work is suggested in the following areas.

6.2.1 Frequency Keeping Back-Up

Recommendation 5: Investigate frequency control when FKC is disabled using island governor response, MFK and SFK to determine a suitable frequency back-up option.

With options 11 and 12 there are currently three possible back-up scenarios:

1. FKC is enabled and MFK is disabled
    - frequency back up will be island SFK
2. FKC is disabled and MFK is enabled
    - frequency backup will be island MFK
3. FKC is disabled and MFK is disabled
    - frequency back up will be island SFK.

When SFK was introduced it was intended to be a temporary measure until the reliability of MFK was proven and could be fully relied on.

Consideration should be given to whether a back-up is needed for scenario 1 and 3. As governor response is in essence controlling frequency, could governor response be relied on until FKC/MFK is enabled again? In the case of FKC and MFK being disabled, scenario 3, it may be possible to control frequency using the governor response in each island until FKC and MFK is enabled again.

Recommendation 6: Investigate frequency control when FKC is disabled using SFK in the North Island only.

If back up SFK is required then it may only be needed in the North Island. The South Island, being mainly hydro generation, has fast acting governor response which should manage frequency when MFK disabled. A back-up is more likely to be needed in the North Island due to its large volatile loads and prominence of thermal and geothermal generation, which lacks the relevant fast governor action.

Recommendation 7: Evaluate the impact of frequency keeping operational back-up options on the processes and workload of system co-ordinators.

Option 12 would introduce an added complication of co-optimisation which has to be managed when transitioning from national MFK to island MFK. If MFK remains enabled then it would be expected to transition from national co-optimisation to island co-optimisation. How this would work with FKC would require consideration.

It is important any frequency keeping operational back-up has a simple transition to the frequency keeping back-up that can be managed easily by the system co-ordinators.

6.2.2 Governor Response Deadbands

Recommendation 8: Investigate the level at which the effect of generator governor deadbands will impact system security through limitation of frequency response.

With options 11 and 12 there would be no compensation for governor response. There is a risk generators will utilise governor deadbands within the normal frequency band. Were this to occur the effect might impact the expected level of governor response and the ability of the SO to manage an event. This concern is relevant given recent informal indications from generator representatives, which suggests that consideration of the use of governor deadbands is increasing.

This work is also important for option 8 (see section 5.1). This work will help determine at what level the effect of governor deadbands become an issue and consider options for dealing with the consequences.

6.2.3 Compliance and Frequency Keeping Performance

Recommendation 9: Investigate options for measuring frequency keeping performance of individual generators when MFK is operating.

Options 11 and 12 would require development of a new frequency keeping performance measure. Determining such measure would be challenging as frequency control provided by MFK would have to be separated from frequency control provided by governor response. Establishing the performance measures would have to precede final design of either option.

6.2.4 Quantity of Frequency Keeping Procured

Recommendation 10: Investigate the frequency keeping capacity required to manage time error.

The change in use of MFK from frequency control to time error has meant less frequency keeping capacity is required from MFK generators. With FKC operations the required frequency keeping capacity has been reduced to 30 MW. If an MFK option were selected, work could be undertaken to further reduce the capacity of the frequency keeping required. The time error recommendation in section 6.1.1 will also assist this work since a revision in the time error PPO limits will impact the frequency keeping band required.

6.3 Hybrid Options

Option 13a and 13b are hybrid options that combine the national market options 12 and 11 respectively with option 8, control response. Before either hybrid option could be adopted, further work should be carried out in the following areas.

6.3.1 Compensation

As per section 6.1.2, recommendation 3 and 4 applies.

6.3.2 Frequency Keeping Back-Up

As per section 6.1.4 and 6.2.1, recommendations 5, 6 and 7 apply.

6.3.3 Compliance & Frequency Keeping Performance

As per section 6.2.3, recommendation 9 applies.

6.3.4 Quantity of Frequency Keeping Procured

As per section 6.2.4, recommendation 10 applies.

7 Summary of Recommendations

While all five options appear technically feasible, further work is required to understand certain technical aspects before determining a preferred future solution.

Recommendation 1: After the Security Tools project is deployed perform operational trials to determine if time error can be managed effectively using only control response.

Recommendation 2: Review time error and determine the best solution for the quality of frequency noting the requirement to eliminate time error daily is likely to remain.

Recommendation 3: Investigate compensation scheme design options and the appropriate balance of efficiency, reward of contribution and recovery of costs for frequency management using control response.

Recommendation 4: Investigate the impact on system security of excessive governor response in the normal frequency band, under an incentivised governor response scheme.

Recommendation 5: Investigate frequency control when FKC is disabled using island control response, MFK and SFK to determine a suitable frequency back-up option.

Recommendation 6: Investigate frequency control when FKC is disabled using SFK in the North Island only.

Recommendation 7: Evaluate the impact of frequency keeping operational back-up options on the processes and workload of system co-ordinators.

Recommendation 8: Investigate the level at which the effect of generator governor deadbands will impact system security through limitation of frequency response.

Recommendation 9: Investigate options for measuring frequency keeping performance of individual generators when MFK is operating.

Recommendation 10: Investigate the frequency keeping capacity required to manage time error.

	Recommendation									
Option	1	2	3	4	5	6	7	8	9	10
Option 8 - Control response with Compensation	√	√	√	√	√	-	-	-	-	-
Option 12 - National Market: National Frequency Keeping Selection with Co-optimisation	-	-	-	-	√	√	√	√	√	√
Option 11 - National Market: National Frequency Keeping Selection without Co-optimisation	-	-	-	-	√	√	√	√	√	√
Option 13a - National Market: National Frequency Keeping Selection with Co-optimisation; Compensation for Control Response	-	-	√	√	√	√	√	-	√	√
Option 13b - National Market: National Frequency Keeping Selection without Co-optimisation; Compensation for Control Response	-	-	√	√	√	√	√	-	√	√

Appendix A

The average scores of each option against the six coarse assessment questions are given below. The options are sorted according to their overall ranking based on the total average score.

		Reliability	Efficiency			Competition			
	Question	At what level does this option ensure reliabitity and resilience to the levels required in a cost-effective	Are the benefits for this option greater than the benefits of the current baseline? (for participants)	Will this option simplify SO operations and easily facilate changes long term?	What is the time/effort/risk associated with implementing this option?	Will this option reduce the barriers to entry for particpants? (No limitations to participation)	Will this option incentivise participants to compete?		
#	**Option Description**	Average Score	Average Score	Average Score	Average Score	Average Score	Average Score	**Average Total**	**Ranking**
8	Governor response only with actual compensation	7.00	7.00	7.00	6.00	7.00	6.20	40.20	1
12	MFK with national frequency keeping selection, co-optimised with energy and reserves	7.00	7.00	6.80	4.00	7.00	7.00	38.80	2
11	MFK with national frequency keeping selection, not co-optimised	7.00	6.00	6.60	5.20	7.00	6.00	37.80	3
13	MFK with national frequency keeping selection and governor response with compensation	9.00	4.00	5.25	4.33	8.00	7.00	37.58	4
1	Multiple frequency keepers in each island	7.00	5.00	5.00	10.00	5.00	5.50	37.50	5
2	Multiple frequency keepers in each island with frequency keeping bands swapped	7.00	5.00	5.00	9.80	5.00	5.50	37.30	6
7	Governor response only with estimate compensation	7.00	6.00	5.25	6.50	7.00	5.20	36.95	7
9	Governor response market based on target frequency	8.00	8.00	6.75	2.40	4.00	6.50	35.65	8
14	Automatic Generator Control (AGC)	9.00	6.00	6.75	3.00	5.00	5.25	35.00	9
15	Governor and load response with compensation	6.00	6.00	6.00	2.40	8.00	6.25	34.65	10
10	MFK with variable frequency keeping band in each island based on conditions	7.00	6.00	5.75	4.00	6.00	5.50	34.25	11
3	Single frequency keeper	8.00	1.00	1.67	9.40	3.00	3.75	26.82	12
4	Single frequency keeper in the South Island only	8.00	1.00	1.67	9.40	2.00	3.25	25.32	13
6	Governor response mandated	6.00	4.00	3.33	7.33	1.00	0.60	22.27	14
5	Governor response only with no compensation	6.00	2.00	3.33	8.75	0.00	1.75	21.83	15

Appendix B

B1 Method of Estimating Quality of Frequency Control

The following steps were followed when performing the quantitative comparison in section 5.6.

1. The three performance benchmark metrics calculated in Phase 1 of this TASC[7] were used as the baseline when comparing the options' quality of frequency control.
2. Frequency datasets were identified (refer list below)
3. The datasets were assessed against each option's conditions (refer tables below) in order to determine which sets best estimated that option. For some option conditions, there was no match with any of the datasets. However, it was possible to still 'match' that condition based on certain assumptions as described.
4. The datasets were assessed to determine whether they could adequately estimate the quality of frequency control for each option.
5. Equivalent benchmark metric values were calculated for each option using the assessed 'adequate' datasets and then compared against the baseline benchmarks.

The following statistically significant datasets were available from various MFK and FKC trials:

Dataset 1: No MFK (i.e. MFK band = 0MW); FKC Enabled

Dataset 2: Standard MFK (NI 20MW; SI 10MW); FKC Enabled

Dataset 3: MFK Bandswap (NI 10MW; SI 20MW); FKC Enabled

Other trials have been undertaken, but are too short to provide meaningful results for this comparison.

[7] Refer Report "*TASC 49 – Normal Frequency Management Strategy, Phase 1: Performance Benchmarks - Benchmark Values for Evaluating Frequency Management Options*"

B1.1 Option 8 - Control response with Compensation

Based on the assessment below, Dataset 1 best estimate the conditions for **Option 8 - control response with compensation**.

Dataset Estimates Each Option Condition						
Option 8 Conditions	**FKC Enabled**	**No MFK**	**No frequency keeping market and hence no procurement costs**	**No frequency keeping co-optimised with energy and reserves**	**Control response**	**Control response compensation**
Dataset 1: **MFK = 0MW** **FKC Enabled**	✓	✓	✓	✓	✓ Governor response only (currently no other energy storage technology)	✘ But, can assume that this is worst case. Implementing compensation may encourage more governors to participate. Implication: frequency quality would improve with respect to this dataset.
Dataset 2: **MFK (NI 20MW; SI 10MW) FKC Enabled**	✓	✘	✘ frequency keeping market was operating during this dataset	✓	✓	✘
Dataset 3: **MFK Bandswap (NI 10MW; SI 20MW) FKC Enabled**	✓	✘	✘ frequency keeping market was operating during this dataset	✓	✓	✘

B1.2 Option 12 – National Market: National Frequency Keeping Selection with Co-optimisation

Based on the assessment below, Datasets 2 and 3 best estimate the conditions for **Option 12 - national market: national frequency keeping selection with co-optimisation**.

Dataset Estimates Each Option Condition						
Option 12 Conditions	**FKC Enabled**	**MFK Enabled**	**Frequency keeping procurement costs**	**Frequency keeping co-optimised with energy and reserves**	**Governor response**	**No governor response compensation**
Dataset 1: MFK = 0MW FKC Enabled	✓	✗	✗	✗	✓	✓
Dataset 2: MFK (NI 20MW; SI 10MW) FKC Enabled	✓	✓	✓ Note: data is whole band clearance only.	✗ But, co-opt is a pure market mechanism, backing off cheaper generation in order to provide more FK.	✓	✓
Dataset 3: MFK Bandswap (NI 10MW; SI 20MW) FKC Enabled	✓	✓	✓ Note: data is whole band clearance only.	✗ Refer dataset 2 comments above	✓	✓

B1.3 Option 11 – National Market: National Frequency Keeping Selection without Co-optimisation

Based on the assessment below, Datasets 2 and 3 best estimate the conditions for **Option 11 - national market: national frequency keeping selection without co-optimisation**.

Dataset Estimates Each Option Condition						
Option 11 Conditions	**FKC Enabled**	**MFK Enabled**	**Frequency keeping procurement costs**	**No frequency keeping co-optimised with energy and reserves**	**Governor response**	**No governor response compensation**
Dataset 1: MFK = 0MW FKC Enabled	✓	✗	✗	✓	✓	✓
Dataset 2: MFK (NI 20MW; SI 10MW) FKC Enabled	✓	✓	✓ Note: data is whole band clearance only.	✓	✓	✓
Dataset 3: MFK Bandswap (NI 10MW; SI 20MW) FKC Enabled	✓	✓	✓ Note: data is whole band clearance only.	✓	✓	✓

B1.4 Option 13a - National Market: National Frequency Keeping Selection with Co-Optimisation; Compensation for Control Response (Hybrid -Options 12 and 8)

Based on the assessment below, Datasets 2 and 3 best estimate the conditions for **Option 13a - national market: national frequency keeping with co-optimisation; compensation for control response**. This option is a hybrid of options 12 and 8.

Dataset Estimates Each Option Condition						
Option 13a Conditions	**FKC Enabled**	**MFK Enabled**	**Frequency keeping procurement costs**	**Frequency keeping co-optimised with energy and reserves**	**Control response**	**Control response compensation**
Dataset 1: MFK = 0MW FKC Enabled	✓	✗	✗	✗	✓ Governor response only (currently no other energy storage technology)	✗ But, acceptable. Can assume that this is worst case.
Dataset 2: MFK (NI 20MW; SI 10MW) FKC Enabled	✓	✓	✓ Note: data is whole band clearance only. But, partial band clearance simply allows more providers to join MFK.	✗ But, co-opt is a pure market mechanism, backing off cheaper generation in order to provide more FK.	✓	✗ But, acceptable. Can assume that this is worst case.
Dataset 3: MFK Bandswap (NI 10MW; SI 20MW) FKC Enabled	✓	✓	✓ Note: data is whole band clearance only.	✗ Refer Dataset 2 comments above	✓	✗ But, acceptable. Can assume that this is worst case.

B1.4 Option 13b - National Market: National Frequency Keeping Selection without Co-Optimisation; Compensation for Control Response (Hybrid -Options 11 and 8)

Based on the assessment below, Datasets 2 and 3 best estimate the conditions for **Option 13b - national market: national frequency keeping without co-optimisation; compensation for control response**. This option is a hybrid of options 11 and 8.

Dataset Estimates Each Option Condition						
Option 13b Conditions	**FKC Enabled**	**MFK Enabled**	**Frequency keeping procurement costs**	**No frequency keeping co-optimised with energy and reserves**	**Control response**	**Control response compensation**
Dataset 1: MFK = 0MW FKC Enabled	✓	✗	✗	✓	✓ Governor response only (currently no other energy storage technology)	✗ But, acceptable. Can assume that this is worst case.
Dataset 2: MFK (NI 20MW; SI 10MW) FKC Enabled	✓	✓	✓ Note: data is whole band clearance only. But, partial band clearance simply allows more providers to join MFK.	✓	✓	✗ But, acceptable. Can assume that this is worst case.
Dataset 3: MFK Bandswap (NI 10MW; SI 20MW) FKC Enabled	✓	✓	✓ Note: data is whole band clearance only.	✓	✓	✗ But, acceptable. Can assume that this is worst case.

B2 Comparison Using 3rd and 4th Order Deviation Benchmarks

Below are comparisons of the short-listed options using the standard deviation, 3rd order deviation and 4th order deviation benchmarks.

The higher the order of benchmark, the greater the weighting placed on larger frequency deviations from the mean frequency. The key observation is that the relative differences in deviations between SFK, Option 8 and the other options do not change much in terms of actual frequency within the normal band when comparing the standard deviation with these higher order deviations (compare figures 3, 4 and 5). For example, the difference in NI upper standard deviations between the SFK benchmark and Option 8 (0.0522-0.0409 = 0.0113Hz) is similar to the difference in NI upper 3rd order deviations (0.0641-0.0496 = 0.0145Hz).

This indicates that all of the options have similar frequency distributions in that they have similar occurrences of larger frequency deviations away from the average frequency out towards the edge of the normal band.

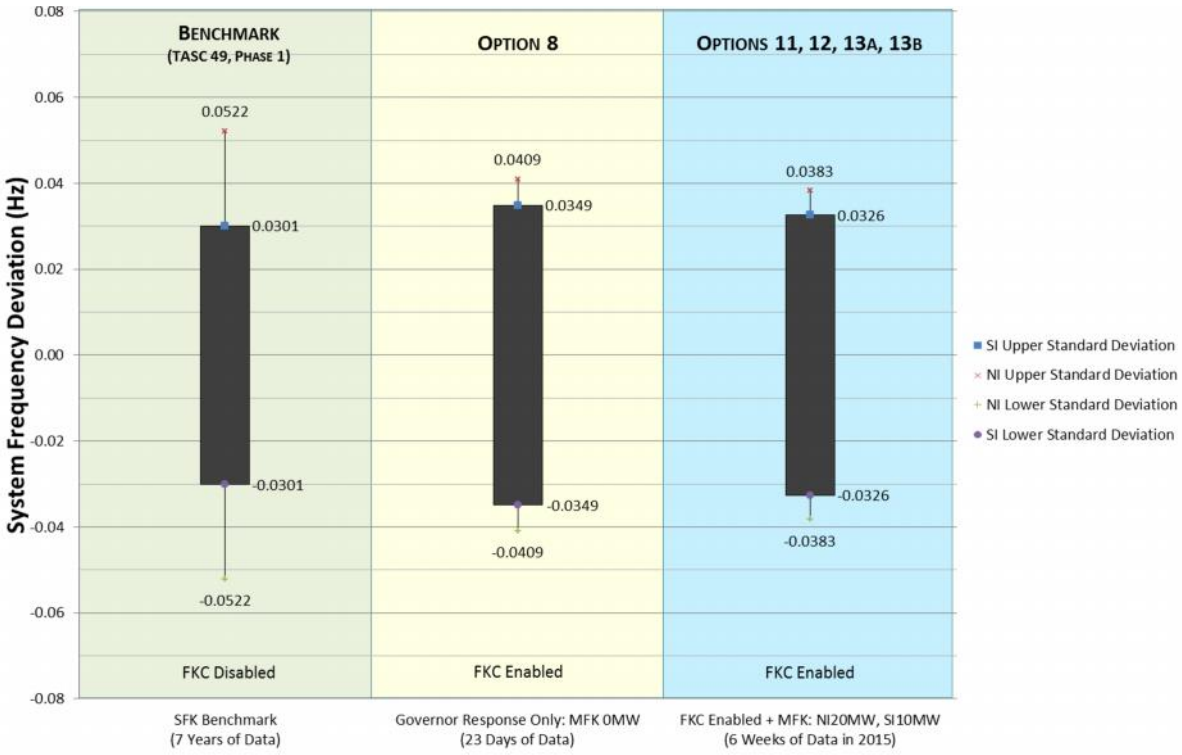

Figure 3 – Average standard deviations of North and South island frequencies for short-listed options during normal operation.

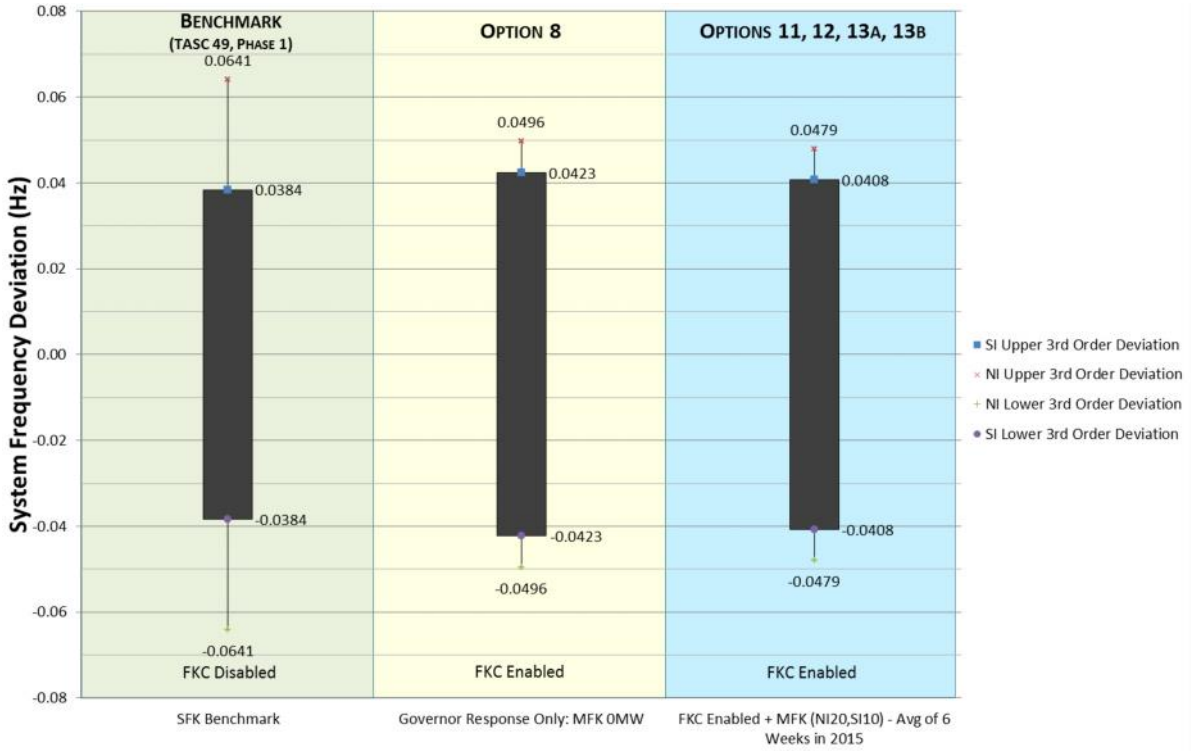

Figure 4 – Average 3rd Order deviations of North and South island frequencies for short-listed options during normal operation.

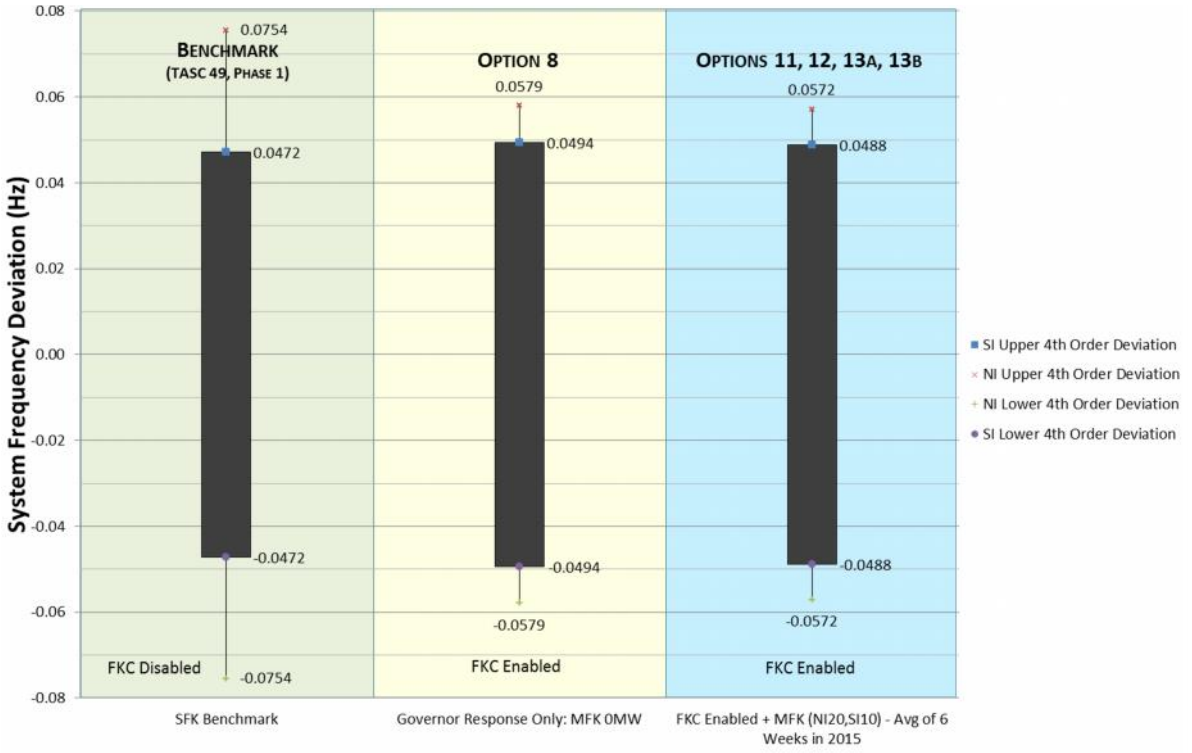

Figure 5 – Average 4th Order deviations of North and South island frequencies for short-listed options during normal operation.