Normal Frequency Management

Strategic Review

Information paper

March 2017

Executive summary

The Electricity Authority welcomes comment

The Electricity Authority (Authority) is seeking submissions on the content of this information paper and the technical investigation reports in the appendices.

Structure of information paper

The structure of this paper is as follows:

(a) Section 1 provides background to the joint review of normal frequency management carried out by the Authority and the system operator

(b) Section 2 describes the accountabilities for normal frequency management

(c) Section 3 gives an outline of the roles of governor response, frequency keeping and dispatch in normal frequency management

(d) Section 4 considers the costs of normal frequency management

(e) Section 5 provides high-level options for procuring governor response

(f) Attachments:

- Appendix A: Performance Benchmarks
- Appendix B: Future Solution Option Analysis
- Appendix C: Multiple Frequency Keeping Refinement
- Appendix D: Governor Response Metric
- Appendix E: Generator Governor Response Costs

Overview of normal frequency management development

The introduction of the high voltage direct current (HVDC) frequency keeping control (FKC) and multiple frequency keeping (MFK)[1] have resulted in changes to normal frequency management[2] – moving more of the duty from contracted MFK providers to inherent generator governor response.

The Authority and the system operator have been investigating the impact of the MFK and FKC initiatives on the previous input assumptions for:

(a) a national market for MFK

(b) asset owner performance obligations for generator governors.

The long-term objective of the investigation is to ensure future arrangements for managing frequency deliver stable frequency of an acceptable quality to consumers at the lowest cost. This would represent a productive efficiency improvement for the long-term benefit of consumers.

---

1 Before 2013, control systems used to manage normal frequency were station-based prior to 2013 and the service provided was referred to as "frequency keeping". In 2013 a centralised control system was introduced to allow multiple stations to provide frequency keeping in the same trading period. This service is referred to as "multiple frequency keeping".

2 Refer to paragraph 2.6 of this paper for a definition of normal frequency management.

The Authority's investigation has concluded that the planned national market for MFK, as originally proposed, would no longer deliver a net benefit as assessed by the Wholesale Advisory Group (WAG) in 2014.[3] Since the WAG carried out its original work, the system operator has been able to reduce the MFK band from 75 MW to 30 MW. Tests suggest that the band could be further reduced to 20 MW, without a material drop in frequency quality.

Analysis carried out by the WAG on a national market for MFK assumed an ongoing requirement for a band of 65 MW. The current smaller band of 30 MW, which may reduce further, considerably reduces the benefits that could be obtained from a national market for MFK. Additionally, while market conditions continue to change, there is limited representative historical offer data available to estimate future cost savings.

After consulting participants in June 2014, the Authority concluded that it should review the performance obligations for generator governor response. The Authority believes it should direct the focus of its investigations to improving or replacing the performance obligations for governor response in order to:

(a) minimise costs

(b) address the problem of duty shifting away from contracted MFK

(c) allow alternative technologies that are not generator-based to participate in frequency management.

High-level options for governor response procurement

This paper presents high-level options for a procured governor response ancillary service, which can be grouped into the following categories:

(a) adapted status quo – codifying existing practices

(b) administered pricing – a required benchmark level of performance with under and over payments

(c) market pricing – providers competing on price to meet specified requirements.

Once the Authority has selected a preferred option for procuring governor response, it will determine what initiatives, if any, are worth pursuing to improve procurement of MFK.

Next steps

The most important requirement is to establish whether governor response measurement can be undertaken in a way that enables the system operator to trade-off the collective amount of governor response against MFK requirements.

The Authority and system operator plan to:

(a) confirm the technical requirements for a governor response service

(b) confirm the associated costs and benefits of procurement based options for a governor response service

(c) confirm a method of cost allocation for governor response costs.

3 (http://www.ea.govt.nz/development/advisory-technical-groups/wag/meeting-papers/2014/5-june-2014/) .

Suggested form for submissions

The Authority is interested in receiving submissions on any aspect of the paper, but it is particularly interested in receiving submissions on the following questions:

(a) Do you have any comments on how governor availability costs availability costs wear and tear costs capacity carrying costs compare between MFK and governor response?

(b) Do you have any comments on the extent to which MFK can be substituted by governor response?

(c) Do you think that there are likely to be net benefits in progressing to a procured governor response service through tendering, given the technical challenges identified in this paper?

(d) Which option or options in section 5 do you agree with and which do you not, and why?

(e) Are there any other features or options you would like to suggest?

(f) Do you have any comments on the indicative analysis of governor response costs in Appendix E?

(g) Are there any other issues you wish to bring to the Authority's attention?

Contents

Tables

Figures

1 Background

Proposed national market for MFK

1.1 In 2014, the Authority started work on developing a national market for MFK. Analysis carried out for the WAG at that time showed that a national market for MFK would result in substantial net benefits from:

(a) increased competition, because four MFK providers could compete nationally and requirements could be selected nationally from the cheapest providers

(b) improved efficiency in the energy, instantaneous reserve, and MFK markets by allowing all three markets to be fully co-optimised

(c) reducing the MFK band procured nationally by up to 10 MW

(d) reducing peaking capacity requirements because of the reduced MFK band

(e) removing barriers to small providers of MFK due to an algorithm limitation in the existing MFK selection tool.

1.2 The Authority estimated net benefits of a national market for MFK to be in the order of $90 million, based on analysis of MFK offer data from July 2013 (when MFK started in the North Island) to May 2014.

1.3 In January 2015, the system operator brought the HVDC frequency keeping modulation control (FKC) into full operational use following trials carried out in late 2014. FKC has allowed MFK and instantaneous reserve to be shared between the North and South Islands and has changed frequency management in the following ways:

(a) The system operator has been able to reduce the quantity of MFK it procures nationally from 75 MW to 30 MW without causing any material deterioration in the quality of system frequency. There is potential to reduce the procured quantity further.

(b) More of the work of managing frequency has shifted from contracted MFK providers to inherent generator governor response. This is because the speed of response of FKC and governors is faster than the speed of the MFK controls. MFK itself, being a slower form of control than station-based frequency control that pre-dated MFK, had already caused some shift in duty towards governors since it was introduced in mid-2013.

1.4 The graphs below show the effects of the changes made to frequency management on MFK price difference between islands (Figure 1) and MFK constrained on and off payments (Figure 2). The coloured areas in the graphs are indicative of the:

(a) potential benefits of selecting MFK providers nationally from the cheapest providers (Figure 1)

(b) potential benefits of fully co-optimising energy, instantaneous reserve and MFK (Figure 2).

Figure 1: MFK volume adjusted price difference between islands

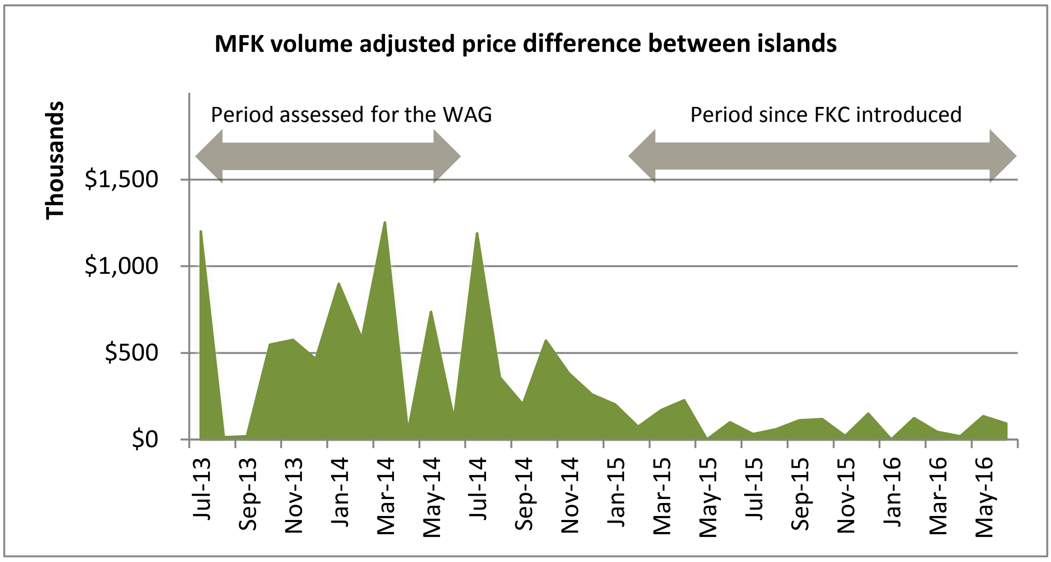
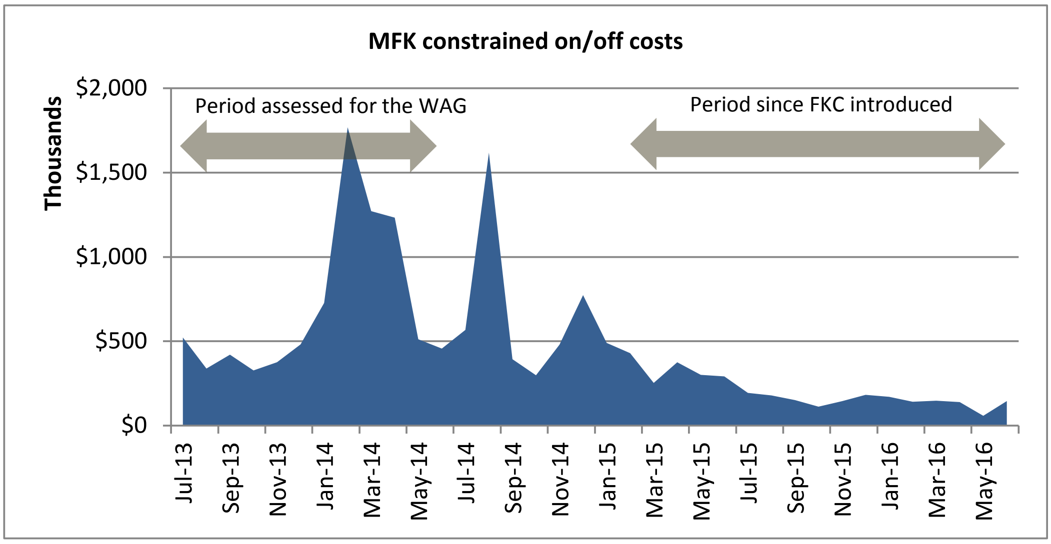


Figure 2: MFK constrained on and off costs



1.5 The graphs show the effect of changes in frequency management made since January 2015. These changes have reduced the potential benefits of a national market for MFK by an order of magnitude or more. This is because many of the assessed benefits have already been realised. In addition, market conditions continue to change as operational experience is gained, and the net benefits of a national market for MFK may continue to reduce if the procured quantity reduces further.

Review of normal frequency management

1.6 In view of the ongoing changes, the Authority has reviewed how frequency is managed, and commissioned the system operator to carry out a number of technical investigations. The objective of this work is to ensure that stable frequency is provided to consumers at the lowest long-term cost. This would represent a productive efficiency improvement for the long-term benefit of consumers.

1.7 The investigations carried out by the system operator were divided into work modules referred to as “TASCs”. Appendices A to D set out the system operator’s TASC reports as follows:

(a) TASC 49 – Performance Benchmarks (Phase 1)

This module looked at historical performance benchmarks that were created to evaluate frequency management options that were trialled.

(b) TASC 49 – Future Solution Option Analysis

This module looked at options for future frequency management, including consideration of options involving no procurement of MFK.

(c) TASC 55 – MFK Refinement

This module reported on the results of testing MFK bands of 0, 20 and 30 MW under various conditions.

(d) TASC 58 – Governor Response Metric

This module investigated a governor response metric to measure relative governor response to frequency changes between 49.8 Hz and 50.2 Hz, both inclusive (the ‘normal band’).

1.8 Work before that shown above explored options for a future national market for MFK. However, the Authority concluded that because the benefits of a national market for MFK had reduced, its frequency management strategy should focus on procuring governor response.

1.9 A procured governor response service would address the problem of duty shifting away from the contracted MFK service. It would enable generators to compete on even terms to provide governor response, with the cheapest providers being selected first. It would also create opportunities for alternative technologies to provide an equivalent response to generator governors.

1.10 There may still be benefit in developing a simplified national market for MFK. It would depend on whether a residual MFK service would be required if a procured governor response service could be developed.

2 Normal frequency management

2.1 Changes in electricity demand and supply due to intermittency, ramping etc occur continuously. The changes must be matched quickly by changes in controllable generation in order to balance supply and demand and maintain system frequency within acceptable limits.

2.2 The system operator is responsible for managing system frequency. In relation to normal frequency management, the system operator’s Principal Performance Obligations (PPOs) include:[4]

(a) maintaining system frequency in the normal band apart from momentary fluctuations

[4] Clause 7.2 of the Code.

(b) maintaining system time error to be no more than five seconds and to be zero at least once each day.[5]

2.3 The Code is silent about the 'quality' of the frequency within the normal band. Lots of significant or rapid deviations from 50 Hz within the normal band would be regarded as 'poor' quality. However, as discussed later in paragraphs 3.60 to 3.65, the system operator seeks to maintain relatively 'good' quality consistent with historical benchmarks.[6]

2.4 Currently, the system operator manages normal frequency using controllable generation through a combination of:

(a) automatic generator governor response

(b) the MFK ancillary service

(c) real time energy dispatch.

2.5 These activities occur over different timeframes:

(a) Generators with responsive governors automatically react to variations in system frequency – increasing their output in response to a fall in system frequency, and vice versa.

(b) Generators selected to provide the MFK service increase or decrease their output in response to a central control signal sent by the system operator. Such changes in output are coordinated to correct system time error or frequency deviations. The system operator selects MFK providers, by island, in accordance with MFK market offers, and coordinates their output via MFK control.[7] Currently, the system operator procures 15 MW of MFK in each island.[8]

(c) The system operator determines generator dispatch trajectories, typically at five minute intervals, in accordance with market offers, so as to meet expected generation requirements during the next 5-minute interval. The system operator uses dispatch to enable least-cost, security-constrained generation scheduling in the energy market, and to help manage system time error and frequency quality. Biasing the generation dispatch above or below the expected demand for the next 5 minutes helps to correct system time error or frequency deviations.

2.6 In the context of this paper, the term *normal frequency management* refers to management of system frequency in the normal band by the system operator (using governor response, MFK, real time dispatch and FKC).

2.7 Governor response is generally capable of being the fastest acting service. However, the extent and speed of response depends on the particular technology and how the governor (or alternative control mechanism) is configured (see section 3). By contrast, MFK responds continuously within the timeframe between fast automatic governor response and real time energy dispatch.

---

5 System time error is the time difference between actual time and a synchronous clock running on mains supply.

6 Refer to the system operator's performance benchmarks report in Appendix A.

7 Frequency keeping is a common feature of electricity markets around the world. It is often called frequency regulation service, with providers coordinated via automatic generation control (AGC), similar to the MFK function in New Zealand. AGC is also used for dispatch purposes in some markets.

8 Since May 2016.

2.8 The timeframes in which governor response, MFK, and dispatch respond overlap. To this extent, the three forms of frequency management are inter-related. For example:

(a) the amount of governor response on the system can influence MFK requirements and vice versa

(b) the choice of dispatch interval can influence MFK requirements, which in turn can be affected by the amount of generator governor response

(c) it is feasible to have no specific MFK service, but rather rely only on governor response and dispatch for maintaining normal frequency and system time error.[9]

2.9 It is possible to operate without any MFK, as detailed in paragraphs 3.7 to 3.11. However, some minimum amount of governor response is essential in order to ensure system stability, particularly during islanding and recovery situations. Similarly, dispatch will always be required to enable least-cost, security-constrained generation scheduling in the energy market.

3 Overview of normal frequency management services

Governor response

Governors respond to changes in system frequency

3.1 A generator's governor regulates the amount of primary energy supply to a turbine (eg, water, gas or steam) in response to system frequency variations. This adjusts the generator output, the amount and rate of adjustment determined by the size of frequency variation and governor characteristics and settings. Thus a governor will typically respond to a fall in system frequency by increasing generator output, and vice versa. This action helps to stabilise (and potentially restore) system frequency movements away from 50 Hz.

3.2 For a fixed system frequency error (ie, deviation away from 50 Hz), the ultimate change in a generator's output, subject to operating headroom,[10] is typically determined by the governor's droop setting. Droop is an indication of the relationship (for a synchronised generator) between changes in system frequency and changes in generator output. For example, a governor with a 4% droop setting would nominally attempt to increase the generator output from no load to full load for a 4% change in system frequency. In practical terms, assuming sufficient operating headroom, if frequency fell by 0.05 Hz, a 100 MW generating unit with a governor droop setting of 4% would attempt to increase its output by 2.5 MW ie:

$$\frac{(0.1\%\ \text{frequency change})}{(4\%\ \text{droop})} \times 100\ \text{MW} = 2.5\ \text{MW}$$

9 For example, as in the UK. In NZ, the system operator has conducted trials with no frequency keeping with FKC available. Refer to the TASC 55 report in Appendix C.

10 A generator operating at full output would not have any operating headroom to increase output 'up' in response to a fall in system frequency, but would have the ability to reduce output 'down' in response to a rise in system frequency.

A 100 MW generating unit with 2% droop would attempt to increase its output by 5 MW. All else being equal, the lower the droop setting, the larger the ultimate response to a change in frequency.

3.3 The speed of response depends on other factors including governor dead-band, and gain:

(a) Dead-band refers to the fact that some generating units will not respond to frequency deviations that are within a so-called ‘dead-band’. Dead-band can be inherent in moving parts. For example, a generating unit with inherent dead-band will not respond, at least immediately, to small changes in the direction of system frequency. Importantly, dead-band can also be a settable parameter. For example a governor with a dead-band setting of ± 0.1Hz will not respond until system frequency is lower than 49.9 Hz or higher than 50.1 Hz.

(b) Gain is a settable governor parameter that affects how quickly a generating unit will move to its new output. This can also be affected by the particular ramping characteristics of a generating unit.

3.4 Another key parameter in some governors is the ability to have an integral response where generating units will respond to the *cumulative* frequency error over time. Thus, a generating unit with a relatively wide dead-band may still start to respond to a small frequency deviation if it has an integral governor setting, and the frequency deviation persists for a long time.

3.5 Governors are standard features of conventional synchronous generation technologies powered by hydro, steam, gas turbines and some modern wind turbines and on which electricity systems depend. Minimum levels of governor response are a common technical requirement in grid codes around the world. However, the operational costs of providing governor response vary by technology, governor settings and market circumstances, including system size (inertia). Technically, similar functionality can also be provided by alternative technologies such as demand response and emerging energy storage devices, eg, batteries.

3.6 Appendix E details some illustrative analysis demonstrating that the cost of providing governor response varies significantly between different types of generation (alternative technologies have not been analysed at this time). Hydro is generally significantly cheaper than other technologies, and geothermal and wind are the most expensive.

Roles

3.7 As well as helping to maintain frequency quality, governor response within the normal frequency band is an essential aspect of power system stability.[11] It automatically and quickly counters frequency deviations, sharing the response among multiple enabled generators without the need for control signals to be communicated between generators.

3.8 Key stability benefits of governor response include:

(a) enabling stable operation during periods of extreme system stress (eg, islanding, or system recovery (‘black-start’) situations)

[11] It is also the mechanism whereby generators can contribute instantaneous reserve during under-frequency contingency events.

(b) assisting generators that are starting-up to synchronise to the grid by maintaining stable frequency.

3.9 The focus of this information paper is the role of governor response in normal frequency management – particularly the interplay with MFK procurement.

3.10 Different types of governor response provide different types of services:

(a) Governor response with no dead-band that is fast provides a responsive frequency regulating service that cannot be easily substituted with MFK. This type of response helps to quickly arrest frequency deviations and keep frequency close to 50 Hz in response to the typical generation / demand imbalances that occur on a minute-by-minute basis.

(b) Governor response with one or more of the following characteristics provides a slower balancing type of service that acts in similar timeframes to MFK:

(i) moderate dead-band

(ii) slow response

(iii) integral response.

It is more readily substitutable with MFK and is useful for restoring frequency following more substantial deviations after a greater generation/demand imbalance.

(c) Governors set with a wide dead-band in the order of 0.2 Hz or greater are unlikely to have any beneficial effect on normal frequency management. However, they will help address very significant deviations outside the normal band (eg, assist instantaneous reserves and AUFLS for major supply interruptions).

3.11 Governor response alone cannot manage system time error. Generator governors typically provide a proportional response to the current system frequency whereas system time error is the accumulation of system frequency variations over time. Correcting system time error thus requires a bias to be applied to system frequency. This is currently achieved through MFK and dispatch.

3.12 In some situations, overly responsive governors can cause system instability. However, the system operator has investigated this issue and confirmed that technically there is scope for materially more governor response on the New Zealand system without compromising system stability.

Governor response providers incur costs

3.13 As is set out in detail in Appendix E, generators can incur costs in providing governor response due to:

(a) loss of plant efficiency (eg, cycling around, or operating away from, efficient loading levels)

(b) constraints on participation in the energy or instantaneous reserve markets (eg, constraining dispatch in order to provide upward or downward governor response capability)

(c) increased maintenance and life cycle costs due to wear and tear.

3.14 These costs vary by technology, plant design, governor settings, frequency quality,[12] and market circumstances. One-off costs can also be incurred in modifying plant or adjusting governor settings.

3.15 Under the existing mandated performance regime (see paragraphs 3.18 to 3.27 below), generators have no explicit means of recovering these costs, other than through their energy market offers. Nor are they able to trade off their cost of compliance against system benefits, or vice versa.

Governor response to normal frequency is largely provided by hydro generation

3.16 At present, governor response within the normal frequency band is largely provided by hydro generators, with significant variations between stations. In contrast, most thermal unit governors, and geothermal and wind plant, are much less responsive within the normal frequency band. This reflects a combination of longstanding historical practices in New Zealand that pre-date the Code, differing interpretations of the Code, and the relative costs of providing governor response from different generation technologies.

3.17 Thermal generators say they would incur significant maintenance and life cycle costs if their thermal plant were to have small governor dead-bands and be continuously responsive to frequency changes within the normal frequency band.[13] Appendix E gives more detail about this. That thermal plants can technically respond to normal frequency variations is not in question, just the cost of doing so.

Governor response is currently a mandated service

3.18 At present the system operator acquires governor response from generators through asset owner performance obligations (AOPOs) and associated technical codes.[14] This is common practice internationally and a low transaction cost means of acquiring the service from traditional synchronous generation technologies. Many jurisdictions make little distinction between the expected capabilities of different generating technologies.

3.19 The New Zealand power system has more diversity of generation technologies than many overseas systems, which tend to be dominated by thermal plant. This is relevant because there can be significant differences between hydro, thermal, geothermal, and wind in the cost and ability to provide governor response.

3.20 In addition, the small scale of the New Zealand system means that it suffers much faster changes in frequency than larger systems that have the benefit of higher system inertia. This creates greater demands for, and imposes greater costs on, governor response.

---

12 Generators (with responsive governors) are likely to incur greater wear-and-tear costs responding to a 'noisy' system frequency that moves around rapidly, compared to a 'smoother' system frequency that moves around more slowly.

13 For example in submissions on "*Normal frequency asset owner performance obligations. Consultation paper*", Electricity Authority, June 2014 (https://www.ea.govt.nz/dmsdocument/18134).

14 Clause 8.17 of the Code and related provisions in Schedule 8.3 of the Code (Technical Code A).

3.21 The New Zealand AOPOs implicitly address such diversity in capability through effectively allowing a wide range of governor settings. The AOPOs specify that generators must be fitted with governors with droop that can be set within a specified range (0% to 7%),[15] but do not specify:

(a) any specific droop settings

(b) any gain settings

(c) any dead-band settings.

3.22 Generally, generation owners have worked with the system operator to implement governor settings that provide stable operation when generators are operated into an islanded load. The settings reflect inherent differences in capability eg, hydro generators usually have lower droop settings than geothermal generators.

3.23 However, it appears that within a technology type there is some diversity in the way generators interpret the requirements for governors. For example, the Authority understands that different hydro generators deliver significantly different amounts of governor response. Generally, North Island hydro generators are more responsive than those in the South Island.

3.24 Further, there are concerns that over recent years, there may have been some re-setting of governors (particularly hydro governors) to deliver less governor response than in the past. This shifts governor response duty between generators, depending on governor settings.

3.25 Generator owners currently have incentives to reduce governor response to:

(a) avoid the associated costs (for which they are not explicitly compensated)

(b) increase to quantity of MFK needed (for which they do get paid explicitly).

3.26 However, from an overall economic perspective, it is not clear whether procuring MFK is a lower cost way to provide normal frequency management than governor response.

3.27 The Authority has identified that the latitude in the existing AOPOs may be having unintended consequences: specifically, some generators delivering less governor response than would be economically efficient.

---

15 The exact clauses in Schedule 8.3 are:

"5 Specific requirements for generators

(1) Each generator must ensure that—

…..

(c) each of its generating units has a speed governor that—

(i) provides stable performance with adequate damping

(ii) has an adjustable droop over the range of 0% to 7%

(iii) does not adversely affect the operation of the grid because of any of its non-linear characteristics

(d) appropriate speed governor settings to be applied before commencing system tests for a generating unit are agreed between the system operator and the generator. The performance of the generating unit is then assessed by measurements from system tests and final settings are then applied to the generating unit before making it ready for service after those final settings are agreed between the system operator and the generator. An asset owner must not change speed governor settings without system operator approval."

The Authority sought to clarify generator obligations in 2014

3.28 In 2014, the Authority consulted on a proposal to clarify normal frequency AOPOs for generators, and associated technical code requirements.[16] Under the proposal, the requirements that would have applied to all generators included:

(a) clarification of the obligation to actively contribute to maintaining frequency when frequency is within the normal band, and not just respond to frequency movements outside the normal band

(b) a governor dead-band of up to +/- 25 mHz around 50 Hz

(c) droop to be set as low as is practical and no more than 7%

(d) an obligation to agree settings with the system operator that could affect the performance of the governor (eg, droop, gain)

(e) the current dispensation process, where the cost of compliance would be excessive.

3.29 In principle, if holders of dispensations faced the impact of their dispensation on system costs, as provided for in clause 8.31 of the Code, this would place all generators on an even footing and minimise overall compliance costs.

3.30 However, submitters raised a number of concerns about the proposed requirements including their ability to comply and the cost of compliance.

3.31 Further, a means of identifying the costs to be allocated to dispensation holders would still need to be developed, and generators would face considerable uncertainty in the meantime.

3.32 As is set out in Appendix E to this paper, it is difficult to estimate the costs associated with providing more or less governor response. It is the key challenge to determining how best to procure governor response.

The Authority is reconsidering options for procuring governor response

3.33 In a subsequent response paper to the consultation, the Authority concluded that it should review options for procuring governor response requirements.[17]

3.34 Since the June 2014 consultation on normal frequency AOPOs, there have also been significant changes in the way the system operator manages normal frequency and system time error, particularly through the introduction of MFK and the HVDC FKC function.

3.35 The FKC function modulates HVDC transfers so as to tie the frequency in the two islands together, and in so doing draws more heavily on generator governor response. This has enabled the system operator to procure a smaller MW band of MFK, but has increased the burden on some generators who provide governor response, with potential cost impacts.

[16] "*Normal frequency asset owner performance obligations. Consultation paper*", Electricity Authority, June 2014 (https://www.ea.govt.nz/dmsdocument/18134).

[17] The consultation paper "*Normal frequency asset owner performance obligations. Consultation response paper*", Electricity Authority, 18 November 2014 is available at (https://www.ea.govt.nz/dmsdocument/18712).

3.36 Section 5 of this paper includes discussion of the high-level options the Authority is considering for procuring governor response in light of the above and overall normal frequency management. The Authority has not yet carried out detailed investigations of the practicality and costs of these options.

MFK and normal frequency management

MFK is an ancillary service coordinated by the system operator

3.37 Whereas generator governors respond to system frequency variations directly, selected MFK providers respond to signals from the system operator's MFK controller to correct frequency and system time error.

3.38 Governor response settings for a given unit loading level are typically fixed.[18] By comparison, MFK providers can be dispatched on or off in each trading period, based on their offered prices, and ramped over a significant load range. For example, an MFK provider cleared for 15 MW (the present North Island or South Island MFK requirement), must be capable of:

(a) being ramped up or down at a rate of 6 MW per minute[19]

(b) being ramped from the top of its range to the bottom (a 30 MW change) over a 5-minute interval.

3.39 The system operator also procures backup station-based frequency keeping (SFK) services in each island, in case the MFK system is unavailable.[20] SFK response is coordinated locally by the selected provider in each island.

Functions

3.40 MFK contributes jointly both to managing system time error (cumulative frequency error) and normal frequency quality. MFK is typically slower acting than generation with responsive governors but assists generators that provide governor response to stay closer to their dispatched levels. As noted previously, the dispatch process can also correct system time error. The amount of governor response can affect MFK requirements and vice versa. Similarly, the dispatch interval for energy and the variability of demand can affect the amount of MFK or governor response required.

MFK procurement is market based

3.41 Potential MFK providers submit offers for each trading period, and the system operator selects the cheapest combination of offers to meet the band size requirement (presently 15 MW in each island).

3.42 Each selected provider is paid at the level of its MFK offer for that half hour (ie, it is 'pay-as-bid'). Providers also receive the energy market price for their generation. In addition, they may be entitled to some constrained on or off payments if energy dispatch is constrained so that the full range of cleared MFK can be provided.

---

18 In some instances the unit's operating mode (eg, boiler pressure) can affect response but governor settings are generally fixed.

19 Frequency keeping must be capable of changing at up to 0.4 MW / min for every 1 MW of frequency keeping capacity purchased.

20 Providers tender a constant fee for availability such that the system operator can call on them if MFK systems are unavailable.

3.43 Unlike instantaneous reserve, MFK procurement is not co-optimised with energy. Further, despite FKC now ‘joining’ the two islands into a single frequency system, procurement is still undertaken on an island basis due to the limitations of the system operator’s MFK selection tool.

3.44 These two factors may be causing material inefficiencies to MFK procurement. However, as detailed later, the Authority has put on hold investigations into introducing these options, pending decisions on the overall future for normal frequency management, including how much (if any) MFK may be required.

Impact of FKC on MFK requirements

3.45 Historically, the system operator procured 50 MW of SFK in the North Island and 25 MW of SFK in the South Island. Before MFK was introduced in July 2013 in the North Island and August 2014 in the South Island, only one provider in each island could be selected for frequency keeping for each trading period. Selected providers were responsible for managing their response to system frequency and system time error in their island. MFK has provided greater flexibility for providers and improved overall coordination of frequency keeping requirements.

3.46 The HVDC FKC function links the frequency in each island together by modulating HVDC transfers. This results in a diversity of load that provides benefits, and enables the transfer of generator governor response and MFK between islands.[21]

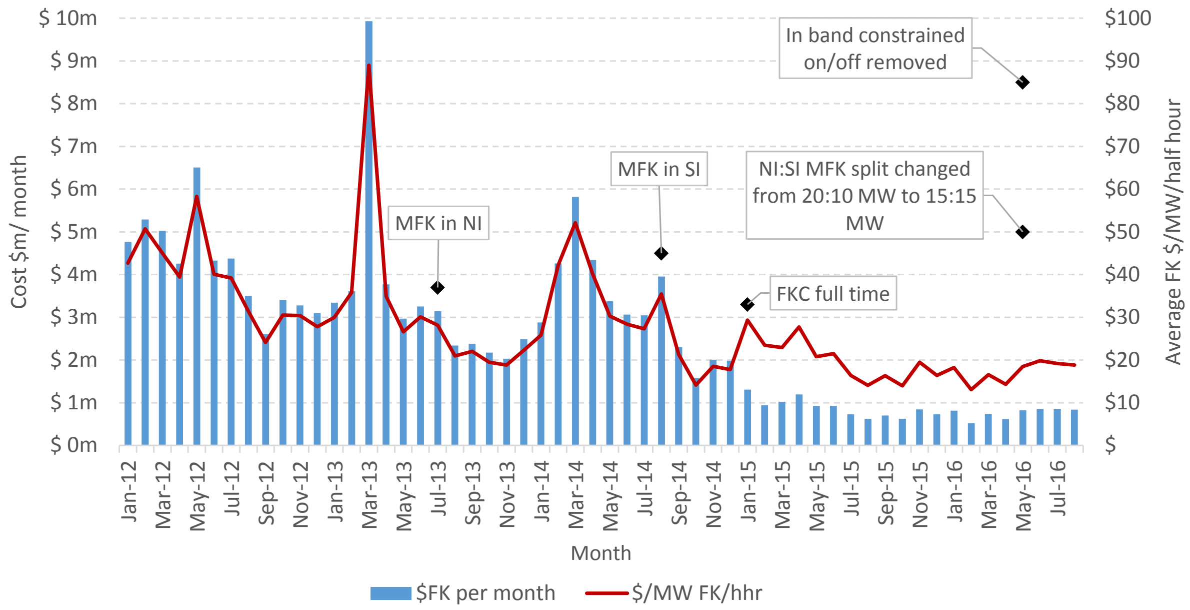
3.47 FKC was introduced fully in January 2015 and has enabled significant reductions in national MFK quantities from 75 MW to 30 MW in total, with little or no change to frequency quality. [22] The impact on MFK procurement costs can be seen in Figure 3. Procurement costs in the year ending 31 March 2016 were approximately $9.4 million compared with $40 million to $50 million in previous years.[23]

21 The diversity of load benefits means that there are relatively greater incidences of load movements in different islands moving in opposite directions and ‘cancelling each other out’. This reduces the overall quantity of frequency keeping required. For example, whereas two 1,000 MW systems may require 10 MW of frequency keeping each (20 MW overall), a single 2,000 MW system may only require 15 MW of frequency keeping.

22 Trials commenced in October 2014.

23 Refer to the Electricity Market Performance Report 2015 at (http://www.ea.govt.nz/monitoring/year-in-review/2015) . Note that other market factors may also affect costs.

Figure 3: SFK and MFK procurement Jan 2012 to Aug 2016



3.48 The system operator currently procures 15 MW of MFK in each Island.[24] The chart above excludes back-up SFK, the cost of which is relatively small as it is infrequently used.[25]

3.49 Note that the reduction in MFK is due to:

(a) the load diversity benefits of joining the two island systems

(b) shifting an amount of the duty of normal frequency management from MFK to governor response.

3.50 In particular, enabling hydro generators in the South Island to provide governor response to manage frequency deviations that previously were managed by MFK resources in the North Island.

Ongoing review of MFK requirements

3.51 The system operator conducted trials between October 2015 and February 2016 to test refinements to dispatch systems and to evaluate power system performance with different levels of MFK procurement nationally (30 MW, 20 MW and 0 MW). The study indicated that:

(a) Reducing MFK procurement from 30 MW to 20 MW showed no significant change in system frequency quality, system time error, or generator off-dispatch variations (although a slight increase in generator off-dispatch was noted).

(b) Reducing MFK procurement from 30 MW to 0 MW showed increased variations in system frequency quality, system time error and generator off-dispatch variations. The system operator noted that:

24 Since May 2016. Previously the split, with FKC in operation, was 20 MW North Island and 10 MW South Island.

25 Contracted providers receive a fixed availability fee to ensure the service is available and, if called upon, their offered price.

(i) frequency quality and system time error were within the range of acceptable operation prior to the introduction of FKC

(ii) management of system time error can be improved using dispatch tools

(iii) the implications of increased generator off-dispatch variations would need to be evaluated further.

3.52 The TASC 55 report (MFK Refinement) in Appendix C documents the system operator's findings.

3.53 These investigations raise the possibility of reducing MFK procurement further, potentially to zero. (Although, if FKC were unavailable, some form of frequency keeping would still be needed in the North Island, at least with the current levels of governor response).

3.54 However, the implications of drawing more on governor response for frequency support need to be considered, and is the key focus of the remainder of this information paper.

Dispatch and normal frequency management

Role of dispatch

3.55 Dispatch is the means by which the system operator manages energy flows around the grid in accordance with market offers and network capabilities.

3.56 The dispatch process typically operates on a 5-minute cycle, with instructions issued in anticipation of the trend in generation requirements during each 5-minute dispatch interval.

3.57 Dispatch can reduce the need for MFK. The closer the alignment of instructions to the underlying trend in requirements, the less dependence there will be on MFK and vice versa. Further, dispatch can also be biased upwards or downwards to correct system time error.

Ongoing work to improve dispatch

3.58 The system operator continues to make enhancements to its dispatch tools and processes. This includes the pre-solve deviation (PSD) tool that projects real time dispatch requirements leading into each 5-minute dispatch interval. During testing of MFK, PSD was tuned to enable system time error management via dispatch without any MFK and with much tighter control than required under the Code.[26]

3.59 The system operator recommended that further testing be undertaken to refine PSD operation and evaluate system performance with no MFK procurement under normal circumstances (FKC in service).

Frequency quality and normal frequency management

3.60 As set out above, the system operator has a normal frequency management PPO whereby it must "*maintain frequency in the normal band*".

3.61 The definition of the normal band is clear – ie, between 49.8 Hz and 50.2 Hz both inclusive. However the Code does not specify the extent to which the system operator must manage frequency movements <u>*within*</u> the normal band.

[26] Refer the system operator's TASC 55 report in Appendix C.

3.62 The nature and scale of frequency movements within the normal band are generally referred to as ‘frequency quality’. Large frequency deviations away from 50 Hz within the normal band, or rapid movements of frequency, are generally considered to be lower quality frequency than small or slow frequency deviations.

3.63 Past work has established that, within reasonable bounds, variation in frequency quality within the normal band has minimal direct negative impact on consumers’ equipment or processes (provided system time error is managed adequately).[27]

3.64 The principal parties affected by frequency quality are generators providing governor response and MFK. Low quality frequency will result in those generators incurring greater costs associated with wear and tear and operating away from their most efficient set point.

3.65 In looking for the best mix of resources to manage normal frequency, one option is to vary frequency quality, while still maintaining frequency within the normal band. As indicated, the system operator has shown it is possible to operate the system with no procured MFK and maintain frequency within the normal band, but with reduced frequency quality (although no worse than before FKC was introduced).

4 Minimising normal frequency costs

4.1 Governor response, MFK, dispatch, and normal frequency quality interact to varying degrees. Questions to be answered include:

(a) There appears to be scope, technically, to reduce MFK procurement further and potentially to zero. However, that could reduce normal frequency quality or place extra demands and costs on governor response providers. Would such costs outweigh any avoided MFK costs?

(b) Procuring more governor response could improve frequency quality and/or reduce MFK requirements and reduce the demands on existing individual governor response providers. Would that reduce overall costs?

(c) Relaxing normal frequency quality could reduce MFK requirements but place extra demands and costs on governor response providers. Would that increase their incidence of off-dispatch, and potentially increase reserve costs?[28]

4.2 Such trade-offs are difficult to make given the number of variables and uncertainty about some of the costs involved.

4.3 In order to make this problem tractable for the purposes of developing an efficient normal frequency strategy, the Authority has identified that the key trade-off is between the amount of governor response and the amount of MFK that should be procured.

4.4 Varying the amount of dispatch or frequency quality, or both, would alter the *amount* of normal frequency management required from governor response and/or MFK. But there

27 Grid Security Committee stakeholder survey regarding frequency quality, Common Quality Development Programme, September 2002.

28 For example, relaxing normal frequency could require more instantaneous reserve to be carried due to a higher risk of system frequency being at a lower level when a contingent event occurs. Or a generator may be less able to provide instantaneous reserve because of the risk it has already consumed some instantaneous reserve capability, through governor response, when a contingent event occurs.

would always be a requirement for *some* combination of these resources – ie, it is not feasible to do away with both governor response and MFK.

4.5 Accordingly, the principal focus of the frequency management strategy is, *for a given level of frequency quality and dispatch provision*, how best to identify and procure the least-cost mix of governor response and MFK. The review does not cover different levels of frequency quality or possible further improvements to dispatch systems and processes in any detail. These considerations may be the subject of future investigations, but are not within the scope of the strategic review.

Initial considerations of relative costs of governor response and MFK

4.6 In principle, if the system operator can maintain system time error through dispatch, and frequency quality remains broadly the same, the overall cost impacts relate largely to trade-offs between governor response costs and MFK costs. However, those trade-offs are still difficult to make.

4.7 Increasing the amount of governor response would likely allow MFK provision to be reduced further – potentially to zero.[29] On the face of it, this would remove market costs of around $10 million per year.

4.8 However, this is likely a false representation of savings, because providing governor response imposes wear and tear and availability costs on the providers, and increased governor response would likely increase the amount of the costs.

4.9 Further, requiring governor response from parties who are not suited to provide it (eg, geothermal, wind) may cost more than procuring MFK from relatively low-cost providers such as hydro.

4.10 This section sets out high-level considerations as to the relative costs of normal frequency management from different types of plant provided via governor response or MFK.

4.11 At a high level, there are three main types of cost associated with the provision of governor response or MFK:

(a) availability costs

(b) wear and tear costs

(c) capacity carrying costs.

Availability costs

4.12 Availability costs are associated with generating units operating away from their most efficient set-point or constraining operation in the energy market, or both (eg, operating at reduced load in order to be able to deliver 'up' governor response).

4.13 In principle, for a given amount of normal frequency response, there may be no significant difference in the availability cost between governor response and MFK. The total availability costs for a few MFK generating units, each delivering a large amount of response, could be similar to the total availability costs for a larger number of generating units individually delivering small amounts of governor response.

---

29 When FKC is not available, it is potentially the case that frequency keeping may still be required, even with higher levels of governor response – particularly in the North Island.

4.14 However, this only holds true if:

(a) There are no quantity differences, ie, 1 MW of MFK has a similar effect in regulating frequency as 1 MW of governor response.

(b) The types of generating units required to provide governor response are those that can provide the service at the lowest cost. For MFK, this is through a market-based process. However, if governor response is specified in an AOPO, this could result in high availability cost units being required to provide the service.

4.15 As Appendix E illustrates, hydro units generally have a much lower availability cost for normal frequency response than other plant. The most efficient set point for hydro generating units is generally at part-load. This means hydro units most often operate at part-load and when doing so will incur much lower availability costs than other forms of generation.[30] Geothermal, wind, and thermal units that would otherwise operate at maximum output would incur significant availability costs in operating at reduced output in order to deliver an 'up' response.

Wear and tear costs

4.16 Wear and tear costs arise from generating units moving around their dispatch set point. This causes wear and tear on moving parts, and thermal generating units may also incur thermal cycling impacts. It appears that wear and tear costs attributable to governor response are lower for hydro plant than thermal plant. That was the view expressed by thermal generators (who also own hydro generators) in submissions on the 2014 consultation paper. They cited significant maintenance and lifecycle impacts if their thermal plant was to be subject to small governor dead-bands and was to be continuously responsive to frequency changes within the normal frequency band.[31]

4.17 However, other than observed practice and some thermal generator submissions, there is little information about the likely wear and tear costs of providing governor response from various technologies. The Authority has provided some commentary on costs in Appendix E and welcomes any further insights generators can provide.

4.18 In general, the faster the rate of output changes, the greater the cost of wear and tear. Providing governor response may result in more wear and tear costs than providing MFK. This is because the speed of response of some governor response generating units is greater than the speed of response required for MFK provision. Further, if plant with relatively high wear and tear cost were required to provide governor response (eg, through an inappropriately specified AOPO), the costs could be greater still.

4.19 However, governors typically deliver some slower integral response that is very similar to that of MFK. Further, if lots of generating units deliver governor response resulting in a good frequency quality, the cost per generating unit will be a lot less, and the overall costs may not be much different from a few generating units delivering lots of response.

4.20 Thus, if governor response is provided from generating units able to provide it at least cost, it is not necessarily the case that overall wear and tear costs from governor

---

30 Availability costs could be higher when a hydro unit would otherwise have to spill to provide up governor response.

31 The references to maintenance and lifecycle impacts were supported by an external engineering report in one instance.

response will be materially different to providing normal frequency management from MFK.

Capacity carrying costs

4.21 Capacity carrying costs are those costs associated with holding sufficient capacity on the system to deliver 'up' response at times of capacity scarcity.

4.22 If too much system capacity is procured, this can result in substantial costs. This is because each extra MW of capacity held on the system is estimated to have a carrying cost of approximately $0.15 million per year, or $1.2 million present value over 15 years.[32]

4.23 The Authority considered whether the existing method of procuring MFK is resulting in economic over-procurement of system capacity. This could be because, during the few periods of capacity scarcity, it may be more economic to allow frequency to move below the normal frequency band (ie, below 49.8 Hz). Doing this would avoid holding back an extra 'X' MW of capacity to maintain the normal level of frequency quality that would be provided at all other times.

4.24 The trade-off would be the loss of some instantaneous reserve resource. The quantity of instantaneous reserve required on the system is calculated assuming a frequency of 50 Hz at the start of an event. If a contingent event happened when system frequency was below 49.8 Hz, the procured instantaneous reserve may not be enough to stop the frequency falling below 48 Hz. As a result, the first block of automatic under frequency load shedding would be triggered more often, resulting in higher lost load costs.

4.25 Initial considerations suggest that it may be more economic to rely on automatic under frequency load shedding instead of instantaneous reserve for such a low probability combination of events (the contingent event occurring at exactly the same time as the few minutes of extreme peak demand that occur over the period of a year). The alternative is to hold additional system capacity to maintain high levels of normal frequency quality during such infrequent periods.

4.26 Any over-procurement of system capacity due to MFK procurement is not an inherent feature of managing normal frequency through such a mechanism. It is the result of the existing approach of procuring a fixed amount of MFK at all times.

4.27 While it may be possible to reduce the MFK band size procured at times of capacity scarcity, there are likely to be trade-offs. Frequency quality is likely to degrade at other peak times.

In conclusion

4.28 There doesn't appear to be much difference in the amount of availability costs, costs of wear and tear, and capacity carrying costs between governor response and MFK for a given level of frequency quality. However, this assumes the right amount of the least-cost types of plant is selected.

4.29 The market-based nature of MFK helps identify the least-cost providers. The mandate-based method of acquiring governor response via AOPOs risks selecting the wrong type of plant, ie, requiring governor response from plant that is not suited to provide it, such

---

32 The marginal source of capacity on the system to meet peak demand is considered to be an open-cycle gas turbine. This is estimated to have capital-recovery and fixed costs of approximately $145/kW/yr.

as wind and geothermal generation. However, the broad latitude of interpretation of existing AOPOs appears to have resulted in governor response provision to date that is broadly in line with appropriate economic outcomes, ie, governor response within the normal band is predominantly provided by hydro generators, which is the most efficient generation to provide the service.

4.30 By comparison, the existing market-based approach to procuring MFK, while relatively simple, is likely resulting in higher costs than a more sophisticated approach. In particular, this is through:

(a) MFK procurement not being co-optimised with energy and instantaneous reserve

(b) MFK procurement being undertaken on an island-basis, despite FKC creating the potential for a national MFK procurement market

(c) the quantity of MFK being procured being specified relatively simply ie, a fixed MW amount that doesn't vary with system conditions (as set out above, this could result in greater system capacity carrying costs than would be efficient).

4.31 Participation in the MFK market is limited to relatively large generators whose scale of response is sufficient to justify installing the relatively expensive control signal receiving equipment. In principle, other technologies can provide MFK services, but not without changes to the system operator's MFK selection tools.

4.32 In contrast, most generators have governors, and there is no external control signal as such—just system frequency. In the future, it is possible that technologies such as inverters on batteries and solar panels could provide a governor-like response as a frequency management service at lower cost than governor response from generators.

4.33 The Authority considers the cost hierarchy of different generating technologies (hydro, thermal, wind etc) to be the same for governor response and MFK. Hydro plant has the lowest cost for both governor response and MFK, but does not have the same cost for the two services.

4.34 The cost hierarchy is evident in the fact that the vast majority of governor response and MFK provision is from hydro plant. Given the large amount of hydro plant on the New Zealand system, it is likely that hydro plant could provide most (if not all) the normal frequency response required for the foreseeable future.

4.35 The Authority considers that there is the potential for hydro plant to provide even more governor response than is currently the case, by using lower droop settings. This extra provision would further reduce the amount of MFK needing to be procured. It is not clear that this would result in materially greater availability or wear and tear costs compared with MFK, and it could also lead to savings in system capacity costs.

4.36 However, the amount of governor response provided by hydro plant over the past years has gradually reduced, as some owners of such plant have altered their governor settings to reduce gain.

4.37 This reduction in governor response may be due to:

(a) generators seeking to avoid the costs associated with delivering governor response (for which they don't get paid)

(b) possible incentives around providing MFK (for which they do get paid).

5 Procuring governor response

Optimising resources applied to establishing quantities and prices for governor response and MFK

5.1 From an economic perspective, the challenge is to design arrangements that allow the system operator to procure the lowest cost combination of governor response and MFK resources in order to meet its normal frequency management requirements.

5.2 However, such trade-offs are inherently hard to make. While MFK is a market-based procurement mechanism, governor response is a mandated service with costs, which vary by plant design and governor settings, being internalised to (or avoided by) providers. While such costs may be recoverable through energy market offers, they are not observable. Nor are the relative governor response contributions of generators to system normal frequency management easily measured (refer to the TASC 58 Report — Governor Response Metric in Appendix D).[33]

5.3 This complicates efforts to minimise overall normal frequency costs.

5.4 Further, in the future, parties could deliver lower-cost, governor-like response using technologies such as inverters connected to solar PV and batteries. Ideally, measures to procure governor response from 'conventional' grid-scale generators would also be suitable for incentivising response from these much smaller-scale resources. However, developing arrangements that can incentivise response from large numbers of very small providers creates its own set of challenges, with transaction costs being a potential issue.

5.5 The Authority has previously described its preferred decision-making and economic (DME) framework in relation to electricity transmission charges.[34] It sets out a hierarchy for recovering costs of preferred arrangements directed at maximising economic efficiency and ensuring the optimum level of resource is applied.

5.6 The principles in that framework, as applied here to procuring governor response and allocating its cost, provide the following hierarchy (in descending order of preference):

(a) Market-based or market-like arrangements—incentivising governor response providers to compete on price under a more market oriented procurement system to facilitate the lowest cost combination of governor response and MFK resources. A market-based approach tends to be more efficient than other approaches because parties, in a workably competitive market, can seek to achieve efficiency gains whenever and wherever possible.

(b) Incentivise exacerbators—exacerbators are parties whose action or inaction contributes to variations in system frequency, and who would change their behaviour if faced with the social cost of their action or inaction.

(c) Recover costs from beneficiaries—a beneficiary is a party for whom the private benefits of an action exceed the cost and who would therefore be willing to pay the cost if that were the only means of acquiring the benefit.

---

33 For example, how should the contribution of a unit with a small governor dead-band but low gain be compared with the performance of a unit with a larger dead-band but higher gain?

34 See (https://www.ea.govt.nz/dmsdocument/12978). The same approach has been used by the Authority for consideration of other issues, such as extended reserves.

(d) Administrative arrangements—where it is impractical to adopt (a), (b) or (c), it may be necessary to socialise some costs of generating units providing governor response.

5.7 The Authority noted a preference in the 2014 consultation response paper for arrangements that incentivise generator governor response or equivalent forms of control response. The system operator also considers that incentivising generator governor response would have merit (TASC Report 49).[35]

5.8 Governor response contributes to an element of electricity quality that is common across the grid and therefore cannot be attributed to an identifiable person or group of persons. Accordingly, the most efficient approach is for it to be procured by a single party, eg, the system operator on behalf of all grid users. The DME framework would allocate the system operator's costs using method (a), as a first preference.

5.9 A number of procurement options are discussed in paragraphs 5.11 to 5.69 below. The focus of the discussion is on:

(a) defining the governor response service to be procured

(b) identifying the lowest cost way to procure the service.

5.10 Cost allocation is covered briefly but would to be developed in more detail as part of future work, consistent with the DME framework.

High level procurement options considered

5.11 The Authority has considered the potential options for procuring governor set out in the table below:

Approach	Option
Adapt status quo	A–codify existing practices
Administered pricing	B–benchmark performance and cost allocation C–over/ under payments vs benchmark performance D–pay providers for relative contributions
Market pricing	E– bid based procurement F– tender based procurement

Adapt the status quo approach

5.12 At present, hydro generators are the greatest source of governor response – an indication that they are generally the most suitable providers.

5.13 The way the existing arrangements have evolved could be likened to technology-specific AOPOs. From a technical perspective, the performance of system frequency in the normal band is satisfactory and that is likely to continue to be the case given the proportion of hydro capacity available.

35 "Interim Solution Option Analysis, Normal Frequency Management Strategy Project" and "Future Solution Option Analysis, Normal Frequency Management Strategy Project, September 2015"

Option A: Codify existing practices

5.14 One option is to formalise such an arrangement in the Code through more prescriptive AOPOs (specifying detailed input requirements for droop, dead-band, gain etc).

5.15 That could either be achieved through:

(a) a common AOPO, or

(b) technology specific AOPOs (ie, different requirements for hydro, geothermal, wind, etc).

5.16 While this option could have low implementation costs, there are concerns that:

(a) governor response costs would continue to be internalised to providers, making it difficult for providers to make trade-offs with MFK and other governor response providers

(b) generators that do not currently provide governor response would effectively be grandfathered, with no incentive to start providing governor response (irrespective of availability cost)[36]

(c) there would be no incentive for hydro plant to provide more governor response than they currently do (or, potentially, even to maintain existing levels of governor response)[37]

(d) applying a common standard to hydro plant would not incentivise units with lower cost to provide more governor response

(e) generators providing governor response would continue to incur costs that others would avoid. Failing to recognise that some technologies contribute to system benefits more so than others which could distort operational, refurbishment, and investment decisions

(f) there is the potential to frustrate possible new technologies (for which technology-specific AOPOs would not have been developed) from participating.

5.17 While existing practices appear to be adequate for frequency quality, it is unclear whether that is the case from an economic perspective. A share of MFK procurement costs could be allocated to generators that do not contribute any governor response to send a modest signal to support a reasonable endeavours approach.

5.18 A potential disadvantage of this idea is that existing providers may opt-out of providing governor response if the cost allocation signal was too weak (even if such action resulted in higher MFK procurement costs).

5.19 Additionally, allocating costs on the basis of non-compliance with input-focussed AOPOs would be problematic. For example, a plant might comply with input-focussed requirements but contribute less to normal frequency management than a plant that does not comply fully. A plant might not meet governor dead-band requirements but otherwise be more responsive (eg, due to a lower droop setting) than a generator that complies with specified dead-band and droop requirements.

---

36 For example a provider may be able to reduce dead-band inside +/-0.2 Hz with high governor droop and low gain may be achievable at relatively low cost.

37 The system operator considers that governors could be somewhat more responsive without compromising system stability.

5.20 The approach in respect of cost allocation would also break down if MFK procurement reduced to zero.

5.21 Given the above issues, the Authority considers that it would be preferable, subject to practicality and cost, if governor response providers were incentivised at a higher level in the DME framework and able to trade-off the cost of provision against system benefits.

5.22 Some high-level options are discussed in the following approaches.

Administered pricing approach

5.23 Some of the issues noted above could be addressed by using output measures for governor response, rather than input parameters. Specifically, an output-based approach would specify the amount of response with reference to an output performance metric rather than by specifying various governor input parameters such as droop, dead-band and gain (as at present).

5.24 By using output measures, it would be possible to differentiate between providers' contributions on a like for like basis, and financial arrangements would incentivise participation, where this is cost effective. It would also be more technology neutral.

5.25 The way that output measures for governor response might be implemented is common to options B to E. The system operator investigated this (see TASC 58 (Appendix D) and it is discussed further in paragraphs 5.38 to 5.47). They differ as to the nature of the financial arrangements.

Option B: Output-based benchmark and cost allocation

5.26 This would involve setting a generic output-based benchmark and specifying a cost allocation methodology for non-compliance (as provided for under the Code dispensations provisions). Alternatively, this could take the form of technology-specific output-based benchmarks along with cost allocation methodologies for each class of technology.

5.27 An output-based benchmark and cost allocation would place all generators on a level playing field. Those unable to meet the benchmark would face the resultant impact on others (provided an efficient price for governor response can be established). Residual costs could be allocated to purchasers to minimise distortions (as is the case for MFK).

5.28 An output-based benchmark would enable contributions from partial compliance to be recognised in any cost allocation. How such a cost allocation might be determined is common to options B to D and is discussed in paragraphs 5.48 to 5.56 below.

5.29 A potential disadvantage of an output-based benchmark and cost allocation approach is that there would be no incentive for governor response contributions above the nominal benchmark requirement. That could be addressed by setting relatively high standards, but that would be a more punitive approach to incentivising governor response contributions.

5.30 An alternative would be to consider establishing an output-based overs and unders payment regime, as discussed in the following option.

Option C: Output-based benchmark with over and under payments

5.31 This would involve establishing an output-based performance benchmark for governor response, against which to assess actual contributions of governor response. The benchmark would need to be scalable with plant capacity. Over-providers (relative to benchmark performance) would be paid, and under-providers would pay an administered price for each contribution or shortfall. Residual sums, which could be a surplus or deficit, could be prorated to purchasers on a MWh basis, in a least-distortionary manner (as for MFK costs at present).

5.32 Advantages of this approach are that there would be no need for dispensations as such, and an appropriate benchmark could be selected so as to reward contributions in excess of the benchmark whilst retaining a level playing field for all generators.

5.33 The key challenge is in getting the price signal 'correct'. Without an AOPO, if the price signal is:

(a) inadequate, sufficient governor response may not be made available – resulting in more MFK procurement than otherwise being required

(b) too strong, an inefficient level of governor response would be provided relative to MFK.

5.34 Another disadvantage is that an overs and unders approach may not fit well with future technologies, such as energy storage devices, unless the benchmark is set at zero. It would be not make sense to place payment obligations on energy storage providers if their contribution is less than the benchmark for governor response. However, these issues may be addressed by de minimis approaches (ie, only specifying requirements for plant above a certain size), or making requirements technology-specific.

Option D: Pay providers for relative contributions

5.35 This option would be similar to option C except that the performance benchmark would effectively be set at zero and providers of governor response would be paid for all contributions they made. Costs could be allocated in the same manner as above.

5.36 This option would remove the punitive aspect of Options B and C and enable all technologies, existing and future, to participate on even terms.

5.37 As with the previous options, the key challenge is getting the price signal 'correct'. In particular, without any AOPO requirement, in the extreme there could be the risk of insufficient governor response to maintain system stability under normal or islanding/recovery circumstances.

Common issues for administered pricing options

5.38 Common issues that to resolve with each of these options include:

(a) how to specify and assess output performance

(b) how to determine the correct price signal.

How to specify and assess the performance of governor response

5.39 An output-based metric would provide a basis to assess the relative contribution of governor response for each generating unit.

5.40 The Authority has considered potential output-based performance metrics. It has concluded that it would be impractical in New Zealand to measure governor response using systems for supervisory control and data acquisition (SCADA) because data sampling rates are inadequate. The system operator shares this view.

5.41 Note that the Australian National Electricity Market (NEM) has a frequency deviations regime that uses SCADA. Contributors to frequency correction are paid and causers of frequency variations make payments. Payments are based on actual movements in generation (via SCADA readings) relative to automatic generation control signals frequency correction. An arrangement like that seems impractical in New Zealand given the available rate of SCADA sampling relative to rate of frequency variation. However, options C and D are broadly similar in intent.

5.42 Instead, the Authority is suggesting some form of ex ante assessment of governor response contribution capability. For example, modelled signal injection using the verified governor models provided to the system operator in asset owners' asset capability statements.

5.43 That would necessarily be an approximation for a provider's actual response that would vary according to system demand, the mix of plant on the system and the dispatched MW level of the provider. A generator that was already at full output would not be able to respond 'up' to a fall in frequency. A plant that was not dispatched at all would not provide any response no-matter how responsive its governors had been assessed to be.

5.44 Contribution metrics would therefore need to be based on a combination of an ex ante assessment of governor response capability and dispatched output levels during a trading period. How to accommodate block dispatch would require careful consideration.[38]

5.45 The system operator has investigated various ex ante governor response metrics to assess providers' governor response including:

(a) modelled signal injection

(b) system time error and revenue metering data

(c) frequency distribution and dead-band-droop characteristic

(d) direct measurement of SCADA data.

5.46 The system operator concluded that it is possible to accurately account for both the magnitude and speed of response of generating units with a 'modelled signal injection' metric based on an appropriately selected injection signal.

5.47 The system operator's findings are included in its TASC 058 report in Appendix D.

How to determine payment rates

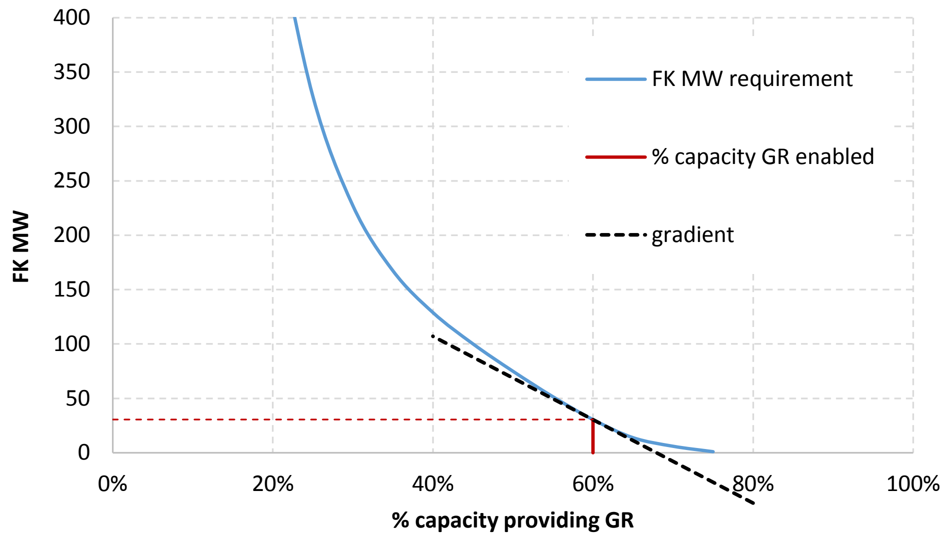
5.48 Ideally, generators would face a marginal cost signal for the impact of altering the amount of governor response they provide to manage normal frequency. They could then consider their own costs against that marginal cost signal.

5.49 Within the framework discussed in paragraphs 4.1 to 4.5 for minimising normal frequency costs, a key trade-off is between the cost of MFK and the cost of governor response. If the relationship between governor response and MFK requirements were known, it would be possible to establish a payment rate for governor response based on its marginal impact on MFK requirements. For example, in the stylised example below, the gradient represents the change in MFK requirements for a change in generation with

38 Ideally, governor response contributions would be calculated for each generating unit based on an ex ante performance metric and unit dispatch. However, under block dispatch, instructions are issued to generation blocks rather than individual generating units. The feasibility of using average unit or station MW loading during an interval instead of dispatch instructions would need to be assessed.

governor response on the system. Multiplying this gradient by the average MFK price per MW would provide a proxy for the marginal value of changes in governor response.

Figure 4: Hypothetical relationship between MFK and governor response



5.50 This illustration is overly simplistic because:

(a) The effectiveness of governor response will vary by contributor and the x-axis would need to be normalised to reflect a standard measure of governor response contribution along the lines discussed in paragraphs 5.39 to 5.47.

(b) Although MFK requirements are fixed, the relationship between governor response and MFK is probably a family of curves. These would vary with system conditions and any relationship of the form in Figure 4 would inevitably be an approximation and may be difficult to establish, objectively.

5.51 At present, the Authority has not conducted studies to establish whether it might be feasible to develop such governor response vs MFK trade-off curves.

5.52 Further, although the price of procuring MFK can be readily determined, it is not clear that the price reflects the 'true' marginal cost of providing MFK. Note also that MFK is neither co-optimised with energy and reserves nor procured on a national basis. In addition, it is not clear that procuring a fixed amount of MFK at all times is itself efficient, with this potentially representing over-procurement at times of capacity scarcity.

5.53 Another significant issue with this approach is the possibility that MFK procurement could be reduced to zero as noted previously. If so, there would be no ongoing basis for establishing governor response payment rates in this manner.

5.54 Instead, some form of administered floor price would need to be established. A price of zero would clearly be inappropriate as it would not compensate providers for their costs.

This would discourage generators from providing governor response.[39] Similarly, setting an arbitrary floor price could also create perverse outcomes if it were too high or too low.

5.55 The possibility of setting a reserve price for governor response price, perhaps by attempting to estimate typical governor response provider costs. Including marginal costs, or using the last MFK-based rate could perhaps be considered.

5.56 Alternatively, it may be more efficient to try to discover governor response costs through an auction process with governor response providers competing on price to provide the service. This would be a market pricing-based approach and is discussed in the following options.

Market pricing approach

5.57 These options would rely on governor response providers competing on price to meet requirements.

Option E: Bid based procurement

5.58 Option E is an instantaneous reserve or MFK-style market for procuring governor response. In principle, it would facilitate price discovery and enable providers to compete on price. However, such an approach has been discounted because of the complexity of a half hourly market for a relatively inflexible service. Other services such as MFK can be turned on or off in a trading period if offers are accepted or not. Adjusting generator governors on the same basis would not be practical, because it would require significant expertise, time and cost.

5.59 Instead, a longer-term contractual model along the following lines might be a lower-cost means of price discovery and a better fit with the nature and value of the service.

Option F: Tender-based procurement

5.60 This option could be based around a medium-term tender process (say for 2 to 5 years). Providers of governor response would submit unit governor response quantities (in output terms as above)[40] and tender prices expressed in half hourly terms. Tender prices would represent expected plant efficiency and costs of wear and tear related to governor response if the plant was dispatched in a trading interval.

5.61 The system operator would stack up the tenders in price order until the amount of governor response was equal to the required level of governor response. However, if generators tendered enough governor response capability, the quantity could be increased until the costs of procuring an incremental amount of governor response equalled the cost of procuring an equivalent incremental amount of frequency. This could reduce or even eliminate MFK altogether. It could also provide better incentives to tenderers, by making them aware that more or less governor response procurement might result.

5.62 This evaluation would need to be undertaken across the range of system conditions, taking into account the extremes of generation levels from the different classes of generators.

---

39 Although under Option B, a benchmark obligation would still exist and the system operator would not grant dispensations unless it could continue to meet the PPOs.

40 Technical capabilities pre-confirmed with the system operator.

5.63 The system operator would form contracts with accepted providers. Their unit is dispatched in a trading interval, they would receive the agreed price modified according to its dispatched level (eg, if dispatched to full output, the price would be halved if only downward response is available).

5.64 Procurement costs could be recovered in the same way that MFK procurement costs are currently recovered – ie, from purchasers on a per MWh basis. To strengthen incentives for potential governor response providers to participate where cost effective to do so, the costs of governor response provision could be recovered from both purchasers and non-providing generators.

5.65 One advantage of tender-based procurement is that it could be staged with a reasonable lead time and a long contract term, to recognise the time and effort involved to adjust governors. Providers would also have certainty about payments for the duration of their contract and could trade-off governor response benefits relative to dispatch and potentially MFK. However, a shorter-term contract period, say 1-2 years, might cater better for new investment and plant retirement. A shorter term (at least initially) may also be more attractive to providers of governor response and to the system operator, who might see the shorter term as less risky.

5.66 The disadvantages of this approach are that it could have significant complexity and high transaction costs. An alternative is that tenderers submit annual or quarterly fees rather than half hourly. That would greatly simplify payment mechanisms. However, providers of governor response would need to build uncertain market dispatch outcomes into their tender prices, probably conservatively, and payments would take no account of actual dispatch outcomes.

5.67 Another limitation of this approach is that generators would have to manage availability costs through their energy market offers. It would be impractical for generators to assess likely availability costs when they submit tenders for governor response under a medium-term contract.

5.68 Further, it requires the system operator to be able to trade-off the amount of governor response provision against MFK provision—as illustrated previously in Figure 4. However, as also previously mentioned, the system operator has not yet carried out any studies to assess whether it could make such a trade-off.

5.69 A tender-based procurement approach can create incentives for providers to increase their governor response contributions and provides for discovery of price without a continued MFK regime. However, the viability of such an approach has yet to be proven.

6 Summary

6.1 Subject to costs and practicality, the ideal approach would involve:

(a) the system operator specifying the amount of governor response required

(b) potential providers of governor response competing on price

(c) the system operator determining the optimal mix of MFK and governor response so as to minimise the overall cost of procuring governor response and MFK

(d) costs being allocated efficiently.

6.2 This would require:

(a) a practical output-based metric for governor response contributions

(b) specifying requirements for overall governor response, taking into account substitution between governor response and MFK.

6.3 If these requirements are feasible, then a key design consideration is the likely cost of implementing a preferred approach, . The DME framework ranks market-based approaches at the top of the hierarchy, but the viability of such approaches, in terms of cost and complexity, is yet to be determined.

6.4 The findings of the system operator's investigation under TASC 058 confirm that a workable metric for output-based governor response is likely to be practical.[41]

6.5 However, how or whether the system operator might determine its requirements for overall governor response, and the interdependence between governor response and MFK, is less clear. A backstop approach could be to determine individual governor response capabilities for each generator in output terms and to calculate overall governor response based on historical dispatch. That might provide a basis for specifying the initial amount of governor response to be procured under a market option such as a tender mechanism (like option F in section 5). It might also allow providers of governor response to trade off the market cost of less (or more) MFK against more (or less) governor response based on prices over or under nominal requirements in a tender.

6.6 The ability for providers to trade-off costs between procuring MFK and governor response would be a prerequisite for any administered pricing options (such as options B, C and D in section 5). The likely non-linearity of the relationship between governor response and MFK (as shown in Figure 4 on page 32) is likely to create particular challenges for administered pricing options.

6.7 If it is impractical or too costly to implement a workable metric for output-based governor response, procuring governor response will need to fall back on an input-based AOPO approach (such as Option A in section 5). In that regard, the simplest approach might be to:

(a) adopt technology-specific AOPOs (for example focussed on the size of the permissible dead-band)

(b) require generators to work with the system operator on a reasonable endeavours basis to agree other governor response settings such as droop, dead band and gain.

6.8 Such an approach would be broadly consistent with how governors are currently set for each technology class—which appears to broadly reflect their relative costs of providing governor response. However, that would not address the issues associated with the current AOPO regime. In particular:

(a) the inability to identify the effects of system cost for dispensation purposes

(b) the inability of generators to trade-off the impact of their governor response performance on system costs (and uneven playing field)

(c) the system operator's inability to make economic trade-offs between governor response and MFK procurement.

41 Refer to Appendix D

6.9 The Authority is interested in receiving submissions on any aspect of the paper, including the technical investigation reports. Suggested questions for submissions are included in the executive summary.

Appendix A TASC 49 Report – Performance Benchmarks (phase 1)

Appendix B TASC 49 Report – Future Solution Option Analysis

Appendix C TASC 55 Report – MFK Refinement

Appendix D TASC 58 Report – Governor Response Metric

Appendix E Insights into potential generator governor response costs

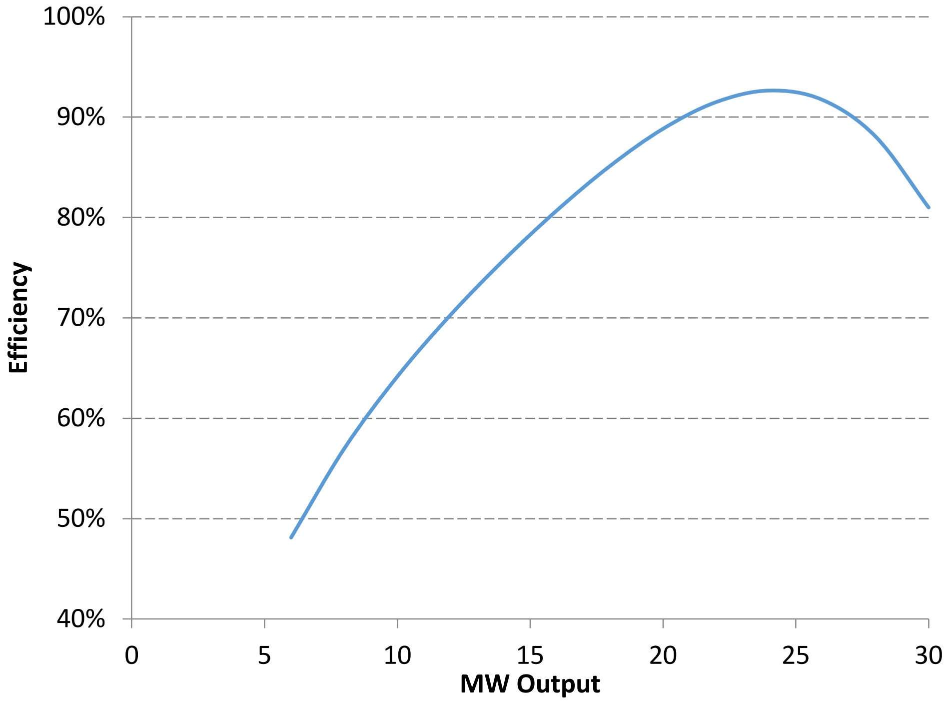
Availability costs

E.1 Availability costs can arise if a generating unit operates away from its most efficient set-point and/or its operation is constrained in the energy market. For example, when operating at a less efficient or a lower load than it otherwise would in order to provide governor response within the normal frequency band it is possible to gain some rough insights into such costs.

Hydro generation

E.2 Consider a hypothetical 30 MW hydro unit with the following efficiency curve.[42]

Figure 5: Efficiency curve for a hypothetical 30 MW hydro generator



E.3 Assume for simplicity that the unit has undamped proportional governor response with no dead-band and that, except for unrestrained governor response, is otherwise able to operate unconstrained at optimal efficiency (ie, at approximately 25 MW output). Table 1 indicates lost annual energy production due to governor response under different governor droop setting due to the unit cycling around its most efficient loading level in response to system frequency.[43]

42 A stylised version of a Francis turbine efficiency curve.

43 The analysis of GWh losses assumes normal distributions for NI and SI frequency as depicted in the System Operator's report on FKC trials during January 2015 (Frequency Keeping Control Trial Technical Review Report, June 2015. (https://www.systemoperator.co.nz/sites/default/files/bulkupload/documents/FKC%20Technical%20Report.pdf)

Table 1: Hypothetical 30 MW hydro unit unrestrained governor response losses

	Undamped droop	NI	SI
GWh loss pa	6%	0.08	0.05
	4%	0.17	0.12
	2%	0.70	0.47
Cost pa	6%	$0.006m	$0.004m
@ $80/MWh	4%	$0.014m	$0.009m
	2%	$0.056m	$0.038m

E.4 In practice the annual effect is overly simplified as hydro plant load factors will be lower than implied above and governors would have some level of damping and dead-band.[44] That could be offset to an extent by greater efficiency penalties due to output continually moving around. There will also be times when a unit would, unless it had to provide upward governor response, operate at full output.

Geothermal comparison

E.5 In contrast, a geothermal unit that would otherwise operate at full load continuously would incur much greater availability costs as illustrated for a notional 30 MW unit in Table 2. As for the hydro example, the analysis assumes undamped proportional responses with no governor dead-band and otherwise unconstrained output.[45]

Table 2: Hypothetical 30 MW geothermal unit unrestrained governor response losses

	Undamped droop	Up & Down	Down only
GWh loss pa	6%	8.94	1.19
	4%	13.40	1.78
	2%	26.81	3.56
Cost pa	6%	$0.71m	$0.09m
@ $80/MWh	4%	$1.07m	$0.14m
	2%	$2.14m	$0.28m

E.6 The downward only response assumes a unit dispatch set point of 30 MW. The upward and downward response assumes a MW set point such that the unit has headroom to respond upwards to a 3x frequency standard deviation movement.[46] Clearly providing both up and down response capability is costly. The impacts will be overstated because the analysis assumes governors with undamped proportional responses and zero dead-band. It also ignores potential impacts of having to vent steam. However, the analysis, summarised below, serves to highlight that, all else equal, availability costs for geothermal units are likely to be much greater than for hydro units.

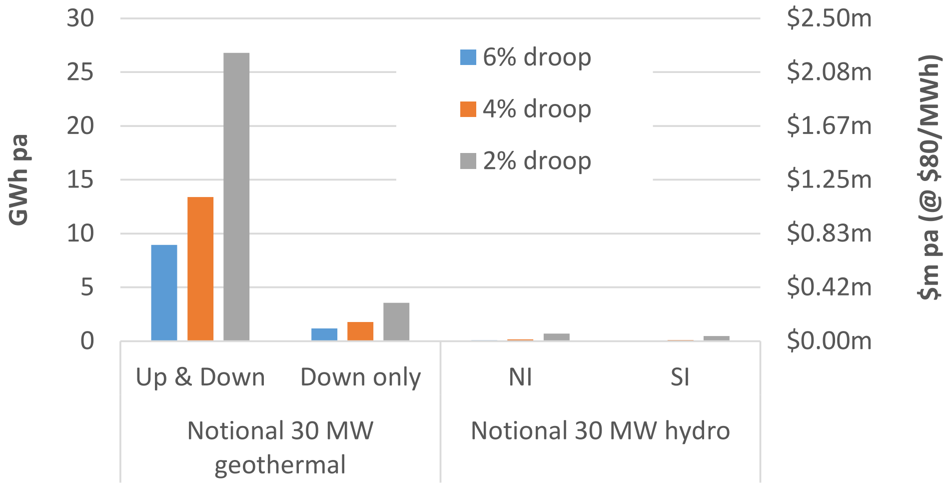
---

44 It is possible that at times of higher inflows the MWh losses could be greater, especially if a unit had to be backed off below maximum to provide both upward and downward governor response. The cost of that would depend on overall market conditions.

45 The analysis assumes a normal distribution for NI frequency as noted previously in footnote 43.

46 Approximately 0.1 Hz with FKC (from system operator's report available at: (https://www.systemoperator.co.nz/sites/default/files/bulk-upload/documents/FKC%20Technical%20Report.pdf)

Table 3: Availability cost comparison



Wear and tear costs

E.7 The Authority is not able to estimate potential wear and tear costs associated with governor response provision. There is little information publically available. Informal discussions suggest that generators can also find it difficult to estimate such costs. The following analysis is therefore illustrative of the approach a generator might take so as to get a rough feel for potential costs and sensitivities. The analysis should be treated accordingly.

Hypothetical hydro

E.8 Assume that:

(a) it costs $0.3 million to overhaul the governor and associated actuating equipment of a hypothetical 30 MW hydro unit, which provides unrestrained governor response

(b) this occurs at 10 year intervals with an outage cost of $1m (foregone revenue).

E.9 Suppose that re-configuring the generator's governor to provide minimal response within the normal band would reduce annual routine maintenance costs by $25k and extend the overhaul cycle to 12 years.[47] Over a 20 year horizon,[48] that would represent annual savings equivalent to around $0.037million or approximately $0.12 per MW of capacity per half hour.[49] Figure 6 illustrates sensitivity of these calculations to assumptions.[50]

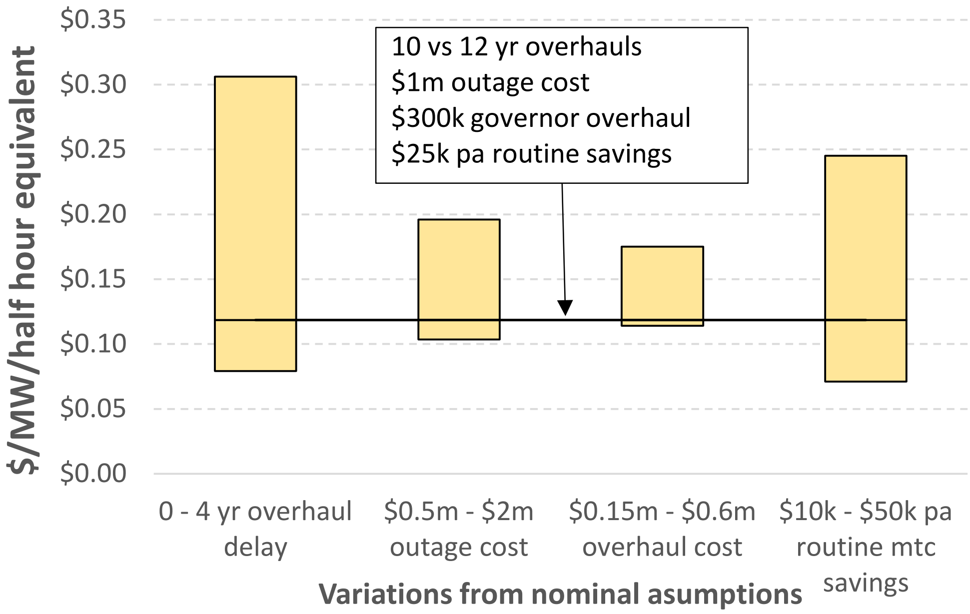
47 Assuming that governor and related equipment overhauls are not linked to other major overhaul intervals and that this could be achieved by applying a dead-band of +/- 0.1 Hz to the governor.

48 Assuming the first 'normal wear and tear' overhauls would occur at year 5 and subsequently at 10 year intervals and that the first alternative 'non response governor' overhauls would occur at year 6 and subsequently at 12 year intervals.

49 Assuming a capacity factor of 60%.

50 This calculation is sensitive to the assumption that the first normal overhaul would occur at 5 years and the first alternative overhaul would be 2 years later.

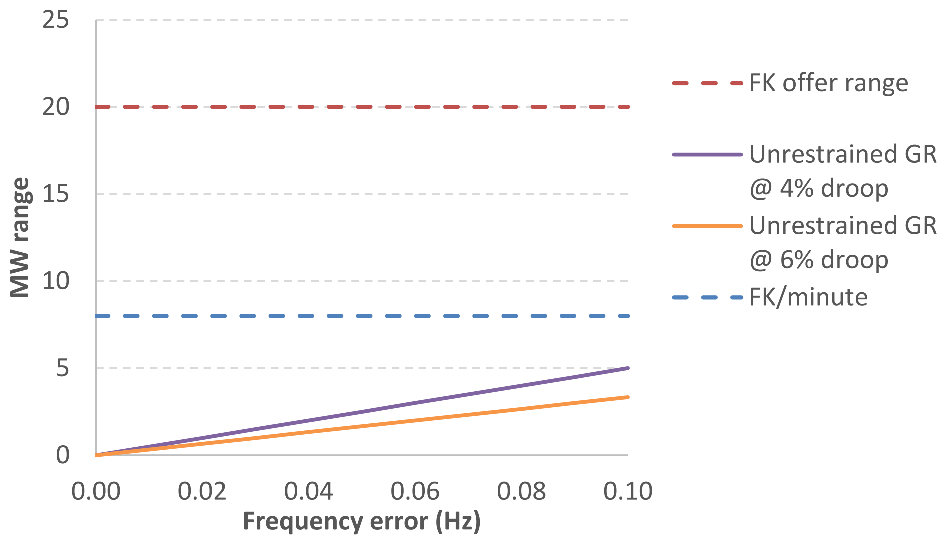
Figure 6: Illustrative approach to hydro wear and tear costs



Can anything be gleaned from thermal station MFK offers?

E.10 MFK providers are expected to respond at up to 0.4 MW per minute per MW of MFK procured. For a thermal unit offering MFK, that can represent a significant MW range relative to governor response ranges as illustrated in Figure 7.

Figure 7: Unrestrained governor response vs MFK range for a notional 100 MW thermal unit offering 20 MW MFK[51]



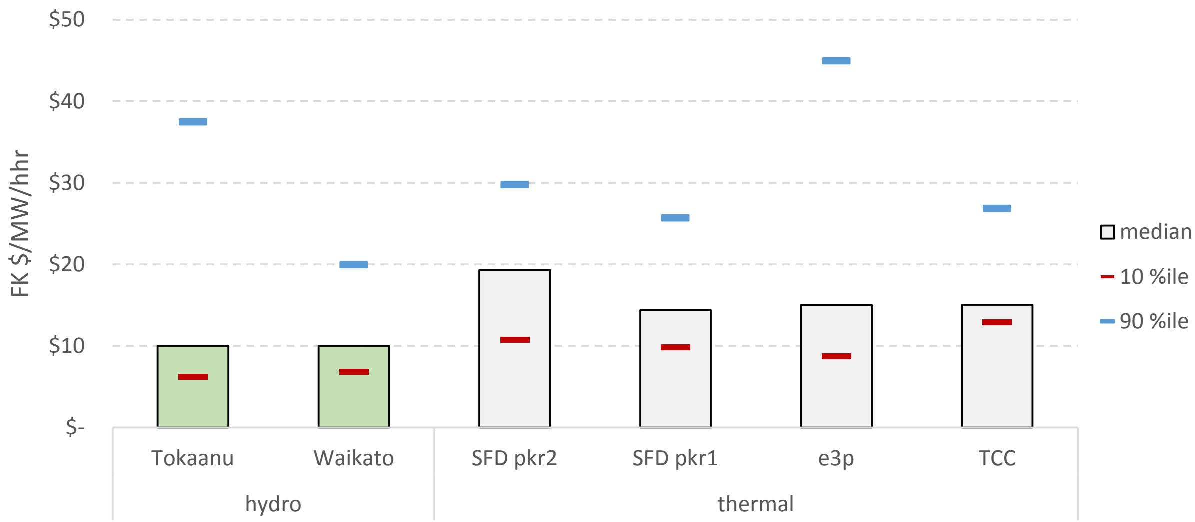
51 Until May 2016, 20 MW of frequency keeping was procured in the North Island.

E.11 Note that 0.1 Hz is approximately 3 standard deviations of North Island frequency error.[52]

E.12 The chart assumes undamped governor response with zero dead-band (ie, infinitely fast) but that MFK is rate limited.

E.13 Accepting that MFK response will generally be slower acting than responsive governor action, MFK offers may provide some insights into thermal wear and tear costs. Figure 8 shows statistics for 20 MW (North Island) MFK offers converted to per MW per half hour values.[53] Hydro providers tend to have the lowest prices but then the underlying capacity providing MFK is generally spread over multiple units or stations whereas thermal offers are by unit.

Figure 8: North Island 20 MW MFK offers (year ending Apr 16)



E.14 MFK offer prices will include estimates of availability costs due to reserving capacity for MFK duty. However, lower percentiles of offer prices may be indicative of intrinsic unit-related costs such as efficiency losses and wear and tear. In this regard, Figure 9 shows lower priced percentiles of 20 MW MFK offers for thermal stations converted to implied half hourly costs per MW of unit capacity. For comparison, the dashed line indicates implied extra maintenance costs of providing continuous governor response within the normal frequency band based on Contact Energy's submission on the 2014 consultation paper.[54] That figure ignores outage costs and life cycle impacts. The chart data are not necessarily inconsistent accepting that:

(a) the required MFK response range is relatively large

---

52 With FKC in operation. Based on the System Operator's report on FKC trials during January 2015 - Frequency Keeping Control Trial Technical Review Report, June 2015. (https://www.systemoperator.co.nz/sites/default/files/bulk-upload/documents/FKC%20Technical%20Report.pdf)

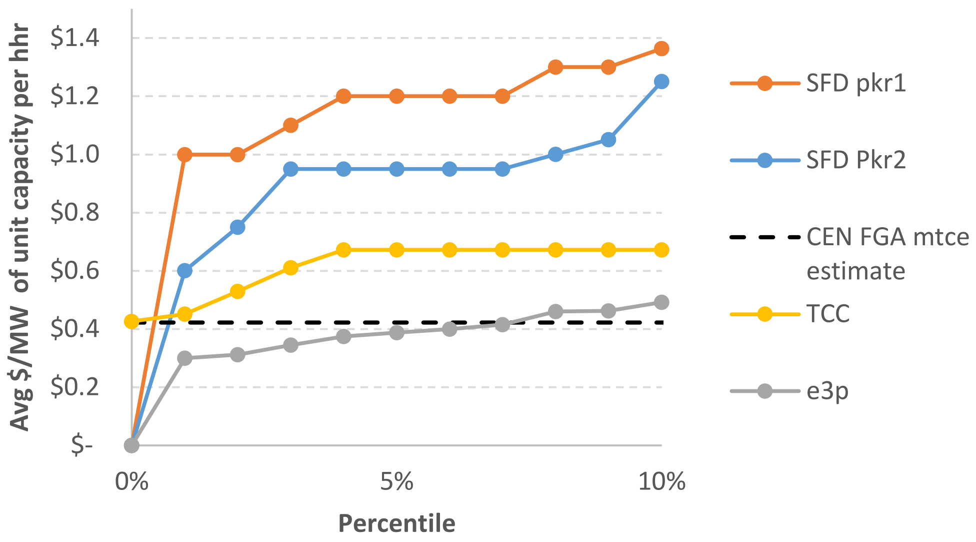
53 During the period covered, the amount of frequency keeping procured in North Island was 20 MW.

54 The public submission indicated $3.5m pa additional maintenance cost if thermal units were compliant with the generator normal frequency AOPO proposal in the 2014 consultation paper. The implied cost in the chart assumes this figure applies to the all of Contact's Stratford and Otahuhu plants (the latter being shut down subsequently) with an average load factor of 50%.

(b) governor response would typically be faster and alter more often than for MFK response

(c) the dashed line ignores outage costs and plant life cycle impacts.

Figure 9: Implied thermal MFK cost/ unit MW (20 MW MFK offers, year ending Apr 16)



E.15 This analysis suggests that on a per MW of unit capacity basis, wear and tear costs will be greater for thermal generation to actively provide governor action with minimal dead-band than for hydro generation. However, it is difficult to draw accurate comparisons given a lack of data. As much as anything, the above analysis highlights that the costs will vary by plant type and that plant owners are best placed to make such assessments.

E.16 It is also important to observe that some thermal governor response within the normal band, even if sluggish and/ or with a degree of dead-band, may be practical at relatively low cost. This was not accommodated by the 'full compliance one size fits all' obligations proposed in 2014.

Observations

E.17 It seems reasonable to assume that:

(a) hydro generators are likely the lowest cost type of provider of normal frequency response (consistent with observed practice)

(b) for hydro generators providing governor response, wear and tear costs could be of a similar order of magnitude to unit efficiency impacts

(c) hydro costs will typically be significantly less than the availability costs a comparably sized geothermal unit would incur, particularly if required to provide both up and down governor response within the normal frequency band

(d) similarly, the cost of a wind farm providing up and down frequency response is likely to be relatively high given it would need to be backed (spilling wind) off to do so.

Glossary of abbreviations and terms

AGC	Automatic generation control
Act	Electricity Industry Act 2010
AOPOs	asset owner performance obligations set out in Part 8 of the Code
Authority	Electricity Authority, the regulatory body established under the Act
Code	Electricity Industry Participation Code 2010
dead band	frequency range within which a generator's speed governor will not respond to frequency movements
droop	a mechanism that changes the apparent output set point of a generator as a proportional response to frequency changes
FKC	frequency keeping control (a modulation control on the HVDC)
governor	a device used to measure and regulate the speed of a generating unit
gain	In a closed-loop feedback control system, the constant (Kp or Ki) applied as a multiplier to the instantaneous error (or the integral of instantaneous error with respect to time) to adjust output.
Hz	Hertz, the unit of measure for frequency
islanding	a situation where local generation continues to power a region even when it is isolated from the grid
Instantaneous Reserve	Instantaneous Reserve, an ancillary service the system operator contracts for to assist in managing frequency disturbances outside the normal band
J	Joule
MFK	Multiple frequency keeping, an ancillary service the system operator contracts for to assist in managing frequency inside the normal band
NEM	National electricity market (of Australia)
normal band	the frequency band between 49.8 Hz and 50.2 Hz (also referred to as normal frequency)
normal frequency asset owner performance obligations	specific AOPOs that apply only to generators that contribute to the maintenance of frequency within the normal band, set out in clause 5 of Technical Code A of Schedule 8.3
PPOs	Principal Performance Obligations, the system operator obligations in Clause 7.2 of the Code
recovery situations	recovery from black system events
SCADA	Supervisory control and data acquisition