TAS 120: MFK Review Phase 1 Report

Version: Final

Date: April 2026

Contents

1 Executive Summary

New Zealand's power system is undergoing a significant transition as increasing volumes of intermittent generation (IG), particularly wind and solar, are deployed to meet growing electricity demand driven by electrification. As IG replaces or supplements traditional firm generation, real-time system balancing is becoming more variable and uncertain. Changes in IG output between market dispatch intervals introduce additional intra-dispatch variability in the supply–demand balance, with implications for frequency quality, transmission constraints, and reserve requirements. As a result, the Multiple Frequency Keeping (MFK) service, designed to manage intra-dispatch frequency deviations, must be assessed to ensure it remains effective under higher levels of intermittency.

In response, the Electricity Authority (the Authority) requested advice from the System Operator on the suitability of MFK for managing intra-dispatch variability and whether refinements or alternative service designs may be required. Phase 1 of this work focuses on understanding the scale and characteristics of intra-dispatch variability, its impact on frequency quality, and the performance of the current MFK design under both current and future IG penetration scenarios.

This study identifies two primary drivers of intra-dispatch frequency deviations, persistent frequency bias arising from generators operating off-dispatch and increased short-term variability driven by the intermittent nature of IG. The analysis also builds on tighter governor deadbands and finds that, while improved primary response is important, increasing intermittency and off-dispatch behaviour will continue to place greater demands on MFK.

Phase 1 findings confirm that MFK remains a critical tool for managing intra-dispatch frequency deviations and does not require repurposing. MFK corrects accumulated frequency errors while governors respond to instantaneous changes, and its role becomes increasingly important as system variability grows. A staged approach is therefore recommended that retains the existing framework while strengthening its effectiveness over time.

- Urgent and highest priority:
    - Increase the MFK band by ≥10 MW per island as soon as practicable and progress national frequency keeping selection within 6-12 months to reduce persistent frequency deviations, improve competition, enable more efficient use of fast-responding resources across islands, and manage MFK cost impacts while improving frequency quality.
    - Start immediately with the Authority to strengthen dispatch compliance and IG dispatch, prioritising monitoring, enforcement, and targeted Code changes.
- High priority in the near to medium term:
    - As providers become available, shift more MFK to fast, low-latency resources to better manage variability and sustained off-dispatch behaviour.
    - Enable full Battery Energy Storage System (BESS) participation via a single bidirectional offer structure within 18 months to support higher-performance frequency keeping.
- Medium priority for longer term:
    - Progress longer term market design changes (e.g. variable or asymmetric bands and integration for full co-optimisation) to support an efficient, scalable framework.

2 Introduction

New Zealand's power system is undergoing a transition as increasing volumes of IG, particularly wind and solar, are developed to meet the growing electricity demand as the economy becomes more electrified. As these replace or supplement traditional firm generation, the increasing share of IG introduces greater variability and uncertainty into real-time system balancing. Changes in IG output, due to its intermittent nature, between market dispatch intervals can create additional intra-dispatch variability in the supply–demand balance, with implications for frequency quality, transmission constraints, and reserve procurement. Hence, the MFK service, currently designed to correct intra-dispatch frequency deviations, may need to evolve to manage this emerging variability more effectively.

In response, the Authority has requested advice from the System Operator on the suitability of MFK for managing intra-dispatch variability and on whether refinements or alternative service designs may be required. Phase 1 of this work focuses on understanding the scale and characteristics of this variability, its implications for frequency quality, and how the current MFK design performs under present and future IG output levels.

The remainder of this document is structured as follows:

- Section 3 provides the background required to understand the current role of MFK within the frequency regulation framework, including the issues introduced by increasing IG and the gaps this exposes in the Electricity Industry Participation Code 2010, ancillary service requirements, and the System Operator's current operational processes. It also describes the frequency-quality metrics used in this study to quantify the effectiveness of MFK under different scenarios.

- Section 4 presents the Phase 1 scope provided to the System Operator.

- Section 5 outlines the study approach adopted by the System Operator and the key assumptions applied to address the given scope.

- Section 6 presents the study results and observations, with a concise summary provided in Section 6.1 for readability.

- Section 7 sets out options considered by the System Operator based on the results of this work, including MFK tool changes, inclusion of fast-responsive providers, and potential Code changes.

- Section 8 details the System Operator's recommendations on the options considered within the Authority's scope and the next potential steps to evolve the frequency regulation framework.

3 Background

The Authority has engaged Transpower in its role as the System Operator to provide advice on the potential for the MFK service to manage intra-dispatch variability. Intra-dispatch variability is the change in system balancing requirement between dispatches, which provide all generators operating in the market with MW set point targets to meet anticipated system demand. The Authority committed to investigate repurposing MFK as a tool for managing intra-dispatch variations in its potential solutions for peak electricity capacity issues (PSPECI) decision paper.[1]

3.1 Drivers of system frequency deviations

3.1.1 Variation in Load

System frequency varies because of imbalances between load and generation, as shown in Figure 1. These imbalances are most pronounced during the morning and evening ramps, when electricity use increases quickly as consumers begin daily activities or return home. Outside these periods, load is typically more stable. Rapid load changes create temporary mismatches that are initially absorbed by generators diverging from their dispatch targets until the System Operator updates dispatch instructions to reflect the new system conditions.

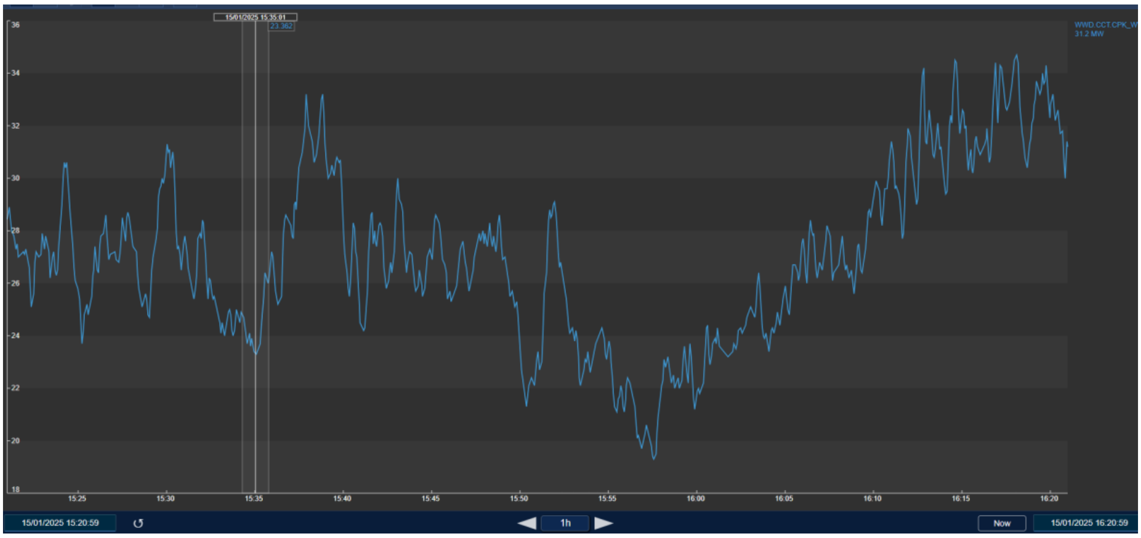

Figure 1. Graph shows frequency variation due to generation or load.

3.1.2 Variation in generation

These imbalances can arise when generating units are delayed or unable to meet dispatch instructions issued by the System Operator. This may occur due to factors such as start-up failures, resource constraints, or slow ramping capability. Recognising such events are sometimes unavoidable, provisions exist within the Code [2] to accommodate these situations. Participants are required to promptly notify the System Operator when they are unable to meet dispatch, enabling corrective adjustments to be made to the next dispatch schedule to restore the imbalance.

---

[1] https://www.ea.govt.nz/projects/all/managing-peak-electricity-demand/

[2] Clause 13.19

3.1.3 Load or generation variations due to contingencies

Sudden loss of a generating unit or the disconnection of a load feeder can result in abrupt and large changes in the active power balance, leading to a rapid frequency deviation. To manage these events, frequency contingency management mechanisms (e.g. reserve products) are procured to arrest the frequency decline or rise and to support the recovery of system frequency back within the normal operating band.

3.1.4 Dispatch errors due to IT or forecasting failures

Variation in system frequency can also arise from errors in load forecasting or failures within IT system resulting in missing or infeasible dispatch instructions being issued to generators. Although such events are rare, they can lead to significant system wide frequency excursions.

An example occurred in Australia in 2025 [3], prompting industry discussion on how system reliability should be maintained under non-traditional failure modes. These events differ from conventional contingencies in that they originate from system-level process or data failures rather than the physical loss of plant, yet they can produce comparable frequency deviations.

3.1.5 Impact of increasing IG on frequency

Intermittent generators frequently deviate from dispatch because their output is determined by variable primary energy sources. Wind generation can fluctuate rapidly with gusts, creating short lived deviations, while broader changes in wind conditions can lead to sustained off dispatch operation over several minutes. Solar photovoltaic (PV) generation behaves similarly, responding to cloud dynamics. Fast moving clouds cause brief dips, while widespread or slow-moving cloud cover suppresses output for longer periods across an entire site.

In a system previously dominated by controlled dispatchable generation, these effects on system frequency were relatively minor. However, as intermittent penetration increases, two distinct impacts emerge which need to be assessed separately when considering the adequacy of frequency keeping products.

3.1.5.1 Variability

The terms *variability* and *intermittency* are frequently used interchangeably when describing the behaviour and system impacts of non-dispatchable or unpredictable generation sources. For the purposes of this study, *variability* is defined as:

"the magnitude and rate of short-term system frequency fluctuations occurring over timeframes of seconds to tens of seconds."

This variability reflects rapid changes in power output from intermittent resources. This increase in variability is evident through the increase in standard deviation of system frequency over the years as shown in Figure 2. This effect is predominantly resource-driven and therefore limits the System Operator's ability to anticipate and manage such fluctuations pre-emptively.

[3] Frequency Monitoring – Quarter 3 2025 – AEMO

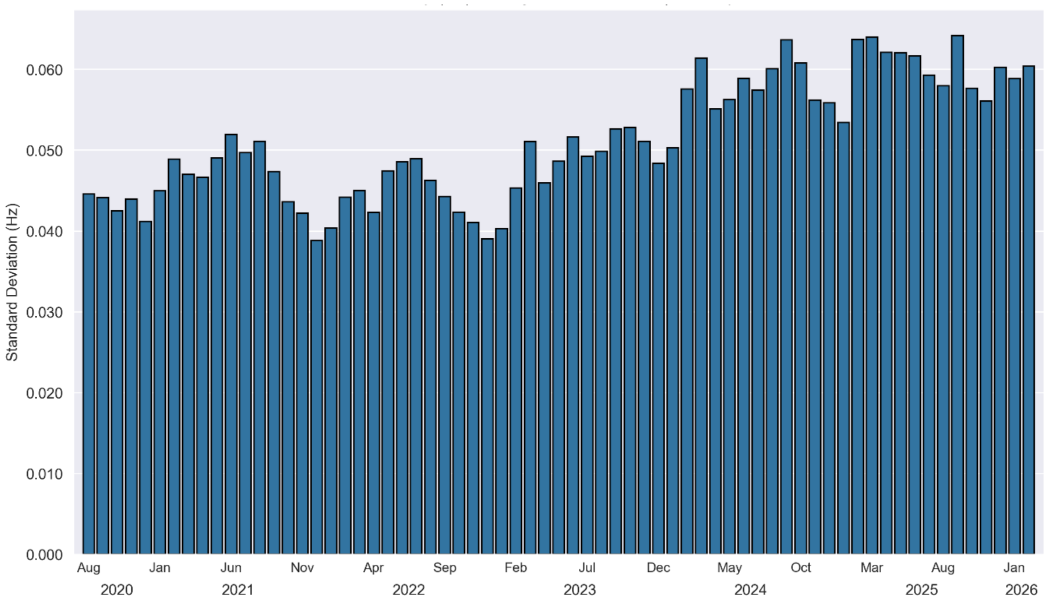

Figure 2 Increase in system frequency standard deviation over the years.

3.1.5.2 Persistence

The second characteristic is the sustained deviation of system frequency from its nominal value, referred to as *persistence*. Persistence arises from prolonged departures of generator output from their instructed dispatch levels (i.e. operating *off dispatch*), either from a single unit or as an aggregated effect across multiple generators, including both dispatchable and intermittent resources. In such cases, the continued mismatch between generation and load results in a systematic bias, causing system frequency to persistently drift away from the nominal 50 Hz.

Figure 1Figure 3 illustrates the distinction between these two frequency behaviours:

- variability-driven deviations arising from intermittent output changes (highlighted in green), and
- persistence-driven deviations caused by generation operating off-dispatch (highlighted in yellow).

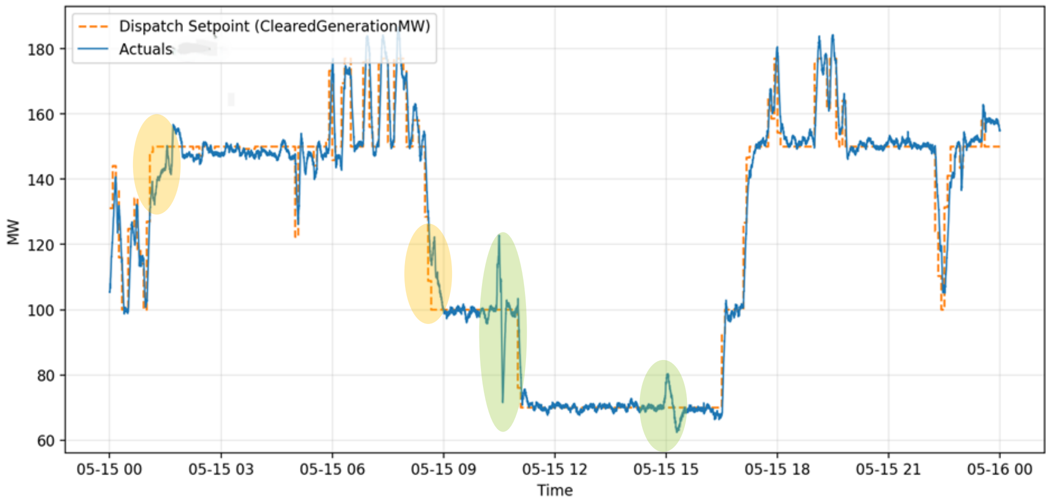

Figure 3 IG being off-dispatch (circled in yellow) and intermittent due to resource changes (circled in green) plotted against time.

3.2 Current frequency regulation framework

Currently the System Operator regulates system frequency in steady state by multiple control systems: the primary frequency response of connected generating units and the procurement of the frequency keeping ancillary service.

3.2.1 Primary frequency response (Governor response / Frequency control system response)

Governor actions provide primary frequency control by adjusting output as frequency changes, but they act only outside their configured deadband. Because the Code only states that the frequency deadband should not be wider than the normal frequency band i.e. ±0.2Hz, settings vary across generators, reducing the aggregate primary response and making it harder to maintain frequency within the normal band. To address this, the Authority has recently decided to amend the Code to state that "Generators must comply with a maximum dead band2 of the greater of ±0.1Hz or the generating unit's inherent dead band, as agreed with the System Operator acting reasonably, at the time of the generating unit's next routine test."[4] This is intended to promote a more consistent frequency support across generating units and improve the ability to maintain system frequency within the normal band (±0.2 Hz).

3.2.2 Frequency Keeping ancillary service

The System Operator's frequency keeping service regulates system frequency within the normal band using MFK, a standalone control tool operating on the System Operator's SCADA/EMS platform. MFK maintains frequency within ±0.2 Hz of nominal and provides tertiary frequency control after primary governor response, restoring frequency to 50 Hz once the immediate disturbance is arrested.

The MFK controller receives the residual frequency error as input and calculates the required active power output needed for this correction. The regulation signal is sent to the designated providers, who adjust generator outputs accordingly. This action allows other governors to return to their operating set points while maintaining stable system frequency.

Currently, the MFK controller does not explicitly account for the magnitude of primary response delivered by generators following an instantaneous frequency deviation. Generators respond autonomously to frequency deviations according to their droop characteristics, after which the remaining frequency error is corrected by MFK based on a frequency bias setting (-20 MW per 0.1 Hz of error). Once the frequency error is eliminated, the MFK response reduces to zero.

It is important to note that the less primary frequency response the system receives, the more persistent the error remains and therefore the more response is required from this ancillary service. Without the MFK tool, a steady-state frequency error remains, meaning the frequency will always be corrected away from nominal.

[4] Promoting reliable electricity supply: Frequency-related Code Amendments - Decision paper

3.2.2.1 MFK based – National Frequency Keeping (NFK)

This is the normal mode of operation, whereby the tool enables multiple generating units, across both islands to participate in frequency regulation without counteracting one another, i.e. a configuration referred to as NFK. This is achieved by designating one island as the master and the other as the slave. The master island frequency error is used as the control input, and the slave island follows this signal to ensure coordinated response. In the past, the time error has also been used as a secondary input to the tool, but this input is disabled and as of June 2025 no longer a Code requirement for the System Operator to manage time error to ±5 seconds[5].

Current operational practice involves selecting at least one frequency keeper per island (each with a 15 MW band) based on the least cost offers within that island. The tool also supports an alternative configuration, e.g. selecting all frequency keepers in a single island, when the HVDC Frequency Keeping Control (FKC) function is enabled. However, selecting alternative configurations is not supported automatically and requires manual intervention by the System Operator.

3.2.2.2 MFK based - Single Frequency Keeping (SFK)

When FKC is disabled or HVDC is unavailable, frequency keeping bands are increased to 25MW/island and MFK tool is changed from the master-slave mode to island mode, allowing for each island frequency to be managed separately. In this scenario, the tool still allows for multiple frequency keepers per island. This mode of operation is referred to as MFK based SFK.

3.2.2.3 Back up Single Frequency Keeping (BUSFK)

If the MFK tool is unavailable, frequency regulation may be managed manually, with or without the FKC function enabled. Under this operating mode, the regulation band is typically increased to 25 MW, and designated frequency keepers are instructed verbally to manage frequency. In this configuration, no automated regulation signals are issued by the MFK controller.

3.2.2.4 Frequency Keeping Selection

Selection for this ancillary service is performed within the System Operator's Market Systems. It is based on the lowest offer price combined with calculated potential constrained on costs to minimise overall frequency keeping costs and automatically triggered whenever a new offer is received. When a change of frequency keeper is required for the next trading period, the new provider is automatically notified 15 minutes in advance. Frequency keeping constraints are then applied in real-time dispatch to ensure selected frequency keepers are not dispatched outside their offered limits. In auto selection mode, selection, constraint creation, and dispatch are all automated. Because current selection is not undertaken in the Scheduling, Pricing and Dispatch (SPD) tool, frequency keeping service is not co-optimised with energy and reserves.

---

[5] Electricity Industry Participation Code Amendment (Removal of Time Error Management Obligations) 2025

3.2.3 Adequacy of Frequency regulation

This sequence of frequency regulation has been sufficient in a system dominated by firm synchronous generation. However, increasing penetration of IG now places greater demands on both primary frequency response requirements and the MFK mechanism.

In the frequency related Code amendment proposal[6], the System Operator acknowledges these changing conditions and proposes, among other measures, to widen the MFK frequency keeping band over the coming years because of IG causing more frequency variability within the normal band. However, this widening of the MFK band may not be as large if there is a permitted maximum dead band on all generation in the vicinity of ±0.1Hz.

Following the Authority's decision to require a maximum governor deadband, it is now necessary to assess the adequacy of the frequency regulation product—and the need for any band widening—using consistent, measurable performance indicators. This requires moving beyond qualitative observations of "more variability" or "more persistence" toward defined frequency quality metrics that capture both short-term fluctuations and sustained deviations from nominal frequency.

3.3 Code and ancillary service requirements

Currently, these are the relevant Code requirements and contractual obligations for frequency keeping, including testing criteria to be adhered to during normal frequency management.

3.3.1 Code requirements

- Under the Code, the System Operator must keep system frequency within the 49.8–50.2 Hz normal band[7] and restore it promptly after any excursion[8], while reporting monthly frequency-fluctuation data for each island[9].
- Dispatch compliance is required under Part 13, but the Code does not specify how close or how quickly generators must meet set points within each dispatch interval, creating a gap in managing intra-dispatch behaviour, particularly for IG, which may deviate materially within intervals under current market rules.

3.3.2 Frequency Keeping requirements

Frequency keeping is procured[10] to maintain operation within a band, and providers must demonstrate adequate control accuracy, response rates, monitoring capability, and follow all regulating instructions with a minimum average response rate.

3.4 IG dispatch implications

Under the current market design, IG is permitted to vary with resource availability rather than follow dispatch, unless constrained. In normal operation, SPD sets their dispatch level based on their actual output, at the start of the dispatch interval. However, during the interval, their output may vary in

[6] Addressing more frequency variability in New Zealand's power system – Consultation paper
[7] Clause 7.2A(2)
[8] Clause 7.2B
[9] Clause 7.2E
[10] Ancillary services procurement plan

response to changing resource conditions. These variations can result in significant deviations from the dispatched level without triggering any non-compliance obligations.

When IG is constrained for system security reasons[11], dispatch instructions flagged as must-follow are issued to the intermittent generator (illustrated by the green circle in Figure 4 where dispatch instructions are shown in blue and actual outputs are in orange). However, once the constraint is released, un-controlled output often ramps back toward the available resource level (red circle in Figure 4). This results in the constraint being re-applied in the subsequent dispatch interval, producing oscillatory behaviour. This behaviour has implications not only for system security but also for generator operations.

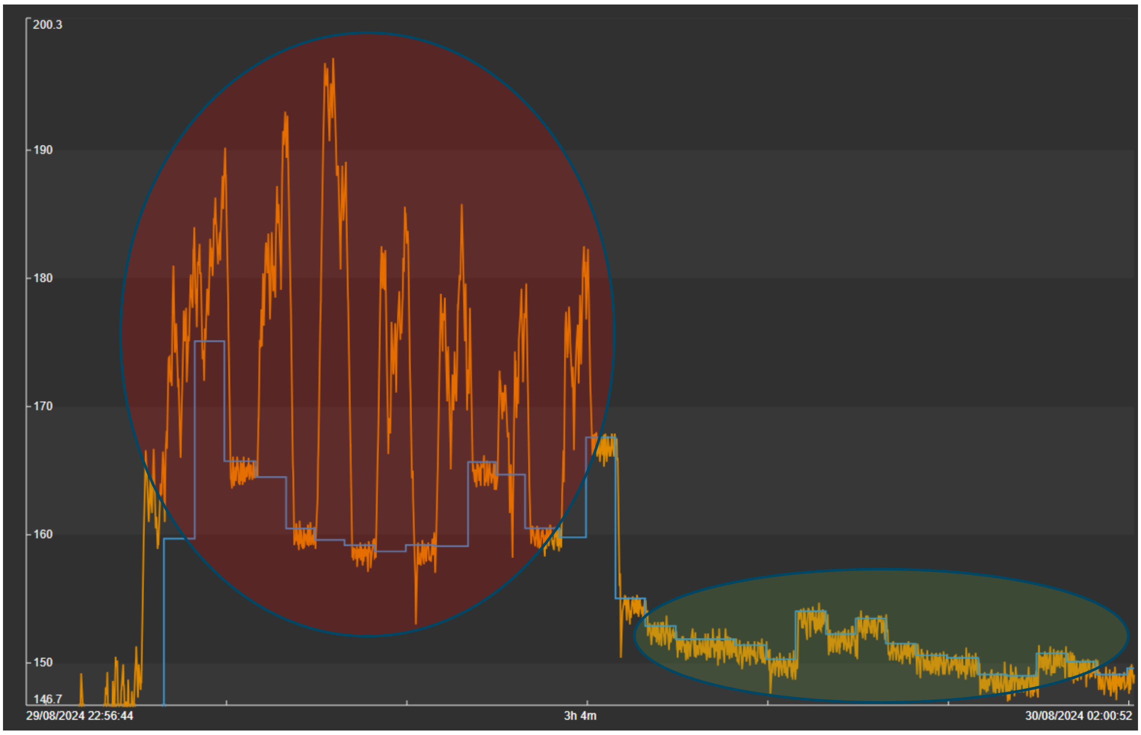

Figure 4 Dispatch oscillation at one intermittent generator site.

While the inherent intermittency of these resources and the associated increase in frequency variability cannot be eliminated through frequency keeping products alone, the uncontrolled IG output permitted under the current market rules can be moderated. Potential options include introducing more controlled IG dispatches, and real-time ramp rate limits within generator control systems. However, any changes to dispatch compliance requirements, along with technical feasibility for intermittent generators, market design implications, and implementation process would require further investigation and potentially industry consultation prior to adoption.

3.5 Frequency quality

Frequency quality reflects how well system frequency is maintained during normal fluctuations and in steady state conditions. With increasing IG, it is important to quantify how these changes affect frequency and assess the effectiveness of current tools for keeping frequency within the normal band.

[11] IG can be constrained due to various reasons including price, network limits, and risk setting.

As New Zealand has no codified frequency quality metric, the System Operator has opted to monitor frequency quality using the following metrics:

- **Mean** and **Standard deviation** - The Mean and standard deviation of system frequency is computed to characterise the central level and spread of frequency behaviour as per the standard formulae below:

$$Mean\ (\bar{f}) = \frac{\sum f}{n}$$

$$Standard\ deviation\ (\sigma) = \sqrt{\frac{\sum_{i=1}^{n}(f_i - \bar{f})^2}{n}}$$

  where f is each frequency measurements, n is the number of measurements.

- **Time spent outside the normal frequency band** - Quantifies the duration for which frequency operates beyond the defined normal band before it returns to inside the band. This metric reflects the aggregate requirement for governor and MFK intervention and signals increased risk of MFK operating at or near its band limits.

- **Number of threshold crossings to outside the normal frequency band** - Captures the frequency of excursions beyond the normal frequency band. Increased crossings indicate more frequency fluctuations and may result in more wear and tear on responding generators.

- **Frequency Area Index** - The Frequency Area Index (FAI) measures the area under the frequency–time curve, representing the cumulative deviation of frequency from 50 Hz. This index captures the combined effects of both variability (frequent deviations) and persistence (sustained deviations). The FAI, expressed below, is computed via the trapezoidal rule as the area under |f−50| over the interval, then normalised by the product of the reference band and interval. The method used is designed to work for uneven sampling due to the nature of the PMU data used as input.

$$FAI\ (\%) = \frac{\int_{t_0}^{t_1} |f\ (t) - \ f_0|\ dt}{0.2T}$$

  Where 0.2 is the maximum interested area away from the nominal frequency, T is the total duration i.e t_1 - t_0 and f_0 is the nominal frequency.

These metrics are also applied in this study to quantitatively assess system frequency and to inform recommendations regarding the adequacy of the frequency regulation products currently employed by the System Operator.

4 Project Scope and Objectives

The Authority has tasked the System Operator, via a Technical Advisory Services (TAS), to undertake a review of the MFK service to manage the challenges introduced by IG in a dispatch period. Phase 1 of this work is intended to be exploratory in nature and focuses on assessing potential options. During this phase the System Operator will assess:

a. whether and how MFK is better suited to providing the proposed new service compared with more frequent energy dispatches

b. whether, and in what circumstances, MFK is still required to assist in maintaining system frequency within the normal band

c. whether there could be any changes to the control signals sent by MFK to optimise it for the proposed new purpose. If so, how may this affect the benefits of the service, the ability to manage system frequency, who can participate in MFK, and the burden faced by generators providing automatic frequency response (i.e. governor response or similar response provided by inverter-based technologies)

d. whether the existing Principal Performance Obligations (PPOs) provide a sufficient basis for procuring and utilising MFK for the new purpose or whether Electricity Industry Participation Code (Code) changes may be required and, if so, what those Code changes would need to achieve.

e. In particular, the System Operator will assess whether procurement and utilisation based on the existing PPOs would result in MFK being scheduled when automatic frequency response would be sufficient on its own for system security purposes. In this case, the Authority may consider additional Code obligations to guide the scheduling of MFK providers so that the MFK market can be utilised as a means of selecting the most efficient generators to manage intra-dispatch variations rather than relying on automatic frequency response.

f. The System Operator will present its findings and discuss them with the Authority. The Authority and System Operator will then agree on the basis for procuring the new service, including whether any Code changes will be required.

The Authority and the System Operator expect there are benefits to changing the MFK service to respond to these new operating conditions resulting from increasing IG. We expect this work will (among other things):

- improve resilience through effective management of peak demand periods
- improve efficiency in the selection of resources to manage variations in the supply-demand balance between energy dispatches
- Improve system security through more effective scheduling of instantaneous reserve and effective management of transmission constraints.

5 High level study approach

In line with the scope of work provided by the Authority, the Phase 1 investigation focused on quantifying the need for a proposed new ancillary service to manage intra-dispatch variability. The study approach is intended to inform items 3.7(a), (b) and (c) in the TAS 120 scope of work. This will also allow the System Operator to consider whether the existing legal basis in the Code and Policy Statement is sufficient to adequately manage frequency as required by scope items 3.7(d) and (e).

Phase 1 investigation aimed to:

- assess the performance of the current MFK service in managing frequency deviations attributable to changes in intermittent generator output
- understand how the demand for MFK may change with increasing proportion of IG
- whether changes are required or recommended to the MFK control system to better respond to changing IG output
- whether, because of recommending changes to the MFK control system, subsequent changes are needed to meet requirements for normal frequency management.

5.1 Study Types

Table 1 The studies to be undertaken to address the given scope.

Type	Description	Objectives
Historical Data Analysis	Using historical datasets from the market and SCADA	• Define and quantify intra-dispatch variability, its impact on frequency quality and attribute to its principal causes, where possible.
System studies	Using the MATLAB/Simulink model	• Evaluate the effectiveness of the current MFK design under anticipated future variability. • Identify potential MFK parameter changes or alternative service design requirements.

5.2 Out of Scope

The following items are out of scope for the studies undertaken as part of this work

- Variability arising from future changes in load behaviour (e.g. AI training cycles) is out of scope. Additional investigation will be required to assess the combined impact of generation and load-driven variability. This project considers variability introduced solely by IG.
- Forthcoming changes associated with the next HVDC upgrade (post-2030) are out of scope. The study will consider the HVDC FKC function only in its current form.
- As this project focuses on the performance of MFK, SFK operation is excluded because it does not involve any interaction with the MFK tool. Separate frequency studies will be required to

evaluate how different frequency-keeping operation modes affect normal frequency management.

- Real-time testing of communication related delays between the MFK tool, SCADA, and providers will be out of scope. However, system data and recorded MFK testing results from current frequency keepers will be reviewed as input to the system studies.

5.3 Assumptions

The following assumptions are adopted to ensure the scope of this work remains focused and relevant:

- Dispatch instructions are issued at intervals of up to 5 minutes; this defines what is meant by *intra-dispatch* variability.
- As the time-error requirement has been removed from the Code, it is assumed to be excluded as an input to the MFK tool.
- HVDC modulation bands and response speeds are assumed to remain at their current default settings.
- The recent Code amendment proposal introducing a maximum governor frequency deadband of 0.1 Hz is expected to improve frequency quality. Although this requirement is not yet in effect at the start of this work, it will be assumed to apply for the purposes of this study.

6 Studies, Results, and Observations

6.1 Key findings from the study scenarios

This section collates the main findings from all the studies described in Section 5.1. More details can be found in Sections 6.2 and 6.3.

- IG penetration has increased over the past five years, with seasonal patterns showing a higher North Island IG penetration in summer and spring and a closer alignment between islands in winter and autumn.
- Studies highlight that HVDC FKC availability is strongly correlated with degraded frequency quality, with the strongest association observed in the increased time spent outside the normal frequency band (more so than threshold crossings). This highlights FKC's role in returning the frequency to the normal band.
- Persistent off-dispatch deviations primarily influence the system frequency mean and total time spent outside the normal band, while variability often driven by IG, has a stronger impact on short-term frequency variability metrics such as standard deviation and threshold crossings. But at higher intermittency levels, the time outside of band is also affected due to the constant large deviations.
- Variability effects are more pronounced in the North Island Power System (NIPS) than in the South Island Power System (SIPS) due to more IG located on the island.
- Normalised intra-dispatch variability is highest for NIPS solar across all seasons, while wind exhibits larger absolute MW ramps, with NIPS wind deviations ranging from -96 MW to +97 MW and solar typically between –24 MW and +24 MW.
- Duration curve analysis indicates that wind deviations above 35 MW occur in ~10% of intervals, while solar deviations vary strongly by season, with spring producing the highest values and SIPS solar recording the largest 10% exceedance deviations.
- MFK performance results show regulation signals increasingly skewed toward the lower bound of the 15 MW band, especially during morning peaks, reflecting a higher accumulated frequency error despite MFK's active correction.
- MFK latency analysis indicates current provider response lags of approximately 14–27 seconds, highlighting limits to real-time controllability.
- Reducing MFK latency improves variability-driven frequency deviations, while increasing the regulation band is more effective for persistence-driven deviations, with the distinction becoming more pronounced at higher bias and gain levels.
- Increasing the MFK regulation band improves regulation under low intermittency but becomes less effective as intermittency increases, leading to poorer frequency quality even without controller saturation.
- Increasing the MFK regulation band helps manage large off-dispatch deviations, but its effectiveness reduces when concurrent with high intermittency, causing the regulation signal to saturate at the band limits more frequently.

- Both increasing the frequency-keeping band and reducing response latency improves the distribution of the MFK regulation signal, halving the time the signal operates within 5 MW of the band limits.
- Increasing the MFK regulation band and reducing response time does not offset governor's participation, despite these MFK changes there is poorer frequency performance, especially in the island where governor response is reduced.
- Allowing all frequency keeping to be procured from one island (with HVDC FKC enabled) shows little change in overall system frequency standard deviation.
- Standard deviation in both island frequencies improve when the frequency keeper is located in the North Island, likely because high proportion of IG and its associated variability occur in the island.

6.2 Assessment of system frequency and MFK performance

The historical data analysis aims to quantify the impact of IG on system frequency, and consequently on MFK response under varying system conditions. The objective is to determine the extent to which repurposing MFK could mitigate the frequency variability introduced by IG and improve overall frequency performance. This work assesses:

- The trend of IG penetration over the past five years and its impact on frequency quality.
- The relative variability of different IG types and the deviation sizes they introduce.
- The magnitude of deviation of each generation type introduces to the generation-load imbalance.
- Duration curves of these deviations for each representative month.

6.2.1 Study methodology and process

Frequency quality, IG penetration levels, and HVDC FKC sensitivity studies were conducted using five years of operational data derived from SCADA measurements (15-second resolution) and higher-resolution data (1-second) obtained from Phasor Measurement Units (PMUs).

For the investigation on the wind and solar generation deviations, additional historical operational data were extracted from the System Operator's PI Historian database for four seasonally representative months (August 2024 - Winter, January 2025 - Summer, March 2025 - Autumn, and September 2025 - Spring). The data sets include island system frequency, system load, system generation, individual IG output, MFK regulation signals, MFK status, and HVDC FKC (FSC/SRS) status. The results obtained from these datasets are indicative of seasonal behaviour; however, the magnitude of deviations could be greater if a longer historical record were analysed.

In addition, IG-flag constraint information was obtained from the System Operator market system database and used to exclude intervals where generation was market-constrained, ensuring the analysis reflects underlying physical behaviour rather than market dispatch configuration.

6.2.2 Results and observations

6.2.2.1 IG penetration trends and frequency quality

Over the past five years, the proportion of instantaneous generation supplied by intermittent renewable sources—specifically wind and solar—relative to total system generation has increased. Following the increased number of IGs being commissioned from 2023 onwards, IG penetration has exhibited a modest upward trend, as illustrated in Figure 5 . It's important to note that the maximum IG penetration levels in the separate islands are not coincidental peaks.

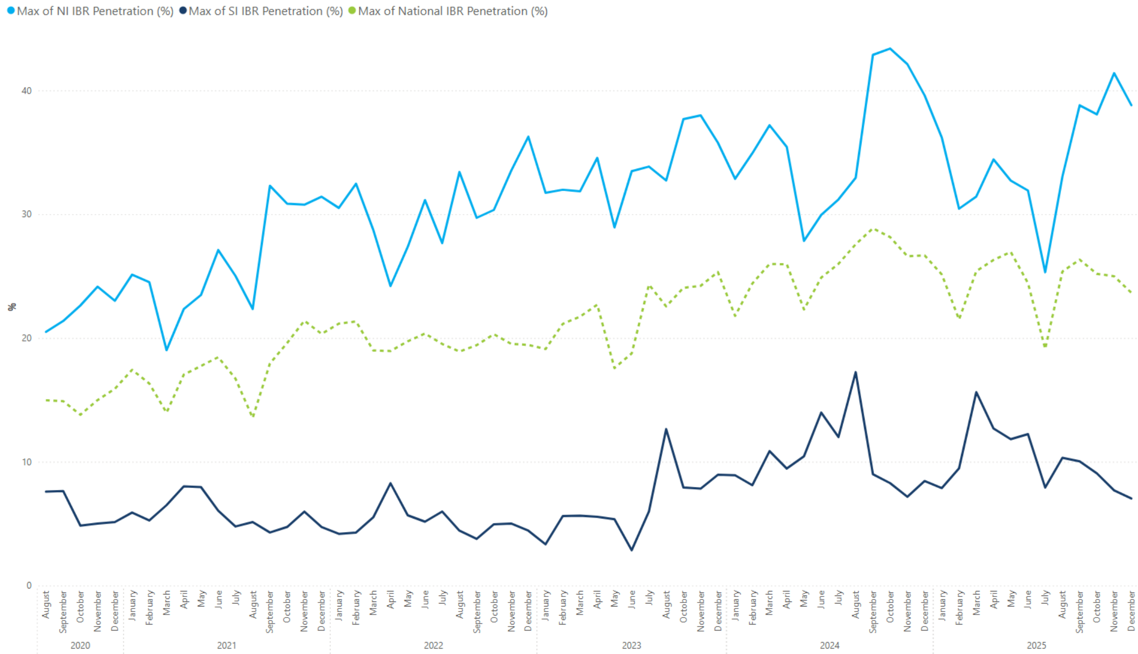

Figure 5 Maximum percentages of IG online (%)

IG penetration is calculated as below:

$$IG\ penetration(\%) = \frac{Total\ Wind\ generation + Total\ Solar\ generation}{Total\ generation} \times 100$$

The cyclical pattern, however, highlights the seasonal influence on the proportion of IG penetration: during summer and spring, this percentage is generally higher in the North Island, whereas in winter and autumn, the spread of IG increases in the South Island, aligning more closely with North Island penetration levels.

The dependence of the different frequency quality indices, described in Section 3.5, on IG penetration was also analysed using the MI directional method (the higher the coefficient the more dependent the metric is on IG penetration).

Table 2 Mutual information (MI) coefficients for Generation mix (%) vs frequency quality indices.

IG Penetration (%)	Mean	Standard Deviation	FAI	Time (outside normal band)	Number of crossings (outside normal band)
North Island	0.00	0.24	0.00	0.00	0.27
South Island	0.00	0.18	0.00	0.01	0.25
National	0.00	0.15	0.00	0.00	0.28

The results indicate that the intermittent nature of generation is more strongly associated with variability frequency metrics—threshold crossings and the standard deviation—than with persistence-type metrics such as total minutes outside the normal band and mean.

6.2.2.2 Relative variability of IG types and deviation characteristics

Given the growing number of solar projects within the System Operator's commissioning pipeline, it was important to distinguish the differing intermittency profiles. Hence, analysis was undertaken to quantify the characteristics of intermittent sources and to attribute their impact by generation type—wind versus solar.

The aggregated intra-dispatch deviations for each resource were calculated and subsequently normalised by installed capacity to enable consistent comparison of generation with different capacities. Variability of each resource was quantified using the standard deviation of these deviations, where a higher standard deviation indicates greater variability of intra-dispatch deviations, as shown in Figure 6.

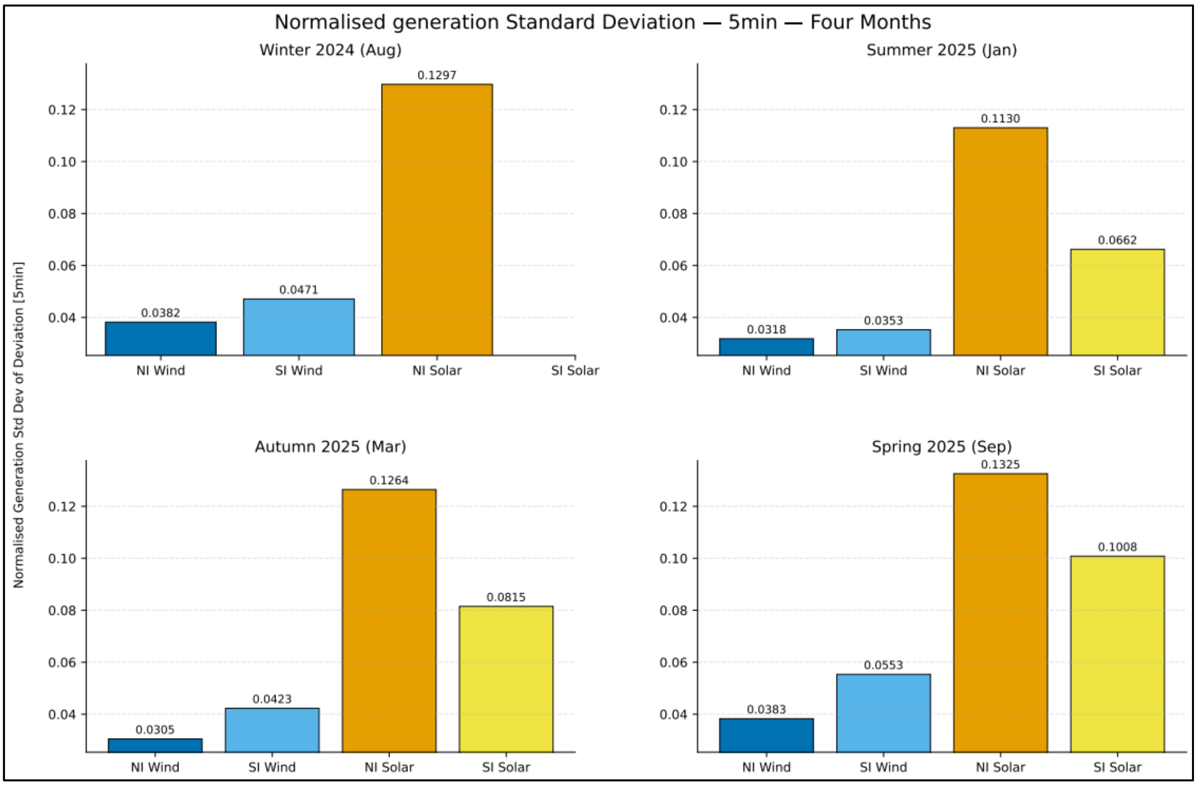

Figure 6 Normalised IG standard deviation for each of the representative months (Note: In August 2024, South island did not have a grid commissioned solar generation)

The results show that NIPS solar consistently exhibited the highest standard deviation across the four study months, followed by SIPS solar with wind generation showing materially lower intra-dispatch variability. These results indicate that solar generation in the NIPS is more variable, and with increasing planned uptake, this would result in increased frequency variability. Also note, SIPS Solar data is based on the one solar farm in operation when this work was undertaken. With additional solar in the future, this finding might change with spatial diversity.

Actual maximum and minimum deviations, tabled in **Error! Reference source not found.**, were calculated to quantify the magnitude of intra-dispatch variations caused by IG. Larger positive values represent strong up-ramps, while more negative minima represent strong down-ramps.

Table 3 Minimum and Maximum active power deviations for IG per island.

Generation Type	Min	Max
NI Wind	-95.60	96.93
SI Wind	-23.60	35.70
NI Solar	-23.87	23.61
SI Solar	-32.82	35.52

Across the different seasons, wind recorded its largest up- and down-ramps in winter, whereas solar exhibited its most pronounced extremes in spring. Although these extremes (shown in Figures 7 and

8) will evolve as the generation mix changes over time, it is important to distinguish between deviation magnitude and variability.

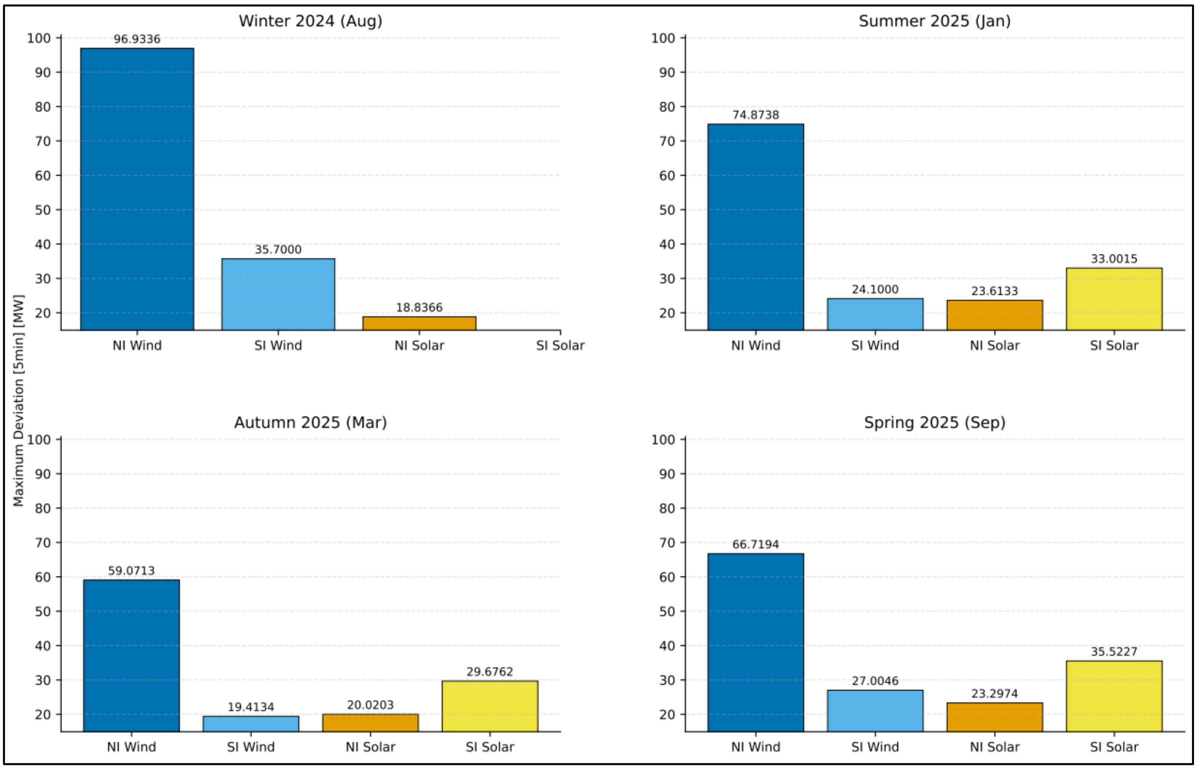

Figure 7 Maximum Deviation

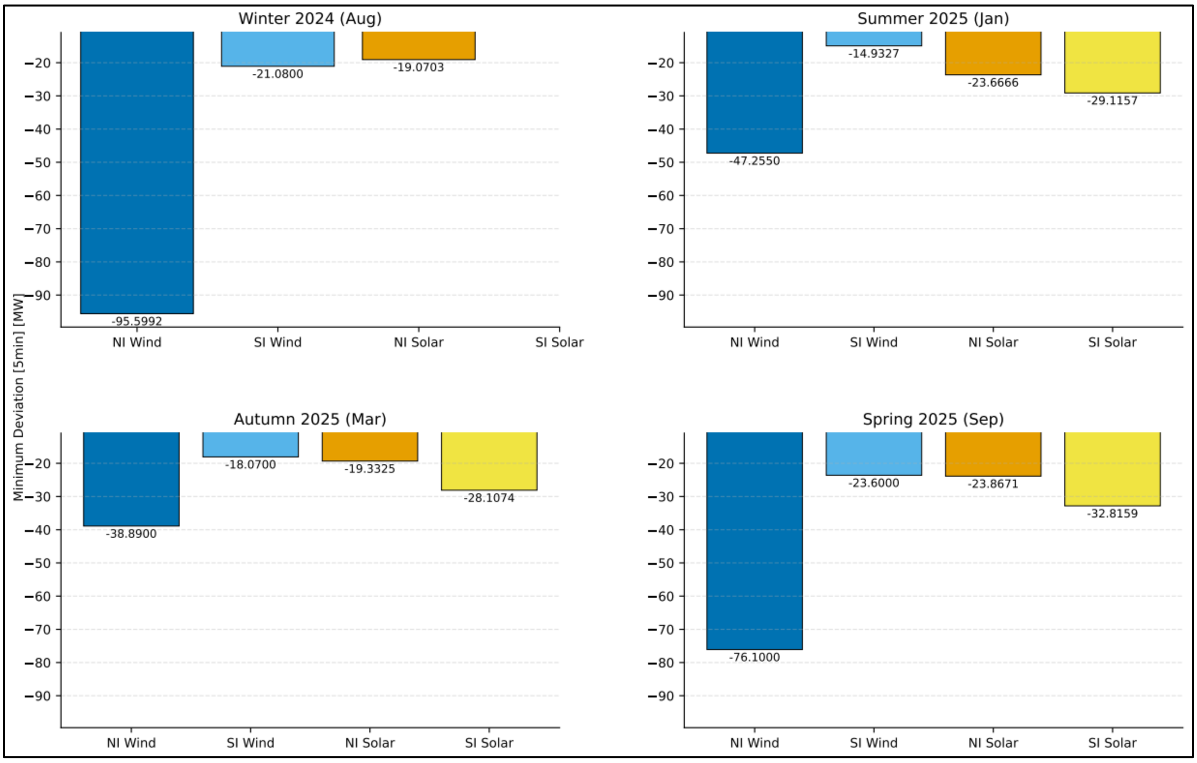

Figure 8 Minimum Deviation

Currently, the NIPS remains prone to higher system frequency variability due to its high IG penetration, however, its solar exhibits higher variability with smaller MW deviations while wind produces larger absolute MW deviations, which may introduce a sustained frequency bias despite exhibiting lower variability.

While this presents clear consideration for the System Operator's frequency management framework, projecting future aggregate MW deviations is not straightforward. The magnitude and variability of deviations will depend not only on installed capacity growth but also on the geographic distribution of new plants, which influences resource diversity and correlation characteristics[12].

Accordingly, it cannot be directly assumed that an increase in NIPS solar capacity will result in an equivalent proportional increase in variability while an increase in NIPS wind will result in an increase in deviation magnitude.

6.2.2.3 Deviation duration curves

Wind and solar generation duration curves were developed to characterise the likelihood of different intra-dispatch deviation magnitudes across seasons for each resource. Figure 9 indicates that, for wind generation, approximately 10% dispatch intervals within a month exhibit aggregate unconstrained deviations exceeding 35 MW, with higher magnitudes observed during winter and spring.

[12] New Zealand Wind and Solar Generation Scenarios , Assessing Complementarity for Wind and Solar Energy in New Zealand

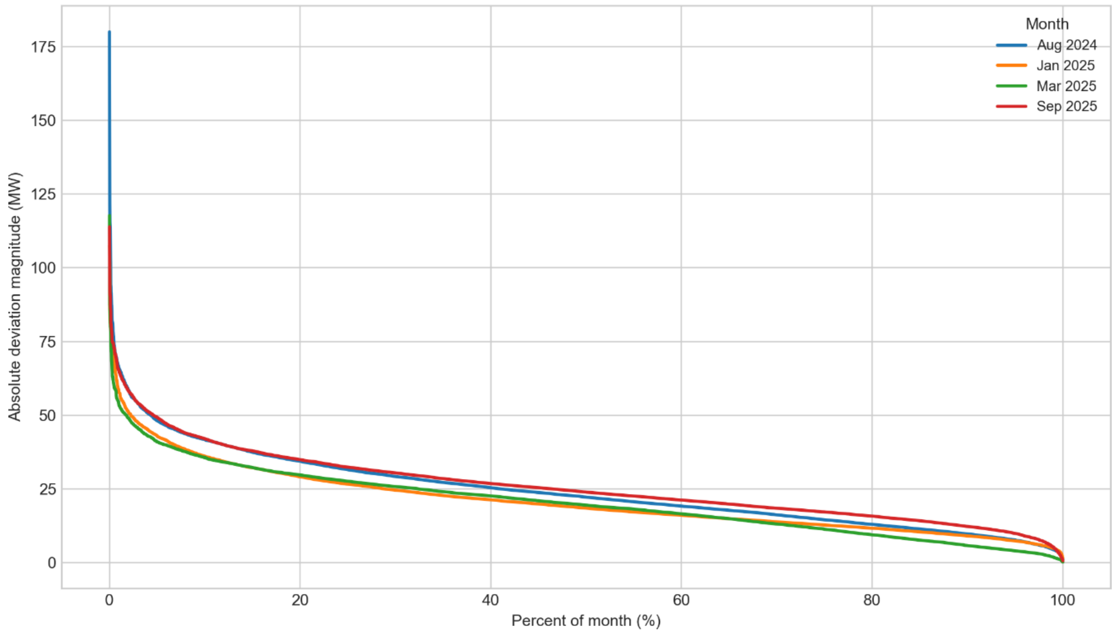

Figure 9 Duration curve of absolute deviations - Wind.

Figure 10 demonstrates greater seasonal variability in solar output. In spring, around 10% of dispatch intervals experience intra-dispatch deviations greater than 20 MW, whereas in winter the corresponding 10% exceedance level is below 10 MW, reflecting a materially lower deviation profile.

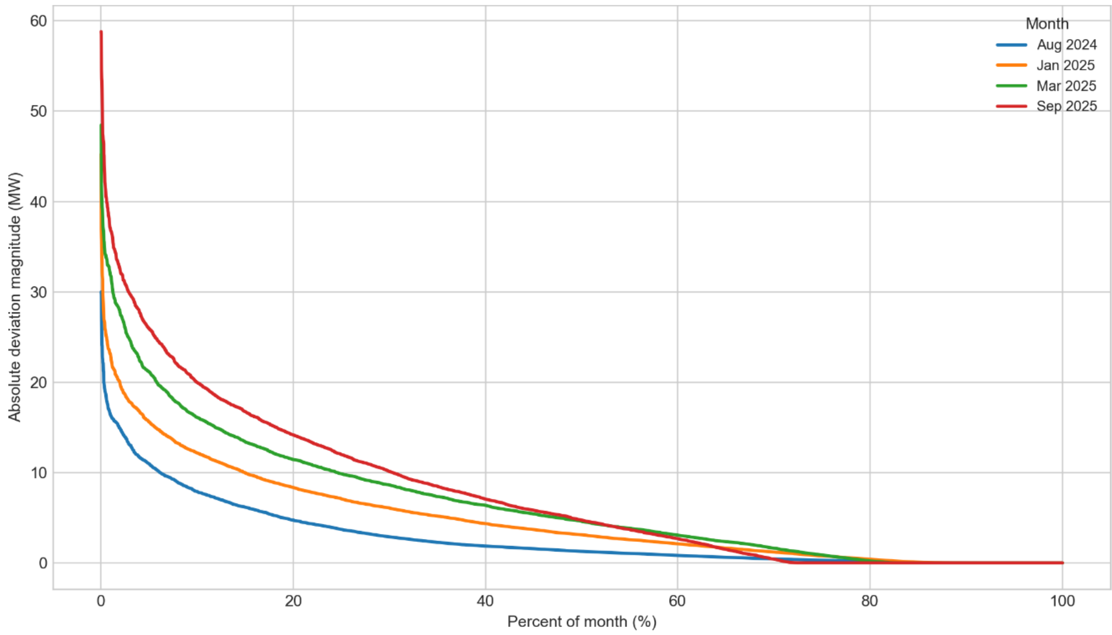

Figure 10 Duration curve of absolute deviations - Solar.

For wind and solar, Spring exhibited the higher magnitude of deviations, so further comparisons were made between islands. Figure 11 shows that for the same 10% of the time, SIPS solar consistently had the biggest deviations.

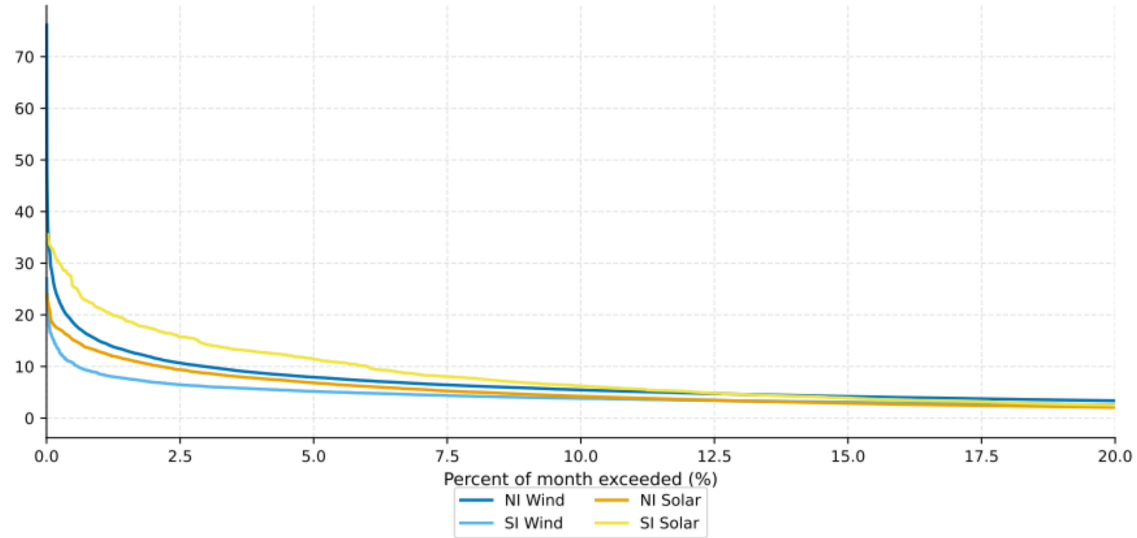

Figure 11 Duration curve of absolute deviations (MW) for IG on each island during Spring 2025.

Focusing on site-specific behaviour, normalised duration curves were produced to describe intra-dispatch deviations by installed capacity. Normalised deviation metrics are useful for future planning because they describe the variability of each generation type independently of today's installed capacity. The normalised duration curves characterise how each intermittent fleet varies relative to its installed capacity, independent of current fleet size.

Because the values in Figure 12 are in per-unit (normalised), a deviation that occurs at x% of the month can be scaled by the expected future capacity to estimate the MW impact of similar events once more wind and solar are built.

Figure 12 shows that during spring, NIPS Solar sites exhibited the largest capacity normalised- deviations for the whole representative month (excluding nighttime hours). For example, a y-axis of ~0.2 indicates that deviations of ~20% of installed capacity were exceeded for 10% of all 5-minute intervals.

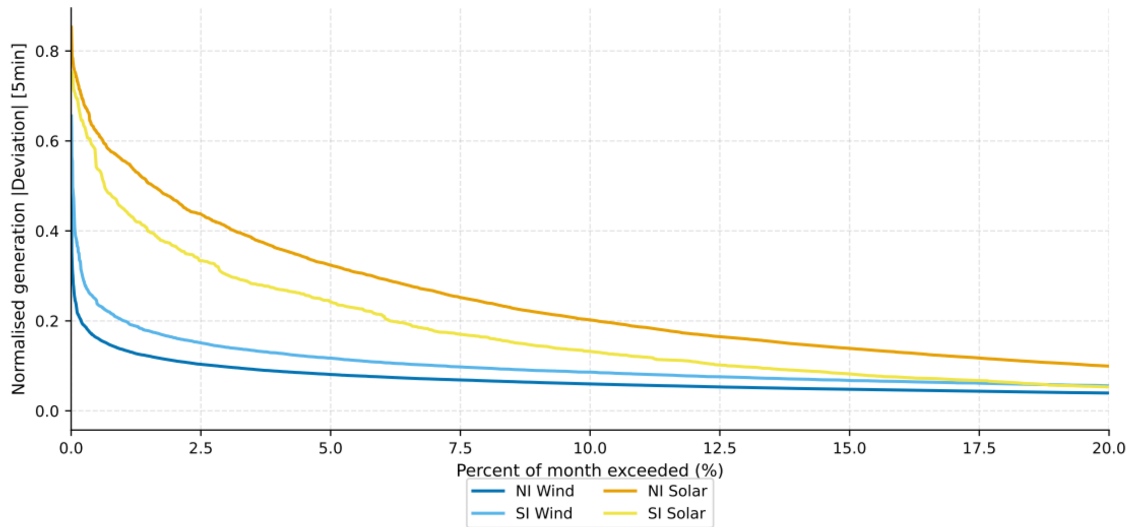

Figure 12 Duration curve of normalised deviations (MW) for IG on each island during Spring 2025.

All results for the other time studied pointed to similar conclusions and can be provided upon request.

As Scope item 3.7(a) considered more frequent dispatches, similar analysis was repeated but considering a dispatch period of 1-minute. Figure 13 shows that even though the 5-minute duration curves sit above the 1-minute duration curves for every fleet (because a 5-minute interval captures a larger step from one interval to the next) the overall pattern of variability remains. The 1-minute curves still show minute to minute movement in both wind and solar generation, meaning the underlying variability does not disappear when the interval is shortened.

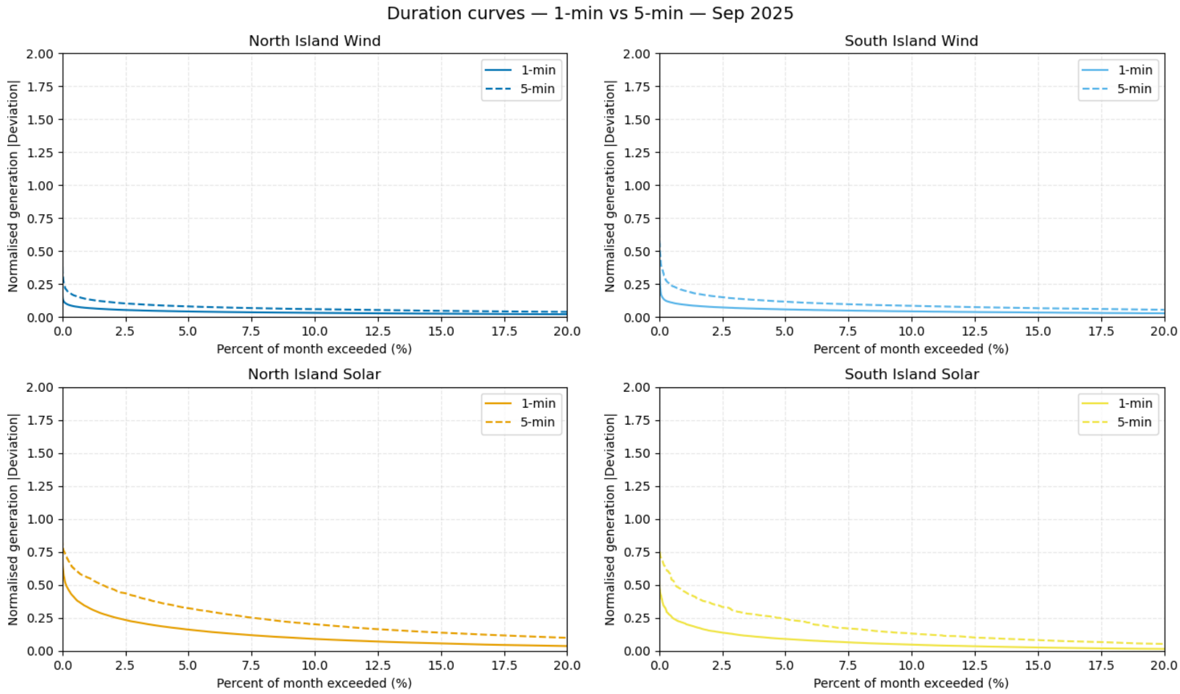

Figure 13 Comparison of 1-Minute and 5-Minute Duration Curves for Spring 2025.

These results show that reducing the standard time between dispatches does not mean there is proportionally smaller deviations to correct than at the 5-minute interval.

6.2.2.4 MFK performance

Analysis was conducted to identify the system conditions that require the greatest response from the MFK tool, and therefore from frequency keepers, and to examine the relationship between the tool output and observed frequency quality metrics.

Under normal operating conditions, the MFK control signal is constrained within a 30 MW regulation band (±15 MW). Positive regulation values indicate that MFK providers are instructed to increase generation (inject power), while negative values correspond to a reduction in output. However, positive regulation values do not necessarily correspond directly to a current negative frequency error. This is because the PI controller is also designed to respond to the overall frequency error rather than instantaneous frequency deviations alone.

Hence, by design, the integral component dominates the controller's response to correct sustained frequency error over time and during load ramping periods this error accumulates requiring more contribution from the MFK providers. Consequently, interpretation should focus on the overall distribution of regulation values rather than the sign of the regulation signal itself.

Figure 14 illustrates that during morning peak demand periods in particular, the distribution of MFK regulation signals is skewed toward the downward end of the 30 MW (±15 MW) regulation band. This suggests that during periods with large load changes and significant dispatch adjustments between dispatches, the persistent frequency error bias becomes larger.

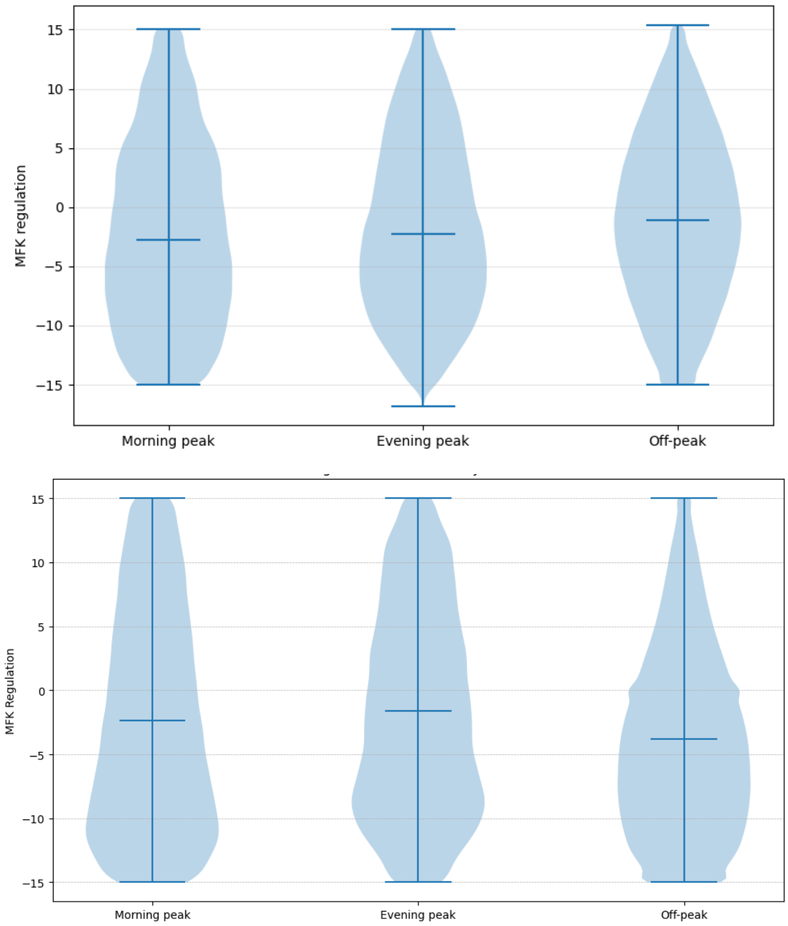

Figure 14 MFK regulation distribution – Spring 2022 (top) v Spring 2025 (bottom). (Morning peak - 06:00 to 08:00, Evening peak - 17:00 to 19:00)

A comparison of regulation signals for the same time of month in 2022 and 2025 was therefore undertaken to assess how the distribution of MFK output has evolved with increasing IG. The results indicate that the MFK regulation signals have become more skewed toward the lower bound of the regulation band, suggesting a greater prevalence of sustained frequency bias requiring correction by the MFK tool.

Despite the MFK tool actively correcting frequency deviations, frequency quality metrics shown in Figure 15, indicate that system frequency quality during morning peak periods is much worse than the other hours of the day. While some degradation is expected during periods of rapid demand change, the results suggest that these conditions remain more challenging for frequency control. If formal frequency quality requirements are introduced for the System Operator in the future, additional operational measures may be required to reduce the frequency deviations observed during these periods.

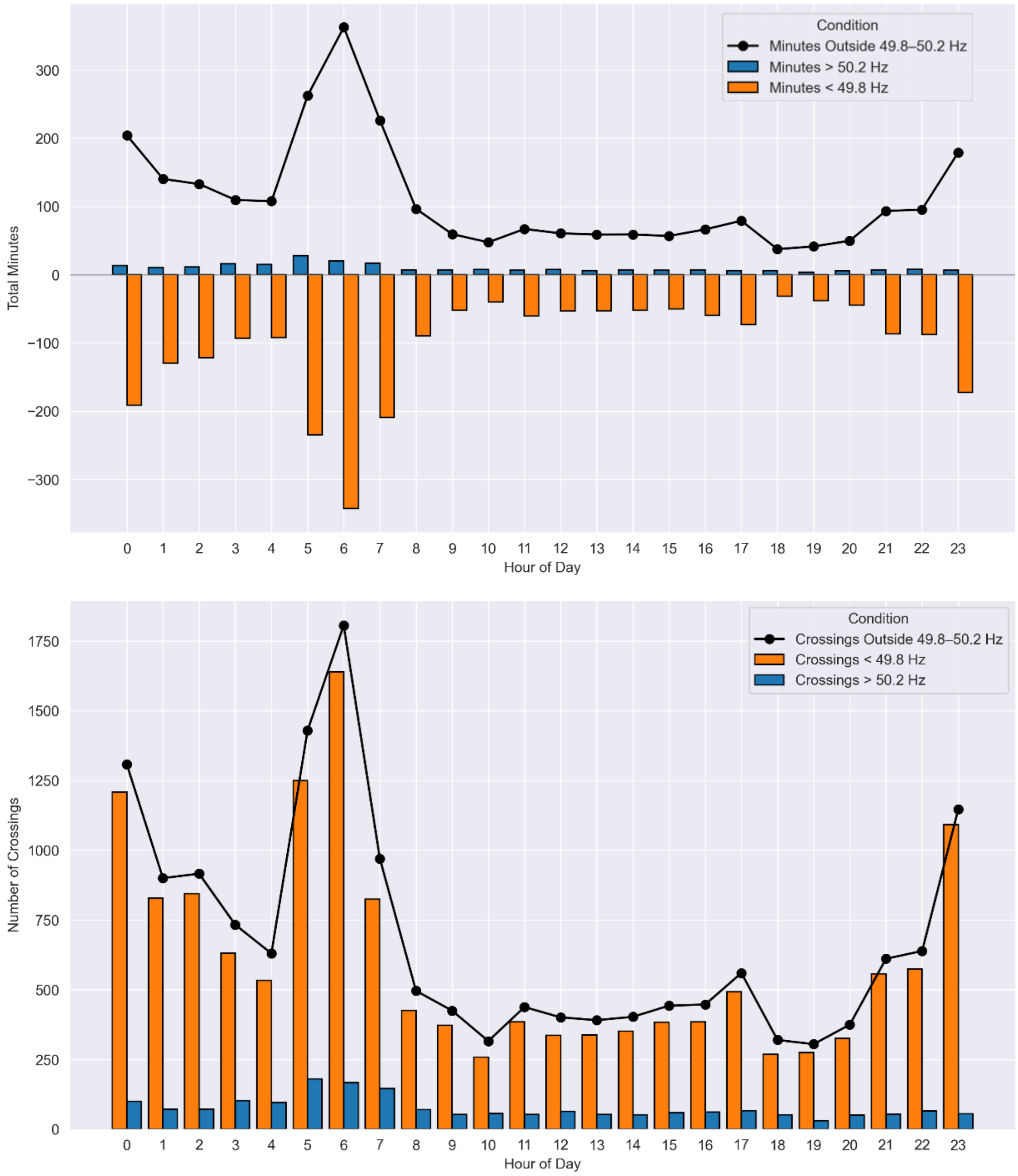

Figure 15 Total time spent outside the normal frequency band (top graph), Total number of threshold crossings (bottom graph) (Aug 2020-Feb 2026).

6.2.2.5 MFK latency assessment

When assessing frequency regulation capabilities for a power system with increasing variability, the delay between grid frequency measurement at the MFK input and resulting generation response from the participating providers is also key metric. Factors that contribute to this delay include:

- MFK control system calculation and sampling periods

- Communication and interface delays from the system operator SCADA to the provider control systems
- The physical response and characteristics of the generating units

To estimate the scale of this lag, a cross-correlation analysis was performed on historical PI data. The expected output (defined as the sum of the dispatch setpoint and MFK control regulation value) was compared against the measured generation MW output.

Figure 16 provides a visual representation of the data used. The analysis was done for different providers and results show response lags in the range of around 14 to 27 seconds across providers.

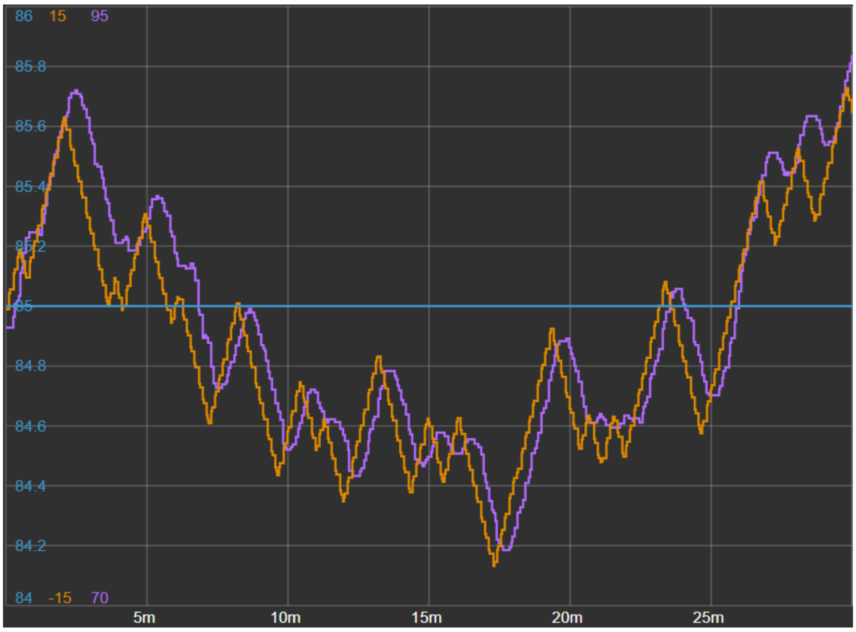

Figure 16 A plot of the MFK control signal (orange), dispatch setpoint (blue) and generation MW output (purple) over a 30-minute period.

This is only an approximation of the time in which providers respond and do not separate delays between MFK calculation and the SCADA control value measurement in PI, or for differing delay times between SCADA output tags across sites. As such, the reported lag range should be interpreted as an indicative baseline against which the MFK simulation studies can be measured for this task, rather than as definitive values.

6.2.2.6 HVDC FKC sensitivity

As mentioned in Section 3.2.2, the operational status of the HVDC FKC (FKC) influences both the MFK provider selection process and the associated MFK band size. Accordingly, further analysis was undertaken to evaluate how the HVDC FKC availability affects overall system frequency quality.

Correlation between the frequency quality metrics and HVDC outage hours was assessed using Pearsons's correlation method. The Pearson correlation coefficients (*r*) between HVDC outages and both *Total Minutes Outside the Normal Band* and *Crossings Outside the Normal Band* are **0.83** and **0.69** respectively (1 being the strongest correlation). This indicates a strong positive relationship between HVDC outages—and consequently FKC availability—and these frequency-quality metrics.

While the correlation is strong for the number of threshold crossings out of the normal band, the time spent outside the normal frequency band shows an even stronger association. This speaks to the power system's ability to return frequency to within the normal band without FKC modulation and less to the possibility of increased variability observed during HVDC outage periods.

6.3 Simulation-based evaluation of MFK effectiveness

Using the System Operator's MATLAB/Simulink MFK model, multiple scenarios were simulated to assess MFK performance under varying levels of generation variability and persistence. The objective of this study is to evaluate how the MFK tool performs under different intra-dispatch variations and to determine whether repurposing the tool could improve the management of these deviations, and if so, identify the most effective approach.

Using a simplified representation of the New Zealand power system, the study captures:

- The type and magnitude of MW deviations
- The resulting system frequency response, along with calculated frequency quality metrics under different MFK parameter settings and latency assumptions.

6.3.1 Study methodology and process

1. A 1-second resolution dataset comprising of system load, generation, and system frequency was extracted for the month exhibiting the highest IG variability and poorest frequency quality metrics. This dataset was used as the base case for the simulations, providing the reference system behaviour against which model parameter changes were evaluated.
2. A high-pass filter with a 5-minute cutoff frequency was applied to the base case to isolate intra-dispatch behaviour only. This filtering removes slower variations associated with load ramping.
3. Supporting MATLAB and Python scripts were developed to:
    a. Generate condensed input signals for the simulation horizon.
    b. Compute the defined frequency quality metrics in accordance with the methodology description in Section 3.5;
    c. Impose the different intra-dispatch variations on the base case to reflect the selected scenarios described in Section 6.3.3.
    d. Process, analyse, and visualise the simulation outputs.
4. Initial model validation checks were also undertaken to confirm previously observed findings by the System Operator. These checks included evaluating the impact of asymmetrical regulation band adjustments, reducing control latency from 25 seconds to 10 seconds, disabling HVDC FKC with FSC/SRS enabled and a 25 MW regulation band applied to assigned frequency keepers, and reducing governor frequency deadbands.
5. The following control parameter adjustments were then implemented across the study scenarios:
    a. Asymmetrical regulation band adjustment – a 30 MW increase in the downward regulation band. The downward band modification was selected based on observations from the historical data analysis presented in Section 6.1.2.4.
    b. Symmetrical regulation band expansion – increasing the total regulation band to 100 MW (±50 MW).
    c. Control latency reduction – decreasing the MFK control latency from 25 seconds to 10 seconds.

6.3.2 Model limitations

- The Matlab/Simulink model accurately models the response of each generation type and not as actual individual stations or units. Hence, there is no ability to model the diversification in the generating stations' responses when parameters change from one generating station to another. This limitation does not take away from the study results as the study focuses on the overall system performance and not contribution from individual generating units. Also note, this limits the model's ability to model generator's individual primary frequency response.
- The input generation signal introduced in the simulations represents a deviation from dispatch, rather than the actual output of a specific generating unit. This deviation may originate from either synchronous generation or IGs; however, the source technology is not the focus of this study. Instead, the analysis concentrates on the characteristics of the deviation itself, which are used to define the study scenarios described in the following section. All aggregated generating units in the model are assumed to follow their dispatch instructions and respond to system imbalances in generation and load according to their governor droop settings.

6.3.3 Study Scenarios

Scenario 1: Gain Adjustment to Represent Increased Intermittency

To represent different levels of intermittency, gain factors were applied to the original deviation signal (example shown in Figure 17) to generate a modified signal ($x_g\,(t)$).

$$x_g\,(t) = \mu + g(x(t) - \mu)$$

Where $x(t)$ is the original deviation signal, μ is the mean for the respective dispatch period and g is the gain factor (gain of 1 corresponding to the original signal). These scenarios are modelled to represent periods where generation follows its dispatch while intermittency increases. These scenarios are modelled to represent periods where generation follows its dispatch on average while intermittency increases.

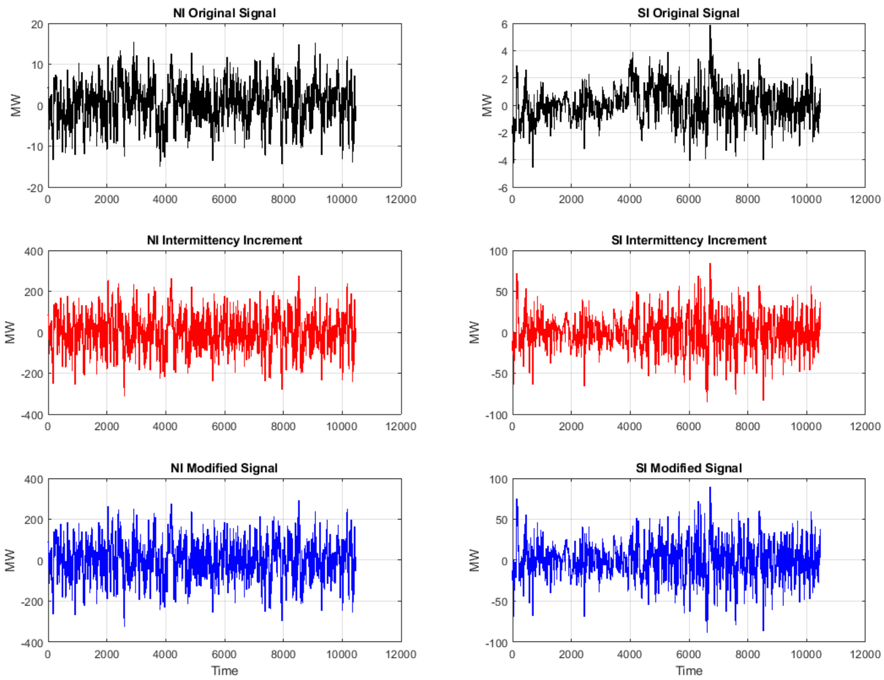

Figure 17 Example of the applied gain used to generate the intermittency increment (red), which is added to the original signal mean (black) to produce a modified signal (blue) representing different intermittency levels.

Table 4 shows how the standard deviation changes for each of the modified signals with gains of 5, 10 and 20.

Table 4 Characteristics of different intermittent input signals

Scenarios	NI input standard deviation (MW)	SI input standard deviation (MW)
Base case	4.824	1.276
Low intermittency (Gain = 5)	22.649	5.519
Medium intermittency (Gain = 10)	45.202	10.980
High intermittency (Gain = 20)	90.357	21.930

Scenario 2: Bias Adjustment to Represent generators being Off-Dispatch

To represent persistent deviations in a dispatch period, different bias factors were applied linearly to the input signal (example shown in Figure 18) to generate a modified signal:

$$x_b\,(t) = x(t) + b\mu$$

where $x_b(t)$ is the biased signal, μ is the mean output for the respective dispatch period, and b the bias factor applied as a proportion of the dispatch mean.

This represents dispatch intervals during which one or more generating units—whether IG or synchronous—operate away from their instructed dispatch levels for a sustained period. The bias remains constant throughout the dispatch interval and is reset at the beginning of the next dispatch period.

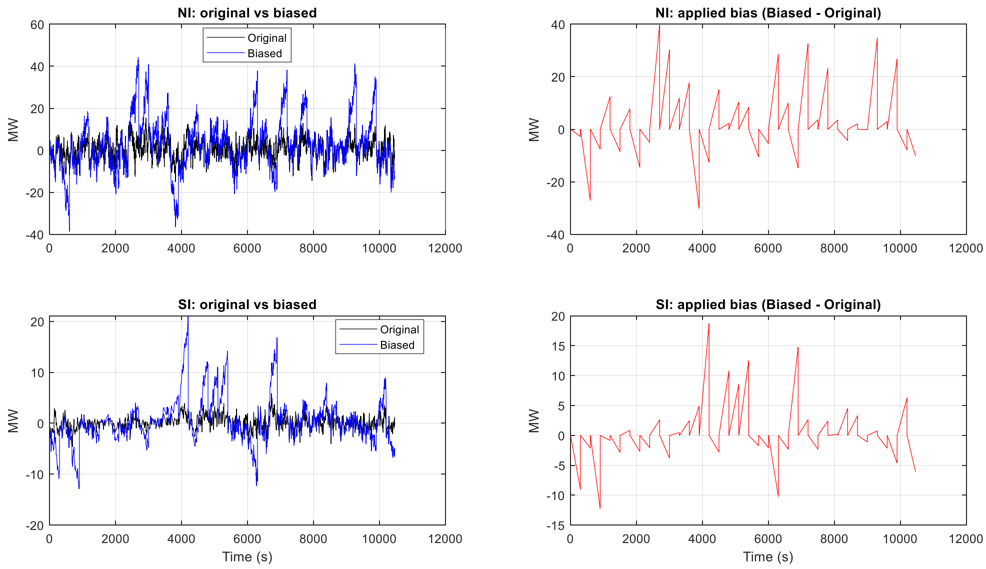

Figure 18 Example of the bias applied linearly to the base case signal to represent different levels of off dispatch.

Error! Reference source not found. summarises the characteristics of each scenario, where the dispatch-period mean is multiplied by the selected bias factor and added to the original signal. This produces different deviation magnitudes across the scenarios, with the resulting maximum deviation for each case also reported in the table. These values represent the *maximum intra-dispatch deviation* modelled for the respective island.

Table 5 Characteristics of different off-dispatch input signals

Scenarios	NI		SI	
	Mean (MW)	Maximum bias (MW)	Mean (MW)	Maximum bias (MW)
Low bias (b = 1)	2.816	39.69	0.45	18.72
Medium bias (b = 5)	12.216	198.45	1.98	93.62
High bias (b = 9)	21.616	357.20	3.50	168.51

Scenario 3: Combined Intermittency and Bias Adjustment

To represent realistic boundary operating conditions, scenarios were developed in which intra-dispatch deviations exhibit both persistence and variability simultaneously. The modified signal , $x_{gb}(t)$, is defined as:

$$x_{gb}(t) = x(t) + b\mu + g(x(t) - \mu)$$

where $x(t)$ is the original deviation signal, μ is the mean output for the respective dispatch period, and b the bias factor g is the gain factor.

This scenario considers realistic boundary operating conditions in which the intra-dispatch deviations are caused by both intermittency and generation being off-dispatch, occurring simultaneously and at varying magnitudes. Figure 19 illustrates the characteristics of the four boundary conditions considered in this scenario. The "Low bias–Low intermittency" case represents conditions closest to the original signal, while the "High intermittency–High bias" case represents a worst-case condition in which a large sustained off-dispatch deviation occurs alongside a high IG profile.

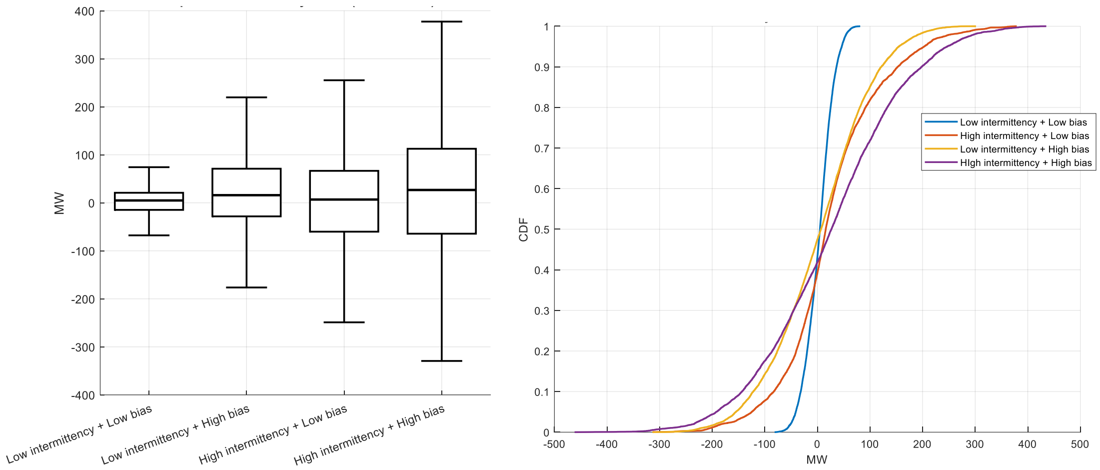

Figure 19 Boxplot and Cumulative Probability (CDF) for the studied boundary conditions.

6.3.4 Results and observations

6.3.4.1 Impact of persistence and variability on frequency quality

An initial assessment of Scenarios 1 and 2 was conducted to compare the different persistence and variability base cases and their respective impacts on frequency quality metrics. Figure 20 to Figure 24 illustrate how changes in the magnitude of the introduced deviations—represented by their standard deviation on the y-axis—affect system frequency performance across the study scenarios.

The key observations are as follows:

- The mean system frequency is influenced by sustained off-dispatch deviations.
- Under both persistence and variability scenarios, the standard deviation of system frequency is higher in the NIPS than in the SIPS.
- Variability has a greater impact on the frequency area index, time spent outside the normal frequency band, and threshold crossings than persistence especially at higher intermittency levels.

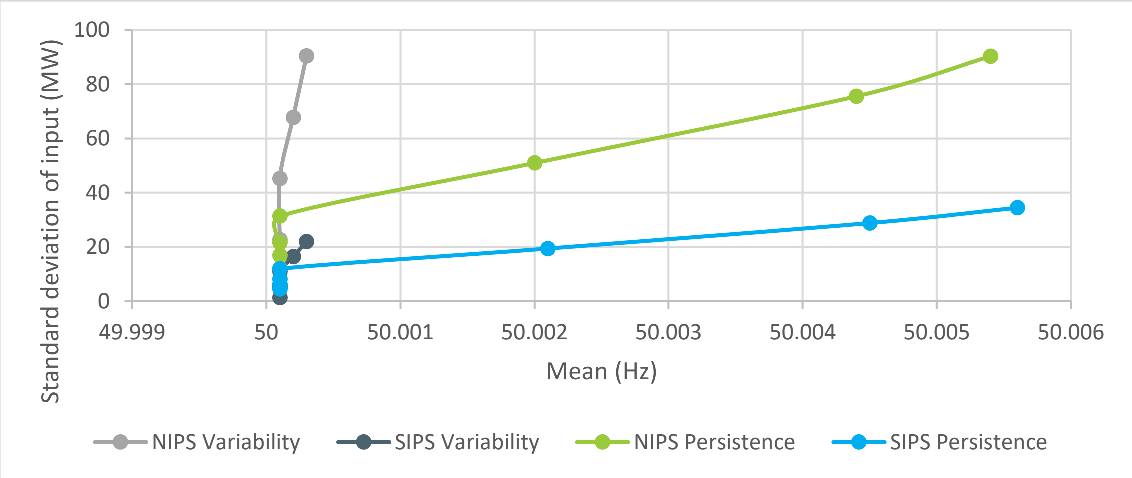

Figure 20 Impact of different Persistence and variability levels on the mean of System Frequency.

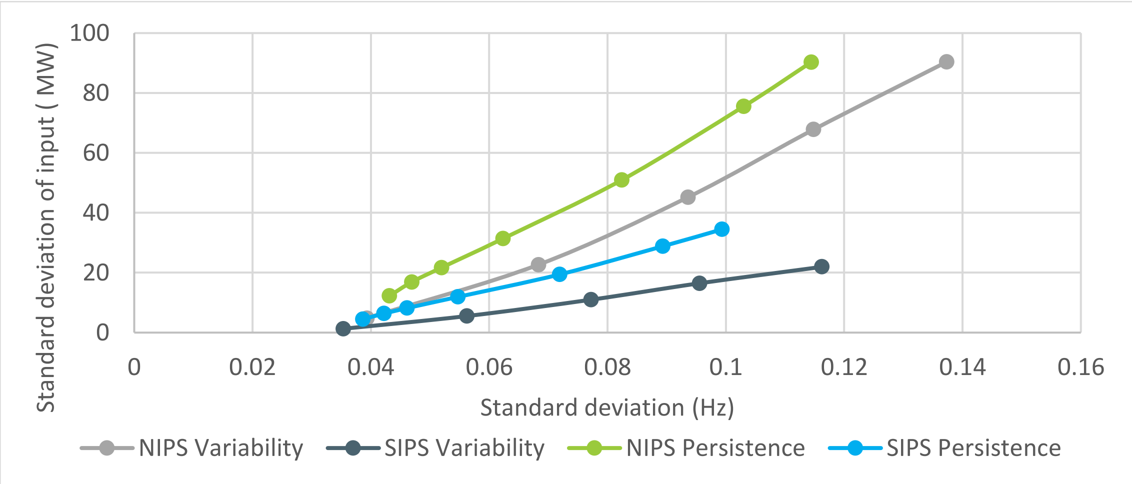

Figure 21 Impact of different Persistence and variability levels on the standard deviation of System Frequency.

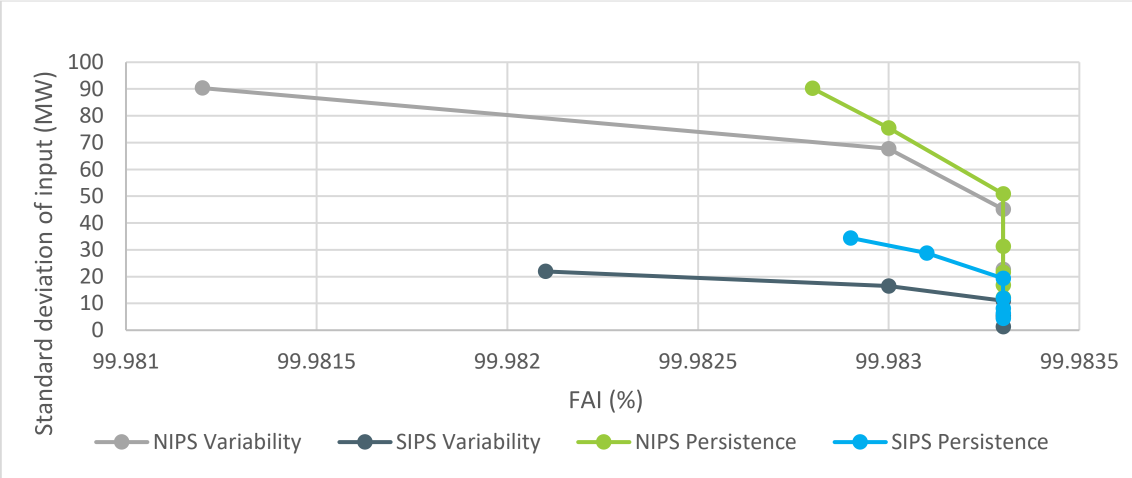

Figure 22 Impact of different Persistence and variability levels on the frequency area index of System Frequency.

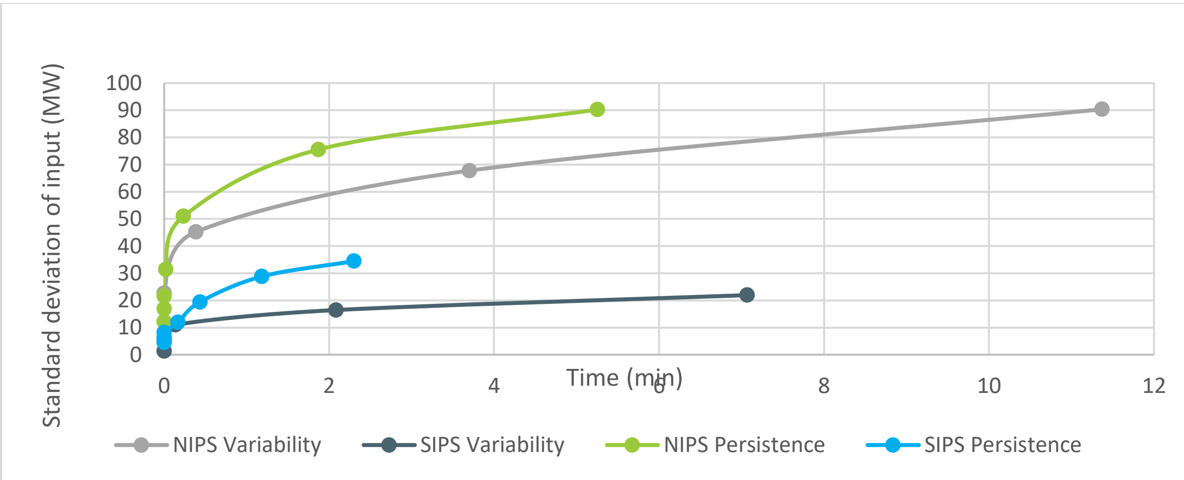

Figure 23 Impact of different Persistence and variability levels on the time the System Frequency is spent outside the normal band.

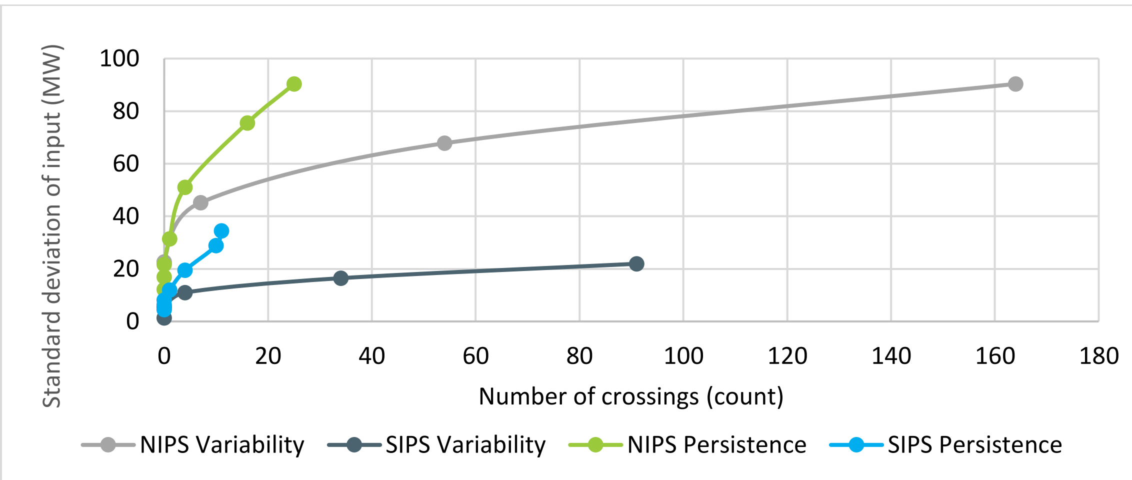

Figure 24 Impact of different Persistence and variability levels on the Number of times system frequency crossed to outside of the normal band.

6.3.4.2 *Impact of MFK parameter adjustments on frequency quality*

Figure 25 and Figure 26 illustrate how the frequency quality metrics change as the MFK control parameters are modified. The key observations are as follows:

- Persistence-driven deviations have a smaller impact on the metrics compared with variability-driven scenarios, where clearer differences are observed between the results of the two cases as MFK was designed to manage off-dispatch behaviour and less for high variable system
- Reducing control latency and increasing the MFK regulation band both improve the frequency quality metrics. However, their effectiveness differs depending on the deviation characteristics: increasing the regulation band provides greater improvement for persistence-driven deviations, whereas reducing latency is more effective in managing variability. This distinction becomes more pronounced at higher levels of bias and gain compared with scenarios involving smaller deviation magnitudes.

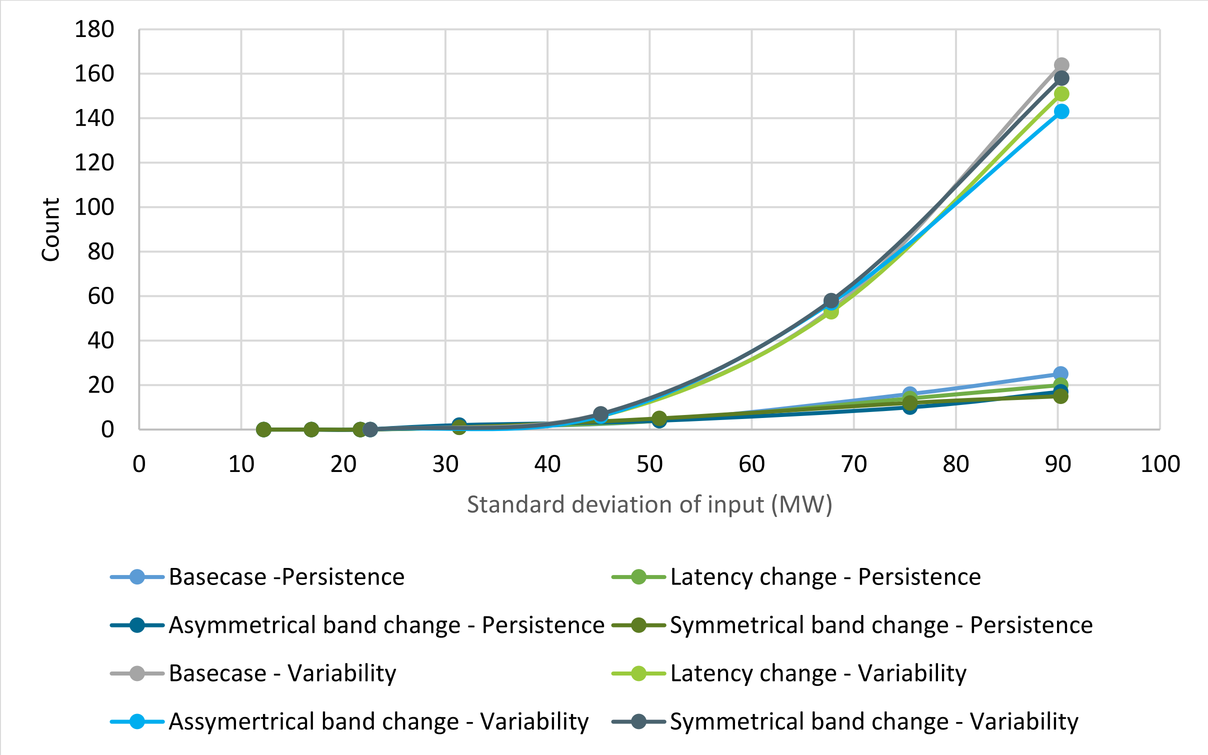

Figure 25 How the "Number of threshold crossings" metric changes with different MFK parameters for Scenario 1 and 2.

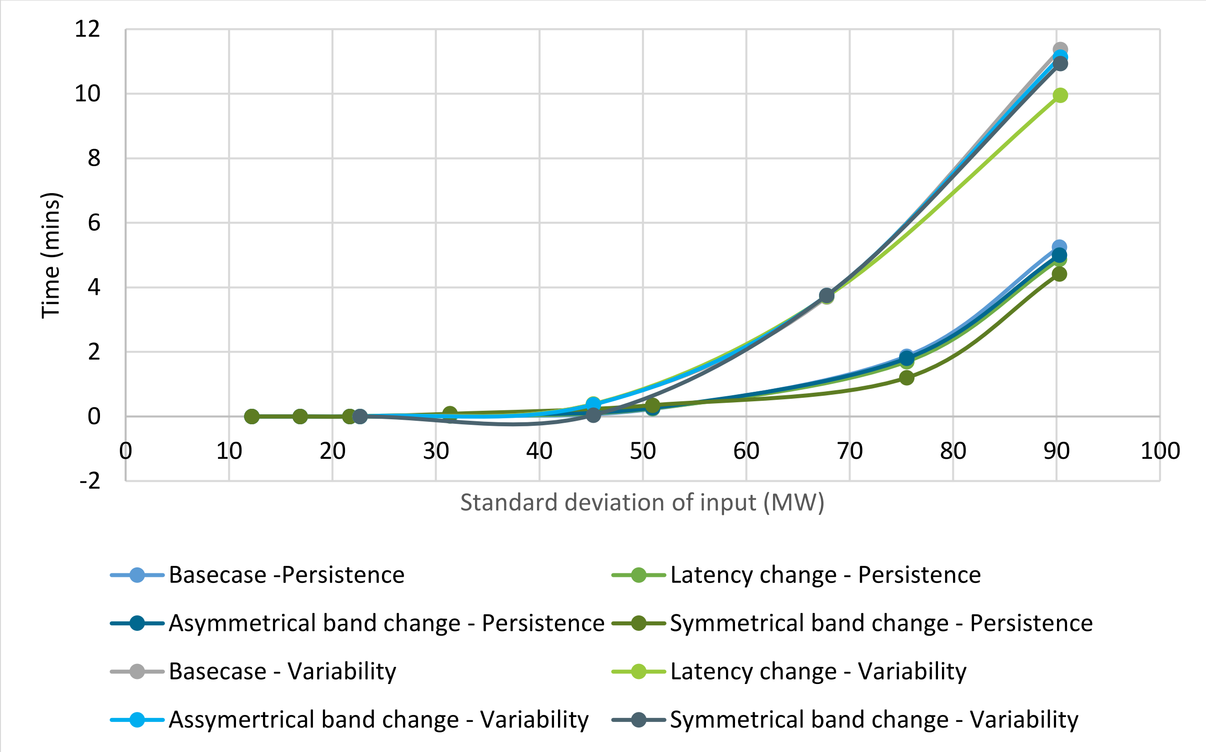

Figure 26 How the "Time spent outside the normal band" metric changes with different MFK parameters for Scenario 1 and 2.

6.3.4.3 MFK band output changes with parameter changes

Further investigation of parameter adjustments was undertaken with boundary conditions to assess system behaviour with a combination of persistence and variability. This analysis evaluated how modifications to key parameters—such as MFK latency and regulation band settings, informed by the results of Scenarios 1 and 2, would perform under these scenarios.

The key observations from this assessment are summarised, with relevant histograms showing the MFK regulation output below:

- With the same bias factor applied, increasing the MFK regulation band in the study provides adequate regulation in low-intermittency scenarios but becomes progressively less effective as intermittency levels increase. Frequency quality deteriorates while the MFK controller output does not saturate at its limits.

- Figure 27 illustrates the distribution of MFK regulation outputs under conditions of low intermittency and low bias.
- Figure 28 shows the MFK output distribution for the same level of intermittency but with increased off-dispatch deviation and
- Figure 29 demonstrates the MFK output distribution for the same level of bias but with increased intermittency.

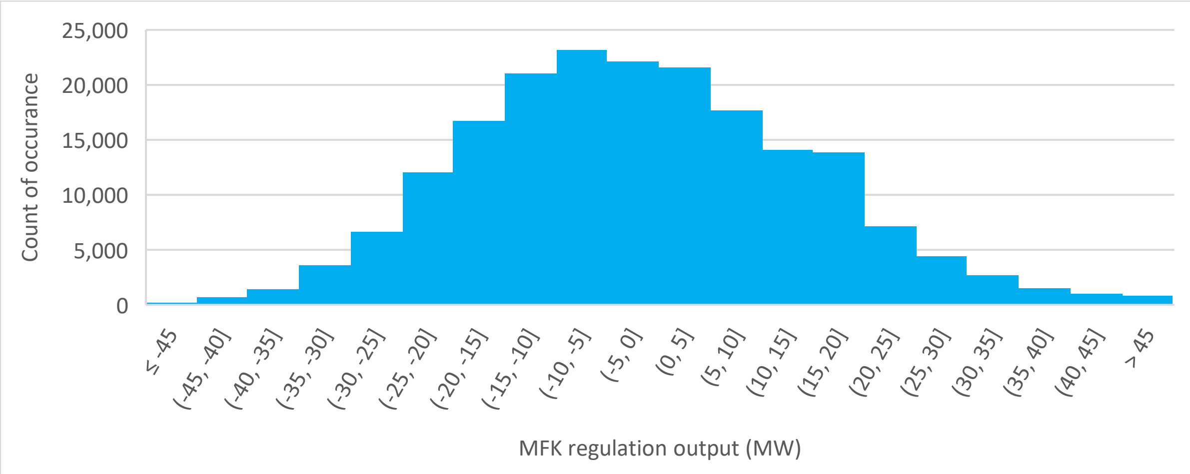

Figure 27 Low intermittency- Low bias – with a ±50MW band.

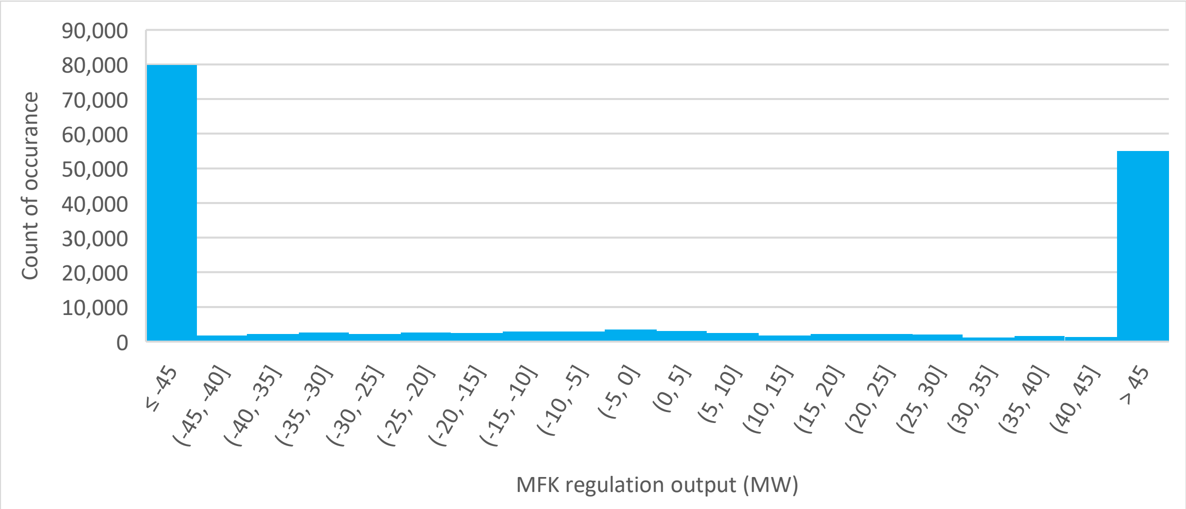

Figure 28 Low intermittency- High bias – with a ±50MW band.

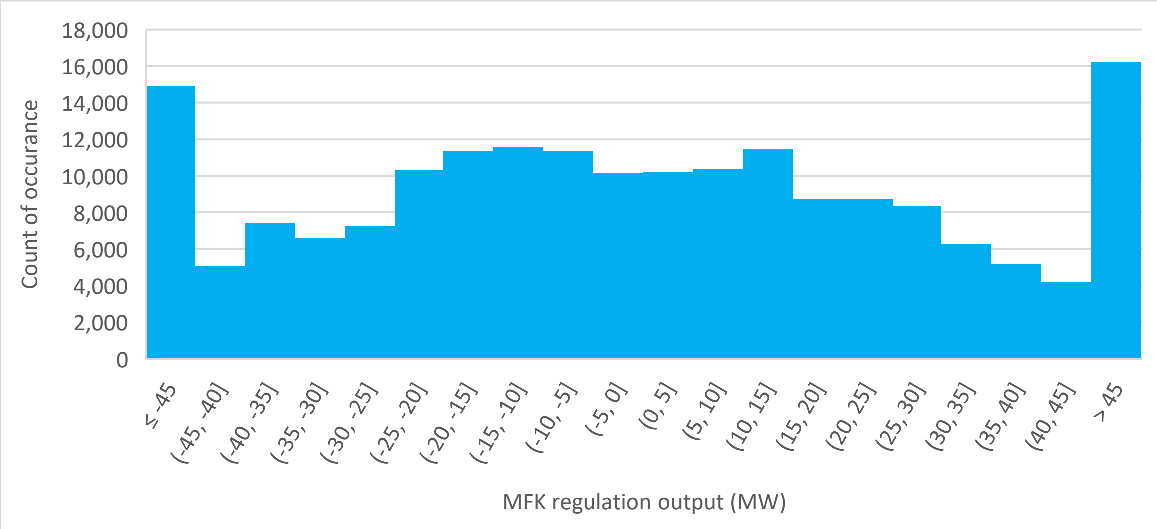

Figure 29 High intermittency- Low bias - with a ±50MW band.

- Figure 30 shows that although increasing the MFK regulation band improves the ability to manage large off-dispatch deviations, its effectiveness reduces when these deviations occur simultaneously with high intermittency. Under these conditions, the MFK output saturates at the lower limit of the regulation band more frequently than observed in Figure 28. This behaviour is similar to current observations, where large, accumulated errors—primarily caused by generators operating off-dispatch—drive the regulation signal toward its lower limit. However, the effect becomes more pronounced, with the regulation signal only oscillating primarily between the maximum and minimum band limits.

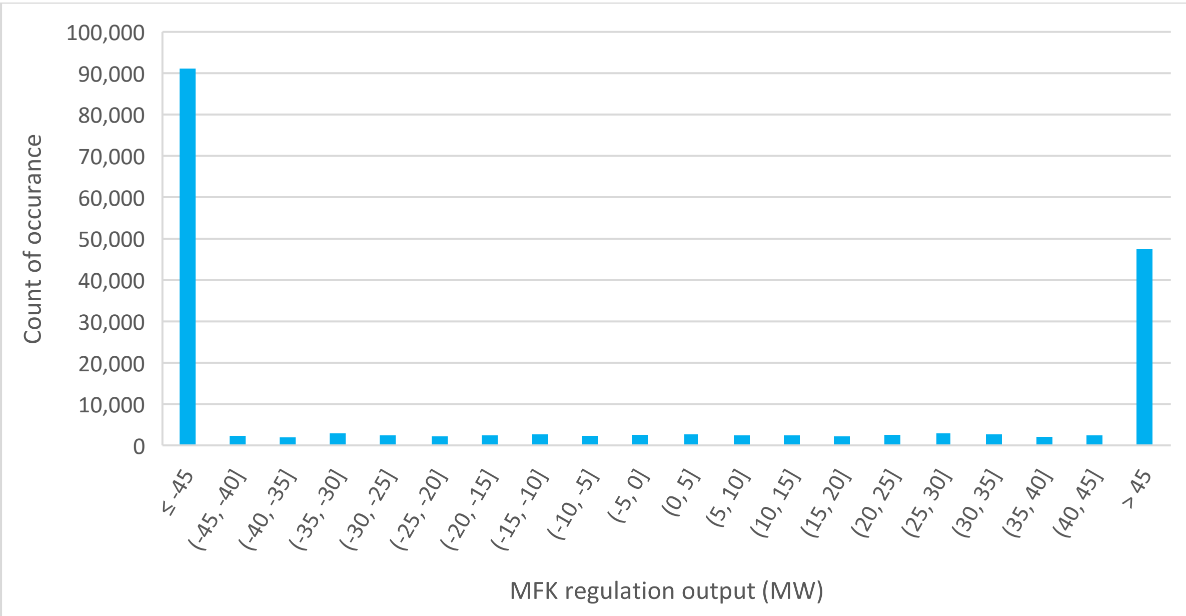

Figure 30 High intermittency- High bias - with a ±50MW band.

- Figure 31 shows that increasing the frequency keeping band, together with reducing the response latency, improves the distribution of the MFK regulation signal by approximately a factor of two. In particular, the proportion of time that the MFK regulation operates within 5 MW of the band limits is reduced by half when the latency reduction is applied in addition to the increased band size.

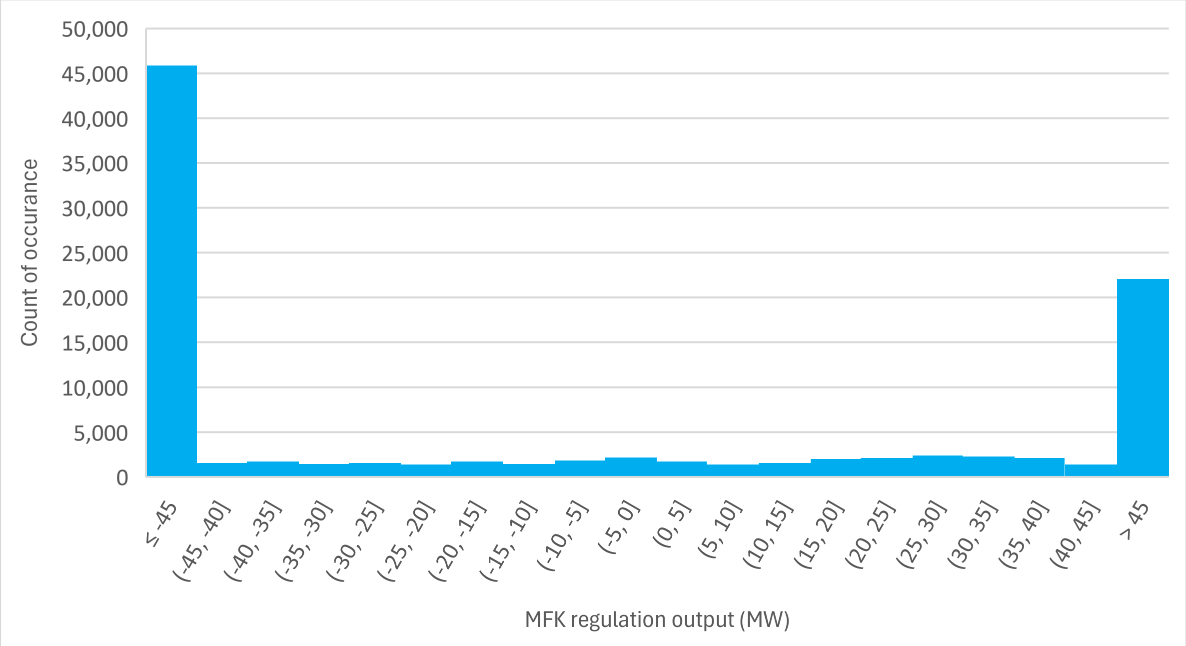

Figure 31 High intermittency- High bias - with a ±50MW band and reduced latency.

6.3.4.4 Role of governor response in maintaining frequency quality

Complementary analysis was undertaken to extend the studies supporting the Code amendment[13], which highlights the need for increased governor response to improve system frequency standard deviation.

The results indicate that implementing a larger MFK regulation band and reducing the response time of MFK providers (labelled as 'MFK changes' in Figure 32) does not compensate for reduced governor participation. In fact, scenarios with less governor action result in poorer frequency performance on the island where the governor response is reduced.

---

[13] Promoting reliable electricity supply: Frequency-related Code Amendments - Decision paper

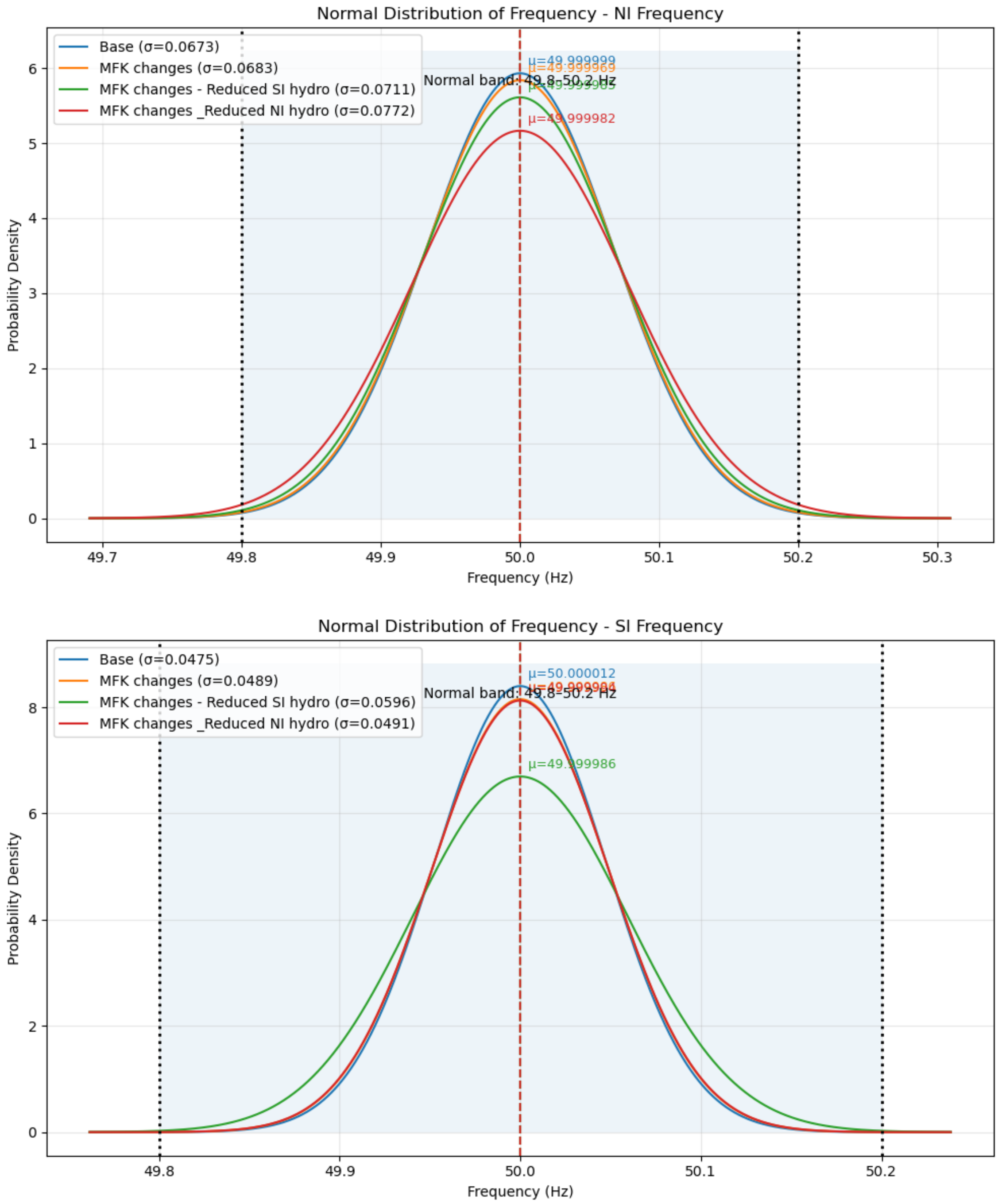

Figure 32 System frequency standard deviation with reduced governor action.

6.3.4.5 Impact of National Frequency Keeping – All frequency keepers in a single island

This study also considered potential changes to the National Frequency Keeping (NFK) service enabling all frequency keeping to being procured from generators located within a single island (through the use of the HVDC FKC function).

This change would remove the current operational requirement to maintain a frequency keeper on each island when FKC is enabled. The analysis evaluates the potential impact of this change on frequency performance in both islands.

Future work would need to be done to examine the cost–benefit trade-off of removing this operating constraint, especially under conditions where only a single frequency keeping offer is available in one of the islands.

The results indicate that the overall system frequency standard deviation does not change significantly under the tested configurations. However, some island-specific differences are observed (standard deviation changes are shown in Figure 33).

- NIPS frequency performance improves when the frequency keeper is located within the North Island.
- SIPS frequency performance also improves when the frequency keeper is located in the North Island.

This behaviour is largely attributable to the fact that a significant proportion of IG and its associated variability is located in the North Island. Locating the frequency keepers with the maximum possible regulation band in the same island as the primary source of variability allows the control action to respond more directly to these deviations, thereby improving overall frequency quality.

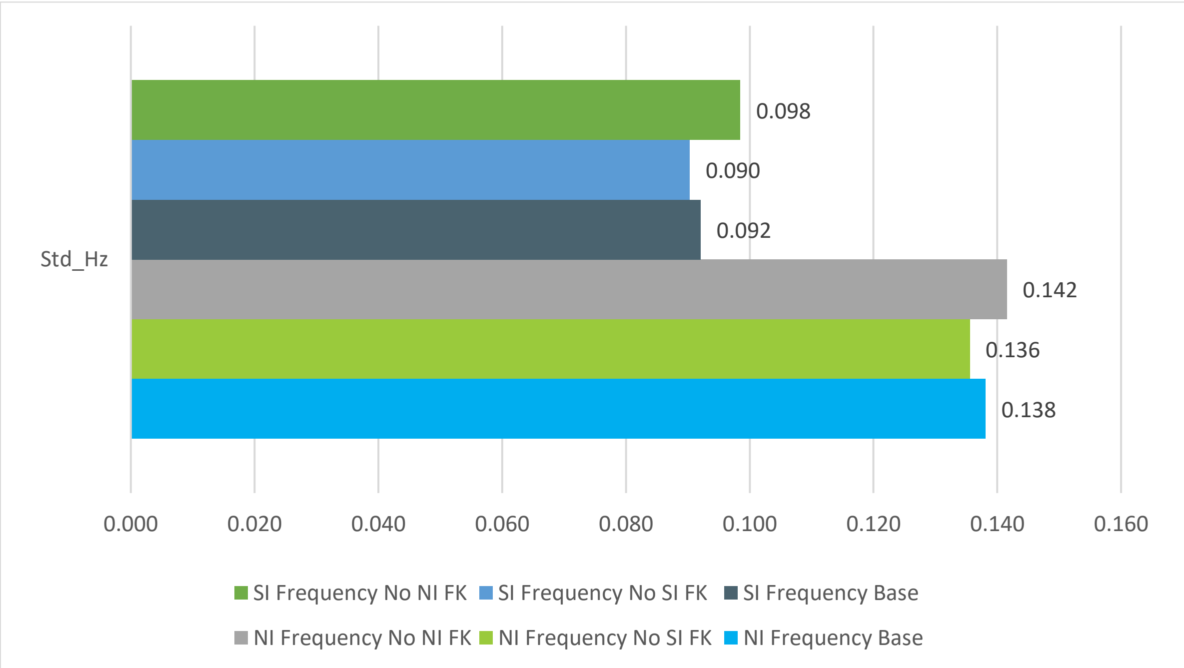

Figure 33 Standard deviation changes as frequency keeping service is procured from a single island.

7 Findings and Options

The studies undertaken as part of TAS120 confirm that MFK remains a critical tool for managing intra-dispatch frequency deviations and therefore does not require repurposing. MFK was designed to correct accumulated frequency errors while governors respond to the instantaneous change. With increasing variability in system frequency, caused by IG, and consequently larger frequency errors, the importance of this function becomes even more significant.

This work catergorised intra-dispatch deviations into two main drivers: persistent frequency bias caused by generators operating off-dispatch, and increased frequency variability resulting from intermittency from IG. This study also extends the System Operator's previous work recommending tighter governor frequency deadbands to improve frequency management within the normal band, indicating that increasing intermittency and off-dispatch behaviour will still require adjustments to MFK. To maximise the effectiveness of the MFK tool, these adjustments—together with potential Code changes or a review of existing requirements—should be targeted at addressing the underlying drivers of intra-dispatch deviations.

Accordingly, this section outlines the options proposed by the System Operator. These include enhancements to the MFK tool that include enabling participation from fast-responding providers, potential Code changes to support the System Operator in meeting its Principal Performance Obligations, and a review of ancillary service requirements.

7.1 Increase MFK band to address persistence

Increasing the MFK band is the most effective short-term measure to reduce the persistent bias in system frequency error. A wider regulation band prevents MW output from saturating at the current limits, allowing larger regulation signals to be issued so that persistent deviations can be corrected more quickly. Further analysis will be undertaken in Phase 2 to assess the feasibility and implications of increasing the band size.

While increasing the band may raise frequency keeping service costs, complementary market efficiency initiatives should progress in parallel. These include exploring national frequency-keeping selection, linking band size to system conditions (e.g. variable bands by procuring additional frequency-keeping capacity during peak periods), and considering asymmetric bands where appropriate, noting that these would involve more complex design changes. Integrating frequency keeping into SPD would enable co-optimisation with energy and reserves, while a review of cost-allocation arrangements could better align costs with cost causation under a causers-pay framework. Strengthening dispatch compliance, particularly for IG, would further support improved frequency quality.

7.2 Allocate dedicated band to fast responsive providers.

Analysis indicates that intermittency from IG manifests primarily as variability-related frequency deviations, such as increased threshold crossing rates and higher frequency standard deviation, rather than as persistence related effects. Consequently, continued procurement of additional slow-acting frequency services is unlikely to address the underlying issue over time.

Allocating a dedicated MFK band to fast-responsive providers, particularly assets capable of rapid, low-latency response (e.g. fast-ramping plant and BESS) directly targets variability driven deviations and provides the most effective and proportionate intervention as IG increases.

We strongly recommend prioritising and accelerating work to enable full BESS participation in frequency keeping, particularly implementation of a single bidirectional offer structure. This would maximise BESS technical capability, support improved frequency quality, and enhance market competition and efficiency.

7.3 Allocate all band to fast responsive providers.

Building on the preceding options, in the longer term all frequency keeping services can be procured from fast-responsive, low-latency providers. These providers can address both variability and persistence related deviations. When combined with consistent deadband settings and national frequency keeping selection, this represents the most efficient and effective service configuration for a system with high levels of IG.

7.4 Adequacy of Existing Principal Performance Obligations

The existing PPOs in Part 8 of the Code provide a sufficient basis for procuring and utilising MFK for its current purpose. The frequency related PPOs require the System Operator to maintain system frequency using ancillary services, and MFK clearly fits within this framework. These obligations give the System Operator flexibility to procure and deploy MFK, including adjusting band size, refining provider performance expectations through contracts and tests, and integrating BESS based frequency keeping based on its capability. They also allow the System Operator to set delivery standards and latency expectations.

However, several enhancements proposed in this report extend beyond what the current PPOs expressly envisage. These relate to introducing frequency performance standards and strengthening dispatch compliance. Targeted Code changes would therefore support the effective implementation of the proposed future state framework.

7.5 Potential Code Changes

The analysis identifies four areas where changes to the Code could support improved system frequency quality as IG increases, including

- introducing a frequency performance standard,
- clarifying dispatch expectations for IG,
- reviewing frequency keeping cost allocation to support a fairer causers-pay framework, and
- strengthening dispatch-compliance requirements.

7.5.1 Frequency performance standard

The absence of a formal, outcome-based frequency-performance standard limits the ability to objectively assess frequency quality. Introducing measurable metrics, such as allowable annual time outside the normal band or limits on normal-band crossing rates, would align New Zealand with international practice, support transparent assessment of obligations under clause 7.2 in the Code, and provide a clearer framework for managing increasing variability from demand, IG, and dispatch behaviour.

7.5.2 IG dispatch

Current Code provisions do not sufficiently specify dispatch expectations for IG. As frequency quality has deteriorated, variability arising from intermittent generators operating away from dispatch targets has become more evident. Clarifying these expectations would improve dispatch stability and ensure generator behaviour better aligns with system-wide frequency objectives. Addressing this issue directly also reduces the risk of attributing frequency degradation solely to ancillary-service limitations while leaving a key driver unresolved.

7.5.3 Frequency keeping cost allocation

As the sources of frequency variability evolve, there is scope to review existing frequency keeping cost allocation arrangements to better align costs with cost causation, including consideration of causers-pay principles. Similar approaches are used in other jurisdictions, including Australia, where frequency keeping costs are allocated to reflect contributors to system variability. Greater alignment would strengthen incentives for behaviour that supports overall frequency quality while maintaining efficient market outcomes.

7.5.4 Dispatch compliance

The Code does not define acceptable deviation tolerances or time-to-reach requirements for dispatch instructions. Introducing clearer compliance parameters would strengthen dispatch performance within the interval, reduce intra-dispatch variability, and support improvements in frequency quality identified in this report.

7.6 Ancillary service requirement changes

The findings imply several changes to the design and procurement of ancillary services. In the near term, the MFK band should be increased as a priority to address persistence, followed by allocating a dedicated portion to fast-responsive providers to manage variability more effectively. Over time, procurement should transition fully to low-latency providers to ensure both variability and persistence related deviations are managed efficiently. Enabling BESS participation through a single bidirectional offer structure remains an essential supporting requirement.

Additional changes may arise depending on the progression of other recommendations, e.g. a shift from island-based to national frequency keeping selection may further influence ancillary service design, procurement and cost allocation.

7.7 More Frequent Energy Dispatch (not considered further)

While increasing dispatch frequency is often proposed to improve real-time supply demand alignment as renewable penetration rises, it has practical limitations. Energy dispatch is economic and typically occurs every 5 minutes in New Zealand market, while frequency deviations arise in seconds and cannot be managed by dispatch alone. Although ad-hoc manual dispatches can be issued when frequency issues are observed, no market operates continuous sub-5-minute energy dispatch due to schedule solve time, communication delays, and response constraints. The study (section 6.2.2.3) further confirmed that the 1-minute (vs 5-minute) duration curves show minute to minute movement in both wind and solar generation, meaning the underlying variability does not disappear when the interval is shortened.

Internationally, markets such as PJM, ERCOT, CAISO and AEMO pair 5-minute dispatch with fast acting ancillary services to manage frequency within the dispatch interval. More frequent dispatch would also increase operational costs and compliance pressure, given acknowledgement requirements[14], and many generators lack the flexibility to ramp faster. Importantly, shortening dispatch intervals alone would not eliminate intra-dispatch variability, reinforcing the need for complementary frequency regulation services.

[14] Clause 13.79(a) requires participants to acknowledge receipt of a dispatch instruction within four minutes.

8 Recommendations

While this work provides recommendations specific to steady-state frequency management, the System Operator wholly advocates for the development of a coordinated **frequency management strategy** in collaboration with the Authority. This would provide clearer direction to industry participants on how frequency management and stability should evolve, while establishing a framework to address emerging challenges such as increasing intermittency, changing generation mix, declining system inertia, new technologies, and evolving load behaviour.

This work should therefore be considered within the broader context of an integrated frequency management approach. Such a strategy would promote alignment between operational practices, market design, and regulatory settings, ensuring ancillary and reserve products remain adequate and enabling a more proactive and coordinated approach to maintaining frequency stability as the power system transitions.

Accordingly, we recommend a staged set of actions to improve system frequency quality as IG increases. Table 6 summarises the recommended actions, priorities, and indicative timeframes, with detailed analysis set out in the preceding Findings and Options section.

Table 6 Recommended actions and indicative implementation timelines

Recommendation	Priority	Indicative Timing
Increase MFK band (≥ 10 MW per island)	Urgent / Highest	Implement as soon as practicable subject to Phase 2 confirmation
National frequency keeping selection	Urgent / Highest	6 - 12 months with Phase 2 initiation
Address generator dispatch compliance and IG dispatch	Urgent / High	Immediate start with Authority
Allocate MFK to fast-responsive providers	High	Near to medium-term (as providers become available)
Enable full BESS participation (single bidirectional offer)	High	Medium-term (~18 months)
Complementary market and design changes (e.g. SPD integration)	Medium	2 years+, while can be developed in parallel

8.1 Retain the existing frequency regulation framework.

Retain the current frequency regulation framework, with governor response supported by MFK control. The proposed ±0.1 Hz deadband limit would further strengthen primary response performance. The transition to a ±0.1 Hz deadband is anticipated to be gradual, and the associated benefits are unlikely to become evident within the next three to four years. MFK therefore remains essential for managing persistent off-dispatch behaviour within dispatch intervals and provides tertiary support following contingent events. We consider a staged enhancement of MFK to be appropriate.

Figure 34 provides a high-level conceptual overview of how frequency keeping arrangements evolve through staged MFK enhancements, with more complex system changes (e.g. a ROM required) explored further in phase 2 of this TAS.

Stages	Timeline	What	Current Limitations	System Changes	Other changes
1. Expand MFK & NFK (National FK Market)	ASAP (once the band increase is confirmed) & NFK in 12 months	MFK band increase & National FK selection	Addressing persistency but not variability	Minor (Band increase) & ROM (NFK)	Dispatch compliance Improve IG dispatch Cost allocation (causers pay)
2. Expand MFK (persistency + variability)	1-2years	Increase MFK band with dedicated fast responsive service allocation	BESS can only offer MFK when discharging	BESS arrangement (bidirectional offer)	Dispatch compliance Improve IG dispatch Cost allocation (causers pay)
3. High performance FK market (fast response)	2+years	Select fast responsive service providers	Enable full BESS participation	ROM	Procurement plan with updated performance requirements (e.g. max latency)
In Parallel: Competition & Efficiency	Can be developed along with Options 2/3	Complementary market and design changes	Island Selection Fixed band quantity	ROM	Variable bands Asymmetry bands FK selection in SPD

Figure 34 Conceptual staging of MFK enhancements under increasing IG.

8.2 Urgent MFK band increase and national frequency keeping selection

Persistent deviations from nominal frequency signal a mismatch between electricity supply and demand, leading to serious technical and operational risks. Small but sustained frequency deviation can cause stress on generators and motors, degrade insulation and damage sensitive consumer electronics. Larger and prolonged deviations pose a direct threat to grid stability, potentially activating protective relays, tripping generators, and initiating cascading failures. Managing such instability significantly increases operational complexity, requiring continuous system wide coordination, real-time interventions, and heightened reliance on reserves to maintain grid reliability.

Given these risks, increasing the MFK band should be treated as an urgent near-term measure to improve management of persistence related frequency deviations. A working assumption of at least an additional 10 MW per island is considered reasonable at this stage, subject to confirmation through Phase 2 analysis. This increase can be implemented by the System Operator with only minor system changes and should not be delayed pending longer-term market or Code reforms.

The additional band should initially be targeted to periods of highest system risk, including peak demand periods and periods of rapid IG ramping (e.g. solar ramps), noting the expected material increase in solar generation over the next 12 months. While increasing the MFK band may raise frequency keeping service costs, competition and efficiency measures should be advanced in parallel. Therefore, national frequency-keeping selection should be progressed as a priority in Phase 2 to improve competition, enable more efficient use of fast-responding resources across islands, and mitigate cost impacts while improving frequency quality.

8.3 Urgent actions to address dispatch compliance

Urgent action is required to address generator dispatch behaviour and compliance, particularly for IG dispatch, as this is a material and immediate contributor to deteriorating frequency quality. We would like to work closely with the Authority to commence this work without delay, including prioritised monitoring and compliance activity under existing arrangements alongside consideration of targeted Code changes. Addressing generator dispatch behaviour directly reduces the risk of attributing frequency degradation solely to ancillary service limitations while leaving key drivers unresolved.

8.4 Progressively allocate MFK to fast responsive providers

As fast responsive providers become available, a greater share of the MFK band should be allocated to assets with low control and communication latency. This is particularly important for addressing sustained off-dispatch behaviour and, to a lesser extent, variability arising from IG.

8.5 Enable high frequency keeping performance market

We also support the Authority to prioritise and accelerate work to enable full BESS participation in frequency keeping, particularly through implementation of a single bidirectional offer structure. This would maximise the technical capability of BESS, provide foundation for the stage 2, and support improved frequency quality, and enhance market competition and efficiency. Over time, combining increased participation from low-latency MFK providers with tighter deadband settings is expected to progressively improve frequency quality as IG continues to grow.

8.6 Advance complementary market and design changes

In parallel, we suggest the Authority should consider complementary market efficiency initiatives progress alongside MFK enhancements. These include linking band size to system conditions (e.g. variable bands by procuring additional frequency keeping capacity during peak periods), and considering asymmetric bands where appropriate, noting that these would involve more complex market design and system changes. Integrating frequency keeping into SPD would enable co-optimisation with energy and reserves and further enhance overall market efficiency. These initiatives are not prerequisites for near-term MFK band increases but are important to support an efficient and scalable long-term framework.