Meeting Tomorrow's Power System Frequency Needs

EEA Conference & Exhibition 2014

18-20 June, Auckland

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Introduction

New Zealand has a unique power system in that it is long, stringy and unconnected to the rest of the world. While European electricity grids are interconnected and can, to varying extents, rely on their neighbours' involuntary assistance with managing the power system frequency during events, the New Zealand grid cannot. If a generator suddenly disconnects from the system and causes the frequency to fall outside normal operating levels the New Zealand System Operator's response is largely pre-determined by the Under-frequency Management strategy.

As the country's power system characteristics continue to change, the strategies used to manage the system frequency need reviewing to ensure the most reliable, secure or cost effective strategies are in place. Future sources of generation and uses of electricity will shape which strategies effectively manage the system frequency. To ensure the strategies used are effective now and in the future the System Operator and the Electricity Authority have established a review of the Under-frequency Management strategy.

This paper outlines the present frequency management strategies, the aim of the Under-frequency Management review, the work undertaken to date, and the way forward.

Frequency Obligations

The quality of frequency in a power system is an indication of how well balanced the load and generation is. Generators, and motor components of loads, are designed and built to operate within a defined frequency. If the power frequency of the network deviates significantly from this the generators may trip to protect themselves, which can increase the misbalance between generation and load, resulting in further assets tripping, cascade failure and, ultimately, system collapse.

The Electricity Industry Participation Code establishes Principal Performance Obligations (PPOs) for the System Operator. The System Operator has an objective of maintaining the power frequency in a normal operating band of 50 Hz, ±0.2Hz. Continual slight fluctuations in frequency occur in real time as demand and generation vary and it is the System Operator's role to co-ordinate a real time balancing act between demand and generation to maintain the frequency within the normal operating band.

An under-frequency event on the system occurs when the amount of demand exceeds the amount of generation, this generally occurs when a generation unit is disconnected. The size and speed of this imbalance influences the speed the frequency falls and the level it falls to.

In New Zealand, momentary fluctuations of frequency outside of the normal band down to 47 Hz are allowed as outlined in the Electricity Industry Participation Code, commonly referred to as the Code. Conversely the Code requires that the system frequency remain below 52 Hz in the North Island or 55 Hz in the South Island.

To deliver the reliability needs of the power system the Code outlines the targets from the System Operator to manage the frequency. Figure 1 shows the frequency management barometer created by Transpower which outlines the number of momentary fluctuations allowed and the magnitude of the frequency deviations. For example under an extended contingent event (ECE), such as the loss of two interconnector transformers, the frequency should stay at or above 47 Hz in the North Island and 45 Hz in the South Island.

Figure 1also outlines some of the strategies used to manage under-frequency events, such as Interruptible load tipping at 49.2 Hz. These are outlined further the next section.

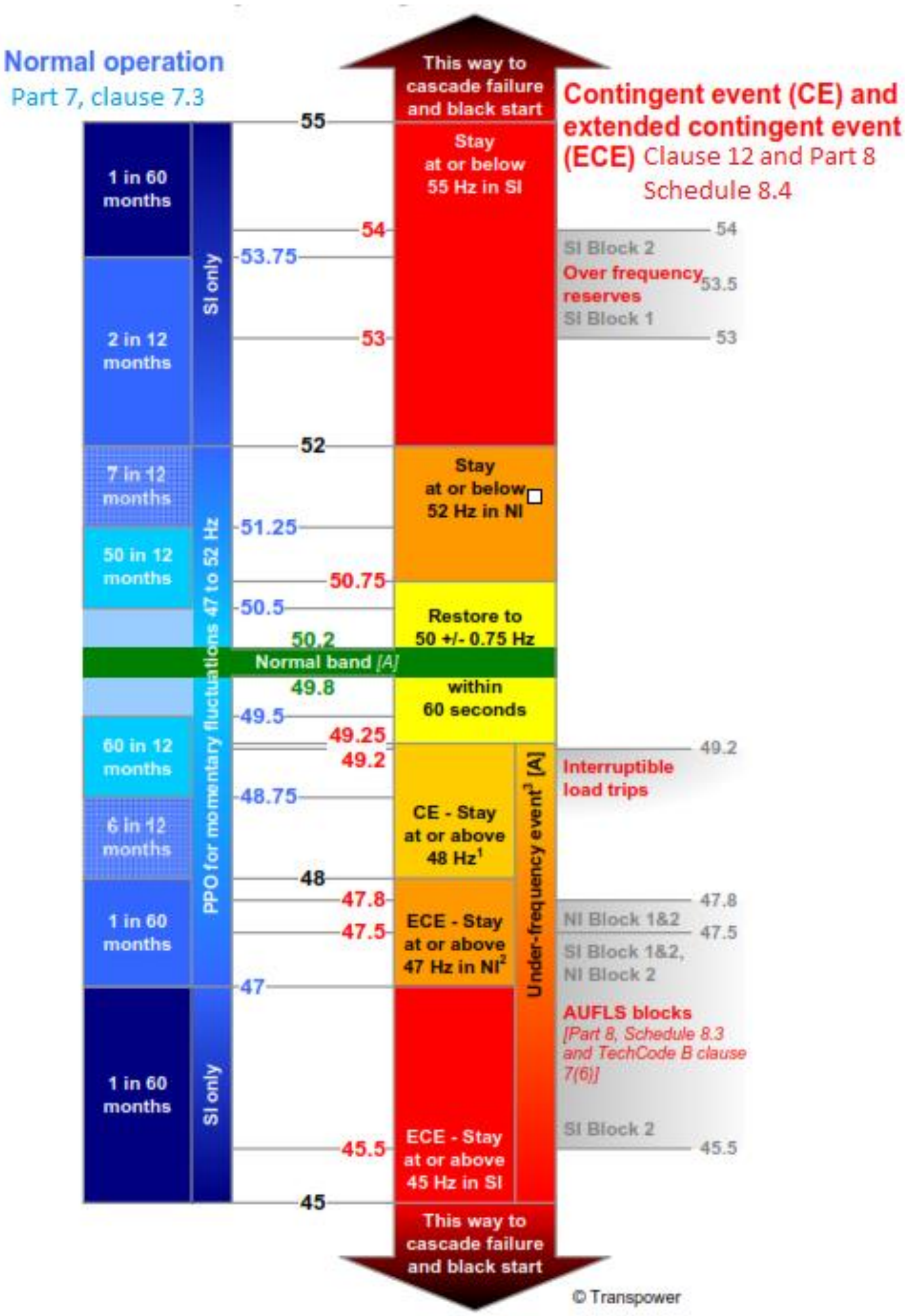

Figure 1: Transpower's Frequency Management Barometer

Managing Under-Frequency Events

If a major event happens on the network, such as the loss of a large generation unit, the system must be bought back to 50 Hz quickly to avoid the cascade loss of generation units and system black out.

The resilience of the system to frequency fluctuations is influenced by the mixture of assets connected and the topography of the network. The rate of change of frequency and the amount of frequency drop depend on the overall inertia in the system and the size of the demand to generation imbalance.

To ensure high levels of reliability, the System Operator depends on various strategies during system disturbances to return the frequency to within the normal and safe operating range. Changes to frequency are presently managed by ensuring there is sufficient instantaneous reserve (IR) to alter the amount of generation and/or load on the network quickly, within 6-8 seconds, to restore the balance and retain the changed settings for at least 15 minutes.

Generators provide instantaneous reserve with either partly loaded spinning reserve (PLSR) or tail water depressed reserve (TWD). Interruptible load (IL) is contracted so providers immediately disconnect some load when needed, and includes dropping part of an industrial load or domestic hot water customers.

The speed of the response from generation units and sources of interruptible load (IL) determines whether the reserves are considered Fast Instantaneous Reserves (FIR) or Sustained Instantaneous Reserves (SIR).

From providers of partly loaded spinning reserve and tail water depressed reserve, FIR is the additional capacity (in MW) provided 6 seconds after a “Contingent Event” that is sustained for a period of at least 60 seconds. From providers of IL, FIR is the drop in load (in MW) that occurs within 1 second of the grid system frequency falling to or below 49.2 Hz that is sustained for a period of at least 60 seconds.

SIR is the average additional output (in MW) provided during the first 60 seconds after a Contingent Event that is sustained for at least 15 minutes after the Contingent Event (unless a new dispatch instruction is given before the expiry of that 15 minute period). From providers of IL, SIR is the average drop in load (in MW) that occurs over the first 60 seconds after the grid system frequency falls to or below 49.2 Hz that is sustained until instructed by the System Operator.

Dropping large blocks of load as Automatic Under-Frequency Load Shedding (AUFLS) is the ‘last resort’ mechanism to prevent catastrophic power failure. It is intended to be used only where the loss of generation is greater than what can be covered by IR alone. The present AUFLS arrangements requires transmission-connected loads to arm two blocks to each provide a minimum of 16% of their load at all times.

Reviewing Frequency Management

The current reserve products on the market (FIR and SIR) are based on the New Zealand grid configuration of 1996 and the present AUFLS scheme was designed in 2000. The power system has changed significantly since then with the addition of a new HVDC Pole, renewable energy integration and the introduction of SMART grid technology.

It is acknowledged that as power system conditions change, existing strategies used to manage the system frequency needs may no longer be the most reliable, secure or cost effective.

A wide ranging Under-Frequency Management review is underway, and sets out to investigate strategies to manage the system frequency to prepare for tomorrow’s system. Six work streams have been set up which are focusing on

- Automatic Under-Frequency Load Shedding (AUFLS)
- Reserve Arrangements
- Investigating the role of over-frequency arming
- Considering the over-provision of interruptible load
- The impact of wind generation on the overall inertia of the system
- Wind generation offering into the reserves market

These work streams are at various stages of completion. Many of the work streams inter link, for example changes to the procurement of extended reserves has an impact on the role of over-frequency arming.

- Automatic Under-Frequency Load Shedding (AUFLS)

The review of the AUFLS scheme was initiated in 2008 and gone through several phases. Work initiated in 2011 has led to a change in design of the AUFLS scheme. The current AUFLS requirements are based around an intended design of two x 16% blocks of load with simple frequency threshold triggers. In August 2013, the System Operator proposed a revised AUFLS scheme design with four blocks of load, configured in a 10%:10%:6%:6% fashion, with the last block additionally triggered by a rate of change of frequency (df/dt) mechanism. Following the scheme design proposal, the Electricity Authority re-initiated work to investigate how load allocated to AUFLS should be procured. On 8th April 2014, the Electricity Authority published a consultation paper outlining possible code changes to accompany the revised AUFLS scheme for consultation with the industry.[1]

- Reserve Arrangements

A review of the FIR and SIR products to determine if they are still applicable to today's power system has started which is testing new reserve products that could be brought to the market place in the future. This work stream is taking theoretical concepts and identifying if they can be developed into new products. The aim is to devise a method of reserve procurement and a proof of concept of a faster reserve product to improve efficiencies in the reserve market.

- Investigations into the role of over-frequency arming and consideration of the over-provision of interruptible load

These two work streams are substantively completed. Separate papers are being presented at this conference on the findings. The first is titled "How interruptible load keeps the lights on" which considers the over-provision of interruptible load on the present network. This investigation studied the over-provision of IL under a variety of scenarios including low inertia, extended contingent events, and HVDC contribution.

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[1] Published 8 April on Electricity Authority website as "Consultation on extended reserves – draft Code amendments
https://www.ea.govt.nz/dmsdocument/17875#mctoc1

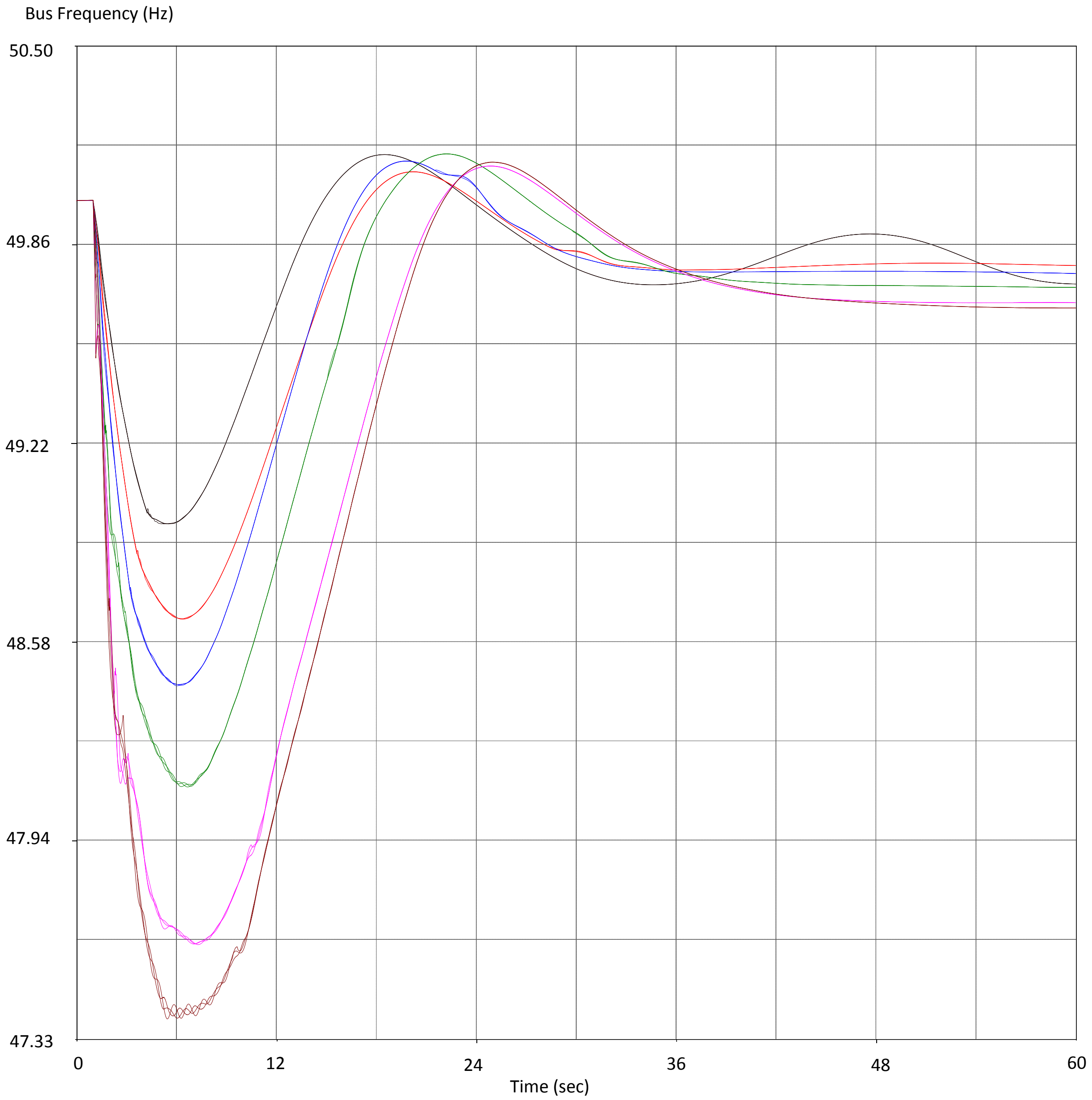
The investigation concluded that the results show that over-frequency due to IL over-provision is not currently an issue nor is it likely to become an issue in the foreseeable future.

The other is titled "Automatic Under-Frequency Load Shedding (AUFLS) Current and Proposed Schemes: Risk Assessment of Over-trip and Possible Mitigations" and investigates the role of over-frequency arming on the existing AUFLS scheme and the proposed one. The existing AUFLS scheme did show a tendency to over-shed AUFLS when a high (>800 MW) north HVDC bi-pole trip is the event causer in a heavily loaded North Island system. It was demonstrated that over-frequency arming can be used to reduce this risk. No other configuration studied demonstrated a material risk of AUFLS over-shedding requiring over-frequency arming mitigation.

- The impact of wind generation on the overall inertia of the system

The New Zealand generation portfolio has traditionally been dominated by hydro, thermal, and geothermal technology. However the penetration of lower inertia machinery, in particular wind generation, is changing how the network reacts to frequency fluctuations. Another major network development has been the upgrade of the HVDC link with the installation of Pole 3, which has increased the size of the risk which needs to be managed.

At the time of writing this report, investigations into the impact of wind generation on the overall inertia of the New Zealand grid with the new HVDC controls were nearing completion. While the final analysis is still ongoing, the effect of low inertia wind generation replacing traditional forms of generation can be seen in Figure 2.



Winter Peak-July 2013 New Wind increased to replace SPL then HLY5 then HLY1 then HLY2 then NAP						
Scenario[2]	Basecase	Replace SPL	Replace HLY5	Replace HLY1	Replace HLY2	Replace NAP
Min Freq	48.79	48.65	48.43	48.09	47.6	47.36

Figure 2: Effect on system frequency when wind generation replaces traditional generation

Figure 2: Effect on system frequency when wind generation replaces traditional generation

Figure 2 shows the minimum system frequency with the loss a 400 MW generating unit in the North Island as wind generation displaces existing thermal generation. Assuming wind generation contributes no inertia to the system means that the rate of change of frequency following the loss of generation increases, and the minimum frequency reached decreases.

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[2] SPL – Stratford, HLY5 – Huntly Unit 5, HLY1 – Huntly Unit 1, HLY2, Huntly Unit 2, NAP – Nga Awa Purua

- Wind generation offering into the reserves market

  The increase of wind generation on the network has seen a call to investigate whether wind generation can offer into the reserves market. The System Operator is assessing the risks of wind generation being dispatched for reserves and the required changes to the market system tools to enable wind generation to offer and clear for reserves. Due to the possibility of the state of the wind changing between the time an offer is made and the end of the delivery of reserves, wind generation offering into the reserves market would need to prove they were able to offer in such a way to ensure they can deliver a dispatched quantity with the same level of confidence as products presently in the market.

  Again this is ongoing work, but represents how the System Operator is looking at both technical and market system changes in the review of the Under-Frequency Management.

What next?

Like the frequency constantly changing on the network, the way under-frequency is managed should be regularly reviewed. The large amounts of wind generation in Europe, or the huge batteries being utilised in America, shows that approaches to under-frequency management may change significantly in the future.

The established programme to review Under-Frequency Management in the New Zealand wholesale electricity market outlined in this paper is on-going and further information will be available at the EEA conference in June. By continuing this work the System Operator can ensure delivery of power quality to all New Zealand consumers on today and tomorrow's system.