Under Frequency Management – Appendix 2

Over Frequency Arming

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22/11/2011

SYSTEM OPERATOR

Keeping the energy flowing

TRANSPOWER

	Position	**Date**
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TABLE OF CONTENTS

1. INTRODUCTION 4
2. BACKGROUND 4
3. ASSUMPTIONS 4
   3.1 HVDC Tripping Event 4
   3.2 Northland Tripping Event 5
4. METHODOLOGY 5
   4.1 Over Frequency Arming 6
   4.2 Governor Response 6
5. ANALYSIS 7
   5.1 HVDC Tripping 7
      5.1.1 Over Frequency Arming 9
      5.1.2 Governor Response 10
      5.1.3 Comparison 10
   5.2 Northland Tripping 10
      5.2.1 Over Frequency Arming 11
      5.2.2 Governor Response 12
      5.2.3 Comparison 12
6. CONCLUSIONS 12

1. Introduction

The purpose of this report is to study the dynamic response of the North Island power system during two over frequency excursion events. The study compares the effectiveness of two main approaches of managing over frequency events, namely, governor response and over frequency arming. This study was conducted in DigSilent power systems modelling software using historical data obtained from PI to model the tripping of two over frequency events that caused over frequency excursions in the North Island: loss of northland load and loss of HVDC.

2. Background

The System Operator (SO) is bound by Principal Performance Obligations (PPO's) as specified by the Electricity Authority (EA) to maintain and manage the frequency of the North Island between 47 and 52 Hz during a momentary fluctuation. A sudden loss of a large amount of load in the form of tripping of a region or the HVDC link could cause a rapid rise in the system frequency beyond acceptable normal operating limits. Transpower manages these over frequency events by procuring over frequency reserves, i.e. by tripping pre-approved generating units at certain frequency levels to automatically reduce the amount of MW being injected into the power grid. This mechanism arrests the unforeseeable rise in the frequency of system when such over frequency events happen.

One example of such an over frequency event is when, on August 1, 2009 at 04:30:52, the HVDC link between the North and South Islands tripped with a loss of 270 MW of power transfer to the South Island. This resulted in a high frequency of 50.91 Hz in the North Island. Even though the frequency excursion to 50.91 Hz did not violate the PPO limits, this event was considered significant because the frequency took a considerable amount of time to return to below 50.5 Hz. Furthermore, if the HVDC would have been carrying greater MW going south, the tripping of HVDC could have possibly led the frequency to rise above 52 Hz. This incident would have potentially violated the frequency PPO's of the System Operator, causing a large amount of generation to be automatically disconnected from the grid, and resulting in the system frequency taking even longer to return to the normal operating band of 49.8 Hz to 50.2 Hz in the North Island power system.

A similar event for Northland was recorded on 30 October 2009 at 07:59:45 when the Henderson – Otahuhu circuit tripped, the only circuit supplying the Northland region at the time. The loss of this circuit led to a loss of system load of 630 MW and system generation of 74 MW. This resulted in a high frequency of 51.22 Hz in the North Island and 51.45 Hz in the South Island.

3. Assumptions

Two different contingent events have been analysed that could potentially cause the system frequency rise to approximately 52.9 Hz. The following are the study assumptions for the two cases considered.

3.1 HVDC Tripping Event

This analysis assumes a dry year scenario when

- North Island load is approximately 1900 MW
- HVDC south transfer is equal to 660 MW

- most of the hydro generators are OFF
- HLY U1 – U4 are selected as slack machines for this study

3.2 Northland Tripping Event

The Northland tripping case assumes the following in the DigSilent model.

- The North Island load was modelled to be approx 4000 MW to represent high loading conditions with 800 MW supplied to the Northland region and the HVDC link out of service.
- The Roskill–Hepburn 110 kV split was assumed to be open to enable the tripping of the Northland region
- The Stratford Combined Cycle Gas Turbine (SPL–CCGT) was assumed as the slack generator for modelling purposes.
- The loss of the Northland region was modelled by tripping the Henderson–Otahuhu-1 220 kV circuit with the Henderson–Southdown-1 220 kV circuit out of service.
- Table 1 lists the generation type and governor assumptions for generators in the North Island.

Table 1: Generation type and Governor Assumptions for the Northland tripping case

Generation	MW	Governor in service
Thermal	1970	selected governors in service
Hydro	1491	✓
Geothermal	648	X
Wind	147	X

4. Methodology

The base case was first created by adjusting the load and generation levels to represent a dry year scenario. This was achieved by using historical data from PI for a previous over frequency event that occurred on 22nd August 2008 at 00:57:32 as a basis. Once the loads were matched with the generation, the North Island, Northland and HVDC loads were scaled according to the levels specified in section 3 to reflect dry year loading conditions. High loading conditions in the North Island and the Northland region were modelled for the northland tripping study. The HVDC tripping study assumed a low North Island load and high HVDC south transfer.

Most hydro generators in the North Island were turned out of service in order to closely represent the generation conditions during a dry year. Wind generation was also turned off as some of the wind generators were modelled as a negative load in DigSilent. This representation was unsuitable for dynamic analysis as the negative representation of load in DigSilent is frequency sensitive and hence not a ture representation of the wind farms during a real time over frequency event.

The post event peak frequency excursion for both HVDC and Northland tripping was approximately 53 Hz. Two approaches have been used to suppress the frequency rise to within the acceptable normal operating frequency limits as listed in the PPO’s (51.9 Hz for the North Island power system).

4.1 Over Frequency Arming

The first approach is one that is presently practiced and called Over Frequency Arming. Over Frequency Arming is the provision of equipment that enables an automatic reduction in the level of injection into the power system to arrest an unplanned rise in system frequency from an event. Generation companies with this capability have an agreement with the System Operator to trip a fixed amount of MW at a certain set frequency in case of a grid emergency or a momentary fluctuation.

As of November 2, 2010 the System Operator has signed contract with over frequency service providers in the North Island. Table 2 lists the plants in the North Island that provide over frequency arming when the system frequency reaches the corresponding tripping level. For example, NAP trips (145 MW of generation) when frequency hits 51.2 Hz and so on. For confidentiality purposes, the service providers are listed as plants A to E.

Table 2: Existing generators with Over Frequency Arming agreements in the North Island

Plant	Unit Max (MW)	Trip Frequency (Hz)
Plant A	104 MW	51.4
Plant B	145 MW	51.2
Plant C	45 MW	51.6
Plant D	20 MW	51.6
Plant E	26 MW	51.5

If the above generators with over frequency arming were not sufficient to achieve the required target frequency of 51.9 Hz, additional generators were tripped to limit the frequency rise during the over frequency event. Most generators with a slow response were identified and tripped for the additional Over Frequency Arming.

4.2 Governor Response

The second approach was to modify the governor parameters to suppress the frequency rise during the over frequency event to 51.9 Hz. The amount of power injected in the grid (to arrest the rise in frequency following an event) can also be controlled by controlling the output power of a generator by adjusting the droop / gain of a generator. By changing the droop values in the governor model of the generators, it was possible to make the system respond faster to a frequency rise. Most generators of considerable size and a fast governor frequency response were identified and modified for the governor reserve.

5. Analysis

The following sections describe the analysis and results for the two tripping cases studied.

5.1 HVDC Tripping

The frequency response of HVDC tripping in this base case shows that the peak frequency excursion is approximately 52.9 Hz (refer to Figure 1 for the dynamic response of tripping of 660 MW of HVDC south).

Note: that generators have not been identified for reasons of confidentiality.

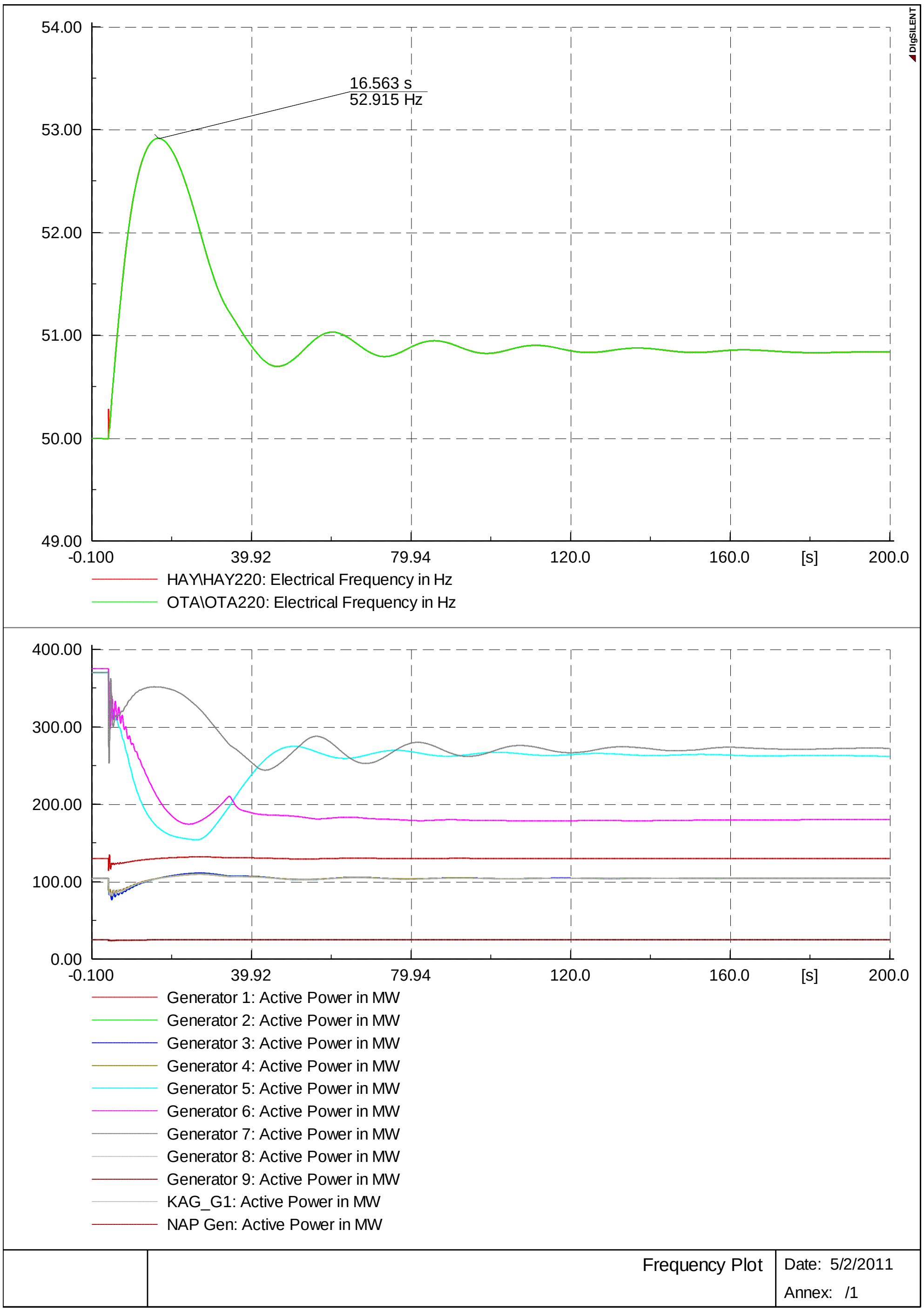

Figure 1: Frequency response of tripping of 660 MW of HVDC South

Figure 2 and 3 show the dynamic frequency responses of the two approaches employed to arrest the frequency rise following the tripping of HVDC south.

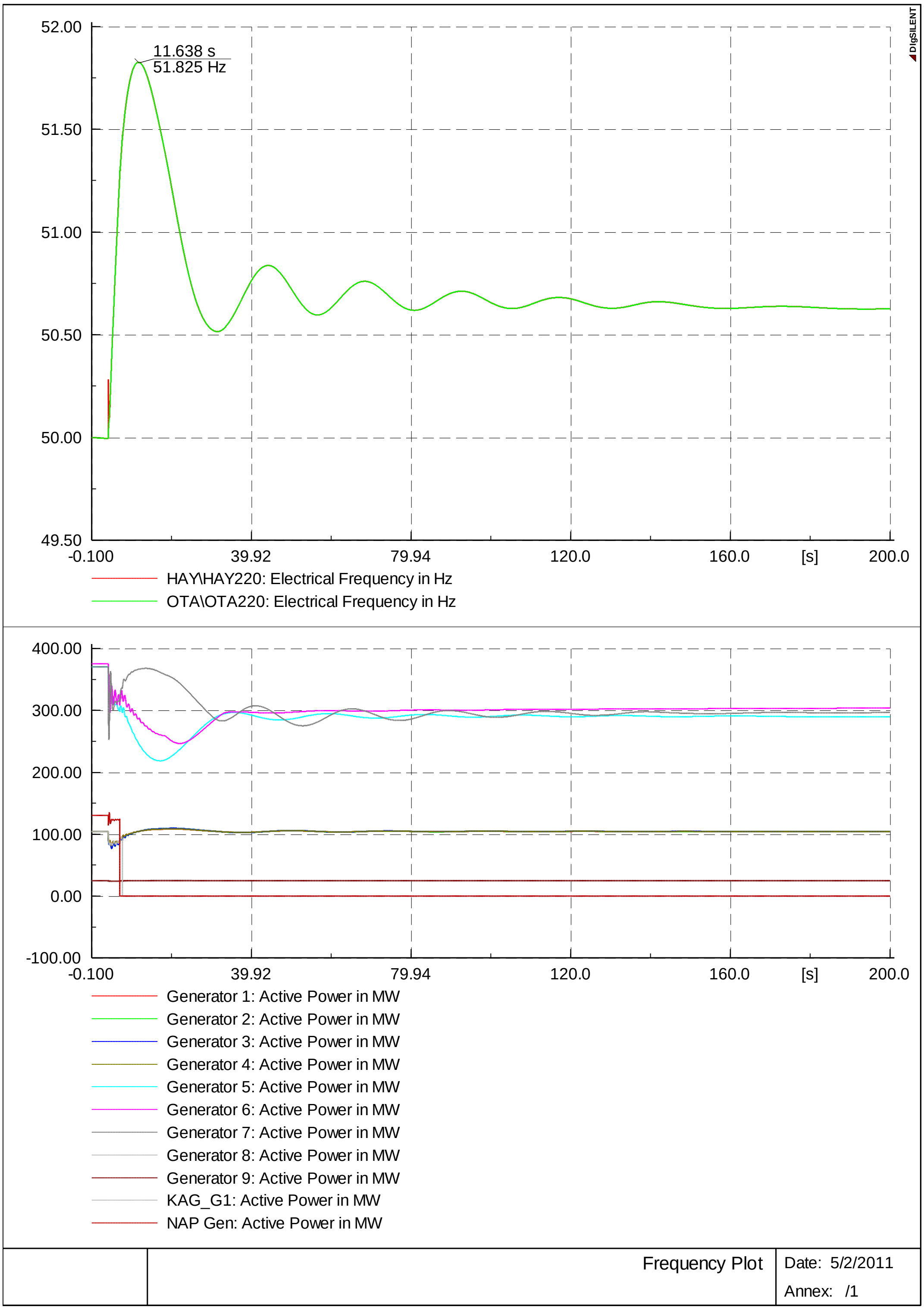

Figure 2: Frequency response with Over Frequency Arming in place at both KAG and NAP

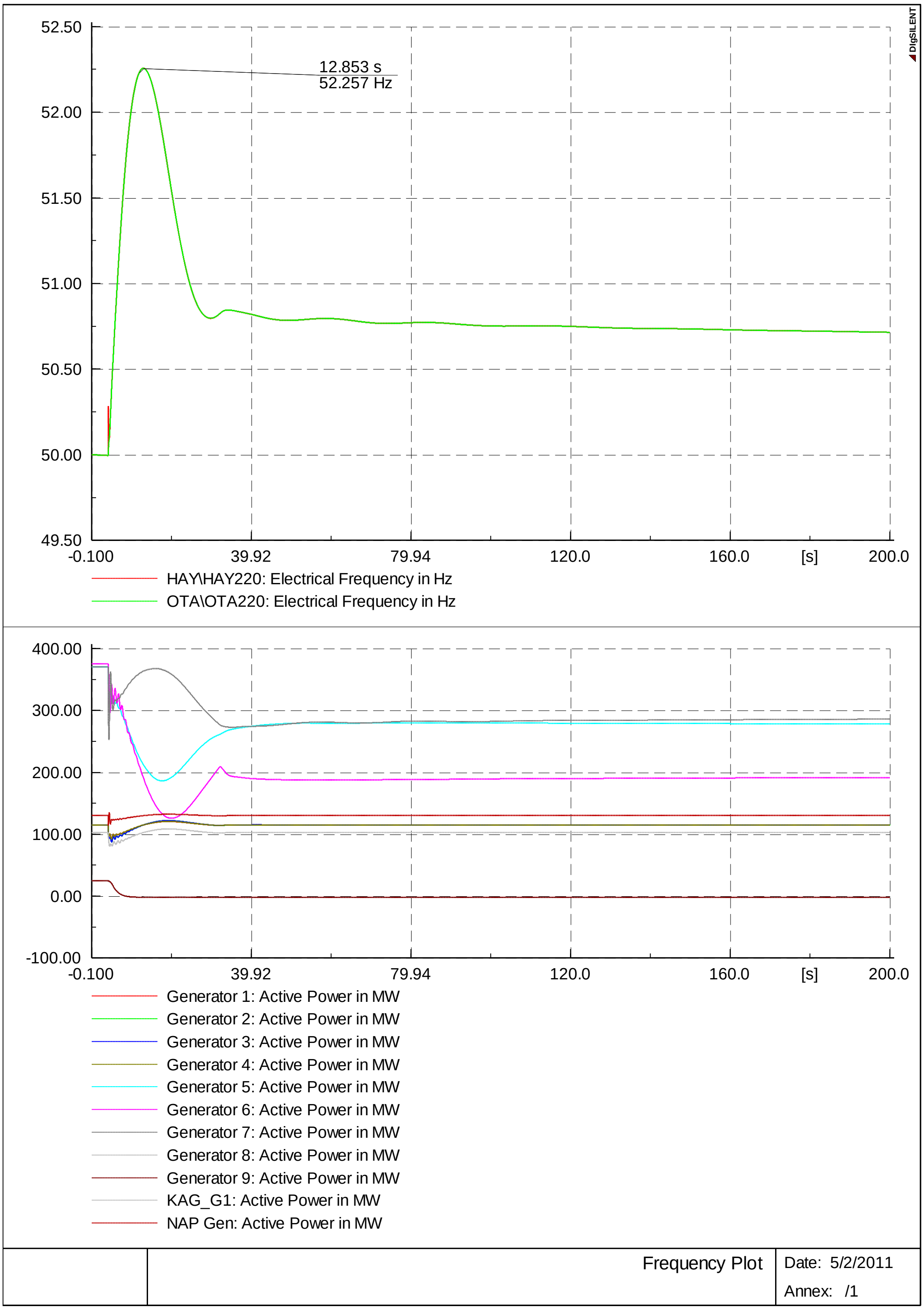

Figure 3: Frequency response with governor response (droop settings and gain of some governors adjusted)

The following subsections present a short analysis of the HVDC tripping results.

5.1.1 Over Frequency Arming

Sequential tripping of 130 MW at NAP (at 51.2 Hz) and 104 MW at KAG (at 51.4 Hz) bring the frequency peak down from 52.9 Hz to an acceptable level of 51.8 Hz. In this study, NAP is dispatched to 130 MW. When NAP is dispatched to 145 MW and tripped at 51.2 Hz, the resulting frequency peak is at 51.77 Hz.

The output of OTC and HLY U5 drops to approximately 20% of their initial dispatch level in response to the over frequency event coupled with the sequential tripping of KAG and NAP.

5.1.2 Governor Response

In this study, some major generators connected to Transpower grid were selected for adjusting the droop parameters or gains of their governor system a dynamic study was run to simulate the loss of 660 MW of HVDC.

The peak frequency achieved using the governor response approach was approximately 52.25 Hz as shown in Figure 3. Further reductions in the peak frequency (to below 52 Hz) can be achieved by further adjustment of the gain/droop parameters of other generators.

5.1.3 Comparison

Either of the two methods described above can be employed to respond to an over frequency event as both methods are effective to bring the frequency level down to an accepted level. However, from an economic point of view, the governor response method may only be viable if Transpower is able to negotiate with the major generators to adjust their droop settings to achieve the desired peak frequency. The Over Frequency Arming approach is equally effective but may come at a cost to Transpower (the cost of procuring over frequency reserves).

5.2 Northland Tripping

The following sections below describe the results of the Northland tripping analysis for the two approaches discussed.

The base case results demonstrate a frequency peak of 52.952 Hz at 9.21seconds when a Northland load of 800 MW is tripped at 4 seconds. Figure 4 shows the generator response for some of the generators in the North Island.

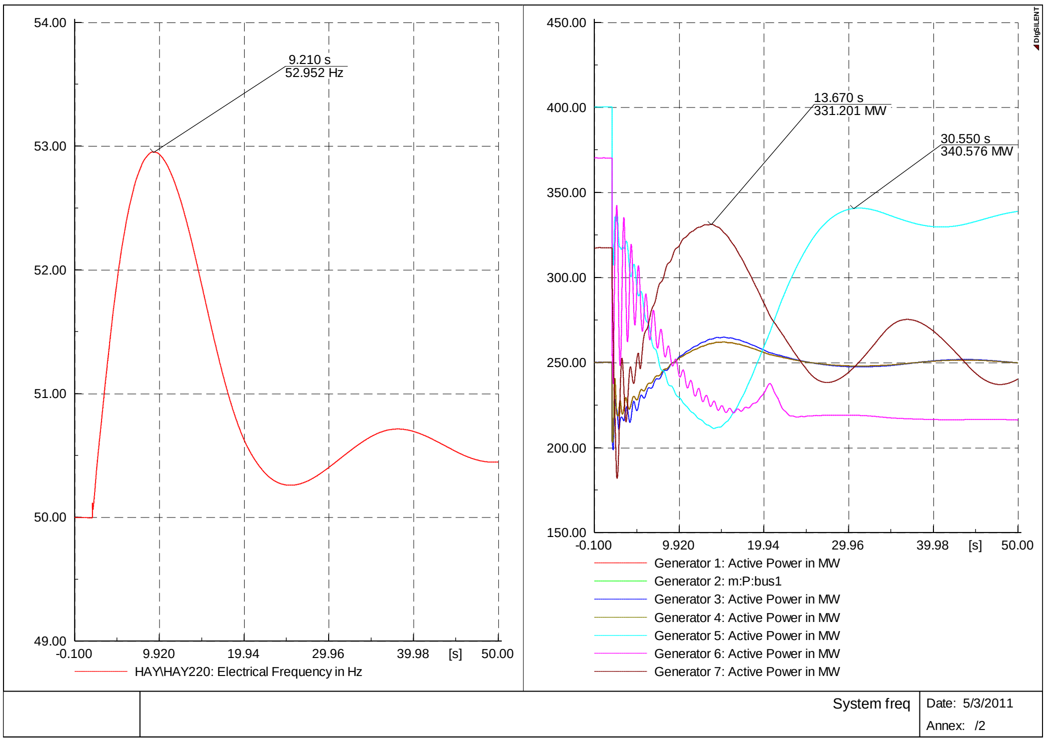

Figure 4: Base case peak frequency and generator response for selected generators in the North Island.

5.2.1 *Over Frequency Arming*

With the existing Over Frequency Arming agreements as listed Table 2, the peak frequency drops to 52.052 Hz following the loss of 340 MW of generation when the frequency hits the 51.2 Hz - 51.6 Hz range. It is clear that this level of tripping is not sufficient to bring down the frequency peak to 51.9 Hz.

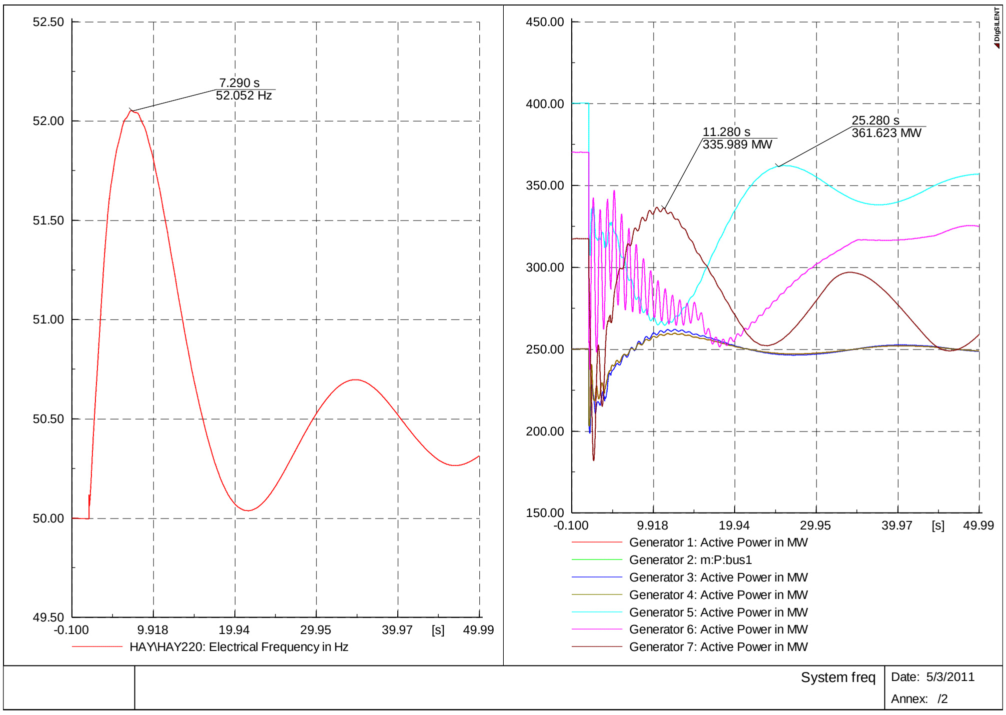

Figure 5: Peak frequency and generator response achieved with the existing over frequency arming providers in the North Island.

The required frequency peak of 51.9 Hz was achieved by tripping an additional 76 MW from the slow responding governors of generators in the North Island.

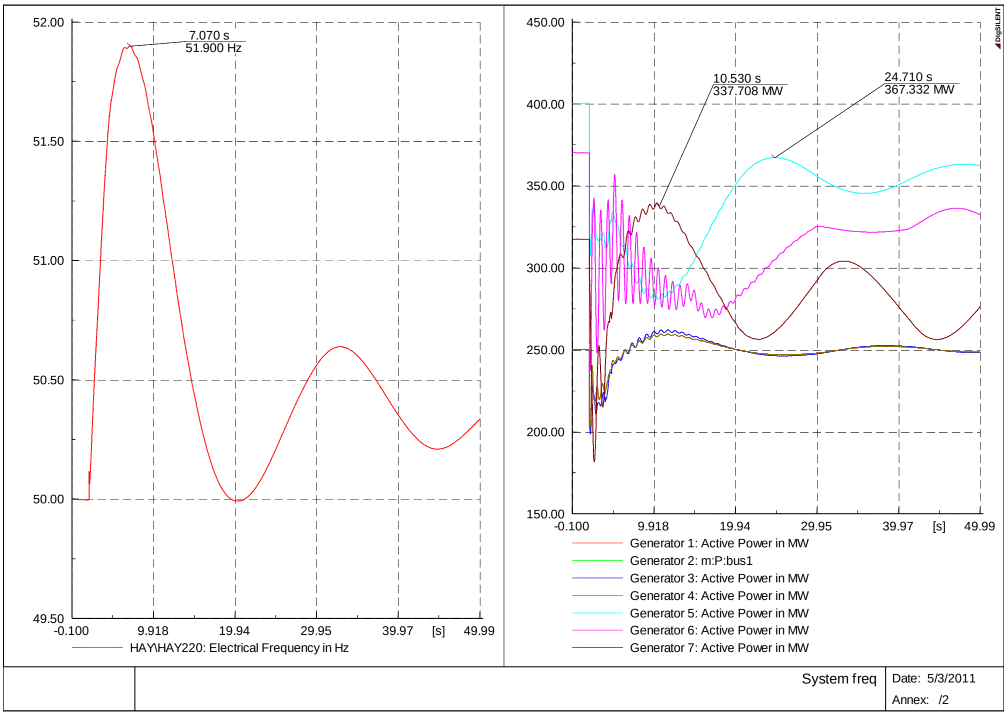

Figure 6: Peak frequency and generator response achieved with the existing and additional over frequency arming for generators in the North Island.

5.2.2 Governor Response

The governor response approach involved changing the governor droop parameters to achieve the desired frequency peak of 51.9 Hz. The base case as in Figure 4 was used as a basis for this approach.

The governor response analysis shows that a frequency drop of approximately 0.7 Hz is achieved by modifying the governor parameters of most of the fast responding governors. Clearly this response is insufficient to suppress the rise in system frequency and restore it to its normal operating limits.

Figure 7 shows that a frequency peak of 52.267 Hz is achieved by changing the governor parameters of the hydro and thermal governors to improve the system frequency. Further reductions in the peak system frequency can be achieved by turning on the governors or modifying parameters of other generator governors.

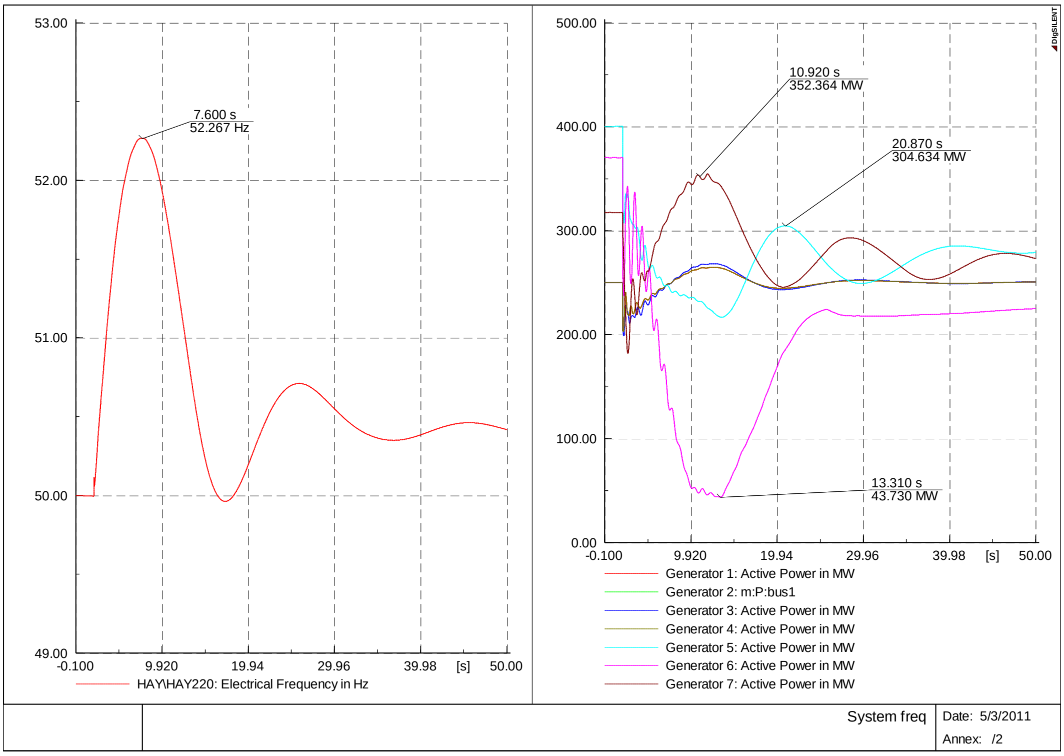

Figure 7: Peak frequency achieved by adjusting governor droop parameters for generators in the North Island.

5.2.3 Comparison

The above analysis reveals that for the case of Northland tripping, Over Frequency Arming approach achieves the desired frequency peak required to maintain the system frequency within the PPO's of the System Operator.

For the governor response approach, the required amount of reserves can be calculated by subtracting the generator MW at the peak frequency after governor adjustment from the generator MW at peak frequency of 52 Hz before adjusting the governor droop parameters. This results in a total of 302 MW of reserves in the North Island for the Northland Tripping case.

6. Conclusions

The above analyses reveal that while both the approaches would result in a peak frequency of 51.9 Hz for an over frequency event, the Over Frequency Arming approach is more effective as it would result in less commercial agreements or changes to generator parameters. Hence it is recommended that Over Frequency Arming approach be implemented by the System Operator as it would achieve the desired frequency level required to maintain the system frequency within the Principal Performance Obligations (PPO) of the System Operator.

It is also recommended that a separate loop be introduced in the generator governors for high frequency testing of generators and this be implemented in the companion guide so that the System Operator has full confidence in the generator governor model.