Effect of wind generation on dispatch

INVESTIGATION 2

WIND GENERATION INVESTIGATION PROJECT
MAY 2007

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Version Control

Version	Date	Change
1	14/12/2006	Draft for issue.
2	8/3/2007	Draft for issue. Revised following peer reviewer and Technical Stakeholder Group review.
3	16/3/2007	Draft for issue. Revised after Technical Stakeholder Group review.
4	7/4/2007	Final.

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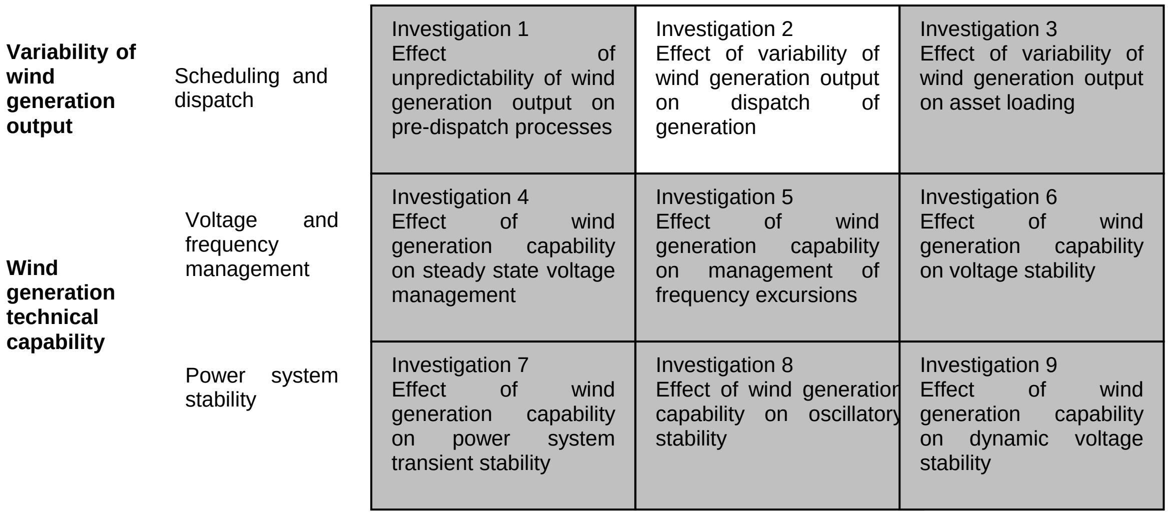
Executive Summary

Introduction

The Electricity Commission has initiated the Wind Generation Investigation Project (WGIP) to determine what changes to the Electricity Governance Rules and Regulations (EGRs) and industry arrangements will be necessary to accommodate the connection of large scale wind generation. The ‘Implications’ phase of the project is an investigation of the impacts of wind generation on the operation of the New Zealand power system and electricity market, for a specified set of wind generation development scenarios.

Nine areas where the variability of wind generation output or the technical capability of wind generation may adversely impact on the operation of the New Zealand power system and electricity market were identified. Each of these areas has been investigated to determine the likely impact under the defined scenarios and whether further analysis is required for the Options stage of the Project.

Figure 1 shows the nine areas of investigation.



Variability of wind generation output	Scheduling and dispatch	Investigation 1 Effect of unpredictability of wind generation output on pre-dispatch processes	Investigation 2 Effect of variability of wind generation output on dispatch of generation	Investigation 3 Effect of variability of wind generation output on asset loading
Wind generation technical capability	Voltage and frequency management	Investigation 4 Effect of wind generation capability on steady state voltage management	Investigation 5 Effect of wind generation capability on management of frequency excursions	Investigation 6 Effect of wind generation capability on voltage stability
	Power system stability	Investigation 7 Effect of wind generation capability on power system transient stability	Investigation 8 Effect of wind generation capability on oscillatory stability	Investigation 9 Effect of wind generation capability on dynamic voltage stability

Figure 1: WGIP investigation areas

This report documents Investigation 2 which is concerned with the effects of wind generation output variability on dispatch processes. Dispatch processes are concerned with the operation of the power system in real time. The effect of wind generation on scheduling processes (those processes occurring before dispatch such as publication of generation volume schedules) is considered in Investigation 1.

Issues related to large scale wind generation development that are found to be significant will be advanced to the next phase of the WGIP which considers options for addressing these issues.

Dispatch of generation on the New Zealand power system

Grid connected generation and embedded generation above 10 MW in size is required to participate within the trading rules in Part G of the EGRs. Generation offered is dispatched through the offer process in real time. Dispatch occurs every five minutes through formal dispatch instructions sent electronically. In New Zealand there is no Automatic Governor Control (AGC). Power system frequency is maintained in the normal band (49.8 to 50.2 Hz) by selected power stations which are dispatched to provide a frequency keeping ancillary service.

The New Zealand power system consists of two island power systems (North Island and South Island) connected by an HVDC link. Figure 12 and Figure 13 (see Appendix 1) show the North Island and South Island power systems respectively. Power system frequency is managed by a frequency keeping provider in each island.

Generation is dispatched to meet forecast load. Changes in load following dispatch of generation are managed through the frequency keeping providers and subsequent re-dispatch of generation. The output of wind generation is variable and will add to the effects of variability of load. This increase in variability will potentially impact upon dispatch processes and tools.

Purpose

The purpose of this study is to:

- determine the effect of variability of wind generation output on the System Operator's dispatch processes and tools,
- identify the level of wind generation where changes to dispatch processes and tools might be required , and,
- If necessary, make recommendations as to further investigation in this area.

Assumptions and approach

Wind generation output variability

The Electricity Commission has developed four possible wind generation development scenarios [1] (A, B, C and D) which have been used in the nine investigations analyses. Garrad Hassan has calculated variability in wind generation output for the four wind generation development scenarios [2].

This report considers the impact of output variability of wind generation (as envisaged in the wind generation development scenarios) upon the dispatch processes and tools used by the System Operator. The wind generation output variability assumed is based on the expected variability stated in the Garrad Hassan Report.

Methodology

The methodology used to analyse the impact of wind generation output variability on dispatch processes was to identify:

1. How the dispatch processes manage load variability and current levels of load variability.
2. Which dispatch processes are affected by variability in wind generation output.
3. The effects of predicted wind generation output variability on the dispatch processes and tools qualitatively.
4. The increased ancillary services requirements needed to maintain present quality targets in the absence of other solutions.

The impact of wind generation output variability on price will not be considered.

Findings and recommendations

Wind generation output variability of the size predicted in the Garrad Hassan report for wind generation development scenario C will affect the processes and tools used by the System Operator to dispatch generation on the New Zealand power system to a limited extent.

In the absence of changes to the EGRs and industry arrangements, it is expected that additional frequency keeping services may need to be procured to maintain frequency quality targets. From this analysis, the amount of additional frequency keeping services is not expected to be great even for the wind generation output variability predicted for wind generation development scenario C.

The variability of wind generation output will affect the need to re-dispatch generation during a trading period. It is expected that some additional re-dispatch will be required for the predicted wind generation output variability for wind generation development scenario C. However, this should not be outside the capability of the present dispatch processes.

It is recommended that the issues around the effects of wind generation on the dispatch of generation should be given a moderate priority for the next stage of the Wind Generation Investigation Project.

1. Introduction

1.1 Background

The Electricity Commission has initiated the Wind Generation Investigation Project (WGIP) to determine what changes to the Electricity Governance Rules and Regulations (EGRs) and industry arrangements will be necessary to accommodate the connection of large scale wind generation.

The Electricity Commission has developed four possible wind generation development scenarios [1] (A, B, C and D) for the New Zealand power system. Garrad Hassan has produced a report [2] for the Electricity Commission which forecasts the unpredictability of output that may be expected for each of the Electricity Commission's wind generation development scenarios.

Transpower has been engaged by the Electricity Commission to undertake an investigation into the impact of the connection of wind generation (as envisaged in the wind generation development scenarios) upon the dispatch processes and tools used by the System Operator. The wind generation output variability assumed is based on the expected variability stated in the Garrad Hassan Report[2].

1.2 Purpose

The purpose of this study is to:

- determine the effect of variability of wind generation output on the System Operator's dispatch processes and tools;
- identify the level of wind generation where changes to dispatch processes and tools might be required; and,
- make recommendations, as necessary, as to further investigation in this area.

1.3 Dispatching generation on the New Zealand power system

All generation offered under the trading rules in Part G of the EGRs is dispatched through the offer process in real time. Dispatch occurs every five minutes through formal dispatch instructions sent electronically. In New Zealand there is no Automatic Governor Control (AGC). Power system frequency is maintained in the normal band (49.8 to 50.2 Hz) by power stations which are dispatched to provide a frequency keeping ancillary service.

The New Zealand power system consists of two island power systems (North Island and South Island) connected by an HVDC link. Figure 12 and Figure 13 (see Appendix 1) show the North Island and South Island power systems respectively. Power system frequency is managed by a frequency keeping provider in each island.

Generation is dispatched to meet forecast load. Changes in load following dispatch of generation are managed through the frequency keeping providers and subsequent re-dispatch of generation. The output of wind generation is variable and will add to the effects of the variability of load. This increase in variability will potentially impact upon dispatch processes and tools.

2. Assumptions

2.1 Wind generation investigation project approach

The Wind Generation Investigation Project has identified nine areas where the variability of wind generation output or the capability of wind generation technology could impact upon the operation of the power system and electricity market. The potential impact on each area has been assessed through an assessment of the effects on current power system operating practice and industry arrangements.

The approach taken during the analysis was to determine for a worst case[1] credible scenario whether the impact of wind generation would result in significant problems for operation of the power system or electricity market during the next 10 years (assuming that current practices and industry arrangements remain unchanged). If the worst case credible scenario shows no significant effects then no further analysis is required.

In keeping with the worst case credible scenario, the following assumptions were made:

- Wind generation technology is assumed to have minimal capability. For example, wind generation turbines are assumed to have no ability to support voltage or frequency. It is recognised that modern turbines do have a certain ability to support voltage and frequency.
- Wind generation development scenario C will have the greatest amount of wind generation output variability and is chosen as the basis of the assessment.
- The displacement by wind generation of other generation will result in the worst case outcome for the area under investigation.

The size and urgency of the impacts of wind generation determined during the analysis will allow the issues to be prioritised for attention in the next phase of the Wind Generation Investigation Project. For example, an issue that will have major impacts on the operation of the power system and electricity market for relatively low levels of wind generation will be given high priority whereas an issue that has no significant impacts can be assigned a low priority.

2.2 General assumptions for this investigation

It is assumed for the purposes of this investigation:

- Load variability will increase proportionately with load growth.
- The current Electricity Governance Rules and Regulations apply. No proposed rule changes are considered.
- Wind generation is offered and dispatched as per the present electricity market arrangements.

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[1] This is in terms of potential effects upon the power system.

- The System Operator’s current suite of tools and processes used to dispatch generation are used. It is noted that the System Operator is currently upgrading its tools but the upgrade is intended to meet the same performance specification as the existing tools.
- There are no major changes to the New Zealand power system or electricity market.

The effects of variability are considered at the daily, weekly and monthly levels. A sudden change that occurs on a daily basis and that requires some operational management may require changes to tools and processes. Similarly, a large change that significantly changes system frequency that occurs once a month may warrant some change to processes and tools.

2.3 *Wind generation development scenarios*

Table 1 shows the location of new wind generation as envisaged in the Electricity Commission’s wind generation development scenarios.

Island	**Region**	**Grid Connection (for modelling purposes)**	**Scenario A (high penetration, concentrated in North Island)**	**Scenario B (high penetration, diversified across the country)**	**Scenario C (very high penetration, diversified across the country)**	**Scenario D (low penetration, diversified across the country)**
North Island	Northland	Marsden 220KV		100 MW	150 MW	
	Auckland	Otahuhu 220 KV		100 MW	300 MW	30 MW
	Waikato	Huntly 220 KV	100 MW	50 MW	100 MW	30 MW
	Hawkes Bay	Redclyffe 220 kV	300 MW	150 MW	300 MW	30 MW
	Wairarapa	Masterton 110 KV		50 MW		
	Manawatu[2]	Bunnythorpe 220 kV	450 MW	350 MW	450 MW	250 MW
	Wellington	Wilton 220 KV	300 MW	150 MW	300 MW	30 MW
TOTAL NI MW			**1150 MW**	**950 MW**	**1600 MW**	**370 MW**
South Island	Marlborough-Nelson	Blenheim 110KV		50 MW	50 MW	
	Otago/ South Canterbury	Timaru 220 kV		150 MW	300 MW	
	Southland	Invercargill 220 kV	100 MW	100 MW	300 MW	50 MW
TOTAL SI MW			**100 MW**	**300 MW**	**650 MW**	**50 MW**

Table 1: Location of new and existing wind generation in wind generation development scenarios

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[2] This includes the existing 250 MW of wind generation (Te Apiti, Tararua I, II and III) located near Bunnythorpe.

2.4 *Wind generation and load variability*

Garrad Hassan [2] has predicted variability of wind generation output for each of the wind generation development scenarios developed by the Electricity Commission. Section 4 contains tables summarising the variability of wind generation output for each of the scenarios. Garrad Hassan [2] has also analysed variability of system load on the New Zealand power system.

The Garrad Hassan analysis is based on a limited amount of data hence care should be applied in interpreting the results. A discussion on the implications of the limitations of the analysis for this report is given in Section 6.1.

The effect of the predicted wind generation output variability upon dispatch processes and tools is assessed in this report.

2.5 *Methodology*

The methodology used to analyse the impact of wind generation output variability on dispatch processes was to identify:

1. How the dispatch processes manage load variability and current levels of load variability.
2. Which dispatch processes are affected by variability in wind generation output.
3. The effects of predicted wind generation output variability on the dispatch processes and tools qualitatively.
4. The increased ancillary services requirements which would be required to maintain present quality targets in the absence of other solutions.

The impact of wind generation output variability on price will not be considered.

3. Load variability

The demand on the power system varies constantly. This variation is due to consumers switching on and off loads throughout the day. Large load changes can arise from:

- rapid increases during morning and evening peaks;
- interruptible load operation during under frequency excursions;
- large industrial loads connecting or disconnecting;
- generation embedded within distribution networks suddenly changing output; and
- distribution company load control systems operating.

Large load changes can be managed if advance notice is provided. For example, the connection or disconnection of a reduction line at Tiwai Point aluminium smelter can normally be managed so that there are no adverse effects on the power system. Similarly, rapid changes in demand during morning and evening peaks are managed through normal generation dispatch processes. The operation of interruptible load during under frequency excursions helps to restore power system frequency.

Planned or predictable large load changes can be managed with small impact on the power system and may even provide benefits to power system operation (e.g. the operation of interruptible load during under frequency excursions). The effects of unpredictable load changes need to be managed through means such as frequency keeping and generation re-dispatch.

3.1 Load variability during morning and evening peaks

Figure 2 shows the North Island demand on 14 June 2005 which was a typical winter weekday. Island demand is lowest in the early hours and increases rapidly between 5:00 and 8:00. The demand then decreases slowly until the time of the evening peak (16:00 to 20:00) when demand again increases rapidly. The rapid increases in demand at times of morning and evening peak are managed through the dispatch process. Sufficient generation is scheduled to be available to meet the rapid changes. It is the predictability of the demand pattern over a day (i.e. the load forecast is reasonably accurate at the island level) that enables such changes to be managed safely.

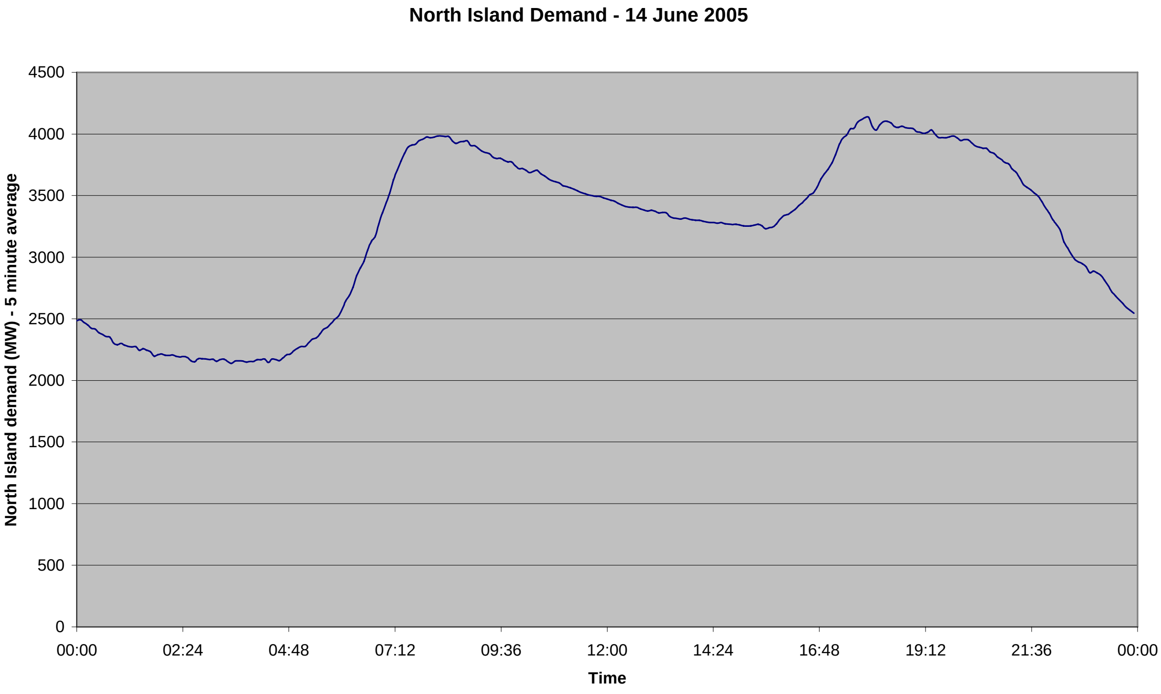

Figure 2: North Island demand - typical daily profile

Figure 3 shows a rapid increase in demand during morning peak time on 1 March 2005. This date was chosen to illustrate a rapid change in load over morning peak times. At 5:05, the North Island demand is 2015 MW. This increases over the next two hours and 15 minutes by 1221 MW. This is an average increase of 540 MW per hour or 9 MW per minute over the period.

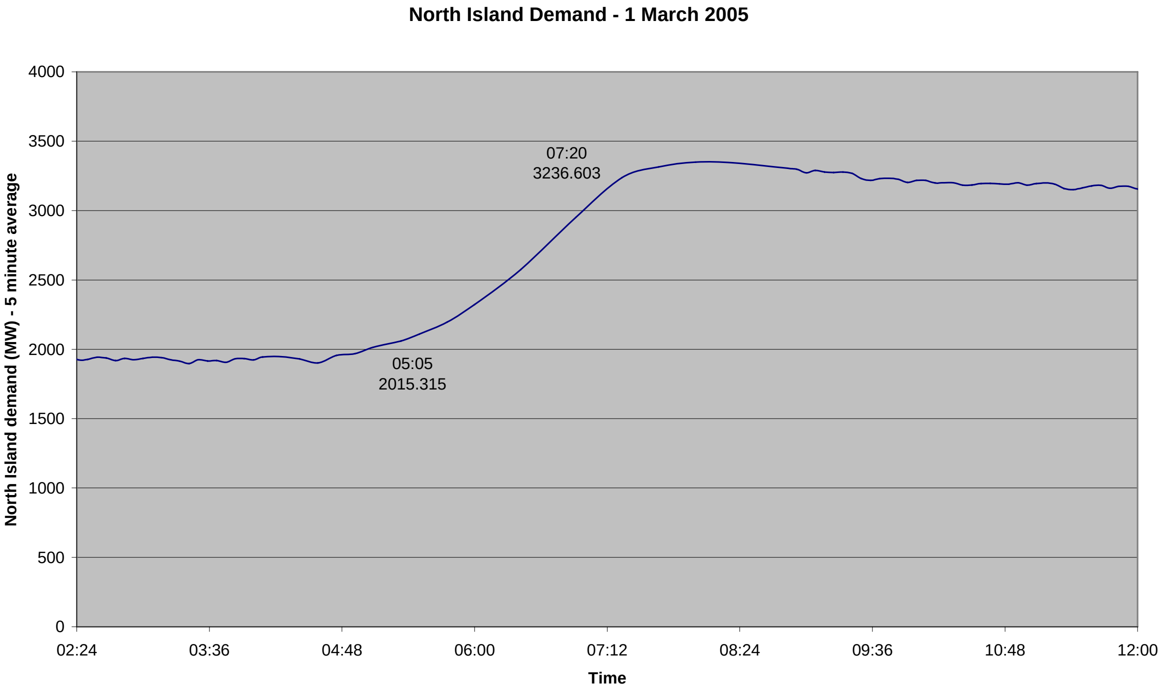

Figure 3: Rapid increase in system demand during morning peak

3.2 *Operation of Interruptible load*

One cause of sudden changes in power system demand is the operation of interruptible load during under frequency excursions. Distributors and retailers offer interruptible load into the instantaneous reserves market. If the offers are cleared then the interruptible load will be dispatched and will operate during under frequency excursions. Figure 4 shows the operation of interruptible load during an under frequency event on 26 March 2006. Around 400 MW of interruptible was shed at about 8:50 and then restored over the next 20 minutes. Note that the data is 5 minute averages.

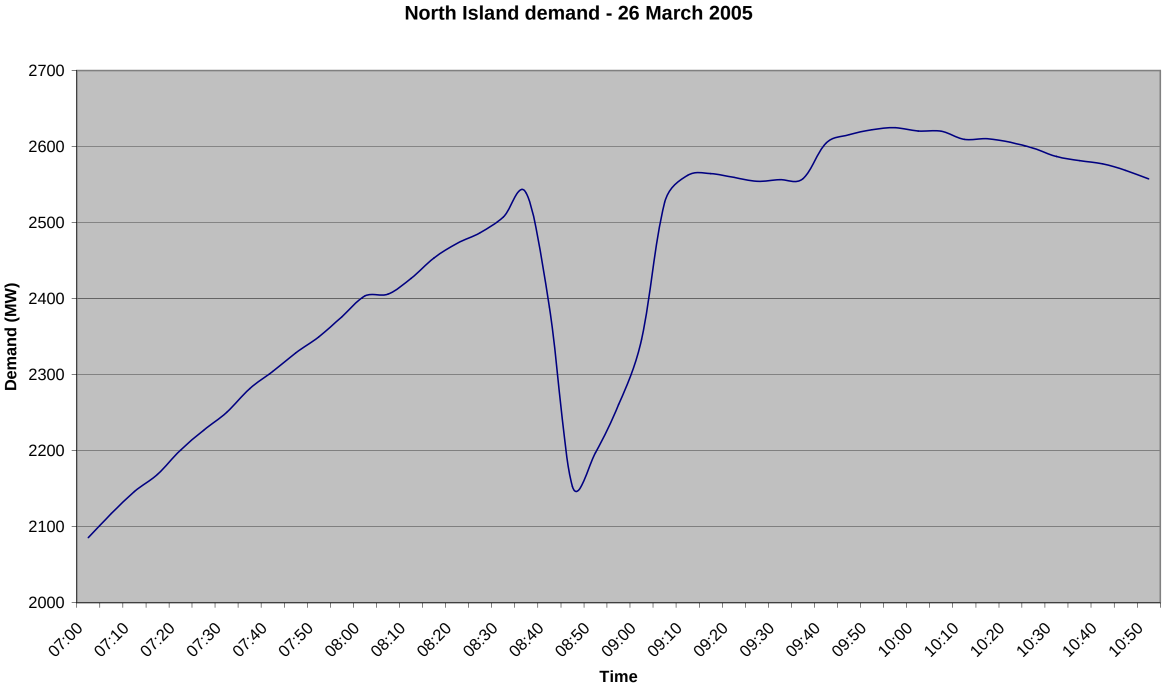

Figure 4: Operation of interruptible load

While the operation of interruptible load does cause a large sudden change to system load, the sudden change is beneficial to the power system in helping to restore frequency during an under frequency excursion.

3.3 *Normal demand variability*

Figure 5 shows the evening peak period on 4 March 2006. This time was chosen because it shows a load drop of around 50 MW occurring around 18:00 and a rapid increase between 20:00 and 20:30. The North Island 10s demand and 5 minute average demand are shown.

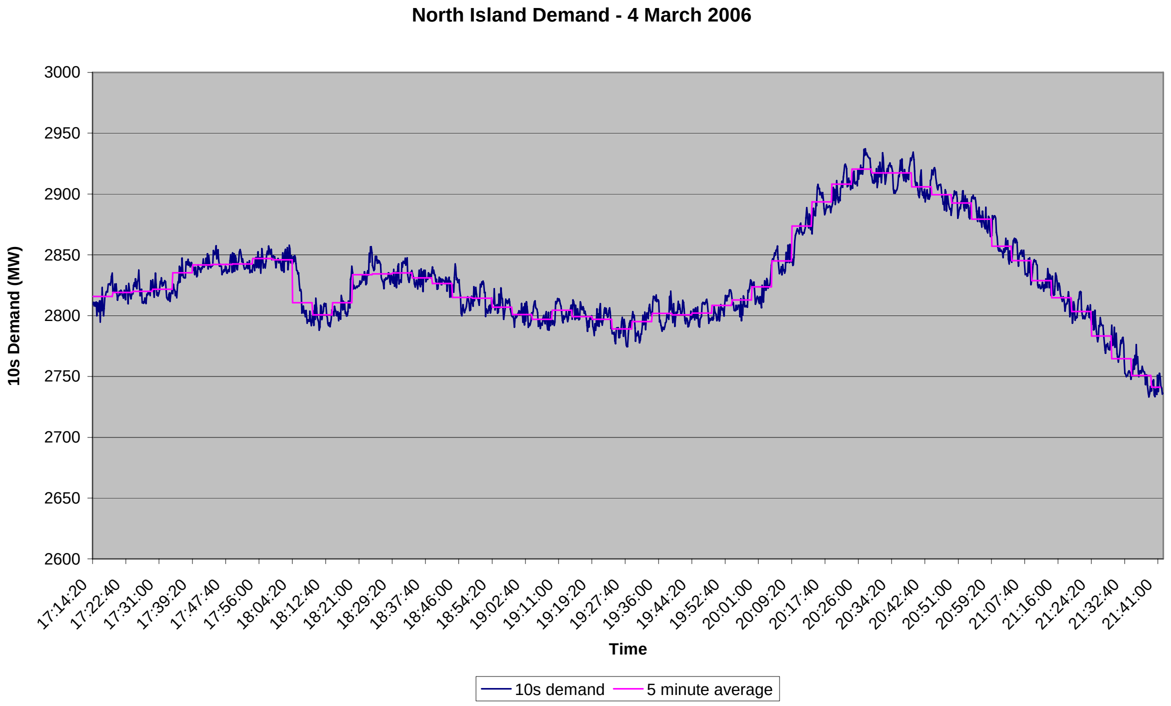

Figure 5: North Island demand - 10s data and 5 minute averages

Figure 6 shows the probability distribution function for the variation between 10s demand and the 5 minute average demand in Figure 5.

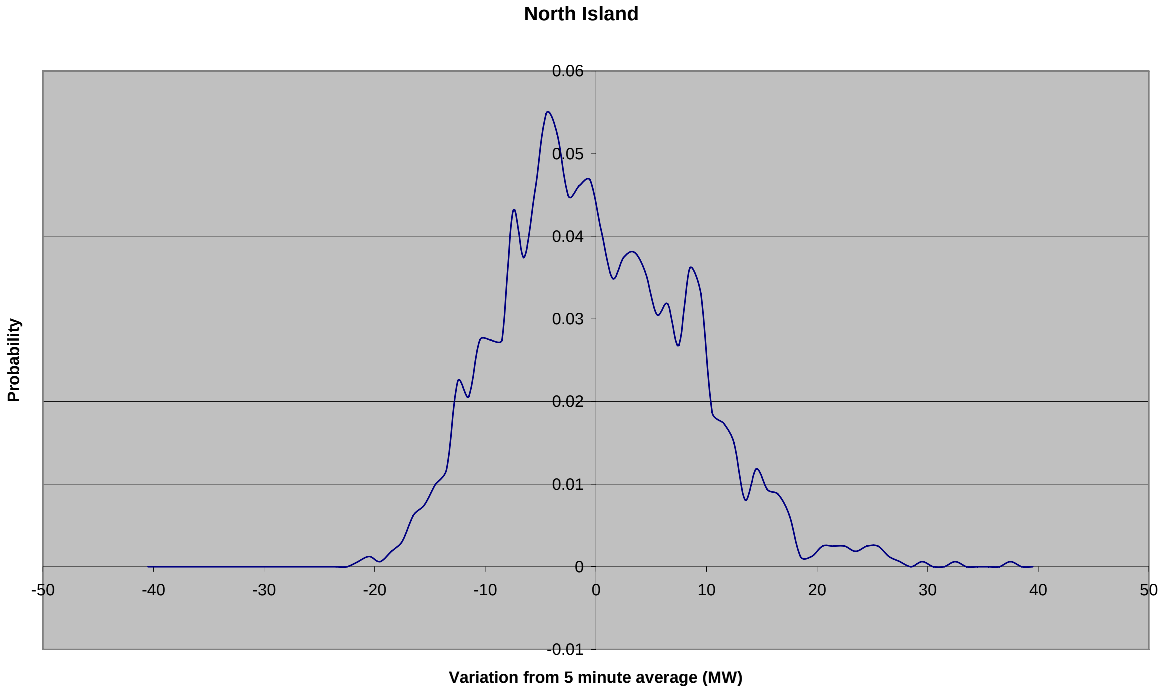

Figure 6: Probability distribution function for the difference between the 10s demand and the five minute average demand shown in Figure 5

Most of the 10 second data variation from the 5 minute average is in the range +/- 20 MW. Generally, generation dispatch will follow the five minute average with re-dispatch when there is sufficient change in demand between five minute periods. The effects of the variability between generation re-dispatches will be mitigated by the frequency keeping provider.

Part of the variability of load observed at a grid exit point will be due to the variability in output of embedded generation in the distribution network behind the grid exit point.

3.4 Large load changes

Distribution companies have the ability to manage load within their networks. This can be disconnection of water heating across the network, the disconnection of non-essential loads or shifting load between grid exit points. Distribution companies will reduce load for a range of reasons ranging from requests from the System Operator to reduce load during grid emergencies to shifting load during maintenance outages.

Directly connected industrial loads can cause large changes in demand at grid exit points as industrial processes are brought on or reduced. Similarly, the sudden disconnection of a large generating plant embedded within a distribution network will appear as an increase in net demand upon the system.

Planned and notified changes in load can be managed so as to minimise the impact upon the power system. The System Operator requires that load changes are limited to 40 MW per minute with a maximum of 75 MW over five minutes. Larger load changes are agreed with the System Operator.

3.5 Load variability – Garrad Hassan analysis

Garrad Hassan calculated probability distribution functions for changes in North and South Island load over different time scales. Figure 7 and Figure 8 show the calculated measured load changes for the North Island and South Island respectively.

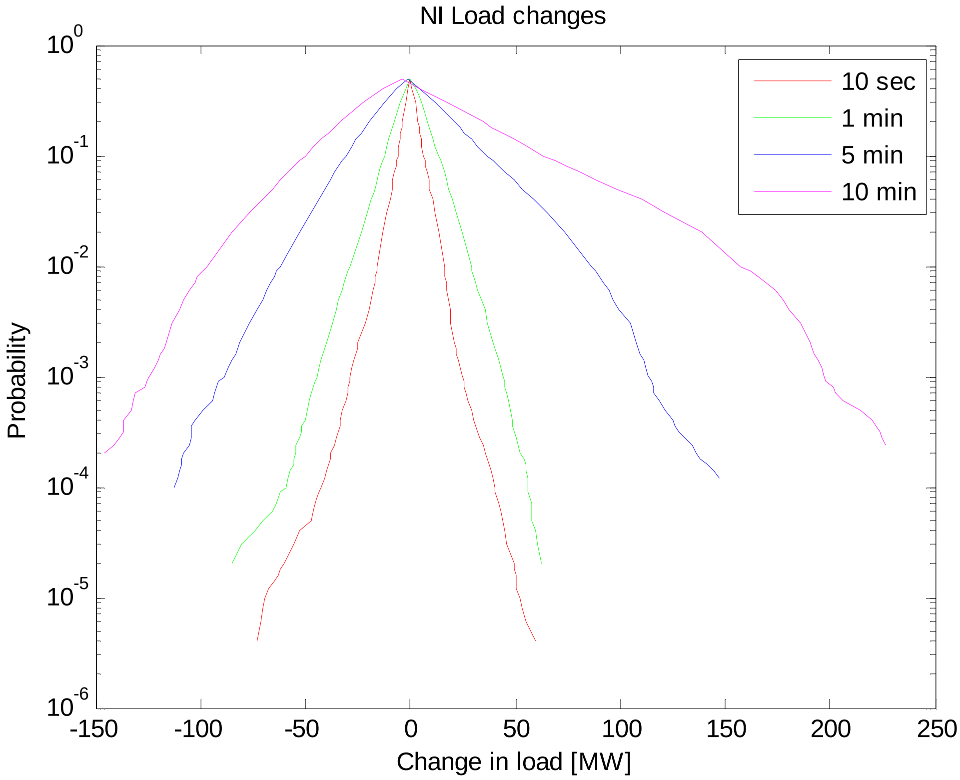

Figure 7: Measured load changes in North Island (adapted from Figure 3.27 of [2])

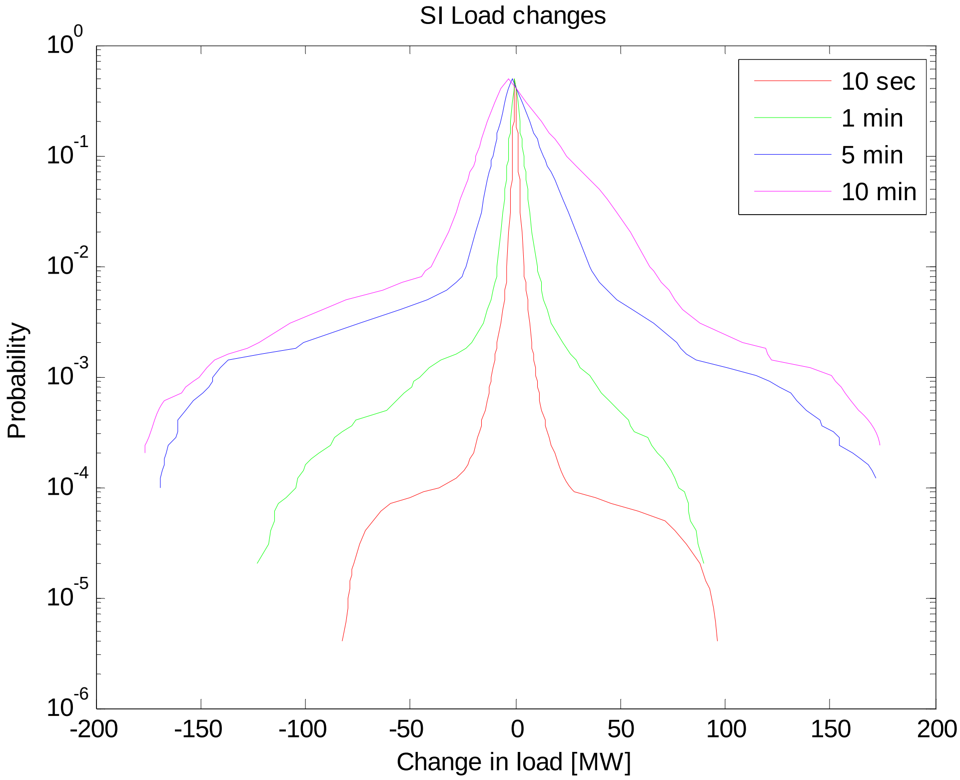

Figure 8: Measured load changes in South Island (adapted from Figure 3.28 of [2])

Large load changes are relatively common in the South Island. Changes of these sizes are typically related to changes in loading at Tiwai when smelter reduction lines (around 150 MW in size) are shut down and restarted. These changes are managed through Manapouri generation increasing or decreasing output to match the change in Tiwai load.

Garrad Hassan acknowledges that the tails of the calculated probability distribution functions rely on a few points only and should be taken as being indicative only. Garrad Hassan notes in paragraph 8 of the discussions and conclusions that

“The Monte Carlo simulations used in this report require a very large number of iterations to produce stable results at the extreme end of tails of distributions. Even with very large number of iterations used in processing the Monte Carlo simulations there will be some variation in results if reprocessed, particularly for events occurring once per month.”

Table 2 and Table 3 show calculated size of change for North Island and South Island load changes respectively for some return periods.[3] The size of change amounts have been estimated taking into account the accuracy of the calculated probabilities.

Return Period	Change over 10 seconds (from Table 3.10 of [2])	Probability (from Table 3.1 of [2])
Once per month	-73/+59 MW	0.000004
Once per week	-62/+50 MW	0.000017
Once per day	-41 /+39 MW	0.000116

Table 2: Return periods for changes over 10 seconds for North Island load changes

Return Period	Change over 10 seconds (from Table 3.10 of [2])	Probability (from Table 3.1 of [2])
Once per month	-83/+96 MW	0.000004
Once per week	-78/+90 MW	0.000017
Once per day	-30 /+24 MW	0.000116

Table 3: Return periods for changes over 10 seconds for South Island load changes

Table 4 and Table 5 show calculated size of change for load changes for some return periods for the North Island and South Island respectively. The size of change amounts have been estimated taking in account the accuracy of the calculated probabilities.

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[3] A return period is a statistical measure of how often a load change of a certain size will occur.

Return Period	Change over five minutes (from Table 3.10 of [2]))	Probability (from Table 3.1 of [2])
Once per month	-112/+154 MW	0.0001
Once per week	-99/+121 MW	0.0005
Once per day	-75/+102 MW	0.0035

Table 4: Return periods for changes over five minutes for North Island load changes

Return Period	Change over five minutes (from Table 3.10 of [2]))	Probability (from Table 3.1 of [2])
Once per month	-169/+172 MW	0.0001
Once per week	-157/+139 MW	0.0005
Once per day	-64/+61 MW	0.0035

Table 5: Return periods for changes over five minutes for South Island load changes

It should be noted that the once per month and once per week changes in the South Island demand are higher than the corresponding changes for the North Island. The once per day changes for the North Island are considerably larger than the once per day changes for the South Island. The reason for this difference is mainly due to the operation of the reduction lines at the Tiwai Point Aluminium smelter. The loading on the reduction lines (around 150 MW in size) is frequently reduced to zero and then restored to full load within a period of several minutes. This change in load is normally managed by Manapouri power station changing output to match the change in load.

3.6 Managing generation and load variability

Changes in system demand are managed in dispatch through a combination of manual and automatic processes. Generation dispatch instructions are issued automatically every five minutes and can be issued manually at any stage. The dispatch instructions will be based on a forecast of demand. Generators will take some time to respond to the instructions once received. Demand will change from the time that real time dispatch (RTD) was initiated to the time the updated generation dispatch instructions are implemented. Figure 9 shows an overview of the process.

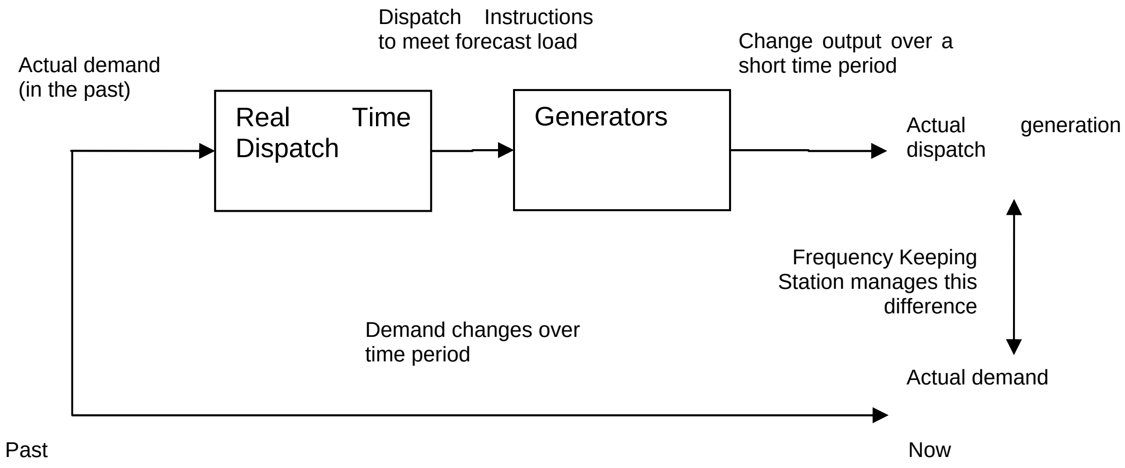

Figure 9 - Managing load variability during dispatch

The frequency keeping provider effectively manages the changes in demand between changes in the dispatch of generation (noting that the governor action of other generating units will provide some support).

Table 6 shows the different types of load variation and the management measures employed to minimise the effects on power system operation.

Nature of load variation	Typical size/rate	Management
Rapid changes during morning and evening peak periods (e.g.	Increases of 10 MW per minute sustained over several hours	Sufficient generation is scheduled and dispatched to meet the rapid changes. Frequency keeping manages unders and overs.
Normal load variation	±20 MW	Frequency keeping
Large industrial loads connecting and disconnecting Operation of distribution companies load management systems	50-150 MW	Generation can be scheduled and dispatched if advance warning is provided. Frequency keeping (and free governor action) if no advance warning is provided.
Operation of interruptible load	Sudden disconnection of tens to hundreds of MW	No management as operation of interruptible load during under frequency events is expected and beneficial.

Table 6: Load variability and management

Predictable changes and changes known in advance can be planned around through scheduling and dispatch processes. Unpredictable changes (e.g.

normal load variation) are managed first through frequency keeping and then generation re-dispatch.

The Electricity Commission is considering initiatives to improve demand side bidding and forecasting. Such initiatives may affect demand variability in the following ways:

- The initiatives may result in demand customers (purchasers) being provided with information about the effect that demand changes will have upon energy prices at grid exit points. This is likely to increase demand variability during dispatch. Some purchasers will now be changing demand in response to price where they would not have done so in the past in addition to all the normal causes of variability. The effect may be more pronounced as price driven demand changes are likely to occur simultaneously at the start of a trading period.
- The initiatives may result in better information about planned changes in load being available. This will help better management of planned changes in load so that effects on the power system are minimised.

4. Wind generation variability

The causes of variability in wind generation output include variability in wind speed and direction, connection and disconnection of turbines, and tripping of part of, or the entire wind farm. It is assumed that major wind farms will have a considerable number of wind turbines and that the loss of a single turbine will make little difference to the total output. The tripping of an entire wind farm[4] will have a similar effect to the tripping of another large generating unit or generating station. The effects of a wind farm tripping will be managed through instantaneous reserves and frequency keeping.

The normal variability of output results from changes in wind speed and direction. To illustrate normal variability, Figure 10 shows the variation of Te Apiti wind farm output over a 20 minute period. The output of the wind farm has dropped by about 25 MW over this period. This type of change can be managed by re-dispatch of generation. Changes in output at the 10 second level are small (of the order of 5 MW) but occur nearly all the time. This type of change will be managed by frequency keeping.

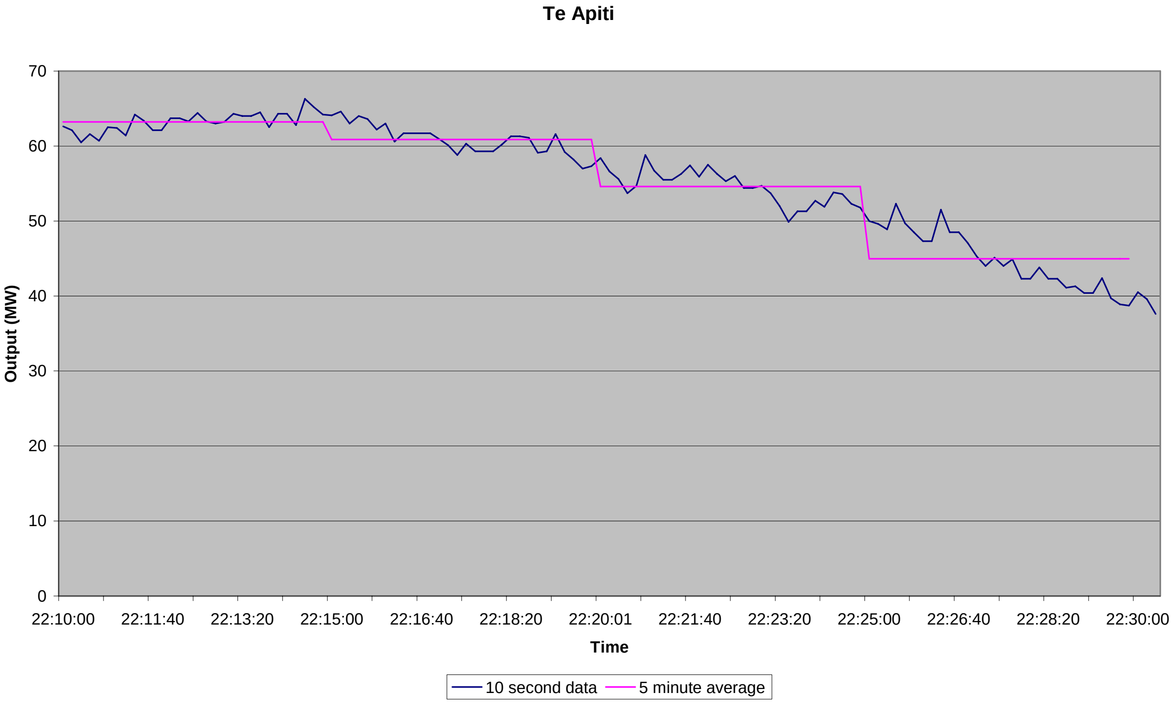

Figure 10: Te Apiti Output

Garrad Hassan calculated probability distribution functions for changes in Te Apiti output. The calculated probability distribution function is shown in Figure 11.

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[4] The entire wind farm might be disconnected to clear a fault at the wind farm or through the action of a wind farm control system.

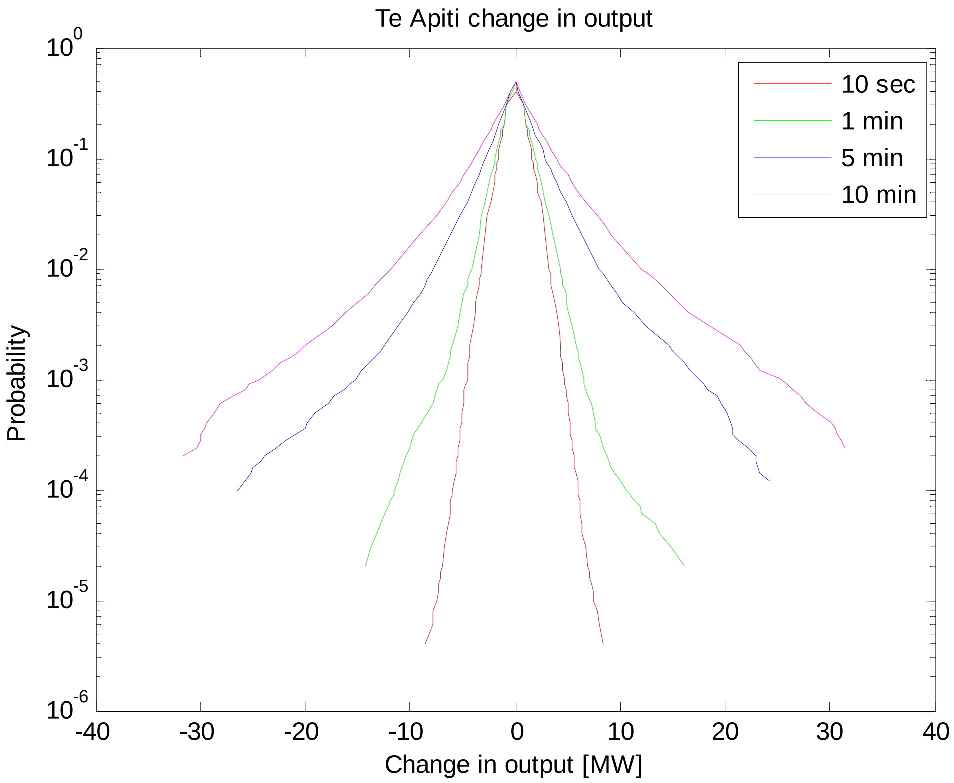

Figure 11: Probability distribution function for changes in Te Apiti output (adapted from Figure 3.1 of [2])

The probability distribution functions were calculated from one year's worth of data. This suggests that the probability distribution functions are reasonably accurate for probabilities down to that equivalent to a return period of a month. This report will consider return periods from once a day to once a month for wind generation output variability which is consistent with approach for load variability.

Garrad Hassan has predicted wind generation output variability based on the wind generation development scenarios. For each scenario, Garrad Hassan modelled the wind generation by two methods [2]:

- *Method 1.* The wind generation output for each region (see Table 1) is modelled as a single wind farm;
- *Method 2*. The wind generation output for each region is modelled as 100 MW wind farms with a correlation equal to the inter-correlation of the 10 minute wind data (i.e. modelled with a 10 minute wind shift between wind farms).

Table 7 and Table 8 show predicted wind generation output changes over 10 seconds for method 1 and method 2 respectively.

	Scenario A			Scenario B			Scenario C			Scenario D		
Return period	**NZ**	**NI**	**SI**	**NZ**	**NI**	**SI**	**NZ**	**NI**	**SI**	**NZ**	**NI**	**SI**
Once per month	-47	-47	-10	-32	-31	-19	-55	-47	-34	-20	-20	-5
Once per week	-41	-41	-9	-30	-29	-14	-50	-43	-31	-19	-18	-4
Once per day	-37	-36	-7	-27	-25	-11	-45	-39	-27	-16	-16	-3
Once per month	48	47	9	36	34	13	57	49	30	24	24	4
Once per week	43	44	8	32	30	12	53	46	29	21	21	4
Once per day	37	36	6	27	25	11	46	40	26	16	16	3

Table 7: 10 second change in output for wind generation scenarios for method 1 (single wind farm in each region) [MW] (Table 3.2 of GH report)

	Scenario A			Scenario B			Scenario C			Scenario D		
Return period	**NZ**	**NI**	**SI**	**NZ**	**NI**	**SI**	**NZ**	**NI**	**SI**	**NZ**	**NI**	**SI**
Once per month	-24	-22	-9	-23	-18	-18	-31	-25	-25	-12	-11	-5
Once per week	-21	-21	-8	-20	-17	-11	-28	-24	-18	-11	-11	-4
Once per day	-19	-18	-7	-18	-15	-10	-25	-21	-15	-10	-9	-3
Once per month	23	22	9	22	19	12	30	25	18	12	12	5
Once per week	22	21	8	20	18	11	28	23	16	11	11	4
Once per day	19	18	7	18	15	9	25	21	14	10	9	3

Table 8: 10 second change in output for wind generation scenarios for method 2 (100 MW wind farm size) [MW] (Table 3.3 of GH report)

Table 9 and Table 10 show predicted wind generation output changes over 10 seconds for method 1 and method 2 respectively.

	Scenario A			Scenario B			Scenario C			Scenario D		
Return period	**NZ**	**NI**	**SI**	**NZ**	**NI**	**SI**	**NZ**	**NI**	**SI**	**NZ**	**NI**	**SI**
Once per month	-146	146	-34	-110	-111	-45	-155	-149	-110	-78	-78	-17
Once per week	-111	-110	-27	-84	-81	-38	-130	-117	-89	-55	-54	-13
Once per day	-77	-77	-16	-57	-54	-25	-95	-83	-58	-36	-35	-8
Once per month	162	162	34	126	124	47	173	163	118	92	92	17
Once per week	118	117	24	86	83	36	138	125	87	57	57	12
Once per day	81	81	18	60	58	26	101	88	63	38	38	9

Table 9: 5 minute changes in output for wind generation scenarios [MW] (Table 3.6 of GH report)

	Scenario A			Scenario B			Scenario C			Scenario D		
Return period	**NZ**	**NI**	**SI**	**NZ**	**NI**	**SI**	**NZ**	**NI**	**SI**	**NZ**	**NI**	**SI**
Once per month	-57	-54	-35	-54	-47	-41	-72	-61	-49	-36	-36	-17
Once per week	-49	-47	-27	-46	-40	-32	-62	-53	-41	-29	-29	-13
Once per day	-38	-37	-16	-36	-31	-21	-49	-41	-30	-20	-19	-8
Once per month	63	60	34	58	53	40	78	67	52	42	42	18
Once per week	54	52	25	49	45	30	66	57	43	30	29	12
Once per day	41	39	18	38	33	22	53	44	31	21	21	9

Table 10: 5 minute changes in output for wind generation scenarios [MW] (Table 3.7 of GH report)

Changes in average wind generation output at the 5 minute level are managed through the re-dispatch of generation similar to changes in demand at the 5 minute level. Instantaneous changes in wind generation output must be managed through frequency keeping.

5. Impact of variability on power system operation

5.1 *Frequency keeping*

Table 11 shows a comparison of the variability of North Island demand and wind generation as envisaged in wind generation development scenario C over the 10 second period. The variability of wind generation output for method 1 is less than the size of North Island demand variation for return periods of a month and a week but is the same a return period of a day. The variability of wind generation output for method 2 is about half that of method 1.

Return Period	Change in North Island demand over 10 seconds (from Table 2)	Predicted Change in wind generation output (MW over 10 seconds) for Scenario C (from Table 7 and Table 8)	
		Method 1	Method 2
Once/ month	-75/+60 MW	-47/+49 MW	-25/+25 MW
Once/ week	-60/+50 MW	-43/+46 MW	-24/+23 MW
Once/ day	-40/+40 MW	-39/+40 MW	-21/+21 MW

Table 11: Comparison of North Island demand and wind generation varability (10 second)

Under the present EGRs and industry arrangements, the variability of the predicted wind generation output under wind generation development scenario C may require the frequency keeping band dispatched to be wider to maintain present frequency quality. The increase in band width will depend on the correlation between load changes and observed wind generation output changes amongst other things.

It is not possible to quantify for what level of connected wind generation an increase in the dispatched frequency keeping band might be required as there are other factors than increased wind generation output variability that will influence the decision. The maximum ramp rate capability of generating units providing frequency keeping services and the cost of frequency keeping are such factors.

The effects of the variability of wind generation output are not major in terms of managing power system security during dispatch.

5.2 *Generation re-dispatch*

Table 12 shows a comparison of the variability of North Island demand and wind generation as envisaged in wind generation development scenario C over the 5 minute period. The variability of wind generation output for method 1 is about the same as the North Island demand variation. The variability of wind generation output for method 2 is about half the North Island demand variation.

Return Period	Change in North Island demand over 5 minutes (from Table 4)	Predicted Change in wind generation output over 5 minutes for Scenario C (see Table 9)	
		Method 1	Method 2
Once/ month	-120/+150 MW	-149/+163 MW	-61/+67 MW
Once/ week	-100/+120 MW	-117/+125 MW	-53/+57 MW
Once/ day	-75/+100 MW	-83/+88 MW	-41/+44 MW

Table 12: Comparison of North Island demand and wind generation variability (5 minute average)

The variability of the predicted wind generation output under wind generation development scenario C will increase the need for generation re-dispatch during the 30 minute trading period as the combined variation of the North Island load and wind generation output will be greater under wind generation development scenario C than the present level of variation. The combined variation will depend on the correlation between load changes and wind generation output at the 5 minute average level.

5.3 Rapid changes during peak periods

The prior analysis of wind generation output variability and load variability has assumed that the two are independent of each other. This may not always be the case. There may be times when the variability of wind generation output and load variability are not independent.

Power system demand can increase rapidly over the morning and evening peak periods. The behaviour of wind generation during these periods is of interest. If wind generation output tended to drop off or increase during these periods then this would have ramifications for scheduling and dispatch during these periods.

The behaviour of Te Apiti wind farm during morning and evening peaks has been examined. Te Apiti wind farm has been chosen primarily because it is the only wind farm for which output measurements are available on the required time scales.

While there is considerable variability between days, Te Apiti generation output across morning and evening load peaks on a particular day is generally quite constant. There are no observed patterns of wind generation output consistently increasing or decreasing across these periods.

6. Discussion

6.1 Limitations of the analysis

It is important to understand the limitations of the analysis described in this report. The analysis relies upon models of the variability of wind generation output and load. These models were derived from a limited data set (covering six to 12 months). The models are likely to be good at predicting events which occur on an hourly or daily basis (as far as those events are represented in the data) but will not necessarily represent less frequent events (as those events may not have occurred in the measured data).

The models also assume that the variability of future wind farm output will be similar to that presently observed at Te Apiti wind farm. The variability of wind at different locations and the use of different wind generating units may result in the observed variability from future wind farms being quite different. The nature of wind may change with climatic conditions so that the variability of wind generation output currently observed at Te Apiti may be different to that observed in the future.

The reliance that can be placed on the analysis in this report is limited by the lack of experience of wind generation connected to the New Zealand power system. Nevertheless, the analysis in this report is based on the best information that is available and should provide good guidance in understanding the impact of frequent events.

It is strongly recommended that review and monitoring of the variability of wind generation is continued until such time that confidence is gained about the levels of variability that might be expected.

6.2 Large changes in wind generation output

The nature of wind generation output variability suggests that large changes in the combined output of all wind generation can occur. Conceptually, as all wind farms continuously vary output, there will be times when the changes in output of many wind farms will be in the same direction.

Where wind farms are co-located (e.g. as in the Manawatu region), local weather conditions such as weather fronts moving into the area can cause the outputs of the co-located wind farms to change in the same way. This has already been observed on a number of occasions for the Te Apiti and Tararua wind farms [3].

There is insufficient information available at this stage to determine the probability of such events and what mitigation measures would be appropriate. The effects on the power system of changes of certain sizes can be quantified.

It is likely that changes in wind generation output for wind farms located in the same region will produce noticeable effects. For example, if there were only

100 MW of wind generation capacity connected to the North Island power system then the operation of this wind generation will not affect power system security under normal conditions although some effects of this generation may be noticed (e.g. see the report on the impact of Manawatu wind generation on scheduling and dispatch [3]).

Large increases in the Manawatu wind generation output over five minutes have been observed to occur on a regular basis (around a dozen times a year). The size of these changes is around 66% of installed wind farm capacity. Wind generation scenario C envisages 450 MW of wind generation capacity in the Manawatu region. If the envisaged Manawatu wind generation shows similar large sudden increases in output then sudden changes of around 300 MW over five minutes would be regularly observed.

A sudden increase in generation of 300 MW over five minutes can be managed through generation re-dispatch. However, a frequency excursion outside the normal band (49.8 Hz to 50.2 Hz) is likely before re-dispatch occurs.

The extent to which wind farms in a region will change their output in the same manner is not well known. Correlation analysis has been carried out for the Manawatu wind farms (Tararua I and II and Te Apiti) and using wind speed measurements at other locations. It is too early to tell whether the correlations determined for Te Apiti and Tararua wind farms will apply to other wind farms in the region. Much depends on the physical locations of the wind farms (e.g. the present Manawatu wind farms are all located on the same ridgeline). The effects of connection of further wind farms should be monitored so that understanding of regional wind farm correlation improves and that if any mitigation measures should be implemented.

It is recommended that the variability of wind generation and correlation between wind farms in a region is further monitored and reviewed.

7. Conclusions and Recommendations

Wind generation output variability of the size predicted in the Garrad Hassan report for wind generation development scenario C will affect the processes and tools used by the System Operator to dispatch generation on the New Zealand power system to a limited extent.

In the absence of changes to the EGRs and industry arrangements, it is expected that additional frequency keeping services may need to be procured to maintain frequency quality targets. The amount of additional frequency keeping services is not expected to be great even for the wind generation output variability predicted for wind generation development scenario C.

The variability of wind generation output will affect the need to re-dispatch generation during a trading period. It is expected that some additional re-dispatch will be required for the predicted wind generation output variability for wind generation development scenario C however this should not be outside the capability of the present dispatch processes.

It is recommended that the issues around the effects of wind generation on the dispatch of generation should be given a moderate priority for the next stage of the Wind Generation Investigation Project.

8. References

[1] Wind Generation Scenarios – see http://www.electricitycommission.govt.nz/pdfs/opdev/comqual/windgen/wind-scenarios-Jun06.pdf.
Wind Generation Investigation Project Website – see http://www.electricitycommission.govt.nz/opdev/comqual/windgen/wgip

[2] Garrad Hassan Report “Wind Power variability and forecast accuracy in New Zealand”, 20 March 2007.

[3] Transpower, “Manawatu wind generation: Observed impacts on the scheduling and dispatch processes”, see http://www.transpower.co.nz/?id=5967.
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Appendix 1 – New Zealand power system

Figure 12 - North Island power system

Figure 13 - South Island power system