

Manawatu wind generation

Observed impacts on the scheduling and dispatch processes

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Executive Summary

1.1 Introduction

This report reviews the effects of the two major wind farms located in the Manawatu area – Te Apiti and Tararua – on the operation of the power system and electricity market. It is a first step in a wider review to identify market and code changes to accommodate wind and other intermittent generation.

The Tararua wind farm is embedded behind the Linton and Bunnythorpe grid exit points and has been in operation since 1999. The Te Apiti wind farm was connected to the grid near Woodville in late 2004. The combined installed capacity of the two wind farms is over 150 MW. The output of wind generation varies with wind speed.

This variability of wind generation output has the potential to impact upon the operation of the power system and electricity market. Sudden increases or decreases in the output of wind generation (resulting from sudden changes in wind speed) must be covered by other generation. It is difficult to forecast wind speed and hence wind farm output. This increases uncertainty in the scheduling and dispatch of other generating plant as it compensates for and accommodates the wind generation. The two wind farms are separated by only several kilometres and lie on an axis at right angles to the prevailing winds.

At present, the installed capacity of wind generation on the New Zealand power system is small compared to the installed capacity of other types of generation. Overseas it has been recognised that there are limits to the amount of wind generation that can be connected to power systems before operational and market issues arise.

This report reviews the operational and market impacts of Manawatu wind generation in November and December 2004. Where relevant, findings have been extrapolated to predict the effect of increasing the amount of wind generation in the region.

1.2 Observed Impacts

Analysis of the output of the Manawatu wind generation yielded some interesting results:

1. There was a high correlation between the variations in output of the Te Apiti and Tararua wind farms during November and December 2004.
2. There were three occasions when the combined output of Te Apiti and Tararua wind farms increased over 100 MW in the five minute dispatch scheduling period and two occasions when the output increased from near zero to full output (150 MW) in fifteen minutes.
3. Existing generation forecasts of wind farm output are poor. In November and December 2004, 10% of forecasts of output at Te Apiti were greater or less than actual output by more than 50 MW (over half the full capacity of the wind

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farm). Forecast accuracy showed little or no improvement whether the forecast was for trading periods 12, 6, or 2 hours ahead.

4. The accuracy of the total New Zealand generation schedule materially decreased as a result of the poor forecasting of wind generation in the Manawatu. The average absolute error in the schedule for the trading period 2 hours ahead increased by 27 MW in November and 34 MW in December (90th percentile).

Correlation between output at each wind farm

The correlation between Te Apiti (TAP) and Tararua (TWF) wind farm output is very high for November and December 2004. Figure 1 shows the output at each wind farm on a typical day. The output at each site is very closely matched but there are times (e.g. between 5.00 and 7.20 hours, and after 22.00 hours in the graph below) when a lag is observed. This may be due to changes in wind direction at these times. Under prevailing wind conditions, changes in output at each site occur within a few minutes of each other.

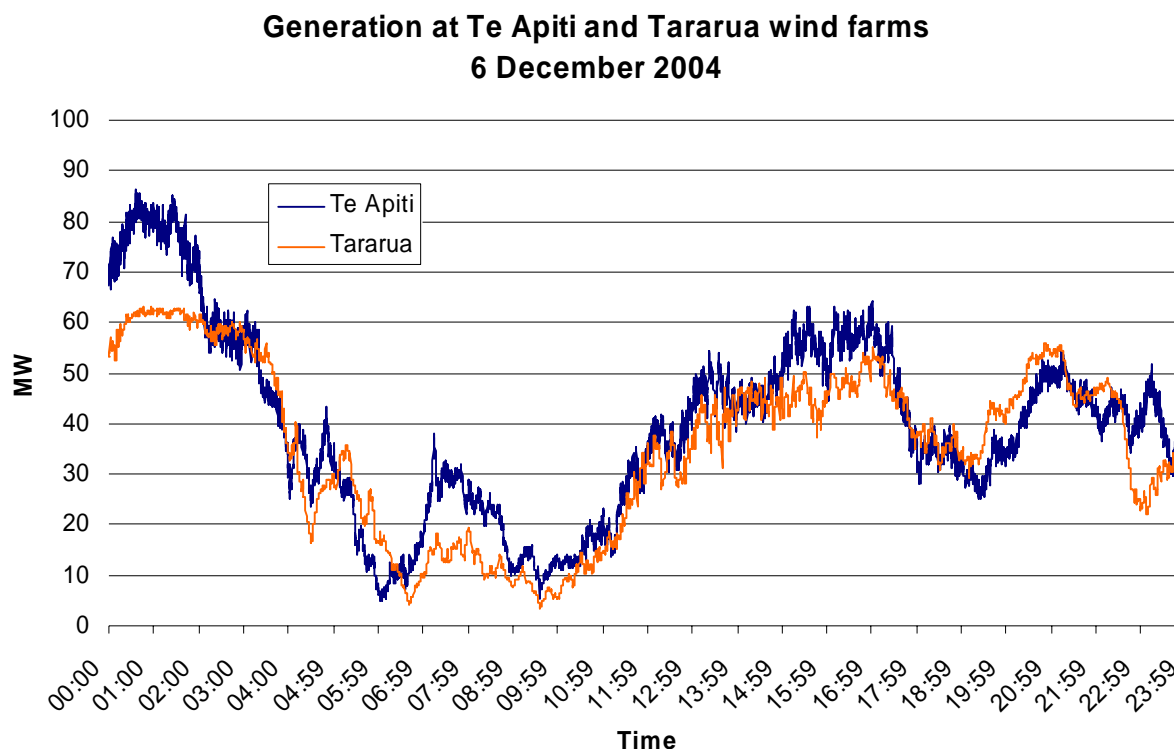


Figure 1 - Manawatu wind generation output

Rapid increases in output

Analysis of the most extreme 5-minute changes in wind farm output recorded in November and December (unaffected by post-commissioning tests) showed there were 3 occasions when the wind output in the Manawatu increased more than 100 MW in five minutes¹. There were also 4 occasions when wind output decreased by more than 50 MW (but less than 100 MW) in five minutes.

¹ Five-minute changes were studied because dispatch is based around a five-minute timeframe

Figure 2 illustrates one such extreme increase in wind farm output during the study period.

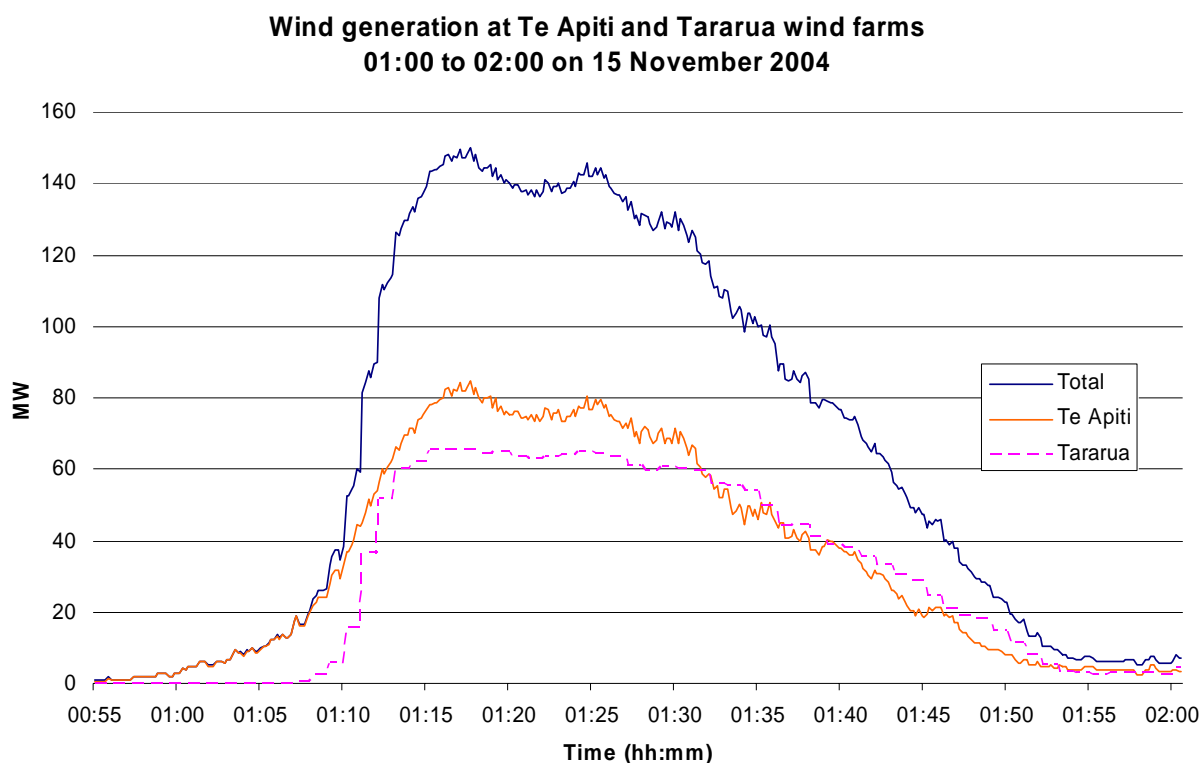


Figure 2 - Rapid increase in Manawatu wind generation output

Forecast Accuracy

A comparison of forecast generation output and actual observed generation output at Te Apiti in November and December 2004 indicates that forecast accuracy is poor.

Only 86% of November's forecasts of Te Apiti's output for trading periods 12 hours ahead were within ± 45 MW of the actual output. Forecasts for 6 or even 2 hours ahead were no more accurate. Results for December were worse with only 83% of forecasts of Te Apiti's output for trading periods 2 and 6 hours ahead, within ± 45 MW of the actual output. Only 78% of forecasts 12 hours ahead were within ± 45 MW of actual output.

There are no forecasts of output for the Tararua wind farm. Instead, the load forecast for the wider Palmerston North area is net of the wind farm output from Tararua. As a result, the accuracy of the load forecast for Palmerston North is relatively poor in comparison with the load forecasts for other areas. In November, 99% of load forecasts 2 hours ahead for nine of the ten load areas (in New Zealand) were within $\pm 10\%$ of the actual load. Only 68% of load forecasts for Palmerston North load area were as accurate.

Generation Scheduling

The poor forecasting of wind output at both Te Apiti and Tararua makes the generation schedule considerably less accurate. For many generators the generation schedule is relied on to provide an accurate estimate of likely actual generation. Table 1 summarises the average absolute error calculated in the schedule for forecasts 2, 6 and 12 hours in the future after Te Apiti offers and the demand forecast for Palmerston North were included. It shows, for the 90th percentile, that the error in the schedule increases by 25-30 MW by the inclusion of relatively uncertain wind generation at Te Apiti and Tararua. Results for December were no better – it is calculated that the schedule 2, 6, and 12 hours ahead was less accurate by 34 MW, 50 MW, and 34 MW, respectively.

Table 1 - Average Absolute Error (MW) in Schedule

90th percentile of forecasts in November 2004

Forecast	Without wind ²	With wind ³	Diff (MW)	Diff (%)
2 hours ahead	±91 MW	±118 MW	+27 MW	+30
6 hours ahead	±109 MW	±134 MW	+25 MW	+23
12 hours ahead	±110 MW	±140 MW	+30 MW	+27

The decrease in the accuracy of the schedule has been remarked on by one trader as an issue of concern in determining the likely generation output at their (non wind) power stations.

1.3 Implications

Expansion of wind farms

A key finding is the close correlation in the output of the two farms to the extent that, within the generation dispatch timeframe of five minutes, both farms can reasonably be considered a single source of generation.

The observed correlation between the output of the Te Apiti wind farm and the Tararua wind farm, suggests that other wind generation developments in the Manawatu region are likely to demonstrate a similar level of correlation with other wind farms in the region. This will likely exacerbate operational and market impacts currently observed.

² New Zealand load forecast less Palmerston North load area (which is dominated by output from Tararua wind farm)

³ New Zealand load forecast (including Palmerston North load area) less Te Apiti offers

Frequency regulating reserve

A mismatch between generation and load on the power system will cause the power system frequency to rise or fall. These mismatches occur constantly as demand on the power system is constantly varying. The resulting changes in power system frequency must be managed. In New Zealand, frequency is managed by the dispatch of specific generating units to provide frequency regulating reserve (FRR).

The frequency regulating reserve provider changes its generation output to match changes in demand and generation on the power system. The physical characteristics of generating units providing frequency regulating reserve determine how fast the frequency regulating reserves provider can change output in response to changes in frequency.

On at least one occasion, the rate of increase exceeded the capability of the frequency regulating reserve provider to change its output in response. Other generating plant and the HVDC link acted automatically to contain the increase in power system frequency until generation could be re-dispatched by the System Operator's power system coordinators.

A 100 MW increase in five minutes is twice the rate of the least-capable frequency regulating reserve provider and double the quantity of frequency regulating reserve dispatched. If the amount of installed wind generation in the Manawatu region were to double, it is likely that increases in wind generation output of over 200 MW in five minutes will be observed. Changes of this speed and magnitude would exceed the capability of most frequency regulating reserve providers and the ability of the coordinator to re-dispatch in time to prevent a sizeable frequency excursion.

The System Operator will review the procurement of frequency regulating reserve in light of the findings in this report. Changes to the capability requirements that frequency regulating reserve providers must meet are possible (potentially reducing the numbers of providers), as is an increase in the amount of frequency regulating reserve procured. These changes are likely to increase the costs of the frequency regulating reserve ancillary service.

Dispatch processes

The rapid increase of wind generation output also affects the loading on transmission circuits. The sudden increase in generation output in the lower North Island combined with a reduction in generation output by the frequency regulating reserve provider causes a change in power flow within the transmission grid. This change in power flow has the potential to cause transmission circuits to exceed their stated rating until re-dispatch of generation occurs, unless the loadings are reduced to allow for the wind generation volatility.

Preliminary analysis indicates that changes in Manawatu wind generation during contingent events will have implications for power system capability limits for HVDC south transfer and power transfer through the Central North Island.

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The System Operator will need to consult with Transpower as Grid Owner on the implications for asset ratings. The System Operator is reviewing power system capability limits in light of the observed rapid increases in wind generation output. It may be necessary to revise dispatch processes and means to ensure that transmission circuits do not exceed stated capability if Manawatu wind generation output was to rapidly change during a contingent event.

Forecast accuracy and generation scheduling

Inaccurate forecasts affect participants in the electricity market and the ability of the System Operator to meet the Principal Performance Obligations contained in Part C of the Electricity Governance Rules. Increased inaccuracy in forecasts affects participants by increasing uncertainty in trading outcomes and makes operational decision making more complex for all participants.

The security impact of greater inaccuracy in the schedule is the increased risk of transmission-constrained dispatch 'surprises' in real time. The System Operator considers that inaccuracy in the generation schedule above a certain level will impact upon its ability to meet its Principal Performance Objectives.

As an interim measure, the System Operator is considering rule change proposals that would provide minimum forecast accuracy limits for uncertain inputs to the schedule.

Introduction

2.1 Background

This report outlines the findings of a study into the effect of two wind farms (Te Apiti and Tararua) located in the Manawatu area on the scheduling and dispatch processes. This study has now been agreed to be part of the first step in a wider study to identify market and code changes to accommodate wind and other intermittent generation.

The output of wind generation varies with wind speed. The consequent variability of wind generation output has the potential to impact upon the operation of the power system and electricity market. Sudden increases or decreases in the output of wind generation (resulting from rapid changes in wind speed) must be covered by other generation. It is also relatively difficult to forecast wind speed and wind farm output, which increases uncertainty in the scheduling and dispatch of other generating plant.

The Tararua wind farm is embedded behind the Linton and Bunnythorpe grid exit points and has been in operation since 1999 with a significant expansion commissioned in 2004. The Te Apiti wind farm was connected to the grid near Woodville in late 2004. The combined installed capacity of the two wind farms is currently over 150 MW.

2.2 Contents

An earlier report⁴ identified three potential issues with regards output at Tararua and Te Apiti wind farms. Analysis has been carried out in respect of each of these issues and the results are presented in the following sections.

- 3.1 Degree of correlation in the output at the two wind farms.
- 3.2 Schedule inaccuracies caused by wind output forecast errors.
- 3.3 Dispatch issues.

Each of these sections has 3 or more subsections containing:

- method used to investigate issue
- finding
- implications.

The observed rapid increases in output of the Manawatu wind generation during November and December 2004 had impacts on frequency management and circuit loading in the grid. Separate analysis has been carried out to determine impacts on frequency management (section 3.4) and the capability of the power system (section 3.5).

⁴ 'Windfarm Co-ordination Project - Impact on Realtime Security – Close out report', prepared by Greg Spence, 22 March 2004

Analysis and Findings

The findings and conclusions drawn from the analysis described in this report are preliminary only. The data used were less than ideal and may not be representative. The data only spanned two months (November and December 2004). Generation data from Tararua wind farm has less resolution (apparently being based on average one minute data), than the Te Apiti generation data. In addition, it should be noted that Te Apiti wind farm was still carrying out commissioning activities during November and December 2004.

Transpower expects the findings and conclusions will be proved robust, however, there remains the possibility that different conclusions may emerge over time. We will refine the analysis as more and better quality data becomes available.

3.1 Diversity / correlation between sites

3.1.1 Method

Generation data from the two wind farm sites was analysed to establish the degree of correlation between output at the two sites. The correlation coefficient (r^2) associated with the output at the two sites were calculated for 6 separate periods in November and December 2004.

A correlation coefficient equal to 1 would indicate that the output of the two wind farms is positively correlated. Both wind farms would show matching increases or decreases in output at any time. A correlation coefficient of 0 would indicate that there was no correlation between the output of the two wind farms. A correlation coefficient of -1 would indicate that the output of the wind farms was negatively correlated. In this case, one wind farm would increase output while the other would decrease output.

3.1.2 Findings on level of diversity/correlation

Generation output at Tararua and Te Apiti wind farms are highly correlated, though the relationship is not a perfect match. Table 3.1.2a (below) shows the weeks chosen and the calculated correlation coefficient. The highest correlation coefficient calculated was 0.96 for 23-29 December. This is an extremely high correlation statistic.

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Period	r^2 statistic
3-9 Nov	0.88
11-17 Nov	0.84
20-26 Nov	0.90
2-8 Dec	0.86
10-16 Dec	0.82
23-29 Dec	0.96

Table 3.1.2a

The other weeks in the study period were not analysed as data was either missing or suspect. (Note that the Te Apiti wind farm was being commissioned in November).

The output data from Te Apiti is the wind farm generation output sampled every 10 seconds. The Tararua generation data is also collected in 10 second samples. However, each generation value is repeated 5 times. The System Operator understands that the data is actually being provided from one minute average SCADA values.

The implication of the Tararua data being based on one minute averages is that the combined wind farm output series displays less variation than would be observed if data from Tararua was sampled every 10 seconds. This lesser variation means that the correlation statistics between the Te Apiti wind generation output and the Tararua wind generation stated above may be understated and the true correlation may be higher.

Discussions between the System Operator and the owner of the Tararua wind farm are underway to improve the sampling rate of the output series.

Figure 3.1.2a shows the output at each site. The chosen day (6 December 2004) shows greater variation between the sites and less correlation than is typical. The lag between the two output series varies throughout the day, presumably due to different wind directions and weather conditions. However, at other times of the day and month, under prevailing wind conditions, changes at one farm are normally observed at the other within 2-3 minutes. The Tararua wind farm output shows less variation than the Te Apiti wind farm output as the Tararua wind farm output is based on SCADA data that is averaged over a period of a minute while the Te Apiti wind generation is sampled every 10 seconds.

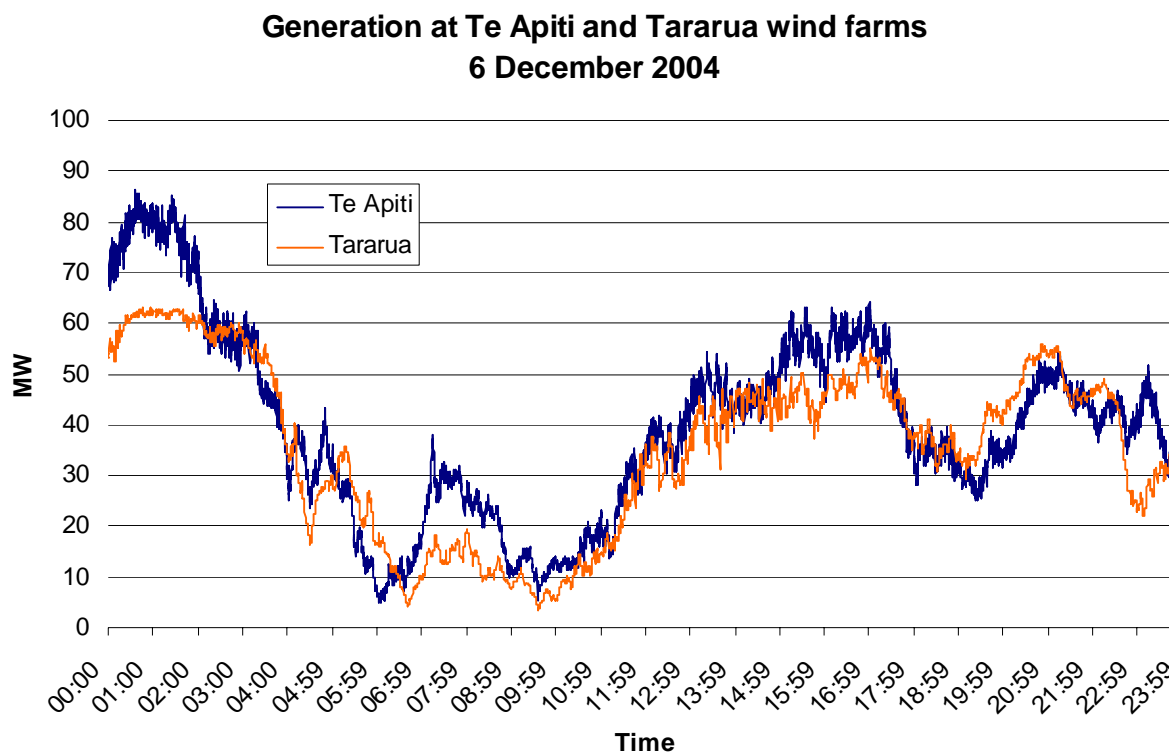


Figure 3.1.2a

3.1.3 Implications

The output of the two wind farms is correlated to such an extent that both farms can reasonably be considered a single source of generation within the generation dispatch timeframe of five minutes. This is a key finding.

The observed correlation between the output of the Te Apiti wind farm and the Tararua wind farm, suggests that new wind generation developments in the Manawatu region are likely to demonstrate a similar level of correlation with other wind farms in the region. This will likely exacerbate operational and market impacts currently observed.

3.2 Uncertainty in the schedule

The System Operator dispatches generation to meet energy and reserves requirements for each trading period on the basis of offered generation and forecast demand. The System Operator prepares generation schedules for each trading period that show the expected levels of generation output and instantaneous reserves provided by each generating unit in that trading period.

Inaccuracy in forecast demand creates uncertainty in the schedule. Intermittent generation (including wind generation) adds to this uncertainty as it is difficult to forecast the amount of energy provided by the intermittent generator in the trading period. Uncertainty in the generation schedule means some generators will be uncertain as to whether they will be dispatched and at what quantity. It also makes it

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harder for some generators to optimise fuel use and identify the most efficient number of generating units to have available. The difference between forecast generation prior to dispatch and that actually required, makes operating the power system more difficult for the System Operator.

3.2.1 Method

The impact of Manawatu wind generation on the uncertainty in the schedule was analysed by comparing the accuracy of:

1. Te Apiti offers⁵ and Palmerston North load forecasts (including influence of Tararua wind farm generation)
2. NZ load forecasts excluding influence of Manawatu wind generation
3. NZ load forecasts including influence of Manawatu wind generation.

Appendix 1 contains more detail on how the series were created.

3.2.2 Findings from analysis of Te Apiti offers and Palmerston North load forecasts

The accuracy of the Palmerston North area load forecast is affected by the amount of wind generation in the Manawatu region. The Te Apiti wind farm offers its generation in the market while the Tararua wind farm does not. Forecasts of Tararua wind farm's output are not made separately because the wind farm is embedded behind the Linton and Bunnythorpe grid exit points and output is not yet offered through the dispatch process by the owner as it is for Te Apiti. The load forecast for the Palmerston North area is net of the output from the Tararua wind farm. The half-hour load in the Palmerston North area in November 2004 varied between a low of 96 MW and a high of 293 MW, net of potential Tararua wind farm output of up to 66 MW.

Figure 3.2.2a and the associated table (Table 3.2.1a) illustrates the poor performance of the Palmerston North (PN) 2, 6, and 12 hour ahead load forecasts, in comparison with the nine other load areas. Only 68% of Palmerston North load forecasts for the trading period 2 hours ahead were within +/- 10% of the actual load. In contrast, between 99-100% of forecasts in the other nine load areas in New Zealand were within +/-10% of the actual load.

⁵ Te Apiti is the only wind farm that offers its generation in the market

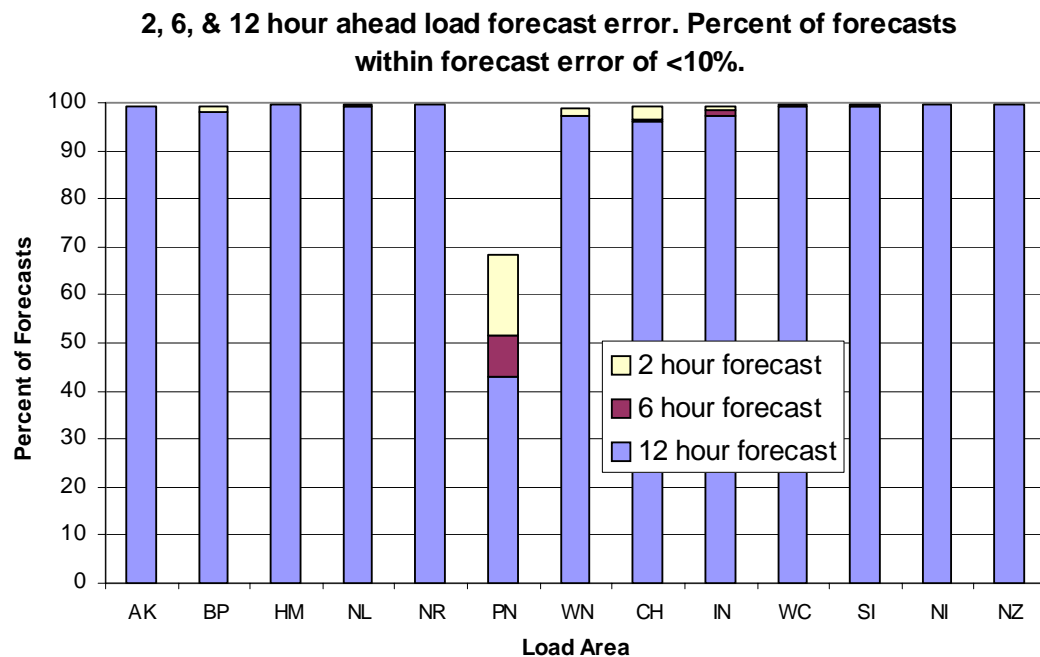


Figure 3.2.2a and Table 3.2.2a. Percent of forecasts within a forecasts error of 10 % for the NZ load areas.

A comparison of generation offers and generation output at Te Apiti in November and December 2004 indicates that the forecasts are not very accurate and do not improve closer to dispatch, (i.e. there is no measurable improvement in accuracy as we go from 12 trading periods to 6 trading periods to 2 trading periods ahead of dispatch.)

Figure 3.2.2b shows a cumulative percentage difference between Te Apiti forecasts and generation for November 2004. Only 86% of November’s forecasts of Te Apiti’s output for trading periods 12 hours ahead were within ± 45 MW of the actual output, i.e. there is only 86% chance a forecast would be within half the installed capacity of the wind farm. Forecasts 6 or even 2 hours ahead were no more accurate.

Results for December were worse with 83% of forecasts of Te Apiti’s output for trading periods 2 and 6 hours ahead within ± 45 MW of the actual output. Only 78% of forecasts 12 hours ahead were within ± 45 MW of actual output.

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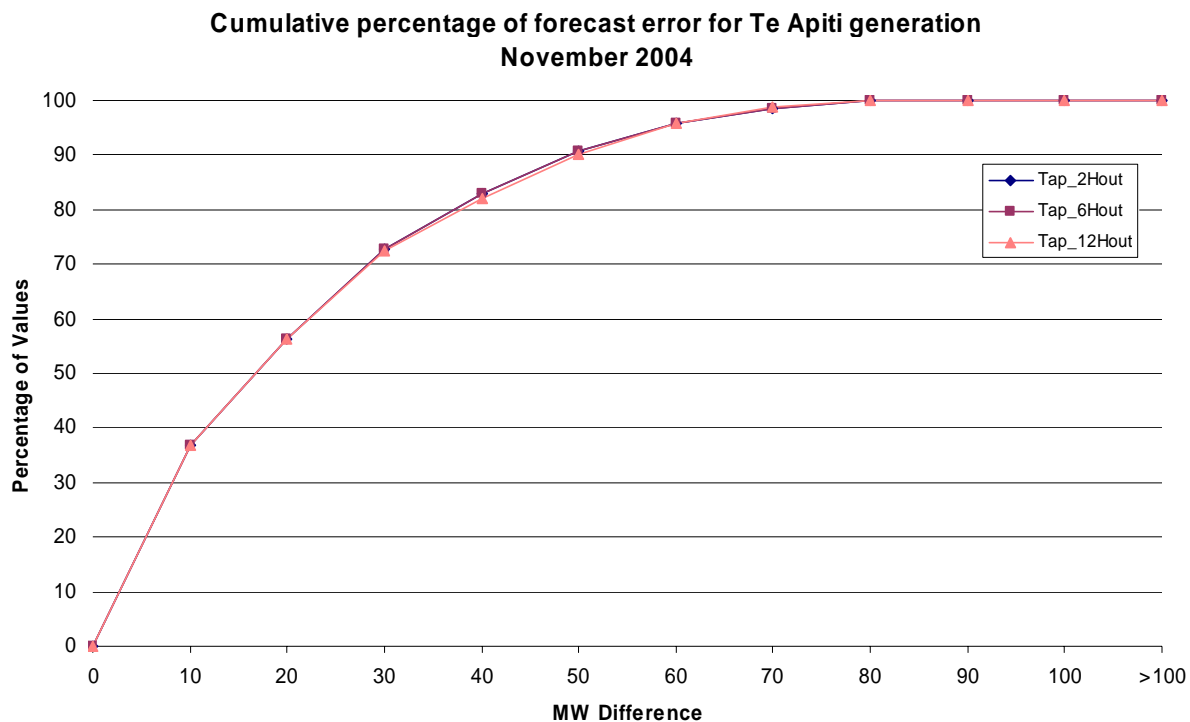


Figure 3.2.2b

Figure 3.2.2c presents the cumulative distribution of the absolute average error between forecasts and actual values 2 hours ahead for:

- NZ load forecast net of the influence of Te Apiti and Tararua wind generation (NZ with wind)
- NZ load forecast excluding the influence of Te Apiti and Tararua wind generation (NZ without wind).

Appendix 1 contains details on how the series were created. Figure 3.2.2d and 3.2.2e illustrate the 6 hour and 12 hour cases, respectively.

Figure 3.2.2c shows that 10% of the forecasts of load for ‘New Zealand without wind’ for trading periods 2 hours ahead contained an error of greater than 91 MW. This error is associated with a forecast of load of up to 4,500 MW. In contrast, 10% of the November’s generation offers/forecasts for Te Apiti output in 2 hours time had an error greater than 50 MW — this error is greater than half the installed capacity (90 MW) of the wind farm.

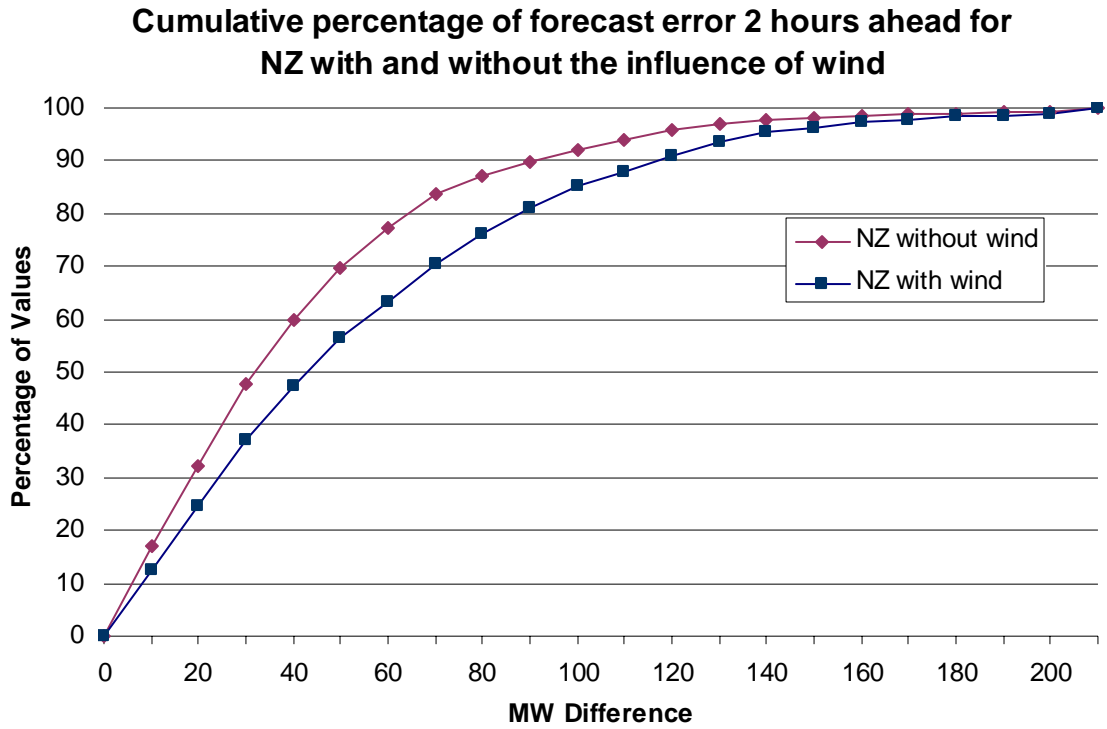


Figure 3.2.2c

Figures 3.2.2d and 3.2.2e show the increase in uncertainty in the forecasts from the addition of Manawatu wind generation (both Tararua and Te Apiti) to New Zealand load for the 6 and 12 hour time intervals.

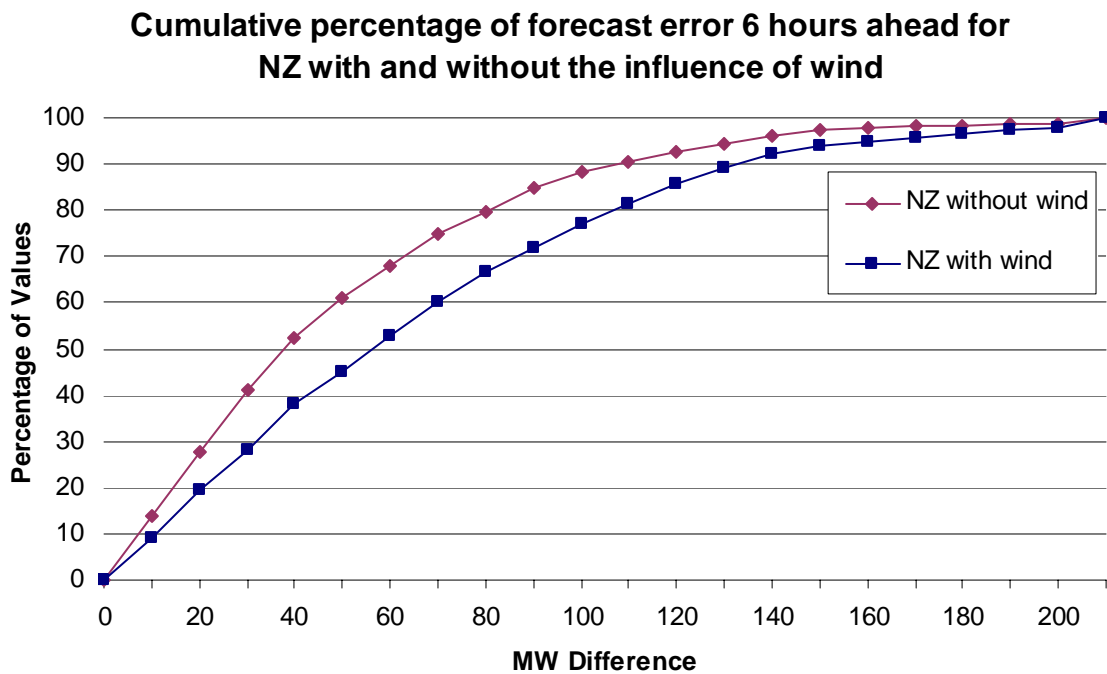


Figure 3.2.2d

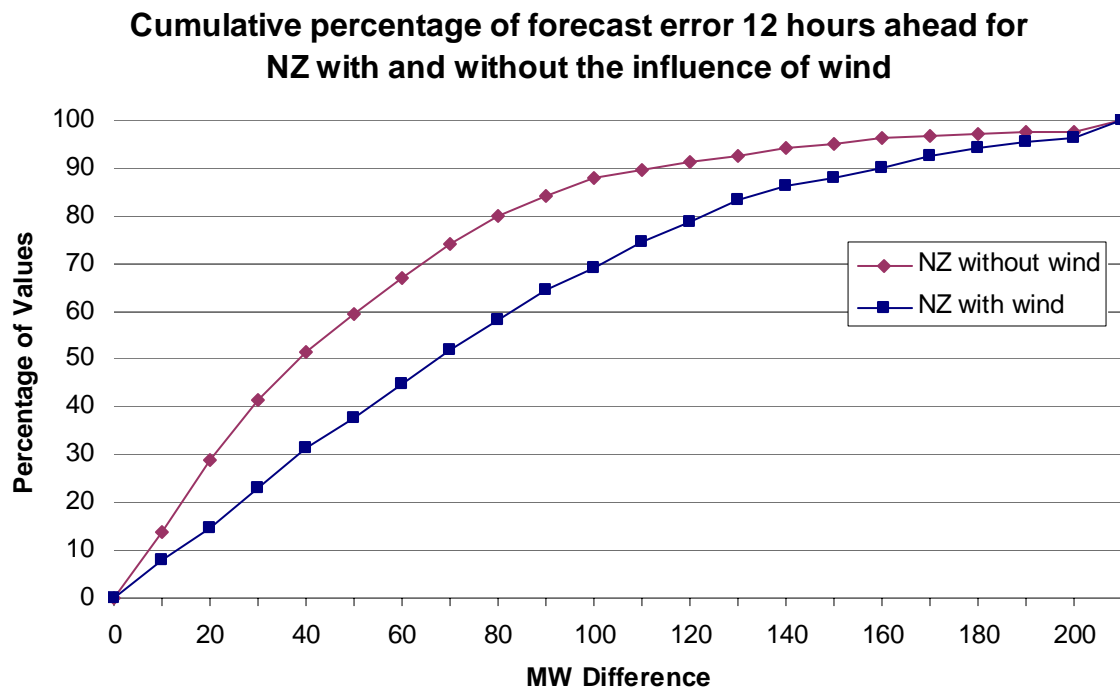


Figure 3.2.2e

The information for the 90th percentile is summarised for November and December in Table 3.2.2b and 3.2.2c and shows that wind generation in the Manawatu area significantly increased uncertainty in the schedule 2, 6, and 12 hours ahead during these two months. Schedule accuracy was reduced by between 25-30 MW in November and 40-45 MW in December.

Average absolute error (MW) in 90 th percentile for November 2004				
Forecast	TAP	NZ without wind	NZ with wind	Diff with & without wind
2 hours ahead	50	91	118	+27
6 hours ahead	50	109	134	+25
12 hours ahead	50	110	140	+30

Table 3.2.2b

Average absolute error (MW) in 90 th percentile for December 2004				
Forecast	TAP	NZ without wind	NZ with wind	Diff with & without wind
2 hours ahead	54	110	150	+40
6 hours ahead	54	145	190	+45
12 hours ahead	54	160	200	+40

Table 3.2.2c

3.2.3 Implications

The decrease in the accuracy of the schedule has been remarked on by one trader as an issue of concern in determining the likely generation output at their (non wind) power stations.

The increase in dispatch uncertainty also has implications for the System Operator in planning to meet its principal performance obligations. Uncertainty in the schedule makes security situations in future trading periods more difficult to identify and manage. The System Operator prefers that the schedule is as accurate as possible. This maximises the chance that potential security situations appear in the schedule with enough time for them to be resolved by market participants themselves subsequently making changes to their offers/bids.

The System Operator will consider proposing rule changes to provide minimum forecasting accuracy standards/targets for schedule inputs to reduce the possible deterioration of schedule accuracy.

3.3 Dispatch issues

3.3.1 Method

The impact of Manawatu wind generation on the dispatch process was analysed by comparing dispatch and actual output at Te Apiti. Dispatch data is only available for Te Apiti as Tararua Wind Farm is not currently dispatched. The dispatch data studied were one-minute averages for the period 1-23 November 2004. This was compared with the generation data for Te Apiti, which was also averaged over one-minute intervals.

Wind generation is dispatched differently to other generation. Normally, dispatch instructions are sent to generators which then change output according to the instruction. Wind generation does not have the ability to follow such instructions as the amount of output is dependent on the wind at the time. The Electricity Governance Rules (EGRs) allow wind farms to operate freely except in circumstances where their output must be constrained down to meet transmission limits⁶. The dispatch schedule contains the most recent output readings from the wind farm and assumes that it will remain at this output.

3.3.2 Findings on dispatching Te Apiti generation

Figure 3.3.2a shows the difference between the dispatch instructions (Dispatch MW) and actual generation at Te Apiti (Actual MW).

⁶ A wind farm cannot be constrained up!

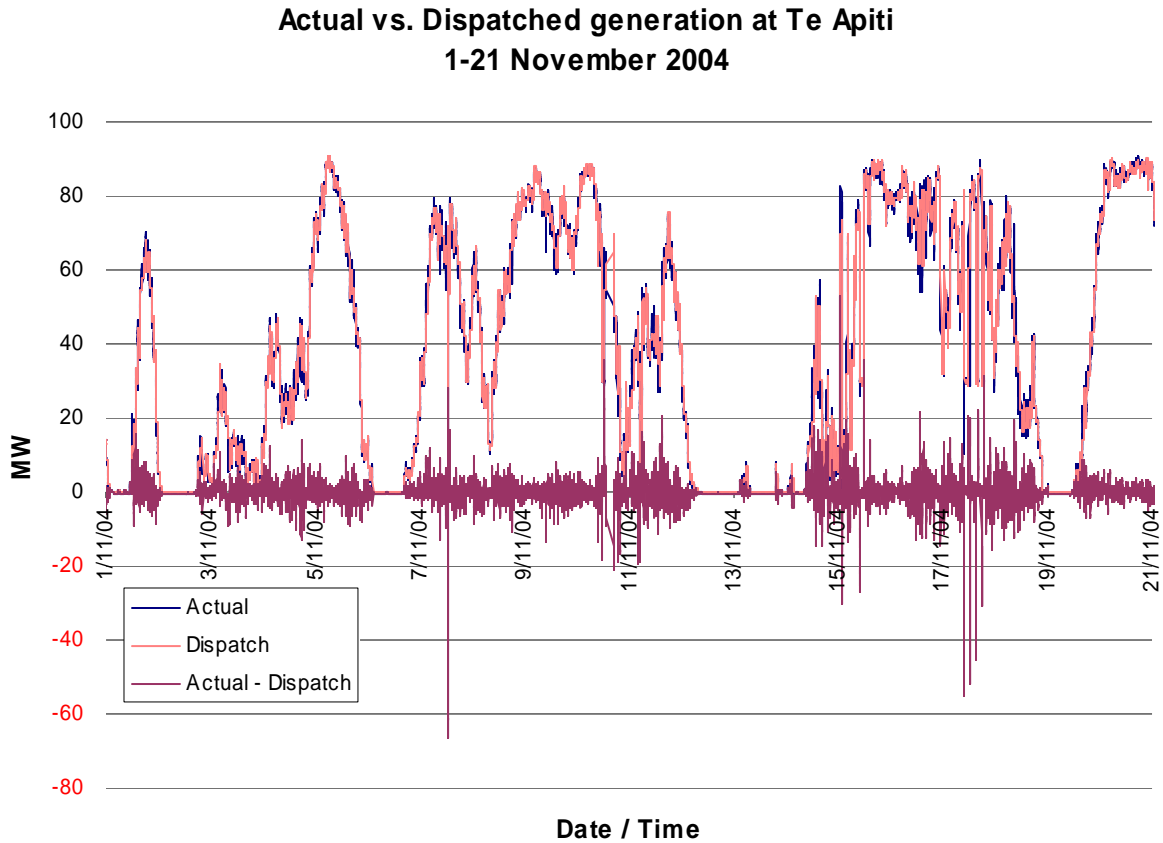


Figure 3.3.2a

The cumulative percentage difference is presented in Figure 3.3.2b. Nearly 97% of the differences are within 10 MW, with the largest difference being 66.4 MW. In summary:

- 88.4% of the generation is within 5 MW of the dispatch
- 96.9% of the generation is within 10 MW of the dispatch
- 0.04% of the generation is above 50 MW different from the dispatch.

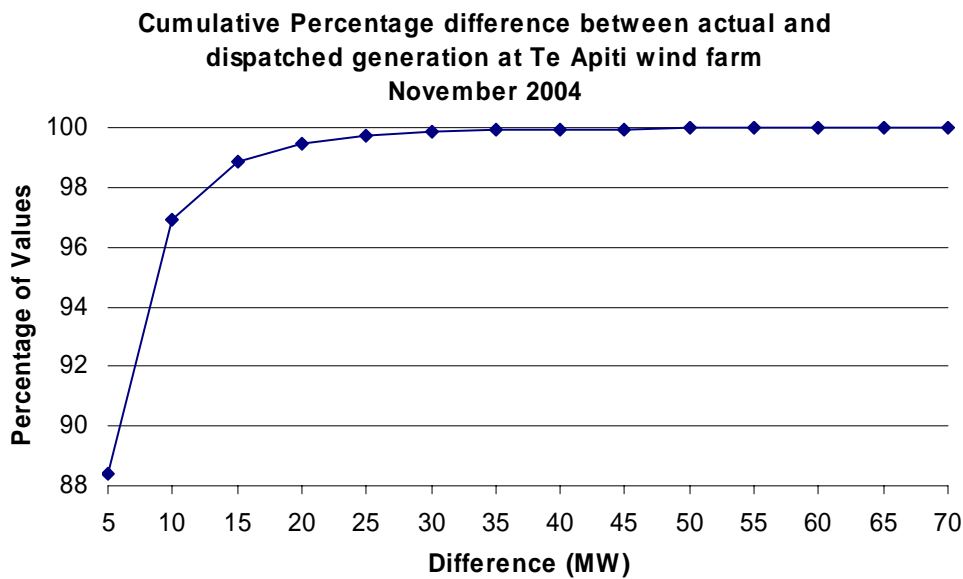


Figure 3.3.2b

3.3.3 Implications

Normally, the difference between dispatch and actual generation is small, although in rare cases, the difference can be high. Because the Te Apiti dispatch values are determined from the last SCADA indication of Te Apiti generation, the error reflects the correlation between successive time intervals within this series.

The dispatch rules and practices appear to be working tolerably for the Te Apiti wind farm. The difference between dispatch and actual generation can be large for a small amount of the time. The implications of this large difference are considered in section 3.4.

3.4 Frequency Management

3.4.1 Method

Five-minute changes in wind output at Te Apiti and Tararua were analysed to determine the effect of Manawatu wind generation on frequency management.

The study period was 1 November 2004 to 31 December 2004. Appendix 1 contains more detail on how the series were created.

3.4.2 Findings from analysis of extreme wind generation ramping events

The output of wind generation in the Manawatu can increase by more than 100 MW in five minutes and without warning. A 100 MW change on the power system is twice the 50 MW of frequency regulating reserve dispatched and twice the rate required of a frequency regulating reserve service provider.

Large changes in Manawatu wind generation output can cause changes in power system conditions which could lead to issues with dispatch and North Island frequency. The maximum change in November in any five minute period was 105 MW up and 67 MW down. Large changes (< -50 MW or > 50 MW) were observed for 12 separate events during the study period. It appears that 10 of the 12 cases of large changes observed in the November records were the result of commissioning activities at Te Apiti. These cases were excluded from the analysis.

The remaining 2 cases of extreme ramp ups occurred on 15 November at 1am and after 11pm on 23 November. These cases are shown in Figure 3.4.2a and Figure 3.4.2b. There was only one case of extreme ramping in December. This occurred after 16:43pm on 30 December 2004 and is shown in Figure 3.4.2c.

Impact of Manawatu wind generation on the scheduling and dispatch processes

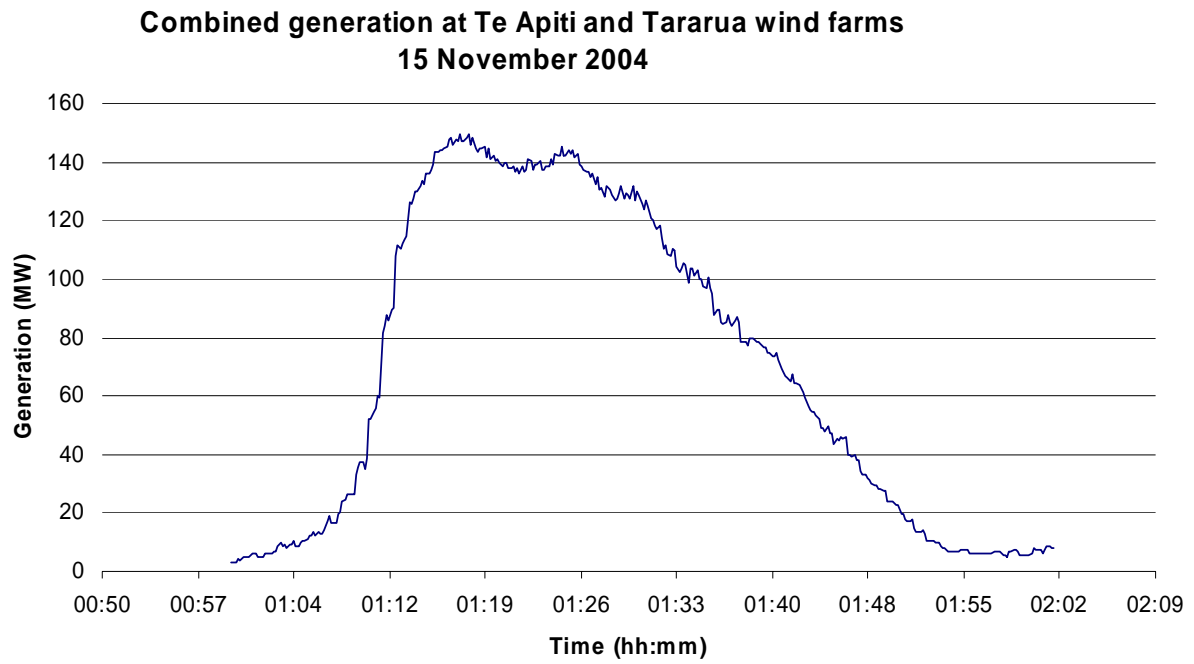


Figure 3.4.2a

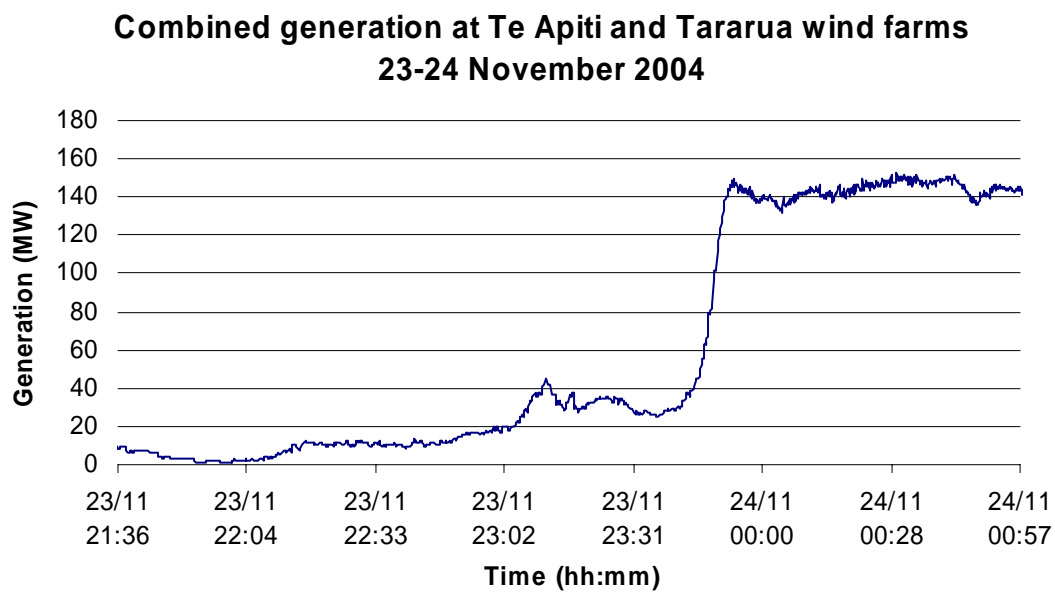


Figure 3.4.2b

**Combined generation at Te Apiti and Tararua wind farms
30 December 2004**

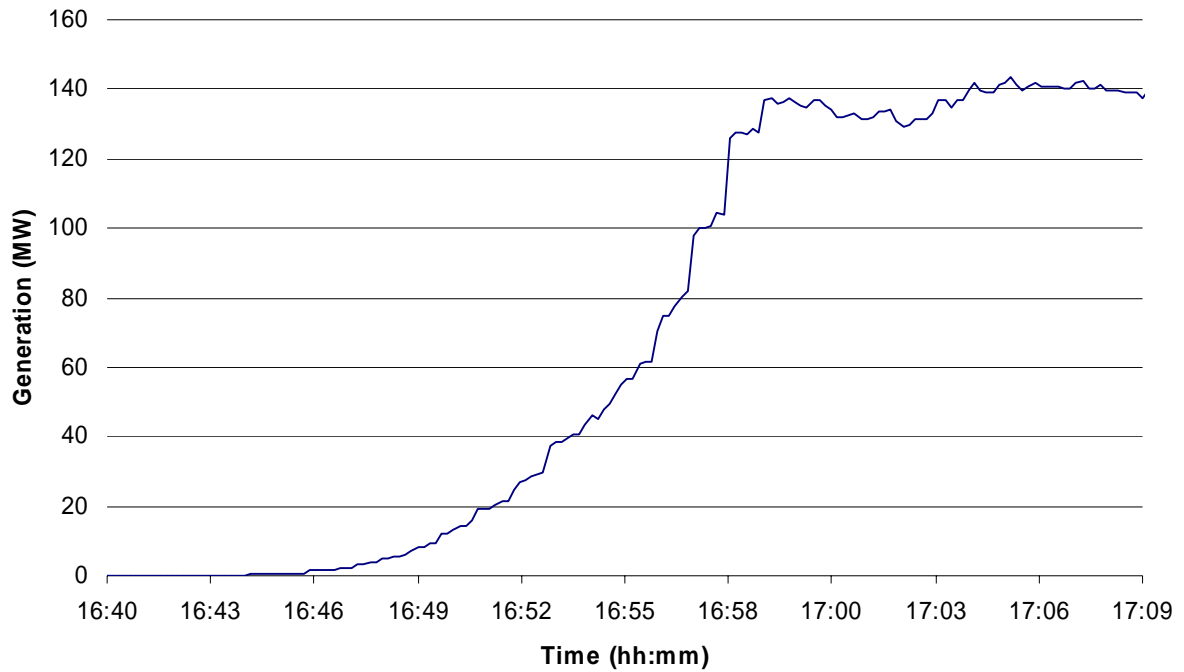


Figure 3.4.2c

Figure 3.4.2d shows the output from Te Apiti and Tararua wind farms separately and combined during the one hour period from 1am to 2am on 15 November 2004.

**Wind generation at Te Apiti and Tararua wind farms
01:00 to 02:00 on 15 November 2004**

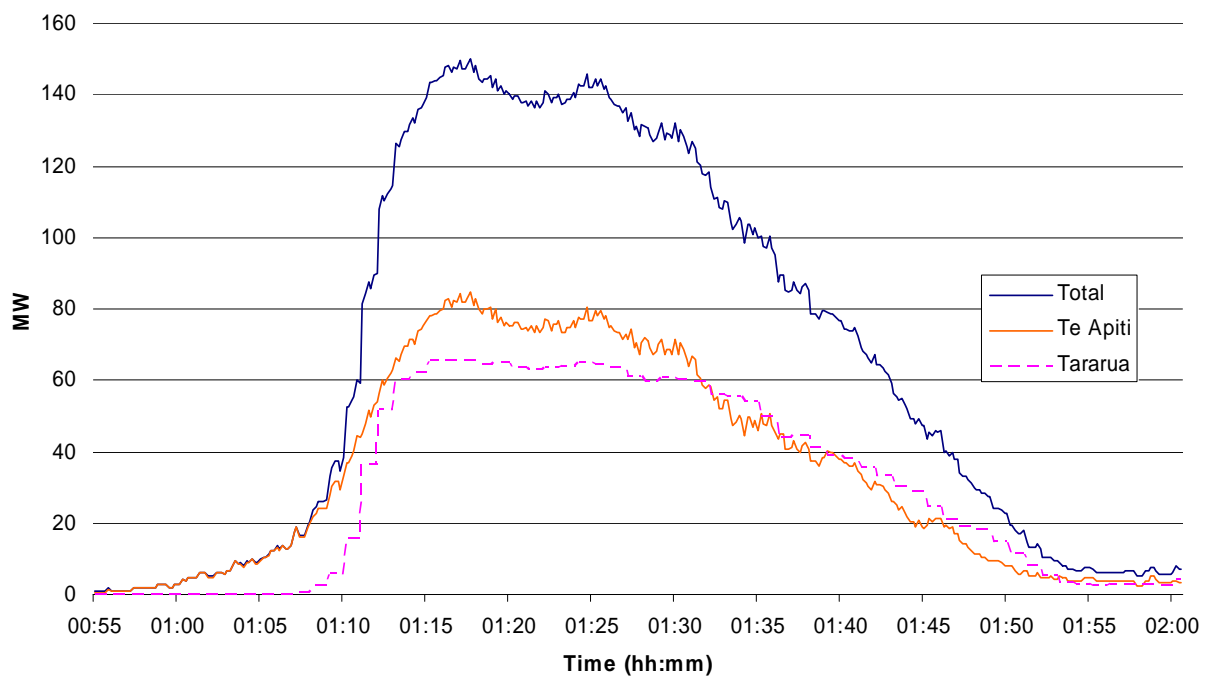


Figure 3.4.2d

Impact of Manawatu wind generation on the scheduling and dispatch processes

Figure 3.4.2e shows the rate of change per minute during the event on 15 November. The rate of change is jagged because the series is a 60-second difference sampled every 10 seconds but Tararua supplies only a 60-second average which is repeated every 10 seconds.

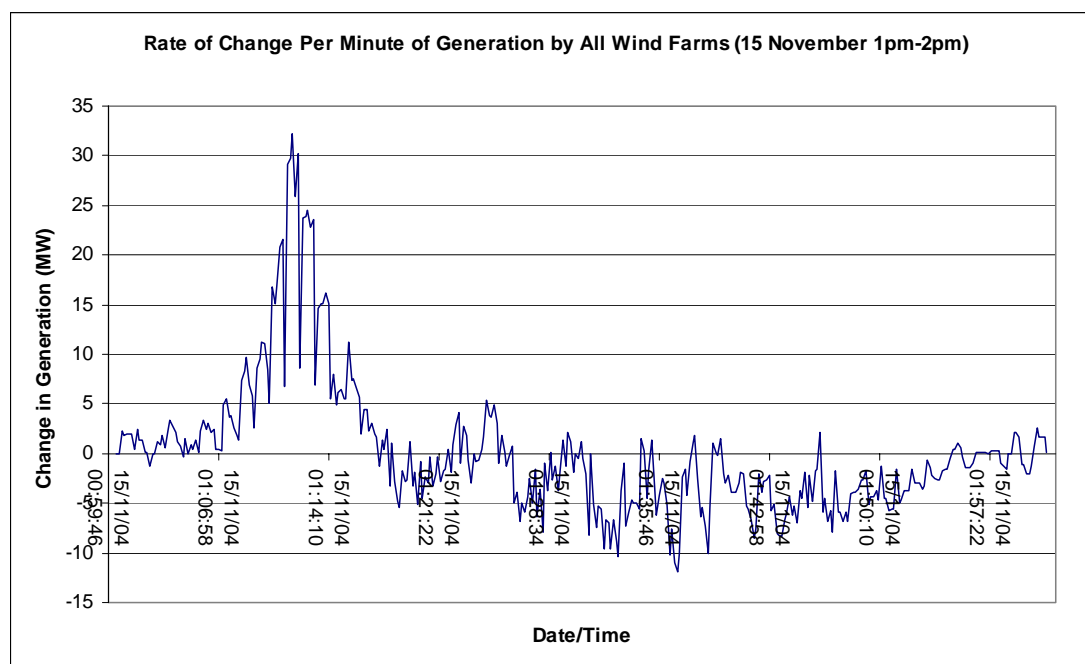


Figure 3.4.2e

During the event, the combined wind generation increases from near 0 MW to 150 MW in about 17 minutes, an average of 8.8 MW per minute. During this time the combined output rises at a maximum ramp rate of 32.2 MW per minute and exceeds 10 MW per minute for about 6 minutes. This exceeds the ramp rate required of a frequency regulating reserve service provider⁷, which means the frequency regulating reserve provider may struggle to keep up with the sudden increase in wind farm output during an event such as this.

In the observed event, wind generation output increased by more than twice the quantity of frequency regulating reserve dispatched (50 MW) in a five-minute period⁸. This required the frequency regulating reserve provider to reduce its output to keep the power system in balance and for the System Operator to dispatch other plant to return the frequency regulating reserve provider to its dispatch set point. However, the new dispatch took a few minutes to have the desired effect, during which time the HVDC and generator governors responded to lessen the resulting increase in system frequency.

The ramp down to zero observed in Figure 3.4.2d is more gradual. It occurs between 1.30am and 2.00am at a maximum (down) ramp rate of 11.9 MW per minute. The rate of change does not exceed 10 MW per minute for more than a one minute so would not (by itself) create a problem for the dispatcher.

⁷ Clause 79.1 of the Procurement Plan 2004/05

⁸ Five-minutes is chosen because it is the usual dispatch period

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The rate of change per minute for the individual wind farm sites is summarised in Table 3.4.2a (below).

Maximum rate of one minute change for each of the wind generation series	
	Both Wind Farms
Max rate of increase per minute (MW)	32.2
Max rate of decrease per minute (MW)	11.9
Number of minutes rate of increase is >10 MW	6
Number of minutes rate of decrease is >10 MW	1

Table 3.4.2a

3.4.3 Implications

A mismatch between generation and load on the power system will cause the power system frequency to rise or fall. These mismatches occur constantly as demand on the power system is constantly varying. The resulting changes in power system frequency must be managed. In New Zealand, frequency is managed by the dispatch of generating units to provide frequency regulating reserve (FRR).

The frequency regulating reserve provider changes its generation output to match changes in demand and generation on the power system. The physical characteristics of generating units providing frequency regulating reserve limit how fast the frequency regulating reserves provider can change output in response to changes in frequency.

On at least one occasion, the rate of increase exceeded the capability of the frequency regulating reserve provider to change its output in response. Other generating plant and the HVDC link acted automatically to contain the increase in power system frequency until generation could be re-dispatched by the System Operator's power system coordinators.

A 100 MW increase in five minutes is twice the rate of the least-capable frequency regulating reserve provider and double the quantity of frequency regulating reserve dispatched. If the amount of installed wind generation in the Manawatu region were to double, it is likely that increases in wind generation output of over 200 MW in five minutes will be observed. Changes of this speed and magnitude would exceed the capability of most frequency regulating reserve providers and the ability of the coordinator to re-dispatch in time to prevent a sizeable frequency excursion.

The likely outcome is an increase in the number of frequency excursions outside the normal frequency band. The Principal Performance Obligations set out in Part C of the Electricity Governance Rules have targets for the numbers of frequency excursions outside specified bands. These targets were set to reflect historical (i.e. from a time before the connection of significant amounts of wind generation to the power system) rates of occurrences of frequency excursions. Increased Manawatu

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wind generation will affect the System Operator's ability to meet the Principal Performance Obligations.

As an interim measure, the System Operator will review the procurement of frequency regulating reserve in light of the findings in this report. Changes to the capability requirements that frequency regulating reserve providers must meet are possible (potentially reducing the numbers of providers), as is an increase in the amount of frequency regulating reserve procured. These changes are likely to increase the costs of the frequency regulating reserve ancillary service.

3.5 Power system capability limits

3.5.1 Introduction

The sudden increase in generation output in the lower North Island combined with a reduction in generation output at the frequency keeping station causes a change in power flow within the transmission grid. This change in power flow has the potential to cause transmission circuits to exceed their stated rating until re-dispatch of generation occurs.

The sudden decrease in generation output in the lower North Island would produce power changes in the opposite direction. Such a decrease could occur by either the wind speed suddenly dropping to zero or by increasing to such a level that the wind turbines automatically shut down. While an event of this type was not observed in November and December 2004, a sudden decrease in wind generation output is a concern for System Operators in other power systems.

As part of operating the power system, the System Operator determines power system capability limits. Operating the power system outside these limits will cause assets to exceed their stated capabilities or quality targets not to be met during contingent events on the power system. A sudden change in generation output during a contingent event could cause assets to exceed their stated capabilities if a suitable margin is not provided for in asset ratings or in power system capability limits to accommodate such a change.

Because of its location the variability of Manawatu wind generation has the potential to impact on power transfer:

- To the South Island when the North island is exporting power southwards and across the HVDC link near or at the maximum transmission limits into the South Island
- Northwards into the central and upper North island from the South Island when near the limits of transmission circuits in the lower and central North Island

3.5.2 Sensitivity factors

An increase in Manawatu wind generation output and a decrease in generation elsewhere (at the frequency keeping station) cause power flows on circuits to change. The amount of change can be expressed as a sensitivity factor. For example, assume the sensitivity factor for the Bunnythorpe-Tokaanu 220 kV circuits

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is 0.2. An increase of 100 MW in Manawatu wind generation output will cause power flow on the Bunnythorpe-Tokaanu 220 kV circuits to increase or decrease by 20 MW. If power was flowing north from Bunnythorpe to Tokaanu, the loading on the Bunnythorpe-Tokaanu circuits will increase by 20 MW. If south flow was occurring, the loading on the Bunnythorpe-Tokaanu circuits will decrease by 20 MW.

Sensitivity factors are a function of grid configuration. The loss of a transmission circuit changes the grid configuration and the sensitivity factors. Circuits will have different sensitivity factors for different contingent events. In order to determine whether circuits will exceed stated capabilities during contingent events with a sudden increase in Manawatu wind generation, the contingent event causing the largest sensitivity factor is analysed for each circuit.

The largest sensitivity factors for key circuits and the contingent events that cause the largest sensitivity factor are shown in Table 3.5.2a.

Circuit	Contingent Event	Sensitivity factor ⁹
Bunnythorpe-Tokaanu 1 and 2	Loss of the parallel Bunnythorpe-Tokaanu circuit	0.29 (Taranua generation) 0.27 (Te Apiti generation)
Bunnythorpe – Woodville 1 and 2	Loss of the parallel Bunnythorpe-Woodville circuit	0.82 (Te Apiti generation) ¹⁰
Brunswick -Stratford1, 2 & 2	Loss of the parallel Bunnythorpe – Stratford circuit	0.16 (Te Apiti generation) 0.17 (Taranua generation)
Tokaanu – Whakamaru 1 & 2	Loss of the parallel Tokaanu – Whakamaru circuit	0.34 (Te Apiti generation) ¹¹ 0.36 (Taranua generation)
Bunnythorpe – Brunswick 1 & 2	Loss of the parallel Bunnythorpe – Brunswick circuit	0.3 (Te Apiti generation) 0.34 (Taranua generation)

Table 3.5.2a - Circuit sensitivity factors to Manawatu wind generation

3.5.3 Changes in power flow

To determine whether the rapid increases in Manawatu wind generation will affect power system capability limits, two generation patterns are considered:

- Maximum HVDC North transfer and minimum Wellington regional demand
- Maximum HVDC South transfer and peak Wellington regional demand

3.5.3.1 Maximum HVDC North transfer and minimum Wellington regional demand

⁹ The circuits have different sensitivities for Taranua and Te Apiti wind generation.

¹⁰ These lines are not sensitive to Taranua generation due to the location in the network

¹¹ These sensitivities do not take into account the Tokaanu bus splitting scheme which will reduce the loading post contingency by splitting the Tokaanu bus and redistributing some of the power down to Bunnythorpe.

220kV Circuits between Haywards and Bunnythorpe

The power system capability limit to avoid voltage instability for transfer from Haywards for North transfer is 1140 MW (assuming all reactive plant at Haywards is in service). The critical contingency in this case is the Bunnythorpe-Haywards 3 circuit. The section of 220 kV circuit between Bunnythorpe and Haywards that is most sensitive to changes in Tararua wind generation is the section between Linton and Bunnythorpe.

The Bunnythorpe-Linton section of the Bunnythorpe-Haywards 3 circuit is capable of accommodating a sudden increase in Tararua wind generation from zero to existing maximum output following the outage of the Bunnythorpe-Haywards 3 circuit even with North transfer at the power system capability limit of 1140 MW.

220kV Circuits north of Bunnythorpe

Power system capability limits on transfer from Bunnythorpe to the North are required to avoid assets exceeding stated capability during contingent events. Power transfer north from Bunnythorpe is dependent on the amount of Manawatu generation, HVDC North transfer and Wellington and Palmerston North regional demand.

At times of low Wellington and Palmerston North regional demand and HVDC North transfer, there will be power transfer north from Bunnythorpe. An increase in Manawatu wind generation at this time will increase the loading on the 220 kV circuits going north from Bunnythorpe.

The sensitivity of the Bunnythorpe-Tokaanu circuits (during the loss of the parallel circuit) to Manawatu generation is around 0.28. An increase in Manawatu wind generation by 100 MW in five minutes will cause the loading on the Bunnythorpe-Tokaanu circuits to increase by 28 MW.

Implications

Power transfer north of Bunnythorpe is affected by sudden changes in Manawatu wind generation. The System Operator will be consulting with the Grid Owner on the implications for asset ratings. Power system capability limits will be reviewed in light of any revised asset ratings in the near future.

3.5.4 Maximum HVDC South transfer and high Wellington regional demand

The circuits that determine the power system capability limits for HVDC South transfer are the Brunswick-Stratford circuits in summer (following the outage of a parallel circuit) and the Bunnythorpe-Haywards circuits 1 and 2 in winter (following the outage of the Bunnythorpe-Haywards 3 circuit). The need to avoid loading on

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these circuits exceeded stated capability during contingent events requires limits on the combined HVDC South transfer and Wellington Regional load. The HVDC link has a stability limit of 626 MW South transfer.

The sensitivity factor of the Brunswick–Stratford circuits to Manawatu wind generation is around 0.16. A 100 MW change in Manawatu wind generation will cause the loading of the remaining Brunswick-Stratford circuits (following the outage of one of the parallel circuits) to change by 16 MW. An increase in Manawatu generation will reduce the loading on the Brunswick-Stratford circuits by 16 MW. However, a decrease in generation of 100 MW will cause the loading on the Brunswick-Stratford circuits to increase by 16 MW.

The sensitivity of the Bunnythorpe-Hayward 1 and 2 circuits to Manawatu generation is very small and changes in generation do not have a material impact on the circuits' loading.

3.5.5 Implications for power system capability limits

The HVDC South transfer limits are affected by sudden changes in Manawatu wind generation. The System Operator will be consulting with the grid owner on the implications for asset ratings. Power system capability limits will be reviewed in light of any revised asset ratings in the near future.

Appendix 1: Data series used in the study

This section describes the series used in study.

(a) Wind Generation output data used in this study

The study used 10 second SCADA output data from Te Apiti and Tararua North and South Wind Farms for November 1–28 and December 2004. For most analyses the generation data from these three series was combined to form a 10 second total wind generation series.

Name	Abbreviation	Unit
Te Apiti Wind Generation	TAP	MW
Tararua North Wind Generation	TWN	MW
Tararua South Wind Generation	TWS	MW

Table A.1

The Tararua generation data is collected in 10 second samples. However, each generation value is repeated 5 times. We understand that the data is actually being provided from one minute average SCADA values. The graph below is typical of the output at Tararua wind farm during the period.

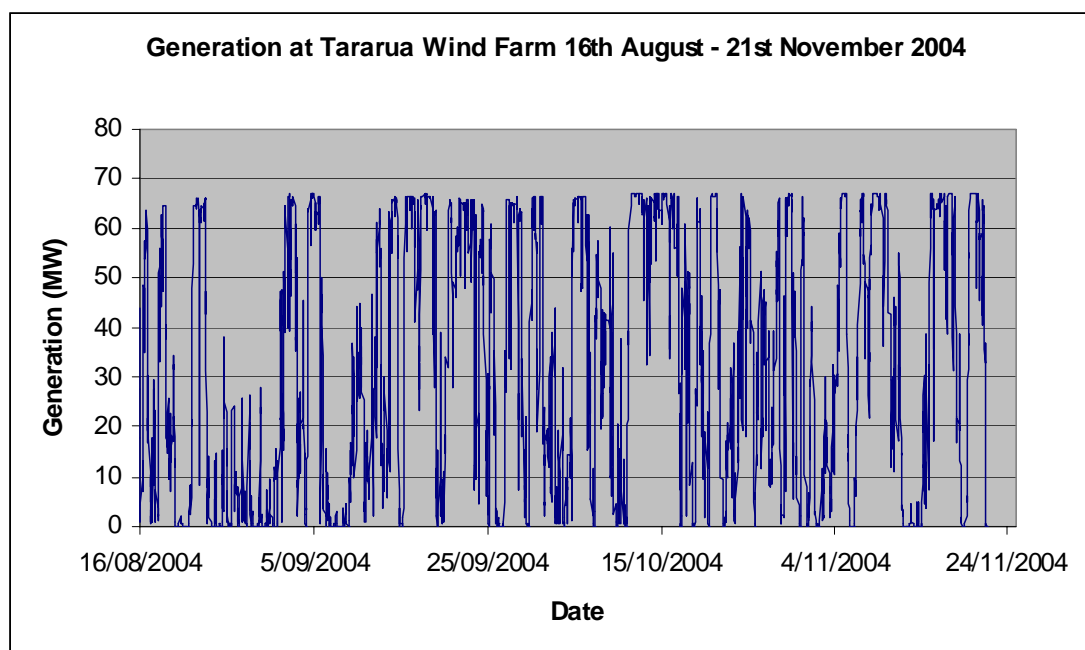


Figure A.1

Te Apiti has been progressively commissioned since July 2004 and was at full generating capacity by early November 2004. However, post commissioning tests have been running throughout November. This has resulted in several outages that have affected generation. The graph below shows the gradually increasing capacity of Te Apiti wind farm between August and November 2004.

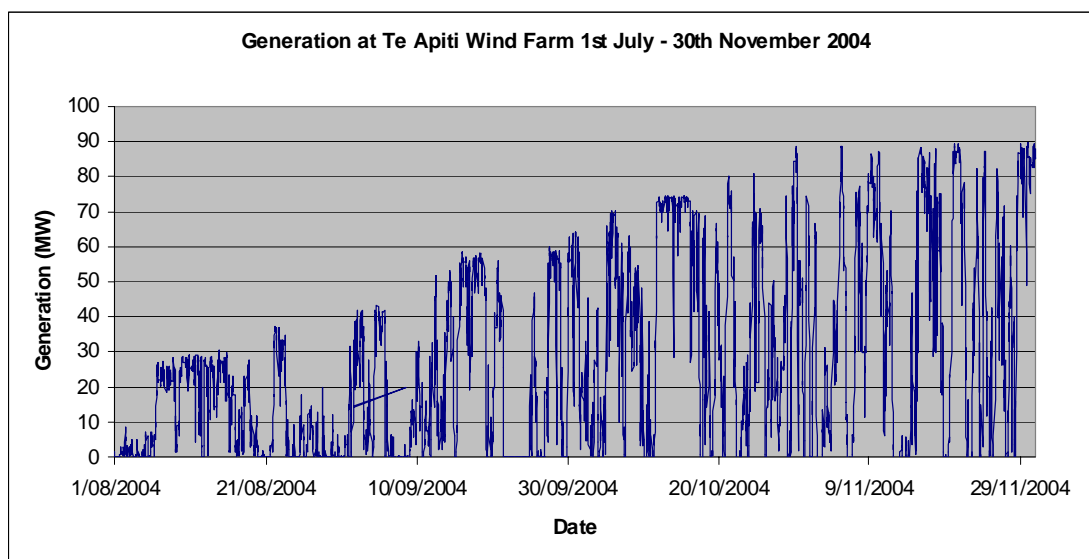


Figure A.2

(b) Meridian offers of Te Apiti generation used in section 3.2

Meridian offers Te Apiti generation to the market. The Te Apiti offers at 12, 6 and 2 hours prior to the current trading period for November 2004 were analysed in this study. Offers are half-hour averages. These offers were compared with metered generation at Te Apiti for the same half-hour.

(c) Dispatch instructions for Te Apiti wind farm used in section 3.2

Dispatch data is only available for Te Apiti because Tararua Wind Farm is not dispatched. The dispatch data used is one-minute averages for the month of November. This was compared with the generation data for Te Apiti, which was also averaged over one-minute intervals.

(d) NZ load forecasts used in section 3.2

The NZ forecast load (includes conforming and non-conforming load) at 2, 6 and 12 hours prior to the current trading period for November and 1-24 December 2004 was also used in this study. The forecast load values are half-hour average load figures, as sourced from the load forecast application. This application uses historic load data and weather forecast data to produce load forecasts.

One series created comprises the New Zealand load forecast (including Palmerston North) and less Te Apiti offered generation. This series includes the influence of both the Tararua and Te Apiti wind farms.

The other series comprises New Zealand load forecast values less Palmerston North area. This series excludes the influence of Te Apiti and Tararua wind farms.

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The two-series used in section 3.2 were thus:

- NZ forecast load without the influence of Te Apiti and Tararua wind farm generation, and
- NZ forecast load including the influence of Te Apiti and Tararua wind farm generation.