Effect of unpredictability of wind generation output on pre-dispatch processes

INVESTIGATION 1 – PART A

WIND GENERATION INVESTIGATION PROJECT
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Executive Summary

Introduction

The Electricity Commission 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 a large volume of 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

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.

Transpower has been engaged by the Electricity Commission to undertake some of the nine investigations. This report documents Investigation One which aimed to identify the potential effects of variability of wind generation output on pre-dispatch processes for increased amounts of wind generation connected to the New Zealand power system.

Pre-dispatch processes

Generation is scheduled on the New Zealand power system on the basis of offers made by generators. Generation is scheduled for the day ahead against a forecast of load and pre-dispatch schedules for generation are published. These schedules provide information about the price and quantity of generation output for the day ahead. Generators can revise their offers up until “gate closure”, which is two hours prior to dispatch, after which time offers can only be revised for specified reasons.

Generation with variable output such as wind generation has a limited ability to forecast its future output as this depends on the resources available at the time (i.e. the prevailing wind in the case of wind generators). Offers made by wind generators cannot be relied upon to the same extent that offers made by other forms of generation can be relied upon. The current arrangements make provision for wind generators to provide a forecast of output in place of the quantity component of their offers.

Wind generators provide updated forecasts of future output for the period from day ahead until dispatch. For the period between gate closure and dispatch, the EGRs require that a persistence forecast methodology is used. Forecasts of wind generation output include some degree of error, i.e. there will be a difference between what was forecast and what was actually produced. Load forecasts also have errors. Forecast errors can result in too little or too much generation being scheduled relative to what is required in real time. Forecast errors can impact upon power system security and economic efficiency.

The scheduling processes include a check that sufficient generation has been offered to meet system demand. Forecast errors in wind generation output can lead to situations where a future generation shortfall is not identified (as more wind generation output is forecast than will be produced) or situations where a shortfall is falsely identified (as less wind generation output is forecast than will be produced).

Checks are made on the pre-dispatch schedules to ensure that the power system will be secure for the generation dispatched within the schedule. The checks determine that circuits will not exceed ratings and that system voltages will remain within target ranges during and following contingent events (e.g. loss of transmission circuits or generating units). The security check will indicate areas of the grid where there is insufficient transmission capacity or local generation offered to meet local demand.

Forecast errors will affect the accuracy of the security check. For example, a pre-dispatch schedule (incorporating a certain wind generation output forecast) may indicate that no transmission circuits will exceed ratings for a contingent event. If wind generation output in a region is lower than forecast requiring the transmission system to meet the shortfall. The loading on transmission circuits will be higher at dispatch potentially leading to the loading exceeding rating during contingent events.

It should be noted that there are errors in the load forecast that affect power system security in the same manner as wind generation forecast errors. The nature of this load forecast error may be somewhat more predictable than wind forecast error and the scheduling and dispatch processes are designed to cope with this error. Further discussion on this is included later in the report.

Assumptions and approach

The WGIP has identified nine areas for investigation. The potential impact in each area has been assessed through screening analyses. The approach taken during the screening analyses was to determine, for a worst case credible situation in terms of potential effects upon the power system, 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. If the "worst case credible" situation shows no significant effects then further analysis is not required.

This investigation has been separated into two parts. This report deals with the first part. A second report which covers the second part will be published later.

Part A

The objective of the first part is to identify which parts of the pre-dispatch processes will be affected by wind generation forecast error.

Garrad Hassan [2] has calculated probability distribution functions for wind generation forecast errors and load forecast errors for the Electricity Commission's Wind Generation Development Scenarios. The calculated probability distribution functions are used to assess the effect of wind generation forecast error in scheduling processes.

The probability distribution functions calculated by Garrad Hassan are statistically reliable only for events with return periods of up to a week. This arises from the limited amount of historic data underlying the analysis. Subsequent comment in this report on implications of wind generation forecast error on the scheduling tools and process is based on consideration of the likely impact of expected daily and weekly forecast errors only. Power system security is concerned with the potential impact of events that may occur annually, or even less frequently, if outcomes would be significant. Therefore further work is recommended to better understand the possible size, rate of occurrence, implications and mitigation for potentially larger but less frequent forecast errors.

The methodology used to analyse the impact of wind generation forecast error on scheduling processes was to:

1. Identify which scheduling processes are affected by variability in wind generation offers;
2. Discuss the effects of predicted wind generation forecast error on the scheduling processes and tools;
3. Use case studies to illustrate the effect of wind generation forecast error on scheduling; and
4. Identify and recommend further areas for investigation in Part 2.

Part B
The objective of the second part is to quantify (where possible) the effects of wind generation forecast error.

Effect of wind generation forecast error on pre-dispatch processes

The unpredictability of wind generation output means that wind generation offer quantities based on wind forecasts can contain a sizable error (i.e. the difference between the forecast output and actual output). Garrad Hassan [2] has calculated wind generation forecast errors for the Electricity Commission's wind generation development scenarios. The 23 hour, 12 hour and 6 hours forecasts are based on a meteorological model. The 2 and 3 hour forecasts are based on a persistence model.
A review of the processes and tools used by the System Operator to schedule generation identified wind generation forecast error would affect the following:

- *Security Assessment*. The security assessment is part of the scheduling process. The security assessment determines for a generation schedule whether any asset will be overloaded or grid voltages will be outside the target range following the occurrence of a contingent event.
- *Standby Reserves Check.* The Standby Reserves Check determines whether sufficient generation and reserves have been offered but not dispatched to allow Sustained Instantaneous Reserves[1] to be restored within 30 minutes following the loss of the largest generating unit.
- *The Scheduling, Pricing and Dispatch model (SPD)*. This application determines the most economic dispatch of the offered generation to meet the forecast load, taking into account security constraints and

[1] Once a generating unit has been lost (i.e. a contingent event has occurred), Sustained Instantaneous Reserves will be used to make up for the loss of generation until generation and reserves can be re-dispatched. Until such time as re-dispatch of generation and reserves occurs, the power system will have a reduced amount of SIR reserves which may not be sufficient to cover a second contingent event.

instantaneous reserves requirements. The application produces a number of generation schedules using a variety of different inputs over different timeframes.

- *Reserves Management Tool (RMT)*. This application calculates the amount of fast and sustained instantaneous reserves required to meet quality targets during under frequency excursions caused by the loss of a large generating unit or the HVDC link.

The security assessment and standby reserves check processes will need to be reviewed and possibly re-designed to accommodate the effects of larger amounts of wind generation forecast error. Wind generation forecast error will likely become the dominant source of error in the security processes within the next 2-3 years.

No changes to the SPD and RMT tools to accommodate larger amounts of wind generation have been identified. It is noted changes to the manner in which instantaneous reserves are procured may be required when the loss of a wind farm potentially sets the reserves requirement. The North Island risk is generally set by a thermal plant, at over 300 MW, and the South Island risk by a hydro unit at about 130 MW

Findings and recommendations

Wind generation forecast errors predicted in the Garrad Hassan report will affect the processes and tools used by the System Operator to schedule generation on the New Zealand power system. This leads to the conclusion that wind generation forecast error will become the main source of error in the scheduling processes for the North Island once the total installed wind generation capacity in the North Island exceeds around 370 MW. This is likely to occur within the next 2-3 years. Scheduling tools and processes will need to be reviewed and redesigned to accommodate large amounts of wind generation.

Increased amounts of wind generation connected to the New Zealand power system will reduce the System Operator’s ability to meet the Principal Performance Obligations. The error in wind generation output forecasts will affect the ability of the System Operator to identify, and participants to respond, to security issues and will increase the amount of issues wrongly identified or not identified. The System Operator will need to implement revised processes in scheduling generation to ensure that power system security is maintained.

It is recommended that:

- The issues around the effects of wind generation on the scheduling of generation are given a high priority for the next stage of the Wind Generation Investigation Project;

- The accuracy of wind generation forecasts is likewise made a priority for the Wind Generation Investigation Project;
- Further analysis of large but infrequent wind generation forecast errors should be carried out for Part B of this investigation; and
- Further analysis around the temporal nature of the wind generation forecast error. This should include security assessment and standby reserves check and be included in Part B of this investigation.

1. Introduction

1.1 Background

The Electricity Commission 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 a significant volume of wind generation.

Nine areas where wind generation may affect the operation of the New Zealand power system and electricity market were identified for investigation (see Figure 1). This report relates to Investigation 1: Effect of unpredictability of wind generation output on pre-dispatch processes.

Transpower has been engaged by the Electricity Commission to undertake an investigation into the impact of connecting a large volume of wind generation (as envisaged in the wind generation development scenarios) upon the scheduling processes and tools used by the System Operator. This investigation is based on the expected unpredictability stated in the Garrad Hassan Report.

1.2 Purpose

The purpose of this study described in this report is to carry out an initial screening of the effects of variability of wind generation output upon the System Operator's scheduling processes and tools and, where necessary, to recommend further investigations in this area.

1.3 WGIP approach

The WGIP has identified nine areas where the variability of wind generation output or the technical 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 preliminary analysis.

The approach taken during the preliminary analysis was to determine for a worst case credible scenario where the impact of wind generation would create stresses for operation of the power system or electricity market during the next 10 years. If the worst case credible scenario shows no significant effects then further analysis is not required.

The size and urgency of the impacts of wind generation determined during the preliminary analysis will allow the issues to be prioritised for attention in the next phase of the WGIP. 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.

The assumptions specific to this investigation have been made so as to be consistent with the general approach of the WGIP, and are discussed in section 3.

2. Background

2.1 Scheduling generation

The New Zealand wholesale market design includes offer-based merit order dispatch using locational marginal pricing (nodal pricing) to determine the overall lowest cost secure dispatch solution. Nodal pricing includes both losses and congestion. The model co-optimises the dispatch of energy and reserves. Reserves are procured sufficient to cover the loss of the single largest generating unit.

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).

The System Operator is required to meet two objectives in scheduling generation on the New Zealand power system:

- The Principal Performance Obligations (PPOs).[2] The PPOs require the System Operator to act as a reasonable and prudent system operator with the objective of dispatching assets made available in a manner which avoids the cascade failure of assets resulting in the loss of demand that arises as a result of frequency or voltage excursions or supply and demand imbalances.
- The dispatch objective.[3] This requires the System Operator to maximise for each half hour the gross economic benefits to all purchasers of electricity at the grid exit points less the costs of supplying the electricity at the grid injection points and the costs of ancillary services purchased by the system operator, subject to the information and offers available to it, and to some defined quality considerations.

The means and procedures by which the System Operator intends to meet the PPOs and the dispatch objective are set out in the Policy Statement.[4] The System Operator has a suite of operational processes and tools which implement the means and procedures in real time.

2.2 Scheduling processes and tools

Generation scheduling in the New Zealand electricity market is based on security constrained economic dispatch. At a high level, the process is quite simple:

- Generators submit energy and reserves offers for the day ahead.
- Purchasers submit load bids.

[2] Section II of Part C of the EGRs
[3] Rule 2 of Section III, Part G of the EGRs
[4] The Policy Statement is contained in Schedule C4 of the EGRs

- The System Operator runs processes to produce schedules of cleared generation (energy and reserves) required to meet the forecast load.
- Generators and Purchasers can revise their offers and bids until two hours before dispatch.

2.2.1 Generation Offers

Generation is scheduled on the New Zealand power system on the basis of offers made by generators. Generation is scheduled for the day ahead against a forecast of load and pre-dispatch schedules for generation are published. These schedules provide information about the price and quantity of generation output for the day ahead. Generators can revise their offers up until "gate closure", which is two hours prior to dispatch, after which time offers can only be revised for specified reasons.

Generation with variable output such as wind generation has a limited ability to forecast its future output as this depends on the resources available at the time (i.e. the prevailing wind in the case of wind generators). Offers made by wind generators cannot be relied upon to the same extent that offers made by other forms of generation can be relied upon.

The EGRs require wind generators to offer in a manner different to other generation. Offer price is limited to either $0 or $0.01 per MWh. Wind generators are required to offer into the electricity market in a manner different to other generators.

Wind generators provide updated forecasts of future output for the period from day ahead until dispatch. For the period between gate closure and dispatch, the EGRs require that a persistence forecast methodology is used. Forecasts of wind generation output include some degree of error, i.e. there will be a difference between what was forecast and what was actually produced. Load forecasts also have errors. Forecast errors can result in too little or too much generation being scheduled relative to what is required in real time.

2.2.2 Load Bids

Purchasers bid load into the electricity market for the coming day. Collectively, these bids are effectively a forecast of load for the day ahead, and represent load in the calculation of pre-dispatch prices and quantities. Errors in the bids (i.e. the difference between the bid and the actual load during dispatch) will cause there to be differences between pre-dispatch and final prices.

An alternate load forecast is produced by the System Operator for use in its power system security checks. This central load forecast takes into account both purchaser bids and historic demand patterns.

2.2.3 *Process*

Figure 2 shows an overview of the process. Forecasts of dispatch prices and quantities are published, together with security notices (in the event that a potential shortfall of generation or transmission capacity is identified).

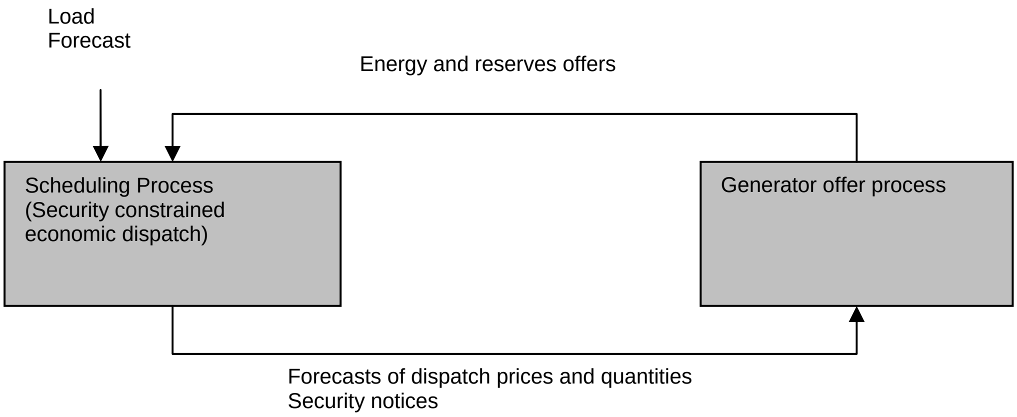

Figure 2 - Scheduling Process overview

This report considers the impact of wind generation forecast error upon the scheduling process carried out by the System Operator. It does not consider how generators' offering strategies might change as a result of increased unpredictability due to growth in wind generation.

Figure 3 shows a more detailed representation of the scheduling process. The wind generation forecast is shown separately from the other generation energy and reserves offers. This is to differentiate the nature of variations in the wind generation offer (which is related to changes in the wind) from variations in other generation offers (which are traders' responses to market conditions including published pre-dispatch prices and quantities).

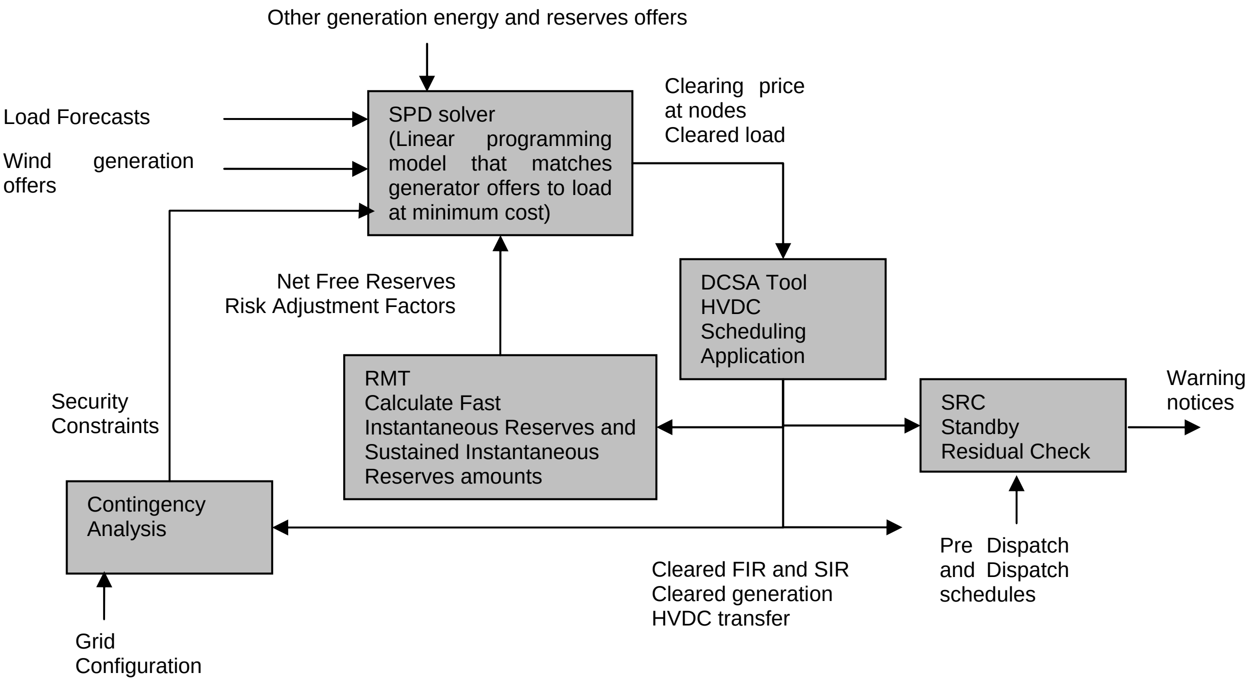

Figure 3: Detailed Scheduling Process

2.2.4 Scheduling Tools

There are a number of market software tools (Figure 3) which interact to determine schedules of generation dispatch:

- Scheduling, Pricing and Dispatch model (SPD). This application determines the most economic dispatch of the offered generation to meet the forecast load, taking into account security constraints and instantaneous reserves requirements. The application produces a number of generation schedules using a variety of different inputs over different timeframes.
- Reserves Management Tool (RMT). This application calculates the amount of fast and sustained instantaneous reserves required to meet quality targets during under frequency excursions caused by the loss of a large generating unit or the HVDC link.
- HVDC Scheduling Application (DCSA). This application automatically applies trading period based half pole configuration constraints. The application aligns the HVDC scheduling with the way the HVDC link is operated in real time.
- Standby Reserves Check Tool (SRC). This tool determines whether there are sufficient generation offers to enable generation and reserves to be restored following the loss of the largest contingent event.

- Contingency Analysis (CA). Currently, this tool is run at least every 6 hours to check power system security based on the cleared generation and central load forecast. Where necessary, security constraints are modified (in the SPD model) to ensure that the power system will be secure following a contingent event.[5]

The Scheduling, Pricing & Dispatch (SPD) tool produces three schedules relevant to this investigation:

1. Pre-Dispatch Schedule (PDS). The PDS specifies expected generation (energy and reserves) dispatch, expected demand, forecast prices for energy and reserves, reserves requirements, reserve offer stacks and HVDC transfer for each trading period in the schedule period. Pre-dispatch scheduling commences at 1300 hours the day ahead of a trading period.
2. Security Dispatch Schedule (SDS). The SDS is an internal System Operator schedule used to assess security. The SDS uses the same inputs as the Schedule of Dispatch Prices and Quantities (SDPQ) but applies to different time periods. A Security Dispatch Schedule (SDS) is produced at least every six hours by the System Operator, from the day ahead of a trading period.
3. Schedule of Dispatch Prices and Quantities (SDPQ). The SDPQ includes arc flows and group constraint formulae, and centrally forecast demand, and is produced only in the 4 hours prior to dispatch.

2.2.5 Effects of load forecast errors and wind generation forecast errors

Load forecast errors and wind generation forecast errors will affect the accuracy of power system security assessments and the accuracy of pre-dispatch schedules. Errors in forecasts many hours ahead of dispatch will have different effects to errors in forecasts close to dispatch.

Errors in forecasts many hours ahead of dispatch will affect the accuracy of the pre-dispatch schedules and this may affect generators' decisions to start or stop plant and result in changes to offers. Some plant may not be offered where the forecasts indicate there is sufficient wind and other generation offered to meet forecast demand. Some plant may be offered in the expectation that dispatch of the plant is likely but end up not being dispatched. This will result in a reduction in economically efficient market outcomes.

Errors in forecasts closer to dispatch may make managing security issues more difficult. Some thermal generating plant can take up to 12 hours to start

[5] The Market System Project, which is developing a replacement for the SPD model, will implement an automatic contingency analysis application which will run more frequently.

from cold. There is a risk that errors in forecasts will cause security issues not to be identified until such a time when it is too late for slow starting generating plant to be brought on to correct the security issue.

It should be noted changes to generation offers and load bids are also a cause of variability in pre-dispatch schedules.

3. Assumptions

3.1 Assumptions specific to this investigation

As a basis for the screening process in this investigation, it is assumed:

- The absolute value of load forecast errors will increase proportionately with load growth.
- The current EGRs apply - no proposed rule changes are considered.
- Wind generation is offered and dispatched as per the present electricity market arrangements.
- The System Operator's current suite of tools and processes used to schedule generation are used. While the System Operator is currently upgrading its tools, it is noted that 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 other than the commissioning of new wind generation.

The effects of unpredictability 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 affects system frequency and occurs once a month may warrant some change to processes and/or tools. The probability, size and management of forecast errors occurring only annually or less frequently will be considered in the second part of this report.

3.2 Wind generation development scenarios

Table 1 shows the location of new and existing wind generation as assumed in the Electricity Commission's wind generation development scenarios (see [1] for further details).

Island[6]	**Scenario A (high penetration, concentrated in the 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	**1150 MW**	**950 MW**	**1600 MW**	**370 MW**
South	**100 MW**	**300 MW**	**650 MW**	**50 MW**

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

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

3.3 Load forecast error

Load forecast error is the difference between the load forecast for a particular trading period and the actual load for the trading period. The System Operator uses its own internal load forecast (the "SO load forecast") for assessing power system security using the SDS. Garrad Hassan [2] has analysed the internal System Operator load forecast errors.

There are a number of factors that can lead to differences between forecast and actual load:

- Unplanned connection or disconnection of load (e.g. the operation of interruptible load during an under frequency event).
- Assumptions in load forecasting that turn out to be incorrect, such as assuming that load on a particular day will be similar to that of another day in the past. Load forecast errors can arise where the nature of demand on the two days is quite different (e.g. one day is a public holiday or atypical weather conditions occurred on one day).
- Errors in inputs to the load forecast algorithm (e.g. forecast weather conditions).
- Timing error for morning and evening peaks (i.e. the peak occurs in a trading period earlier or later than forecast).

Figure 4 and Figure 5 show the calculated load forecast errors from Table 3 of the Garrad Hassan report [2] for the North and South Islands respectively. More detailed tables of the load forecast errors are contained in Appendix 2.

The following points can be noted from Figure 4 and Figure 5:

- The SO load forecast error for the North Island at 23 hours ahead of dispatch is expected to be about 204 MW once each day. This equates to 4-13% of North Island load.[7]
- The SO load forecast error for the North Island at 2 hours ahead of dispatch is around 140 MW once per day, which equates to 3-9% of the North Island load.
- The SO load forecast error for the South Island at 23 hours ahead of dispatch is expected to be about 116 MW once each day. This equates to 5-9% of South Island load.[8]
- The SO load forecast error for the South Island at 2 hours ahead of dispatch is around 80 MW once per day, which equates to 3-6% of the South Island load.
- In summary, SO load forecast errors for the period from day ahead to 2 hours ahead of dispatch are in the range of 3-13% of North Island load, and 3-9% of South Island load, throughout the day.

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[7] North Island load ranges from (approximately) 1,550 MW to 4,500 MW over a day
[8] South Island load ranges from (approximately) 1,300 MW to 2,270 MW over a day.

The effects of the present level of SO load forecast error, which is represented by the data above, are managed within the existing scheduling and dispatch processes and tools. Many of these errors are short timing errors between scheduling periods during the steep increase in early morning load. The effects can be managed by ensuring sufficient generation is available for early pick-up in load.

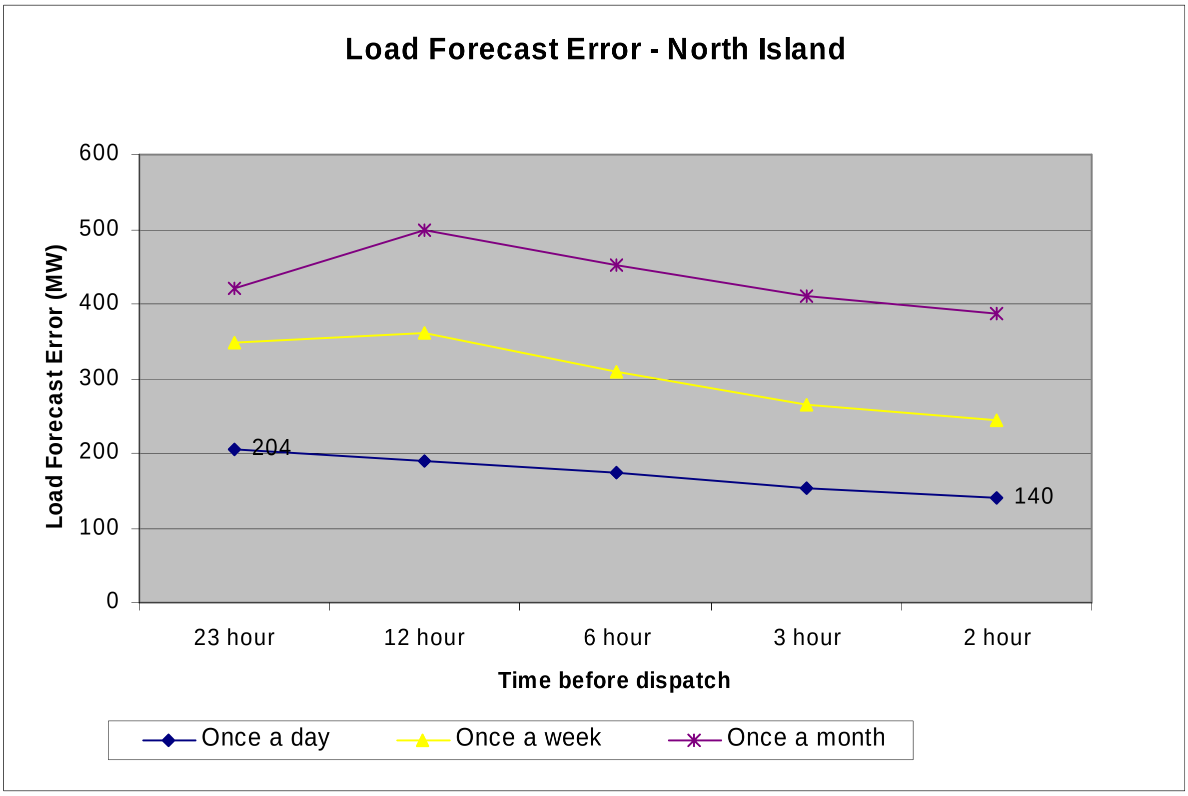

Figure 4 - Load Forecast Error for North Island (adapted from Garrad Hassan Report [2])

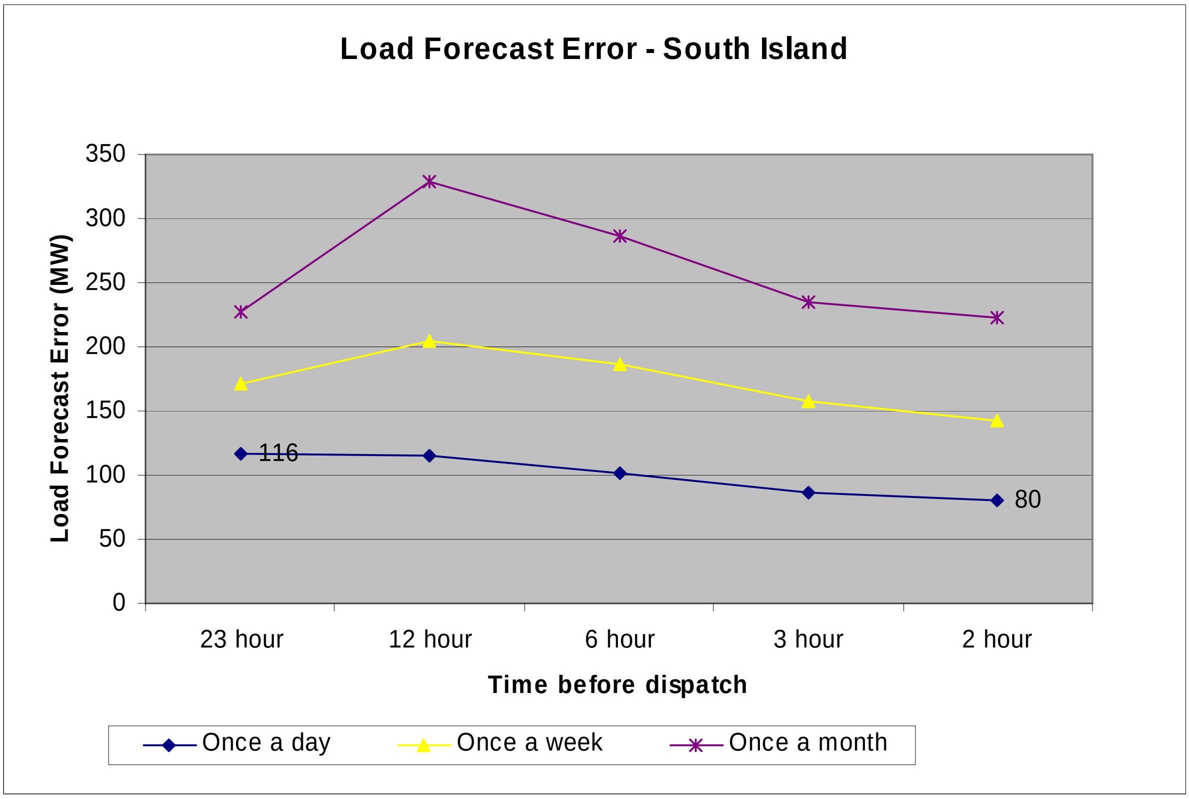

Figure 5 - Load Forecast Error for South Island (adapted from Garrad Hassan Report [2])

3.4 Predicted wind generation forecast error

The unpredictability of wind generation output means that wind generation offer quantities based on wind forecasts can contain a sizable error (i.e. the difference between the forecast output and actual output). Garrad Hassan [2] has calculated wind generation forecast errors for the Electricity Commission's wind generation development scenarios. The 23 hour, 12 hour and 6 hours forecasts are based on a meteorological model. The 2 and 3 hour forecasts are based on a persistence model. Limitations of the analysis are discussed in Section 5.3.

Figure 6 and Figure 7 show wind generation forecast errors for wind generation development scenario C in the North and South Islands respectively. Figure 6 shows that wind generation forecasts for the North Island, 23 hours ahead of dispatch, can be expected to be in error by over 800 MW (50% of installed wind generation capacity in the North Island) once per day.

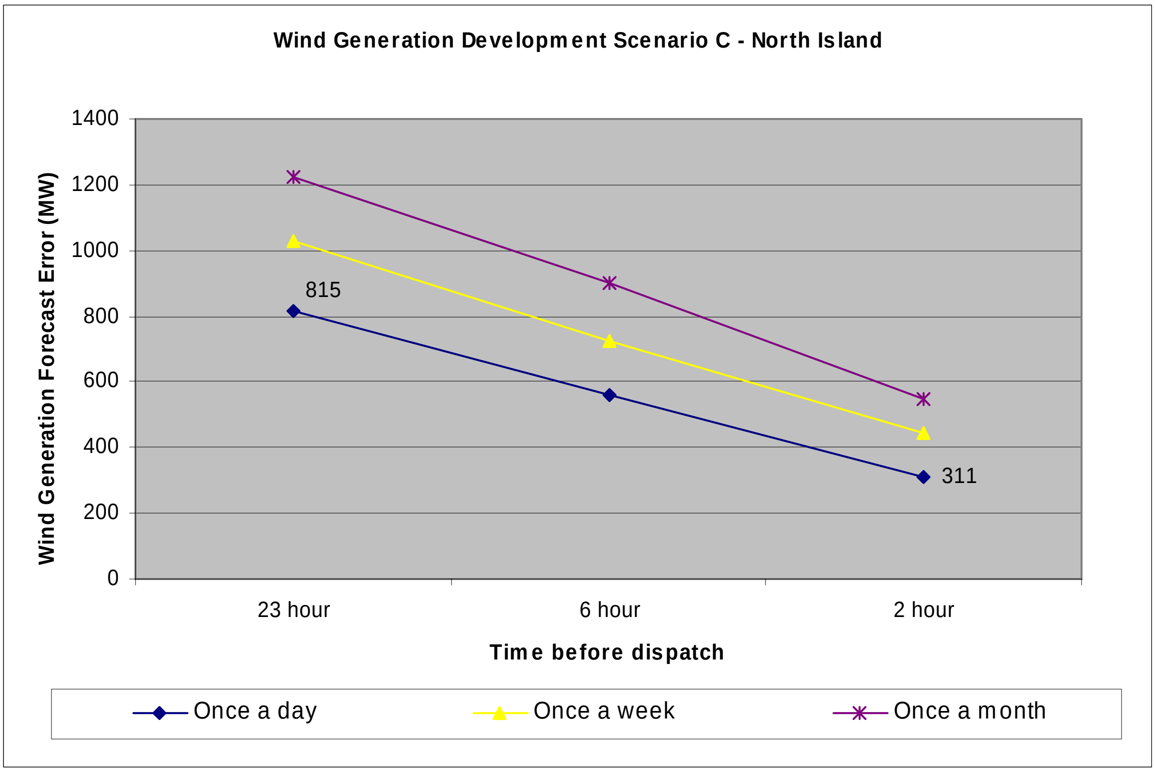

Figure 6 – Wind Generation Forecast Error for North Island (scenario C adapted from Garrad Hassan Report [2])

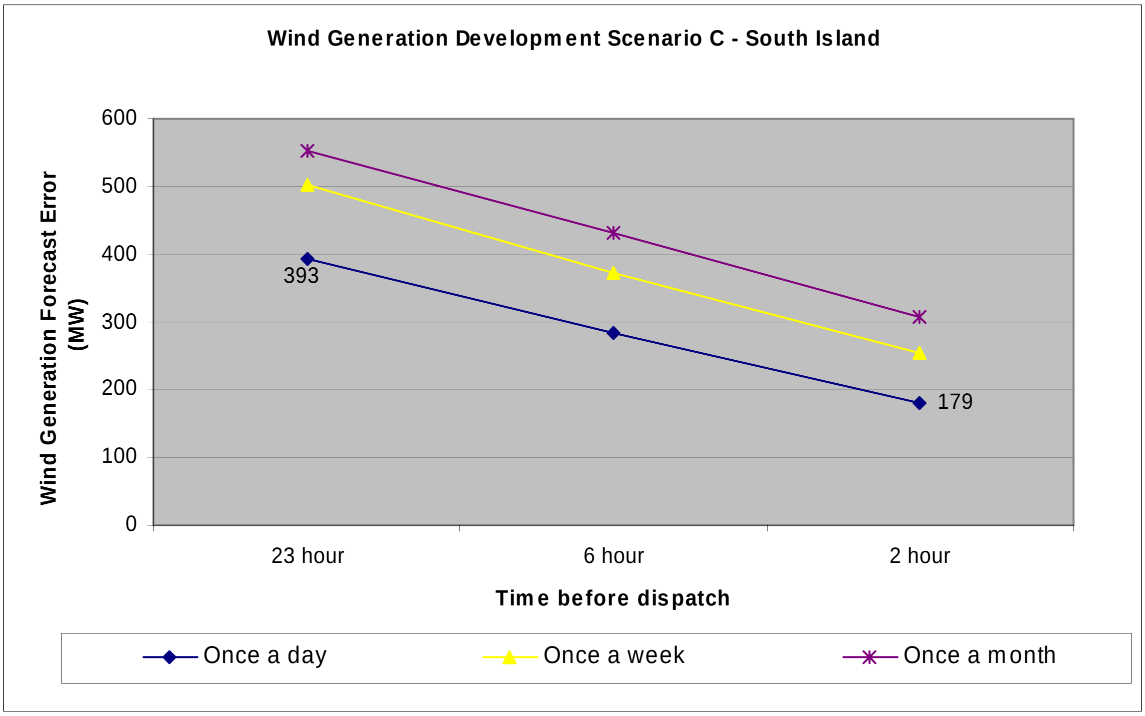

Figure 7 – Wind Generation Forecast Error for North Island (scenario C adapted from Garrad Hassan Report [2])

Once per day wind generation forecast errors for wind generation scenario C are approximately double the load forecast errors for the North Island for the 2 hour forecast, rising to approximately four times greater for the 23 hour forecast. Wind generation forecast errors for the South Island will be more than double the SO load forecast errors in the South Island. The multiples are slightly lower for the once per month forecast.

Figure 8 shows the predicted wind generation forecast errors for all of the wind generation development scenarios and SO load forecast error in the North Island. The wind generation forecast error is greater than the load forecast error for all scenarios except for scenario D (where the wind and load forecast errors are approximately equal). This leads us to conclude that wind generation forecast error will become the main source of error in the scheduling processes for the North Island once the total installed wind generation capacity in the North Island exceeds around 370 MW.[9] This is likely to occur within the next 2-3 years.

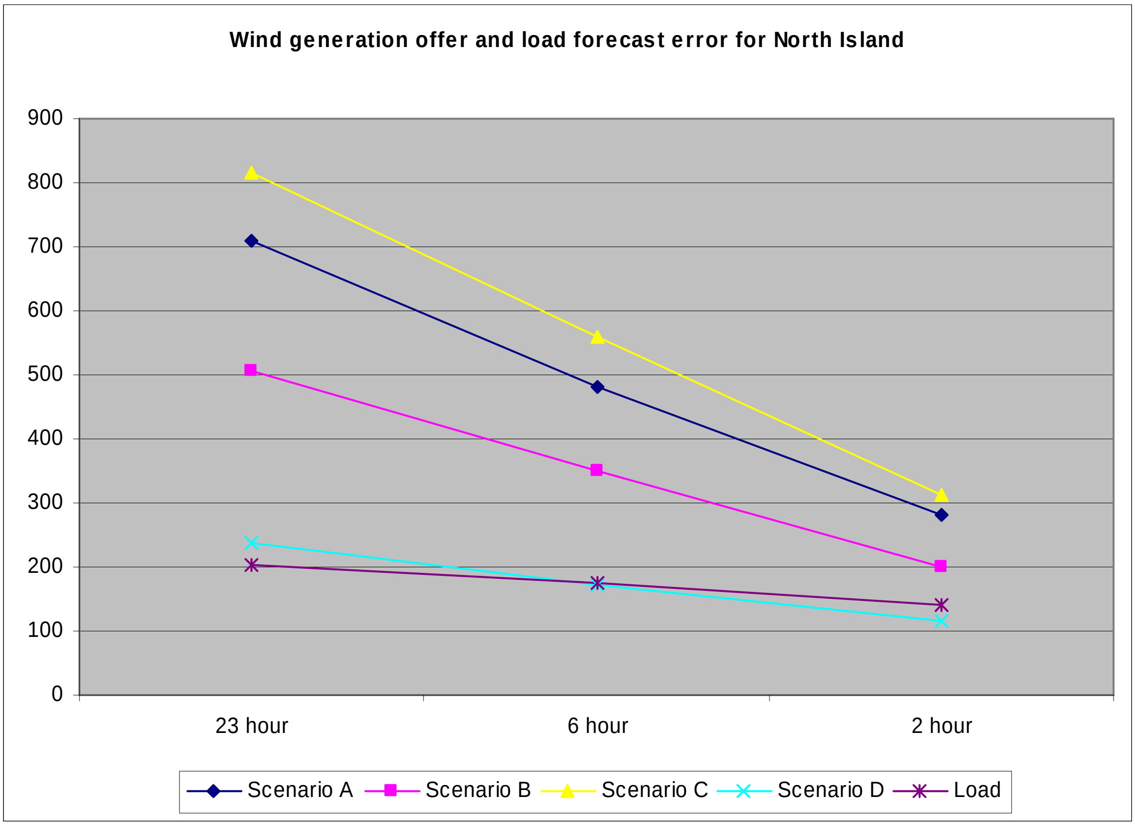

Figure 8: Wind generation forecast and SO load forecast errors for the North Island expected to occur once per day (based on Garrad Hassan [2])

[9] Scenario D includes a total of 370MW of wind generation in the North Island. The amount of installed wind generation capacity in the North Island is currently 170 MW and will rise to 263 MW by the middle of 2007 with the commissioning of Tararua III wind farm. The commissioning of further wind generation in the North Island (which is likely to occur within the next 2 years) is likely raise the total amount to above 370 MW.

4. Effects of wind generation forecast error on scheduling tools and processes

4.1 Methodology

The methodology used to analyse the impact of wind generation forecast error on scheduling processes was to:

1. Identify which scheduling processes are affected by variability in wind generation offers,; and
2. Discuss the effects of predicted wind generation forecast error on the scheduling processes and tools.

The impact of wind generation forecast error on price will not be considered.

The following sections review the impact of wind generation forecast error on the Security Assessment, Standby Reserves Check, and the SPD and RMT models.

The security assessment is part of the scheduling process. The security assessment determines for a generation schedule whether any asset will be overloaded or grid voltages will be outside the target range following the occurrence of a contingent event.

The Standby Reserves Check determines whether sufficient generation and reserves have been offered to allow SIR reserves to be restored within 30 minutes following the loss of the largest generating unit.

4.2 Security Assessment

4.2.1 Process

Generation is scheduled on the basis of offers made by generators and the need to maintain power system security. The scheduling process (SPD and RMT) includes a security assessment for this purpose. A contingency analysis is carried out to assess whether the power system will be secure[10] following the occurrence of a contingent event. The assessment is carried out using cleared generation offers.

The process will identify where there is insufficient generation or transmission capability to meet the forecast load. Once a security issue has been identified, a warning notice is sent to participants (if the issue was identified more than 2 hours before dispatch) or a grid emergency declared (if identified less than 2 hours before dispatch). Participants may revise their offers or bids in

[10] The power system is deemed to be secure following a contingent event if no assets exceed their stated capability and grid voltages are within the quality targets.

response to the warning notice or can be required to take action under Technical code B of Schedule C3 ("Grid Emergencies").

4.2.2 Effect of wind generation forecast accuracy

Significant differences between the cleared generation quantities used in the security assessment and actual generation available at time of dispatch may result in security issues either not being identified in the contingency analysis or being flagged when there is no issue at all at dispatch time.

For example, if wind generation forecasts are higher than the amount of wind generation available at dispatch then the contingency analysis may not flag security issues that will be evident closer to dispatch. This will allow less time for generators, transmission providers, and purchasers to revise their offers or bids, making management of security issues during dispatch more difficult. If wind generation offers are lower than the amount of wind generation that is actually available at dispatch then security issues may be falsely identified in the contingency analysis, and flagged to market participants, though there will be no issue at the time of dispatch.

The effect of wind generation forecast accuracy will be to reduce the System Operator's ability to identify security issues in advance and reduce the time for participants to respond to the issue, potentially leading to an increase in warning notices and participant offer revisions for issues that will not exist in dispatch. A reduction in the time available to respond to security issues means that slow starting plant may not be able to be started in time to respond to any issue. A particular possible effect is where slow starting thermal units are not dispatched but are later required when the forecast wind generation output did not eventuate.

Figure 6 indicates that wind generation forecast errors greater than 550 MW can be expected at 6 hours out to occur once per day, for the North Island, under wind generation development scenario C. Figure 7 indicates that once daily wind generation forecast errors greater than 275 MW can be expected at 6 hours out, for the South Island, under wind generation development scenario C. Assuming that the last contingency analysis is carried out six hours[11] before dispatch, the generation inputs to the contingency analysis can be expected to have these inaccuracies once per day. This level of error is around three times the size of the error in the load forecast.

4.2.3 Implications

In the year to date, the System Operator has issued 15 warning notices and 73 grid emergency notices asking generators to increase generation offers. Some of the notices were updates for the same event. There were 54 events for

[11] Contingency analysis is carried out at least every six hours. The worst case assumption is therefore that the last contingency analysis was carried out six hours before dispatch.

which one or more notices were issued asking generators to increase offered quantities. On average there are 4 to 5 events per month that require the use of warning or grid emergency notices requesting that generators increase their offered quantity.

This issue of sufficient generation offers already requires management on a weekly basis. An increase in the number of potential events or grid emergencies being missed may cause significant operational difficulty. Among the most serious risks is for significant security issues not being identified until such time that slow starting thermal can not be started in time to correct an arising security situation.

The security assessment process will need to be reviewed and possibly re-designed to cope with larger amounts of wind generation output unpredictability. Wind generation forecast error will likely become the dominant source of error in the security processes within the next 2-3 years.

4.3 Standby Reserves

4.3.1 Process

The Standby Reserves process identifies whether there is sufficient energy and reserves offered by generators to allow reserves to be restored following the loss of a large generating unit. The Standby Reserves process will be directly affected by wind generation forecast error:

- The process may incorrectly show that there are sufficient energy and reserves offers based on a forecast of high wind generation output.
- The process may incorrectly indicate that there are insufficient energy and reserves offers based on a forecast of low wind generation output.

When this calculation indicates insufficient energy and reserve offers, a Standby Reserve notice is issued to the market. Standby Reserve notices advise participants of the projected deficit, and the potential implications of the shortfall.

A “Standby Residual Check” (SRC) is performed on the most recent Security Dispatch Schedule (SDS) results. The SDS is currently produced at least every six hours by the System Operator.

4.3.2 Wind generation forecast accuracy

Predicted wind generation forecast errors expected to occur on a daily basis under scenario C are shown in Table 2.

Wind generation forecast Error	6 hours out	2 hours out
North Island	550 MW	300 MW
South Island	275 MW	180 MW

Table 2 - Wind generation forecast errors - once per day (from Garrad Hassan [2])

The North Island 2 hour forecast error is comparable to the size of the larger thermal units in The North Island. The South Island 2 hour forecast error is comparable to the size of the largest unit in the South Island.

4.3.3 Implications

If the last Standby Reserves Check was carried out 6 hours before dispatch, the check would be expected to have an inaccuracy of 550 MW in the North Island and 275 MW in the South Island once per day if wind generation forecasts (based on installed wind generation capacity as in scenario C) are used in the check. These errors are equivalent to about 12% of peak island demand.

For comparison, a standby reserves deficit of 400 MW is likely to mean that there are insufficient offers to meet energy and reserves requirements. Such a deficit is likely to show up in the SDS as infeasibilities.

If the last Standby Reserves Check is carried out 2 hours before dispatch, it can be expected to have an inaccuracy of 300 MW in the North Island and 180 MW in the South Island once a day if wind generation forecasts (based on installed wind generation capacity as in scenario C) are used in the check. These errors are equivalent to about 6% of peak island demand.

All things being equal, the effect of the inaccuracy will lead to unnecessary Standby Reserve notices being issued where wind generation offers are lower than wind generation output in real time and Standby Reserves notices not being issued when offers from wind generation are lower than wind generation output in real time.

The System Operator has issued 9 Standby Reserves notices in the last year.

The Standby Reserves process will need to be reviewed and possibly re-designed to cope with larger wind generation output unpredictability.

4.4 SPD and RMT

4.4.1 Process

SPD determines schedules of generation and reserves that meet the dispatch objective. SPD takes into account offers and bids from participants and outages of assets making up the power system. The inputs to SPD which are affected by wind generation forecast accuracy are the wind generation offers.

RMT calculates the instantaneous reserves required to cover the loss of a generating unit or HVDC pole. RMT uses the schedules from SPD and HVDC scheduling as inputs. The inputs to RMT that are affected by wind generation forecast accuracy are the cleared generation and reserves from SPD.

4.4.2 Effect of wind generation forecast accuracy

Inaccuracy in the wind generation offers are not likely by themselves to cause SPD or RMT to fail, however they will produce a corresponding error in the cleared generation and reserves schedules produced.

For example, if wind generation offers are higher than the amount of wind generation available at dispatch then additional generation which was not cleared in the schedules will need to be brought on. Late notice of the need to bring on additional generation may result in slow starting generation not being able to be started in time and being bypassed in favour of more expensive but faster starting generation, assuming this is available.

Wind generation forecast errors may result in the security assessment process (see Section 4.2) failing to spot upcoming security issues or erroneously identifying such issues. Such instances can be reflected in the SPD schedules as infeasible prices.

RMT determines the reserves required such that the power system frequency will meet frequency quality targets following contingent and extended contingent events. The size of the largest generating unit (e.g. 400 MW in the North Island and 130 MW in the South Island) usually sets the risk. Individual wind turbines being small in size compared to the larger thermal and hydro units will not set the risk. The loss of an entire wind farm could potentially, if defined as a contingent event, set the risk.

Consider a South Island wind farm of 300 MW connected to the grid through a single grid connection point. An electrical fault on the wind farm could result in the entire wind farm being disconnected by the protection systems at the grid connection point. The loss of the entire wind farm is then considered a contingent event.

Assume that the output of the wind farm can range between 0 and 300 MW. The loss of the wind farm when its output is above 130 MW would set the reserve “risk” for the South Island. The variability of the wind farm output also poses some issues for the procurement of reserves. If reserves for the trading period are procured based on forecast wind farm output and the actual wind farm output is greater than the forecast amount then insufficient reserves will have been procured. If the actual wind farm output is lower than forecast then extra reserves above the required amount will have been procured (assuming this is available).

The manner in which instantaneous reserves are procured will need to be reviewed when the amount of wind generation output that can be lost as a contingent event will set the reserves requirement.

4.4.3 Conclusions

The security assessment and standby reserves check processes will need to be reviewed and possibly re-designed to accommodate the effects of larger amounts of wind generation forecast error.

No changes to the SPD and RMT tools to accommodate larger amounts of wind generation have been identified.

Changes to the manner in which instantaneous reserves are procured may be required when the loss of a wind farm potentially sets the reserves requirement. The North Island risk is generally set by a thermal plant, at over 300 MW, and the South Island risk by a hydro unit at about 130 MW.

5. Discussion

5.1 Changing scheduling tools and processes

The cost of redesigning market tools and processes could be significant. For example, the System Operator is currently updating its existing tools and software which are 10 years old. The cost of the project is around $50M, and will take several years to complete.

A major change to market tools and processes to accommodate large amounts of wind generation will take considerable effort and time (including the time required for rule changes if these are required).

The effects of wind generation forecast errors are likely to be noticed for moderate levels of wind generation such as might be connected in the next 3-5 years.

The need to redesign market tools and processes may possibly be delayed if the accuracy of wind generation forecasts is improved.

The process for the review and redesign of scheduling tools and processes, and options to reduce the size of the forecast error should be given priority in the next phase of the Wind Generation Investigation Project.

5.2 Managing unpredictability

Load forecast errors arise from two sources - normal variation in load profiles, and unplanned changes in demand.

The effect of errors caused by variation in load profiles can be managed at dispatch because the System Operator can plan the operation of the power system in anticipation of these errors, even many hours ahead of dispatch. For example, the System Operator expects increases of demand of 1,000 MW over an hour during morning and evening peaks, and can ensure that sufficient generation is scheduled in advance to meet the increase. Similarly, when the System Operator is aware of a step change in industrial load, it can schedule plant accordingly.

Unplanned changes in demand such as the unannounced connection or forced disconnection of a large load (e.g. a reduction line at the Tiwai Point aluminium smelter) may not always be anticipated by the System Operator and must be managed in or close to real time to avoid undesirable effects on the power system. This is discussed in the Transpower's report on the effect of variability on dispatch processes.[12]

[12] "Effect of Wind Generation on Dispatch", December 2006, Transpower System Operator

In summary, because daytime load follows a generally consistent pattern day to day and year to year, the unpredictability of load can be managed more easily than the unpredictability of wind generation, which does not follow a pattern to the same extent. Even if wind generation forecast errors were of the same order of magnitude as load forecast errors, the management of wind generation unpredictability will need to be different to that of load unpredictability.

5.3 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. Further work

The analysis of wind generation errors to date has been based on probabilistic methods. The results given by these methods indicate how often large forecast errors might be expected. This allows a preliminary assessment of how and when such errors might affect scheduling processes and tools. The probabilistic methods do not provide insight into how the effects of wind generation forecast errors might be mitigated.

Further work is required to better quantify the effects:

- The Garrad Hassan analysis has indicated that large but infrequent wind generation forecast errors are possible. The probability or return periods of such events can not be calculated with accuracy due to historic data limitations. Further work is required to better understand these types of event and their effects on the management of power system security.
- Improved methods of wind generation forecasting should reduce the size of wind generation forecast errors and reduce the effects of the errors on power system security management and the accuracy of the pre-dispatch.
- The probabilistic analysis does not indicate the temporal nature of the wind generation forecast error. For example, the error may be a timing error related to a sudden increase in wind generation. The forecast may predict the increase in a trading period earlier or later than when the increases actually occurs. An understanding of the temporal nature of the error is important for developing options in the next phase of the WGIP.

There are several areas where further work is envisaged.

6.1.1 Time domain security assessment

The scheduling process includes a security assessment. The process will identify where there is insufficient generation or transmission capability to meet the forecast load. Significant differences between the cleared generation quantities used in the security assessment and actual generation available at time of dispatch may result in security issues either not being identified in the contingency analysis or being flagged when there is no issue at all at dispatch time.

Analysis of security issues using system loads and wind generation forecasts derived from historic data is proposed. Analysis will be limited to power system capability limits where wind generation affects the limit and where demand will be required to be shed when transmission capacity is insufficient.

The analysis will consider

- The calculation of probability distribution functions for transfer margins into regions with varying amounts of wind generation installed within the region. Monte Carlo analysis may be applied.
- Examples of the effects of wind generation forecast error in the time domain. Time domain sequences corresponding to forecast errors with return periods of a week and a month will be used as inputs to the security issues to illustrate the effect of large but infrequent wind generation forecast errors.

6.1.2 Standby Reserves

The Standby Reserves process identifies whether there is sufficient energy and reserves offered by generators to allow reserves to be restored following the loss of a large generating unit. The Standby Reserves Check Tool (SRC) determines whether there will be sufficient generation offers to restore generation and reserves following the loss of the largest contingent event. This tool does not record historic information.

Historic SRC margins are not available and will have to be recreated using historic market information. This will involve:

- Loading historic SPD input files for each trading period to be analysed into SPD.
- Rerunning SPD to calculate offered generation totals, system requirements (energy, instantaneous reserves, and frequency keeping) and the largest generating unit for each trading period.
- Exporting the results to a spreadsheet.
- Carrying out the SRC process.

Analysis will carried out for selected trading periods (e.g. typical winter evening peak and 19 June 2006 evening peak) for the 12 hours out and 6 hours out schedules.

7. Conclusions and recommendations

Wind generation forecast errors predicted in the Garrad Hassan report will affect the processes and tools used by the System Operator to schedule generation on the New Zealand power system. This leads us to conclude that wind generation forecast error will become the main source of error in the scheduling processes for the North Island once the total installed wind generation capacity in the North Island exceeds around 370 MW. This is likely to occur within the next 2-3 years. Scheduling tools and processes will need to be reviewed and redesigned to accommodate large amounts of wind generation.

Increased amounts of wind generation connected to the New Zealand power system will reduce the System Operator's ability to meet the Principal Performance Obligations. The error in wind generation output forecasts will affect the ability of the System Operator to identify, and participants to respond, to security issues and will increase the amount of issues wrongly identified. The System Operator will need to implement revised processes in scheduling generation to ensure that power system security is maintained.

It is recommended:

- The issues around the effects of wind generation on the scheduling of generation are given a high priority for the next stage of the Wind Generation Investigation Project;
- The accuracy of wind generation forecasts is likewise made a priority for the Wind Generation Investigation Project;
- Further analysis of large but infrequent wind generation forecast errors should be carried out for Part B of this investigation; and
- Further analysis around the temporal nature of the wind generation forecast error. This should include security assessment and standby reserves check and be included in Part B of this investigation.

8. References

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

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

[3] Review of 19th June generation shortfall, see http://www.transpower.co.nz/upload/notion/sectionimages/20369_so-review-19-jun-2006-shortfall.pdf.

Wind Generation Investigation Project Website – see http://www.electricitycommission.govt.nz/opdev/comqual/windgen/wgip

Appendix 1 – New Zealand power system

Figure 9 - North Island power system

Figure 10 - South Island power system

9. Appendix 2

Garrad Hassan [2] has analysed present load forecast error and has made a forecast of wind generation forecast error based on the wind generation development scenarios.

Table 3 shows the load forecast (made at different times prior to dispatch) errors.

Return period	23 hour			12 hour			6 hour		
	NZ	NI	SI	NZ	NI	SI	NZ	NI	SI
Once/month	-534	-403	-227	-697	-500	-329	-613	-452	-286
Once/week	-456	-347	-171	-472	-360	-204	-412	-310	-187
Once/day	-288	-204	-116	-273	-190	-115	-236	-167	-101
Once/month	606	422	220	529	386	191	523	375	176
Once/week	423	304	154	414	307	147	384	299	140
Once/day	266	195	110	247	184	101	226	175	90

Return period	3 hour			2 hour		
	NZ	NZ	NZ	NZ	NI	SI
Once/month	-578	-410	-235	-526	-387	-223
Once/week	-371	-265	-158	-352	-243	-143
Once/day	-204	-146	-87	-184	-132	-80
Once/mth	398	323	143	363	289	131
Once/wk	332	255	119	309	232	110
Once/day	198	154	75	177	140	68

Table 3: Load forecast errors [MW] (Table 5.1 from [2])

Table 4, Table 5 and Table 6 show the estimated wind generation forecast error (for different times prior to dispatch) for each of the wind generation development scenarios.

Return period	Scenario A			Scenario B			Scenario C			Scenario D		
	NZ	NI	SI	NZ	NI	SI	NZ	NI	SI	NZ	NI	SI
Once/ mth	-497	-502	-75	-381	-356	-135	-627	-545	-306	-197	-190	-38
Once/ wk	-411	-397	-65	-307	-288	-118	-510	-445	-254	-168	-164	-33
Once/ day	-282	-280	-43	-216	-200	-80	-358	-311	-177	-118	-116	-22
Once/ mth	498	497	79	358	337	131	570	535	305	192	189	39
Once/ wk	384	386	66	311	284	110	498	428	254	169	168	32
Once/ day	266	265	42	210	192	78	348	300	179	115	113	21

Table 4: 2-hour derived wind forecast errors [MW] (Table 4.12 from [2])

Return period	Scenario A			Scenario B			Scenario C			Scenario D		
	NZ	NI	SI	NZ	NI	SI	NZ	NI	SI	NZ	NI	SI
Once/ mth	-733	-751	-90	-588	-553	-189	-975	-903	-432	-258	-264	-45
Once/ wk	-631	-624	-78	-525	-464	-163	-873	-722	-371	-228	-225	-40
Once/ day	-492	-481	-62	-400	-350	-125	-679	-559	-283	-177	-172	-31
Once/ mth	591	614	83	463	443	150	726	663	351	225	219	41
Once/ wk	514	517	71	368	344	127	593	529	286	186	187	36
Once/ day	334	338	52	251	239	90	419	372	204	126	129	26

Table 5: 6-hour derived wind forecast errors [MW] (Table 4.9 from [2])

Return period	Scenario A			Scenario B			Scenario C			Scenario D		
	NZ	NI	SI	NZ	NI	SI	NZ	NI	SI	NZ	NI	SI
Once/ mth	-994	-1000	-97	-838	-751	-255	-1424	-1222	-553	-322	-316	-49
Once/ wk	-907	-891	-95	-760	-643	-224	-1259	-1030	-501	-296	-292	-48
Once/ day	-718	-708	-80	-595	-507	-173	-995	-815	-393	-244	-238	-40
Once/ mth	942	930	96	770	642	227	1238	1043	523	313	296	48
Once/ wk	809	812	90	638	576	192	1054	904	430	272	275	45
Once/ day	578	589	67	449	408	136	735	640	305	199	201	34

Table 6: 23-hour derived wind forecast errors [MW] (Table 4.7 from [2])