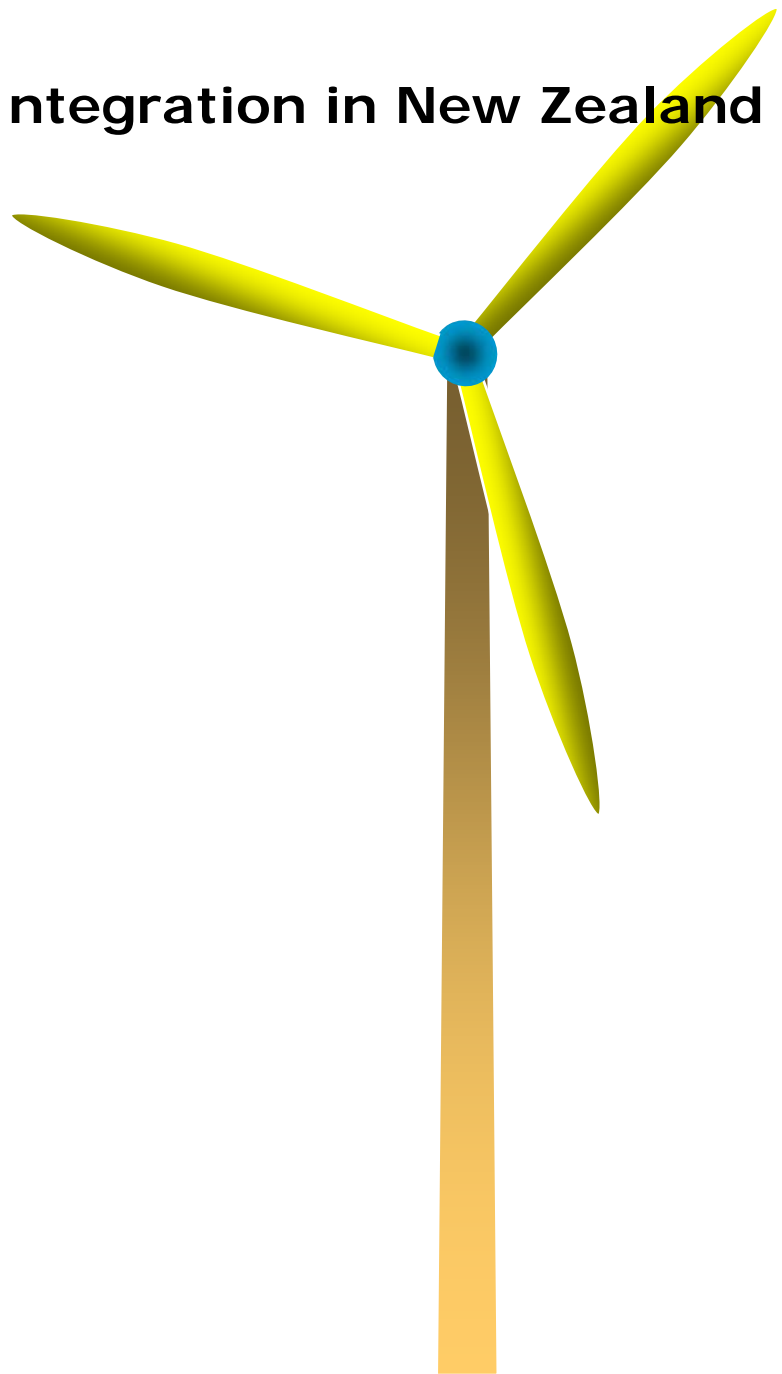


Wind Energy Integration in New Zealand



Prepared by Energy Link
and MWH NZ for Ministry
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and Energy Efficiency and
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Energy Link
Limited



MWH

Foreword

The New Zealand energy sector continues to change, creating both challenges and opportunities.

New wind generation proposals are being announced at an accelerating rate. As wind generation becomes an increasing part of the total generation mix, the intermittent nature of wind leads to new system management challenges and the possible need for paradigm changes in both expectations of developers and expectations of current industry participants.

This publication helps us to look ahead and consider an electricity supply system with a different mix of generation. It is not intended to be conclusive, but provides some guidance at this early stage. It is a first step, with further work planned in a co-ordinated effort with the Electricity Commission, the System Operator (Transpower), and others.

It is hoped that the contents will stimulate comment and discussion. You are encouraged to provide feedback on the document's contents.

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Wind Energy Integration in New Zealand

The Potential for Integration of Wind Energy into the New Zealand Electricity Supply System

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The Ministry of Economic Development (MED) and the Energy Efficiency and Conservation Authority (EECA) are collaborating on a project to investigate the extent to which wind-generated electricity can be integrated into New Zealand's electricity supply system. The wind integration study was commissioned as the first phase of the overall project.

This paper is a brief non-technical summary of this first wind integration report, which is available from either MED or EECA.

The study complements the significant work being done by the Electricity Commission (EC) in conjunction with the System Operator (SO) which is focussed on ensuring ongoing effective market operations and system security with increasing levels of wind integration.

Context

New Zealand's wind energy resource is extensive because the country is located in the prevailing mid-latitude westerly air flow. New Zealand also has a long coastline (relative to its small land area). So the country has the twin advantages of predominant westerly winds and sea breezes. Given this renewable energy resource, it is highly beneficial to understand what contribution wind-generated electricity can make to New Zealand's future energy needs.

Around the world, electricity supply systems have developed incrementally over many decades, largely predicated on the use of thermal generation that has a highly controllable and stable output. However wind generation, by its very nature, is highly variable in the short term. This variability creates many challenges (though not necessarily barriers) for the operation and management of a secure electricity supply system.

Objectives of the Study

The overall aim of MED's and EECA's collaboration on this topic is to quantify the volume of wind-generated electricity that can be integrated into the New Zealand electricity supply system. With this in mind, the outcomes specifically sought from this initial study are:

- Identification of the pertinent parameters affecting the potential for wind integration (largely based on a review of international research);

- Development of a methodology that can be used to quantify the potential for the integration of wind-generated electricity;
- Initial application of this methodology; and
- Identification of further work that would increase understanding of the limits on wind integration.

In applying the methodology, the brief for the study allowed for the exclusion of technically and operationally feasible scenarios where there was reasonable doubt that wind energy would be viable, or even acceptable, based on either its cost relative to other forms of generation or on its impact on the electricity market.

Nevertheless, the study is more about what could happen rather than what might happen in the context of a healthy electricity market.

Wind Integration Defined

In this study, wind energy integration is defined as "the ability of wind farms to connect to, and operate within, the New Zealand electricity supply network in a manner which is compatible with the day-to-day operation and short term security of the electricity supply system as a whole."

Wind energy integration is quantified by its *penetration* and its *market share*. Wind energy penetration is defined as the ratio of installed wind capacity in MW to peak generation in MW, expressed as a percentage value. Penetration is expressed relative to the peak demand of the country as a whole. Wind energy market share is defined as the total annual wind generation in GWh divided by total annual generation in GWh, expressed as a percentage. Market share is expressed relative to the total annual generation of the country as a whole.

Comparison with International Experience

Wind energy is currently in its infancy in New Zealand with penetration having reached only 2.5% by the start of 2005.¹ However, wind energy penetration has reached over 60% in West Denmark, and is around 15% in a number of other countries. Most of those countries that currently have high wind penetration also have high capacity power transmission links to the electricity grids of neighbouring countries. These transmission links can be beneficial as they help to cope with the short-term power output variability inherent with wind-generated electricity.

New Zealand's situation is different as we have no transmission links to other countries and we also have a relatively small load relative to the size of our grid. A further complication is that our electricity supply system is effectively split into two islands

¹ New Zealand currently has approximately 168 MW of installed wind capacity, and a system generation peak of approximately 6600 MW.

connected by the HVDC link.² However, New Zealand does have a significant amount of flexible hydro-based generation that that could play an important role in offsetting the variable nature of wind-based generation.³

Wind energy has seen dramatic growth in the last two decades. The global installed wind capacity increased from 2,500 MW in 1992 to over 40,000 MW in 2003, representing annual growth of almost 30%.

Technology Trends

A wind turbine generator typically consists of two or three blades connected to a hub to form the rotor assembly. The rotor hub connects to a shaft which turns a generator, usually through a gearbox. The electrical output of the generator is then fed to the grid either directly or through a system of power electronics that converts it to the correct grid frequency and voltage.

A wind turbine generator has no output at all until the wind speed exceeds its low wind cut-in speed, which is typically between 14 and 22 km/h. Power output then rises until rated output is reached at a wind speed of about 54 km/h, after which power output remains constant until the high wind cut-out speed is reached at about 90 km/h. When the average wind speed exceeds the cut-out speed the wind turbine drops its output to zero to avoid structural damage.

In the early 1980's wind turbine generators were typically around 50 kW capacity with rotor diameters of 20 m. In contrast, wind turbine generators of up to 5 MW and 100 m rotor diameters are currently being tested for operation in off-shore wind farms. The rapid growth in the sector has provided manufacturers with incentives for research and development leading to lower costs per megawatt of installed wind turbine generator capacity. This has also led to improvements in the efficiency of conversion of wind energy to electricity and the addition of safety and grid support features which are helping to raise the limits on integration of wind energy around the world.

Specifically, the latest trends in wind turbine generator technology include the addition of technology which allows them to contribute to grid security in many of the same ways as conventional generators:

- controlling voltage at the output terminals of the wind turbine generator;
- maintaining a consistent output during faults on the grid where voltage drops suddenly;
- maintaining output over a range of grid frequencies around the nominal 50 Hz frequency at which the New Zealand grid operates.

² The HVDC link is a high-voltage direct-current transmission line that connects Benmore in the centre of the South Island and Haywards near Wellington. A key impact of the HVDC link, because it is a DC and not an AC circuit, is that the grid frequency is managed separately in each island.

³ Hydro-based electricity can respond quickly to changes in generation requirements, and water can be stored for later use. These attributes make it complimentary to wind generated electricity's inherent variability. However, the degree to which hydro can compliment wind has not yet been quantified.

The latest generation of wind turbine generators have the ability to connect together to form large wind farms which can be controlled to exhibit most of the attributes of conventional generators, within the limits of how much the wind blows at any particular time.

Factors Limiting Integration

Given the current trends in wind turbine generator technology noted above, it can be seen that some of the key factors thought to be limiting wind energy integration are already being addressed. However, there are still a variety of issues that are relevant in quantifying the limitations on wind generated electricity integration. These are as follows (each being discussed in further detail below):

- Frequency management;
- Short term variation in wind farm output;
- Generation scheduling;
- Clustering of wind farms; and
- Development of standards and policy.

Frequency Management

The electricity supply system normally operates at a more or less constant frequency of 50 Hz. If frequency moves outside normal safe limits then damage may occur to some generators or loads, and hence any event that causes frequency changes must be quickly corrected.

Frequency management takes place at three levels, each with its own requirements and issues. Frequency changes occur when the difference between generation and demand changes. So if demand is constant and generation increases then frequency will increase, and vice versa.

In each of the North and South Islands, there is currently one generating station that is designated in each half hour as the 'frequency regulating station'. It constantly regulates its output at a rapid rate to maintain the frequency within the limits of 49.8 Hz and 50.2 Hz. High levels of wind integration potentially cause large, rapid swings in generation which in turn can create rapid frequency changes, possibly to the point of being too much for the regulating station to cope with. As wind integration increases the performance of the frequency regulating stations will be monitored closely.

Large, rapid and potentially damaging drops in frequency can occur, though infrequently, when a large amount of generation is suddenly lost to the electricity supply system, e.g. a large generating station malfunctions and disconnects from the grid. This possibility requires the SO to ensure that prudent levels of reserve generation are always connected to the grid and able to increase their output instantaneously⁴.

How far the frequency falls when generation is lost is highly dependent on the physical characteristics of all generators connected and running at that time. While some modern wind farms are capable of providing so-called 'instantaneous reserves' while the wind

⁴ Reserves can also be provided by non-essential load that can be disconnected instantaneously.

blows, a more important consideration is how individual wind turbine generators assist in slowing the rate at which frequency falls. Not all wind turbine generators are capable of contributing to the restoration of frequency to 50 Hz in the same way that conventional generators are. Therefore, high levels of wind integration will require a detailed understanding of how wind turbine generators influence the frequency after generation is unexpectedly lost.

Short Term Variation in Wind Farm Output

Large swings in wind farm output over periods ranging from minutes to hours require commensurate changes in the output of other generation to ensure that demand is always met. This other plant must be available and be able to make large output changes, either individually or in aggregate. We are fortunate in New Zealand to have a large amount of hydro-electric generating plant which is ideally suited to this role.

Large swings may also increase the frequency of occasions when wires on the grid reach or exceed their safe operating limits, requiring greater efforts on the part of the SO, or other measures, to manage the security of the grid.

Generation Scheduling

In addition to very short term uncertainty over wind farm output, there is even greater uncertainty about wind farm output extending from about 3 hours ahead out to the next day. In New Zealand we have large coal and gas fired generating stations that can take several hours to start from cold. The potential of large scale wind energy to increase the uncertainty around the need to start these stations is considerable.

Planning ahead to ensure capacity is available from real-time out to the next day, therefore, requires the development of suitable methods of forecasting wind farm output to assist in this process.

Clustering of Wind Farms

When the wind blows it does not blow equally at all locations across the country. However, clusters of wind farms within small geographical regions on the grid will tend to increase or decrease their output together, potentially creating large swings in their collective generation.

A significant cluster of wind farms is developing in the Manawatu and currently includes the Tararua wind farm and the Te Apiti wind farm. In the next few years it will also probably include the Te Rere Hau wind farm and an expansion of the Tararua wind farm. The evidence to date is that this wind region is already creating large swings in generation output which are causing the System Operator, Transpower, to review its operating procedures and the capacity of the nearby lines on the grid⁵.

On the other hand, if wind farms are geographically dispersed in future then swings in the combined output of all wind farms will be minimised and the limits on wind energy integration will potentially be higher than they would be if wind generation develops in one or two clusters in each island.

⁵ This is the issue noted by Transpower in their report to the Electricity Commission "Manawatu wind generation - Observed impacts on the scheduling and dispatch processes" dated 28 February 2005.

As wind turbine technology develops, control functions that can also limit the magnitude of swings in wind farm output will increasingly become standard issue..

Development of Standards

Looking ahead there is a high likelihood that there will be continued investment in wind-generated electricity in New Zealand – it is already the fastest growing sector of the generation market. In anticipation of this, the adoption or development of appropriate standards for wind farms connecting to the grid is a matter of increasing importance. Progress has already been made in New Zealand in updating the Electricity Governance Rules (EGRs), by which electricity sector participants must abide, to accommodate the particular characteristics of wind farms into the wholesale electricity market.

Wind Energy Integration Methodology and Results

A methodology has been developed to quantify the technical and operational potential for integrating wind power. The methodology uses a ‘top down’ analysis whereby the essential volumes of generation required to operate (e.g. to provide the ancillary services of frequency reserves and instantaneous reserves) are subtracted from the generation required in a given half hour. The methodology aims to subtract all essential generation, with the remaining non-specific generation being the potential limit to wind integration.

It is noted here that this methodology only assesses technical and operational issues, not other factors such as the relative economics of wind versus other generation. Furthermore, this is a projected wind integration limit that could only be approached in the longer term. This is because investment in wind-based generation is unlikely to replace existing generation, but could make significant contributions to meeting ongoing growth in electricity demand.

Our hypothetical analysis used the forecast lowest generation for 2005 in each of the South and North Islands. The current year was chosen because the mix of generation is already known, thus not requiring modelling or estimation of generation growth scenarios for years further into the future.

From each generation figure was subtracted an allowance for conventional generation plant that would have to run:

- to perform fine control of frequency in the range from 49.8 Hz to 50.2 Hz;
- to be on standby in the event of frequency suddenly falling below the normal operating range;
- to maintain safe voltage levels on the grid;
- to make up for very short term swings in output of wind farms;
- to ensure that adequate generating plant is available to operate, if required, in a few hours time or even tomorrow.

The result of the analysis was penetration of about 35% and market share of 20%, based only on technical and operational issues.

These initial wind integration estimates are reliant on these key assumptions:

- that future wind farms will consist of modern wind turbine generators which can provide grid support capabilities similar to those of conventional generators;
- that wind farms will be geographically dispersed rather than clustered in one region; and
- that wind speeds can be forecast with sufficient accuracy up to the end of the next day.

A high level of wind penetration is by no means assured, not least because wind competes with other equally viable types of more conventional generation. Nevertheless, this initial analysis indicates that advancements in wind turbine generator technology have the potential to support much higher levels of wind integration than we currently have, quite possibly to the point of being comparable with countries which currently lead the world in wind energy. This possibility places challenges in front of the electricity supply industry.

Further Work

This study has identified a number of areas where additional work will assist in further assessing the issue of integrating wind energy into the New Zealand electricity supply system.

1. Develop a wind speed dataset for use in more detailed and more accurate studies around large scale wind energy.
2. Investigate the impact of large scale wind integration and current trends in wind turbine technology on the ability of the New Zealand supply system to provide sufficient reserve capacity in the event of a sudden drop in system frequency.
3. Develop a consistent set of connection standards for wind farms which anticipate a much larger installed wind energy base.
4. Consider what issues might create barriers to the development of smaller wind farms in many, diverse locations, with a view to obtaining the greatest possible geographical dispersion in the development of wind farms.
5. Develop appropriate wind farm output forecasting methods and related market rules to ensure that the market and the System Operator have the information they need to plan ahead to cover the variability of wind farm output on a national and regional basis.
6. Assess the impact of large scale wind energy integration on dry year security of supply.

In addition, the study has raised a number of related issues considered worthy of consideration by the industry:

- Determine if an additional reserve service should be scheduled to cover large "wind events" such as storms which could shut down a number of wind farms within a short period (or alternatively, investigate reorganising the existing continuum of reserve services).

- Assess the potential for more significant deviations in frequency away from 50 Hz with high levels of wind penetration.
- Undertake a study of the power flowing on grid lines around the Manawatu wind farm cluster to determine how this concentration of wind farms might affect the occurrence of line constraints.
- Undertake a study of the impact of high levels of wind penetration on the ability of the grid to maintain stable operation during and after grid events (e.g. an under frequency event).
- Consider the potential to introduce rules allowing combinations of wind and hydro or wind and thermal generation to make offers into the electricity market in "blocks."
- Consider changes in the market rule to require all plant to be offered in if it is reasonably available to run. The purpose of this potential rule change is to ensure the SO has information about all plant that is able to run to cover changes in the aggregate output of all wind farms, up to the end of the next day.

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