Planning Council Wind Report to ESCOSA

April 2005

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WIND ENERGY IN SOUTH AUSTRALIA

SUMMARY AND CONCLUSIONS

On 23 December 2004 Mr Lew Owens, the Chairperson of the Essential Services Commission of South Australia (ESCOSA), wrote to the Planning Council seeking its advice in relation to a number of generation licence applications for the development of wind-farms in South Australia.

Specifically, ESCOSA requested that the Planning Council provide advice on any impacts that the proposed wind-farm developments might have on the long term interests of South Australian consumers with respect to the price, quality and reliability of electricity services.

At this stage, ESCOSA has requested that the advice be general in nature rather than an assessment of the individual applications.

In response, the Planning Council examined the issue of wind development in South Australia from two different perspectives:

- a detailed, South Australian specific analysis was conducted using local data, actual projects and real market conditions; and
- a review of international experience with wind generation and the potential impacts of increasing levels of wind.

The two reviews combine to provide a broad basis for the report's findings and conclusions.

In undertaking this study, the Planning Council has welcomed comments and assistance from industry participants and NEMMCO, the national electricity market operator.

South Australian Specific Analysis:

The Planning Council has:

- developed a detailed half-hourly model of output of each wind-farm and combined those into an aggregate State output;
- analysed the resulting wind generation to determine average patterns and the extent of variability over 30 minute to seven year time-frames;
- supplemented this deterministic model with a statistical approach to look at the variability of wind-farm output over shorter time-frames from three seconds to half an hour; and

- used the wind generation profiles from the modelling in our market simulator to determine the dispatch implications and likely market response to increasing levels of wind energy.

This phase of the study concluded that the average generation pattern from wind in South Australia is very good by world standards and broadly supports the shape of demand. However, the variation around the average is very large and complex, and average outputs provide no guide to impacts.

With a good understanding of the expected generation patterns for each of the cases and expected variability around those general trends, the report examines the key issues of interest to ESCOSA, namely:

- Quality ;
- Reliability/security; and
- Price.

Power Quality

The performance and safe operation of electrical machines and appliances used by customers depends upon maintaining power quality. Not only customers but network service providers and other generators depend upon the quality of the power supply remaining within tightly specified limits. The nature of wind generation and the technology adopted can potentially raise issues with power quality.

The Planning Council reviewed the technical capabilities of the wind turbines and the connection arrangements with the South Australian network service providers and is satisfied that the combination of improving machine types and the commendably high quality of network agreements delivers adequate assurances that power quality will not be adversely affected by increased levels of wind generation.

Our conclusion is that power quality is being managed.

Reliability and Security

The delivery of a reliable wholesale market supply and the maintenance of system security in the National Electricity Market depends upon:

- setting appropriate requirements on plant prior to allowing them to connect; and
- effective operation and management of the power system.

The range of technical requirements which may be imposed on generators seeking to connect are set out in the *National Electricity Code* and the detailed standards to apply to a particular case are negotiated through the connection process.

As the proportion of wind generation increases in South Australia, higher standards will need to be imposed to ensure system security can be maintained. Consideration needs to be given to ensuring that wind-farms are able to:

- ride through a more severe low voltage event;
- generate and absorb reactive power and control voltage;
- smooth short term fluctuations in output; and
- be remotely controlled and to curtail output where necessary.

The negotiated approach has delivered reasonable outcomes to date and the technology offered in the more detailed licence applications would, or could with some adaptation, meet the sort of specification envisaged. Our analysis has though raised some uncertainty with respect to the ability of wind-farms to ride through a frequency excursion and their performance in high ambient temperatures.

The Planning Council concludes that wind generators seeking to connect should comply with clearer and more appropriate technical standards. In the short term, new generators should be required to conform to the automatic access standards in the National Electricity Code. In the medium term these standards should be updated to reflect emerging world's best practice.

Appropriate connection arrangements and adherence to technical standards is only a baseline precondition to a secure and stable power system. Maintaining the reliability and security of the system is an ongoing task delivered through:

- market incentives and the subsequent behaviour of generators to make the right level of plant available to the market when required;
- market mechanisms designed to deliver "security constrained optimised dispatch" along with the necessary ancillary services to control frequency; and
- NEMMCO having the responsibility and capacity to ensure security is maintained through the market mechanisms and the use of its powers of direction when necessary.

To assess the likely impacts of various levels of wind energy on security and reliability the Planning Council has modelled the national market with different levels of wind generation. The market generally absorbs the 400 and 500 MW of wind generation with only moderate impacts on the number of other generators online at any time. In most circumstances for these low cases there is, therefore, sufficient response to demand and wind variability and adequate inertia to maintain security.

However, in the higher cases the variability of wind generation increases and displaces more of the conventional generation that would otherwise be available to provide the necessary inertia and ramp rates that ensure security. In the 800 and 1,000 MW cases the variability of such a concentration of wind energy exceeds the variability of all other causes of uncertainty in the market today and would significantly increase the difficulty of forecasting future scheduled generation requirements. These factors would make it difficult to ensure that appropriate generators are available, committed and operating in advance.

Even where the wind variability is of a type that can be predicted, appropriate market incentives will be required to ensure that other generators are prepared to be available to provide system security measures.

The Planning Council concludes that the security and reliability of the power system with up to 500 MW of wind generation in South Australia should be maintained provided there is attention given to particular and rare situations.

With higher levels of wind generation, we need to introduce state of the art forecasting. The degradation in the accuracy of forward forecasts we would have without such forecasting would challenge the market's ability to provide:

- *adequate ramp rate response in the short term; and*
- *timely commitment of other generators and fuels*

to ensure that the security and reliability of the system is maintained.

This conclusion is not only consistent with international practice, it is also consistent with the open access regime underpinning the market. This regime allows any party to connect to the market provided they meet the required connection standards. Connection though does not assure dispatch. Dispatch in the market is always subject to the maintenance of system security, or "security constrained, optimised dispatch".

Price

In a competitive market, the prices in the spot market are determined by the bid behaviour of participants. However, the prices paid by customers are affected not only by the wholesale spot price, but also by contract market prices.

There is no clear outcome on the impact of wind on prices. Instead, the Planning Council observed a number of balancing pressures on price:

- While wind energy never acts to set the wholesale pool price and is simply paid the going rate as determined by the bids of other generators, it effectively lowers the overall volume of energy to be supplied by the rest of the generators. The result, at least in the short term, will be increased competition and a corresponding downward pressure on wholesale pool price;
- Variability of wind imposes costs on other market participants by:
    - Increasing the number of times generators start and stop;
    - Increasing per unit costs (including fuel) as fixed costs need to be recovered over shorter operation times;

  - Increasing the overall cost of market ancillary services.

  Any increase in underlying costs will create upward pressure on price as participants attempt to cover the higher costs of operation; and

- Given the nature of the contract market, increasing volatility or uncertainty will have a corresponding impact on the cost of risk instruments and will create an upward pressure on the contract price for electricity.

Modelling based on simpler bidding strategies show the impact of the competitive forces, particularly in the short term. However, the key will be medium to longer term effect on market investment and hence prices. More complex bidding approaches show, particularly in larger cases, an ability for other players to gain rewards from being able to respond quickly to short term opportunities created by the variability of wind. With more wind generation in the market there will be an increasing and negative correlation between state-wide wind generation and spot market price. When wind generation is high, prices will be driven down. When wind generation is low, particularly on occasions where it drops quickly, prices can be expected to be high.

There will be costs associated with ensuring that security is maintained in a market with a high penetration of wind energy. These will have a minimal effect on outcomes if the market design is adapted to deal with these higher levels of unscheduled and varying generation and, in particular, if costs are allocated efficiently, primarily on the basis of the causer-pays principle. Efficient cost allocation will also and drive appropriate investment and behaviour by participants and drive effective market outcomes.

Wholesale, spot market effects are only part of the story. Retailers hold a portfolio of contracts to manage the cost of their electricity purchases for South Australian customers. This portfolio only need contain around 2% renewable energy so retailers would only purchase additional wind energy at a competitive price against other options taking into account its value in the portfolio and the need to purchase risk instruments in a market that is potentially more volatile.

Our conclusion on price is that the market should be adapted to ensure efficient operation, pricing and cost allocation with increasing levels of wind generation, by:

- *allocating costs efficiently, primarily on the basis of the causer-pays principle;*
- *allowing the periodic curtailment of output to ensure an optimal market dispatch; and*
- *increasing the transparency and accuracy of information to the market.*

The competitive market should, on the whole, be allowed to work. Without appropriate changes to address the above issues, the effects on the market and consumers is expected to rise significantly with over 500 MW of wind generation in South Australia.

International Review

South Australia is fast becoming world ranked in terms of wind generated power with 400 to 500 MW of installed capacity. Based only on the wind energy projects already licensed, the proportion of South Australia's energy and capacity supplied by wind is already high by international standards. Increasing the level of wind energy beyond current levels places South Australia amongst, if not at the top of, the world leaders in wind.

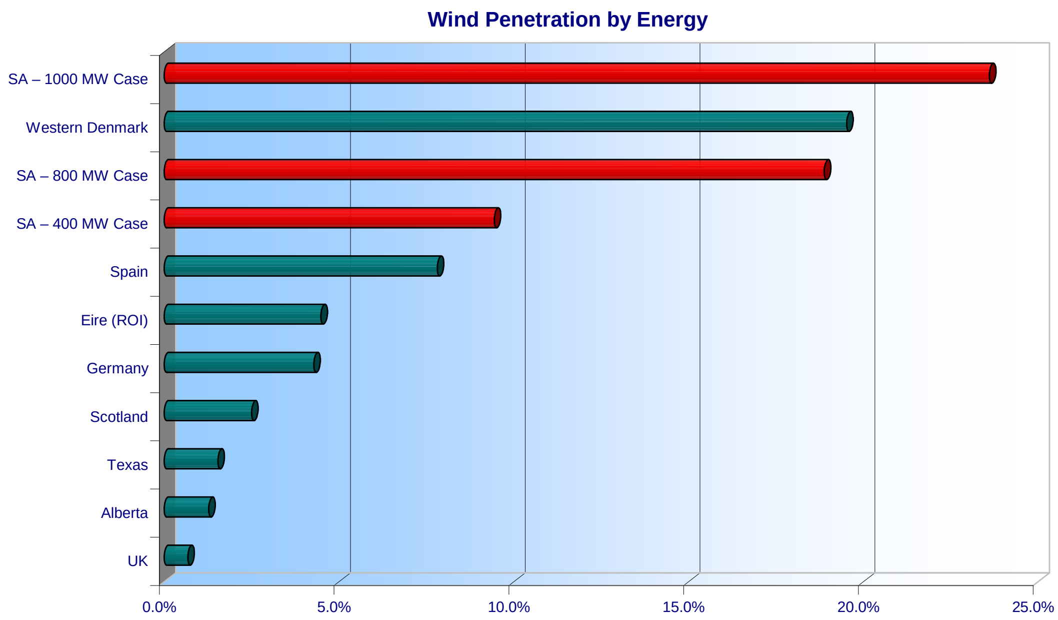


Figure 1-1 - South Australia in an International Context

Lessons can be learned from international power systems and their response to the challenge of increasing wind energy.

At significantly lower levels of wind penetration, emerging wind markets such as Alberta, the United Kingdom, Ireland and the United States are adopting recommendations similar to those of Planning Council with respect to:

- the performance required of the wind turbine generators; and
- the market arrangements in which the wind generators operate.

While there have been issues internationally, our conclusion is that there is no firm technical limit to wind evident in international experience to date, provided market arrangements are modified appropriately.

Installing between 800 and 1,000 MW of wind generation in South Australia would make this State the world leader in terms of the amount of wind as a proportion of total energy. While this should not act as a limit in itself, the Planning Council considers that even having implemented the following recommendations, care should be taken in applying security and price projections and advice beyond those levels.

Key Conclusions

The Planning Council analysis has examined the expected character of wind generation in South Australia for four cases and its projected impact on the network, the power system and the market. The average wind generation profile is good but belies the complexity of the variability of wind generation in every timescale.

The analysis indicates that impacts on power system security with 400 and 500 MW of wind generation should be modest. There are risks to be managed at this level of wind, but they are only expected to occur on rare occasions. However, wind generation at the 800 and 1,000 MW cases raises concerns, under the current arrangements, with growing impacts on system reliability, security and price. In these cases, variability in wind generation will become a dominant influence on the operation of the power system significantly increasing the current variability and uncertainty faced by the power system and national electricity market.

An analysis of the impacts on the market again demonstrates a difference between the lower cases (400 to 500 MW) and the high cases (800 to 1,000 MW). The impact in the lower cases, while noticeable, is expected to be modest. Depending upon the incentives and behaviour in the higher cases there are risks of very volatile prices and market inefficiencies.

While the Planning Council does not recommend an absolute limit to wind generation, it is clear that the impacts of wind generation on the power system will result in progressively rising risks with higher penetration rates. Rather than focus on the possible impacts, we recommend that action is taken to ensure the market and regulatory arrangements work effectively and efficiently with wind generation. To go beyond the 500 MW level of wind generation in South Australia the Planning Council considers that the following changes need to be introduced to ensure any adverse impacts are minimised:

- *Recommendation 1: Appropriate technical standards*: In the short term the Planning Council recommends that new generators be required to conform to the automatic access standards under the *Code*. In the medium term we should look to align these standards with emerging world's best practice. Most modern wind turbines are already capable of meeting these standards.

- *Recommendation 2: State of the art wind energy forecasting*: The market needs to be informed to allow participants to make efficient decisions on the commitment of plant and scheduling of fuel. Otherwise, costs could rise and security be put at risk.

- *Recommendation 3: Optimisation of unscheduled generators in the dispatch engine*: NEMMCO must be able to automatically optimise unscheduled generators (as is currently done for scheduled generators) to ensure that the market continues to operate efficiently and securely.

- *Recommendation 4: Proper cost allocation and market design measures*: Market changes should be made to require unscheduled generators to participate in Ancillary Service markets, both to pay for effects they cause and earn revenue for services they provide, will drive appropriate investment and operational decisions.

The Planning Council is reassured to see that these recommendations are consistent with both emerging international practice and the preliminary findings of the Ministerial Council on Energy's taskforce into wind related issues.

Based only on the wind energy projects already licensed, the proportion of South Australia's energy and capacity supplied by wind is already high by international standards. Increasing the level of wind energy beyond current levels places South Australia amongst, if not at the top of, the world leaders in wind. The prospect of leading the world in wind energy reinforces the need to ensure that the market is structured appropriately so that such high levels of wind generation can be safely, efficiently and reliably accommodated.

If the recommendations described above are adopted, market forces should determine an appropriate level of wind generation in South Australia. A successful investment in wind generation depends upon revenue from both the renewable energy market (via RECs) and the electricity market. The Planning Council estimates that the market for RECs is nearly fully subscribed and that soon revenue from that source will not be available, creating a natural economic limit to the growth of wind energy.

In any case, if the recommendations above are implemented, increasing penetration of wind generation in the market will require proponents to factor in the costs of decreasing dispatch volumes as constraints act more frequently and a corresponding reduction in the market value of wind generation. The costs of development will rise with the imposition of higher standards although the evidence, both internationally and from the detail contained in licence applications, is that this impact will be small. As the relative contribution of wind generation rises, the costs directed to wind generators as causers of ancillary services can also be expected to rise. Lower revenues and increasing costs will be met with innovation by wind developers and wind turbine manufacturers but at some point a balance will be achieved.

While this analysis is as complete as possible, it is important to note that real operational data is necessarily limited and there is only a short history of a small number of projects in South Australia and indeed across the national market. The Planning Council considers that care should be taken in applying its current projections and advice at very high wind penetration levels without updating this analysis with experience at levels expected later this year.

CONTENTS

1 PURPOSE OF THE REPORT

The rapid development of wind energy in South Australia and its relative magnitude compared to systems overseas has prompted the need to better understand the implications of such growth on the State's energy market.

The Planning Council, having produced a report in 2003 looking particularly at the impact of wind energy on the supply-demand balance, has since been preparing more detailed wind profiles to allow it to analyse the broader market implications of wind generation.

On 23 December 2004 Mr Lew Owens, the Chairperson of the Essential Services Commission of South Australia (ESCOSA), wrote to the Planning Council seeking its advice in relation to a number of generation licence applications for the development of wind-farms is South Australia.

Specifically, ESCOSA requested that the Planning Council provide advice:

- on the impact that the proposed wind-farm developments might have on the long term interests of South Australian consumers with respect to the price, quality and reliability of electricity services;
- in relation to any impacts the proposed wind-farm developments might have on the electricity market, market prices, network operations and system security; and
- whether there were any limits to the amount of wind generation capacity that could be developed in particular regions, having regard to transmission line capacity and diversity.

At this stage, ESCOSA has requested that the advice be general in nature rather than an assessment of the individual applications.

Section 6E(1) of the *Electricity Act* 1996 sets out the functions of the Planning Council, including:

(c) to advise the Minister and the Commission on matters relating to the future capacity and reliability of the South Australian power system; and

(e) to advise the Minister and the Commission, either on its own initiative or at the request of the Minister or the Commission, on other electricity supply industry and market policy matters.

The Planning Council has undertaken to provide the requested advice to ESCOSA under these provisions.

2 PLANNING COUNCIL APPROACH

The Planning Council examined the issue of wind development in South Australia from two different perspectives:

- a review was conducted of international experience in relation to accommodating increasing levels of wind energy; and
- a detailed, South Australian specific analysis was conducted using local data, actual project information and real market conditions.

The two reviews combine to provide a broad basis for the report's findings and conclusions.

Comparative/International Review

Given the relatively mature market for wind energy overseas, the Planning Council engaged Garrad Hassan to review the extent of wind penetration in a sample of international systems and to summarise the issues and response mechanisms identified by other jurisdictions, particularly those that may be applicable to South Australia. The full version of this report, titled *Review of Impacts of High Wind Penetration in Electricity Networks* is available from the Planning Council's website[1].

Wind generation is now a fast growing feature of a number of new markets. Authorities in those markets have, therefore, been prompted to examine their connection requirements and market arrangements to ensure that they are able to cope with the forecast growth. The Planning Council has reviewed material available on the emerging requirements in Canada (Alberta), the Republic of Ireland, the United States (the Federal Energy Regulatory Commission and the New York Power Pool) and the United Kingdom. A review of these international examples provides support for conclusions drawn from our fundamental analysis. It also allows us to recommend a course of action and technical standards which are consistent with best international practice.

First Principles Analysis

Given the local wind resource and market specific issues in South Australia, the Planning Council has also conducted a detailed, bottom-up analysis of the nature and likely patterns of wind generation in the State.

To do this, the Planning Council has:

- developed a number of "cases" with varying wind quanta based on real projects across the State;
- utilised Bureau of Meteorology and wind proponent data to assess the wind patterns at specific sites and in aggregate across the State over various time horizons;

[1] www.esipc.sa.gov.au

- analysed the nature and variability of the wind resource across the various sites; and
- modelled the dispatch implications and market response options to increasing levels of wind energy.

Wind Generation Cases

There are currently six projects either operating or under construction in the State and license applications for another six projects under consideration by ESCOSA.

From this, the Planning Council created four cases that cover a range of South Australian wind energy capacities from the completion of the construction of the current projects (~400 MW) up to ~1000 MW with all of the projects listed in *Table 2-1* in operation. *Table 2-1* lists these projects and their respective status.

PROJECT	STATUS	CAPACITY	400MW	500MW	800MW	1000MW
Canunda	Commissioning/ Operating	46	✓	✓	✓	✓
Cathedral Rocks	Under Construction	66	✓	✓	✓	✓
Starfish Hill	Operating	34.5	✓	✓	✓	✓
Mount Miller	Under Construction	70	✓	✓	✓	✓
Lake Bonney S1	Commissioning/ Operating	80.5	✓	✓	✓	✓
Wattle Point	Under Construction	90.5	✓	✓	✓	✓
Clements Gap	Licence Pending	58		✓	✓	✓
Myponga	Licence Application	40		✓	✓	✓
Lake Bonney S2	Licence Application	159.5			✓	✓
Snowtown	Licence Application	165			✓	✓
Barunga	Licence Application	200				✓

Table 2-1: Cases Considered

The choice of which projects to include in the different cases was undertaken primarily to ensure that the cases rounded to convenient totals and should not be seen as any indication of the Planning Council's judgement regarding the likelihood or appropriateness of the project.

Wind Data

The Planning Council's approach considers all of the wind turbines on a farm collectively. Wind-farm developers put considerable effort into the optimisation of individual turbine locations on the proposed site, to achieve the most viable energy yield. In recognition of this process the Planning Council developed a methodology for the conversion of wind data from the Bureau of Meteorology into power using proponent turbine array layouts. The Planning Council requested information from each developer on the output of each project with respect to the anticipated wind regime on the site. The process the Planning Council employed to create the long term wind dataset on which the statistical analysis and chronological modelling has been performed is described in *Appendix* 1.

Shorter term data was also collected from operational wind-farms from ElectraNet and ETSA Utilities' SCADA.

Statistical Assessment of Wind Patterns

The above wind data was analysed by the Planning Council to assess the average pattern and variability of wind over time-frames ranging from three seconds to seven years. Given the complexity of some of this analysis particularly with respect to the extrapolation of limited real time wind data to State-wide wind regimes, the Planning Council engaged Dr John Boland, leader of the Environmental Modelling Research Group within the University of South Australia's School of Mathematics and Statistics, to assist.

Market Simulation

In order to better understand the implications of wind energy on the South Australian electricity market the Planning Council has performed detailed market simulations exploring some of the potential dispatch outcomes for indications of possible challenges and market trends.

3 GENERAL CHARACTER OF WIND ENERGY

Capacity Factors

South Australia is recognised as having an excellent wind resource with many viable sites in reasonable proximity to strong transmission and distribution systems. In fact, the forecast capacity factors of many of the proposed wind-farms in South Australia are up to three times that of their European counterparts.

While the actual capacity factor changes as a result of annual variations and the specific wind-farms used in the various cases, typical capacity factors for the State are consistently between 32% and 40%.

CASE	AVERAGE OUTPUT (MW)	CAPACITY FACTOR
400 MW	148.8	37.6%
500 MW	181.8	37.0%
800 MW	297.5	34.6%
1000 MW	371.8	36.6%

Table 3-1: Typical Capacity Factors

The seven year dataset on which this analysis is based is a comparatively short period of time and European experience in wind analysis suggests that there can be up to a ±15% variation in the total wind resource annually. Therefore, while the average capacity factors listed above are very strong across all the cases, Figure 3-1 highlights the type of annual variations that, even over only seven years, have been observed:

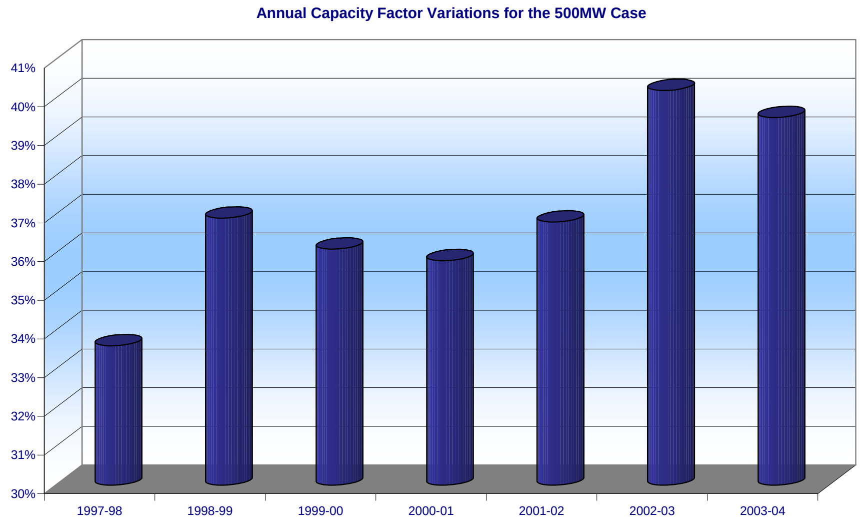


Figure 3-1 - Capacity Factors over Time

Figure 3-1 indicates that the last two years have had higher than average wind speeds compared to the previous years and raises the possibility that wind in South Australia may experience long term cyclical patterns.

Wind Patterns

Daily wind profiles across the State vary by season as a result of differing weather patterns. Figure 3-2 illustrates the average pattern of aggregate wind-farm output for the 500 MW case:

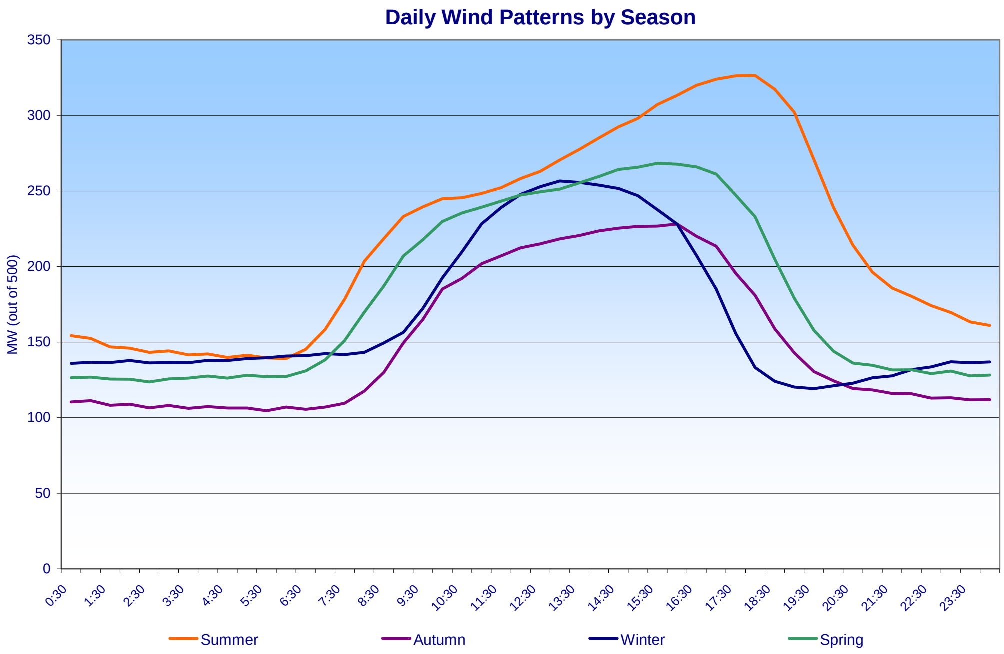


Figure 3-2 – Seasonal Variation in Average Wind-farm Output Vs Demand (500 MW case)

The seasonal patterns for the other cases exhibit the same daily form. The strongest average wind speeds occur during the summer months, December to February, while the autumn and winter periods are typically less windy. All months exhibit a strong diurnal pattern where overnight winds are, on average, less strong than during the day.

More specifically, Figure 3-3 shows the daily patterns for each month:

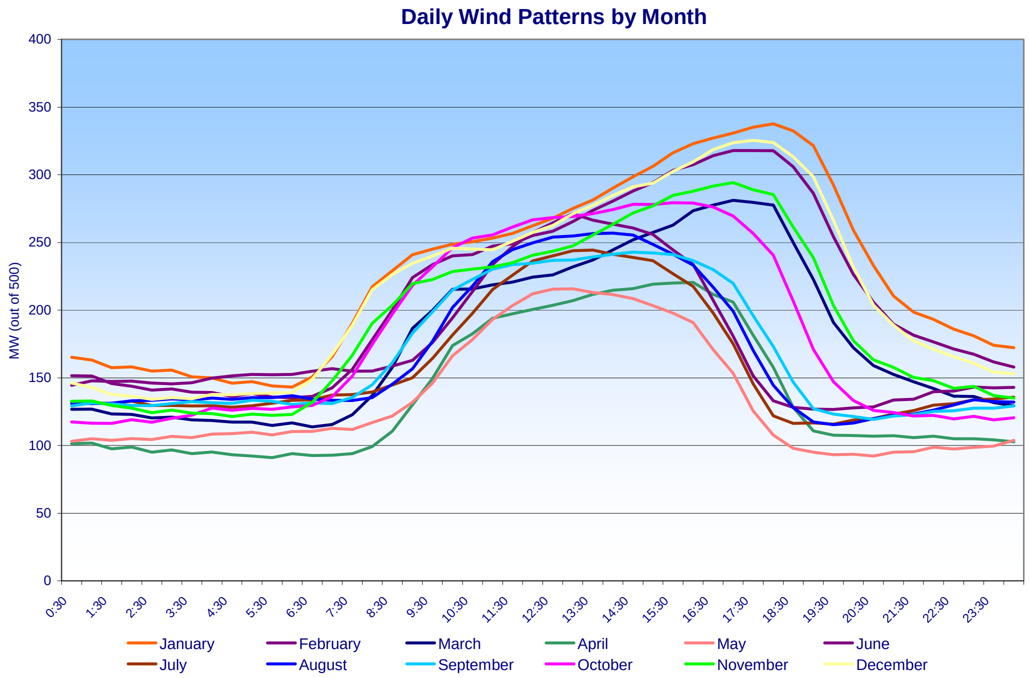


Figure 3-3 - Monthly Variation in Average Wind-farm Output (500MW case)

While the above patterns, both seasonal and monthly, suggest a wind trend that is complementary to demand by showing higher output at times of generally high demand, the *Figure*s are only averages and the variability, as indicated by the standard deviations in Figure 3-4, is significant.

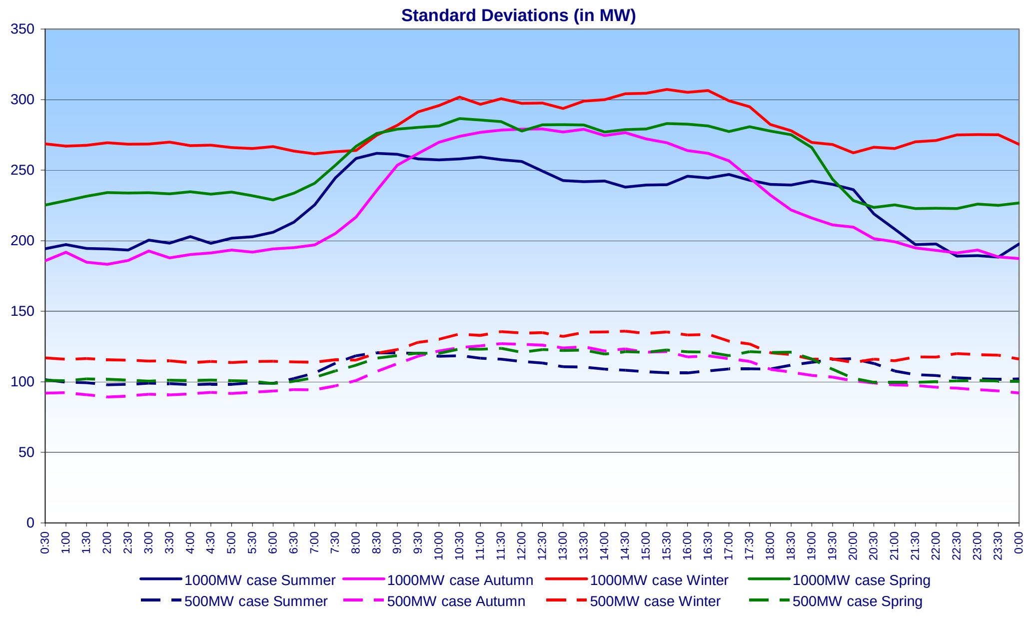


Figure 3-4- Standard deviation of the Seasonal Variation in Average Wind-farm Output

4 VARIABILITY OF WIND ENERGY

Unlike most forms of conventional generation, wind generation is, by its very nature, subject to variations across a wide range of time-frames. Wind speed always fluctuates over the short term as a result of gusts that create small scale variations in the instantaneous energy content of the wind. The magnitude of this variability depends on several factors including weather and surface conditions. Gusting is typically spherical in nature and its affect on power generation varies with the size of the gust and the technology of the wind turbines. Across a wind-farm gusting can affect the output over very short time-frames.

Over longer time-frames, wind speed is also subject to weather fronts and diurnal patterns. Weather and temperature conditions typically mean most locations around the world are 'more windy' during the day than during the night. Two primary reasons explain this diurnal variation:

- temperature differences between sea and land surfaces are usually larger during the day than at night, and
- the wind is usually more turbulent and changes direction more frequently during the day than at night.

Variability would appear to be the single largest challenge to the integration of wind energy into the National Electricity Market as it affects a broad range of market mechanisms from the security of dispatch to the management of contractual risk instruments.

Variability in the output of wind-farms is primarily an issue where:

- it cannot be predicted; and
- it is significant with respect to demand in the State.

That part of the variability that is due to predictable weather patterns has, with the introduction of reasonable forecasting tools, the potential to be adequately managed. However, the demonstrated accuracy of currently available forecasting tools is not high.

Diversity across the State will also contribute to a lessening of the impact of variability. This reduction has already been factored into the following analysis. Short term, local variations are not only much harder to predict, but they appear to be uncorrelated and therefore less affected by spatial diversity.

The variability of wind generation is complex and the benign nature of the average generation profile belies this complexity. The following chart shows the average generation profile for all January days over the seven years studied. The actual generation for 1 January of each year is overlain to demonstrate the type of variability around that average. Wind generation is variable in every timeframe. That variability is a critical characteristic that must be understood in order to infer impacts on power quality, security and price.

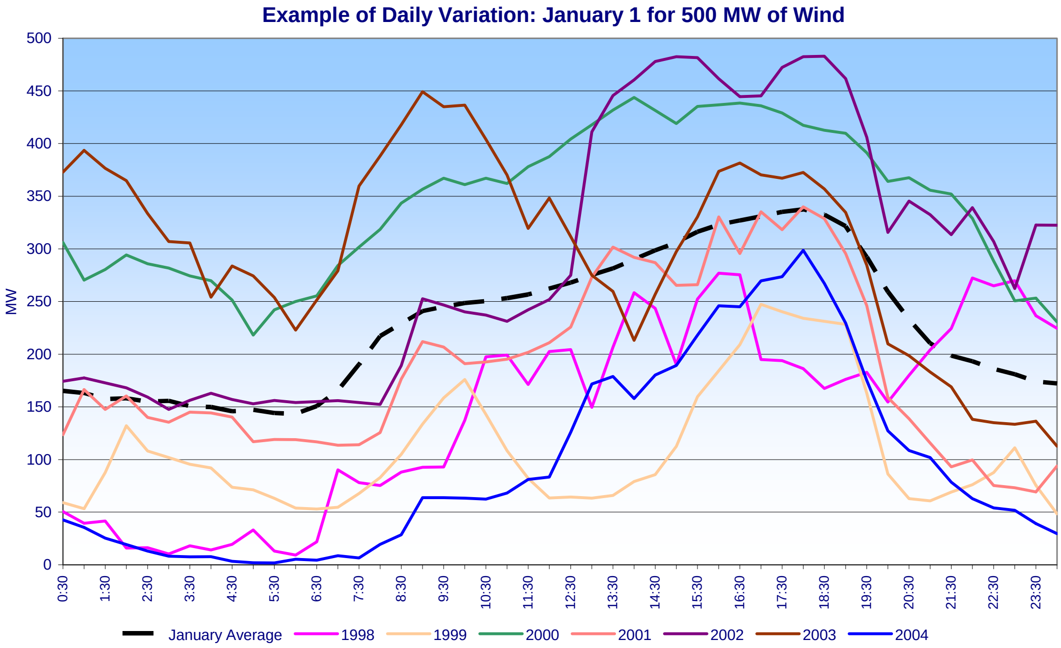


Figure 4-1 - Daily Variations for January 1 around the January Mean

In order to simplify the analysis of the variability of wind the Planning Council sought to categorise both the relevant time-frames for variability, the materiality of the variations and the market mechanisms currently available to compensate for them.

Figure 4-2 summarises the effect that variations over different time-frames will have on aspects of the operation of the National Electricity Market:

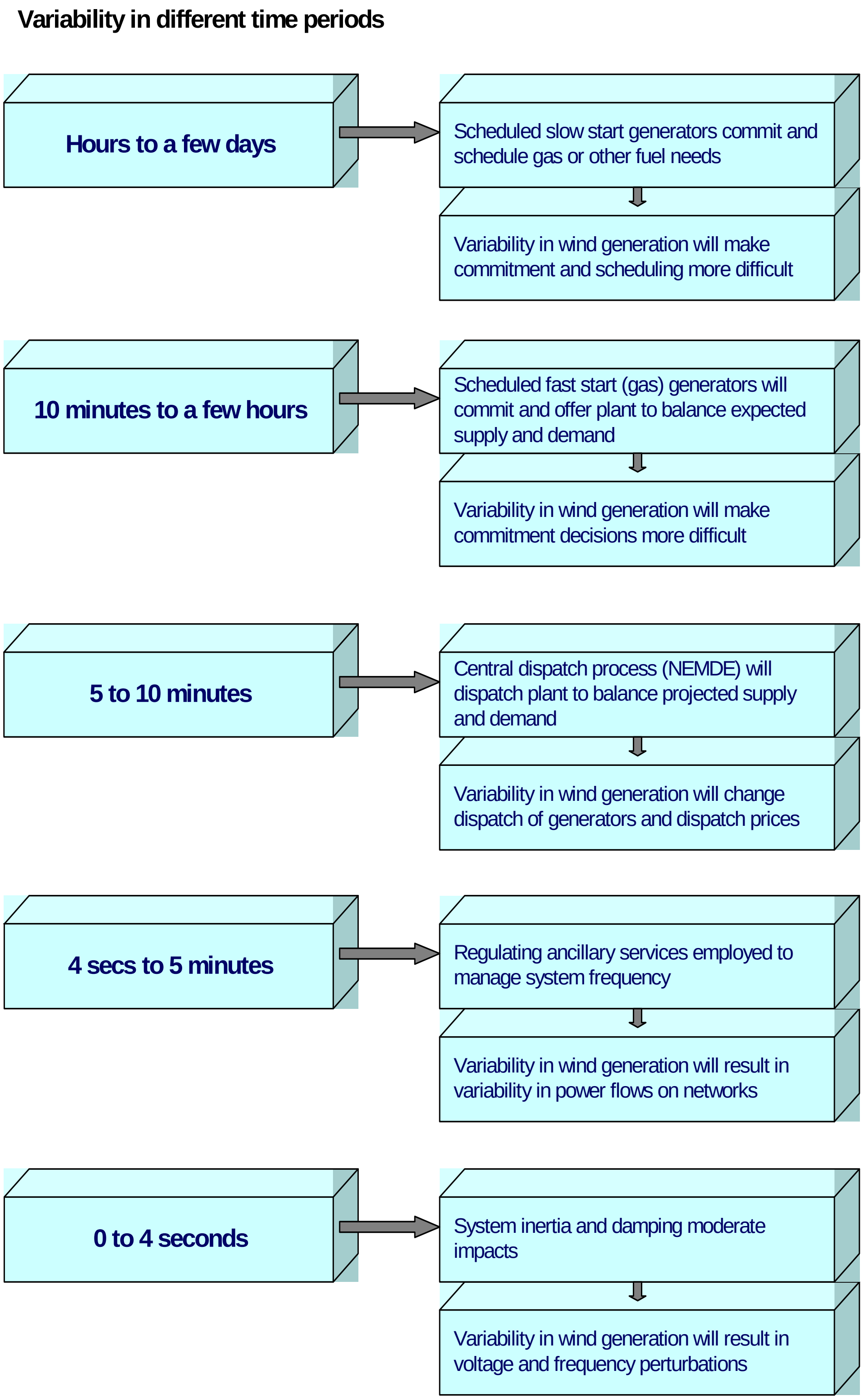


Figure 4-2 - Impact of Variation over Different Time-Frames

GREATER THAN 30 MINUTES VARIABILITY

Using the the wind generation model described in detail in *Appendix* 1, a database was developed of the half-hour by half-hour generation expected from each proposed wind-farm over the seven years modelled. The output from individual wind-farms was aggregated into each of the four cases studied. This provided the data which underlies the market modelling described later and is the basis for an analysis of how wind generation can be expected to vary over half-hourly and greater time-frames.

Of most interest is the variation from one period to the next which will be met or exceeded on a given percentage of occassions. The results are summarised in the following *Table* and the 1% probability of exceedance variations are displayed in Figure 4-3.

OCCURRENCE	HALF-HOURLY	HOURLY	2 HOURS	3 HOURS	4 HOURS	6 HOURS
10%	38.6	59.6	90.6	116.6	138.3	172.4
5%	50.2	77.1	116.7	147.4	172.5	208.3
2%	65.5	100.1	148.5	184.3	210.9	246.8
1%	77.1	116.8	170.3	207.9	235.8	272.4
Once per annum	153.2	214.8	284.8	322.3	342.1	359.8

Table 4-1- Case 1 - 400 MW of wind capacity in SA- Variation in MW

OCCURRENCE	HALF-HOURLY	HOURLY	2 HOURS	3 HOURS	4 HOURS	6 HOURS
10%	42.5	67.0	104.7	136.7	163.5	204.9
5%	55.0	86.4	134.5	173.1	204.2	248.4
2%	71.2	111.9	171.5	217.0	250.0	296.0
1%	83.5	130.0	197.4	245.3	280.8	325.7
Once per annum	162.5	242.2	329.2	381.6	402.1	439.7

Table 4-2- Case 2 - 500 MW of wind capacity in SA- Variation in MW

OCCURRENCE	HALF-HOURLY	HOURLY	2 HOURS	3 HOURS	4 HOURS	6 HOURS
10%	82.7	135.2	210.3	271.0	322.8	398.5
5%	109.6	178.2	272.0	344.3	401.5	479.2
2%	145.7	230.4	343.7	427.5	484.8	558.5
1%	171.8	263.6	391.6	477.0	536.4	601.9
Once per annum	355.8	485.9	612.8	676.8	703.8	756.4

Table 4-3- Case 3 - 800 MW of wind capacity in SA- Variation in MW

OCCURRENCE	HALF-HOURLY	HOURLY	2 HOURS	3 HOURS	4 HOURS	6 HOURS
10%	113.6	192.1	300.3	383.2	449.7	546.3
5%	156.7	261.3	389.4	481.1	552.9	648.4
2%	210.8	339.5	483.9	587.9	656.2	741.9
1%	252.0	389.5	544.8	647.3	715.9	789.5
Once per annum	495.9	653.9	804.5	873.7	902.0	954.1

Table 4-4- Case 4 – 1,000 MW of wind capacity in SA- Variation in MW

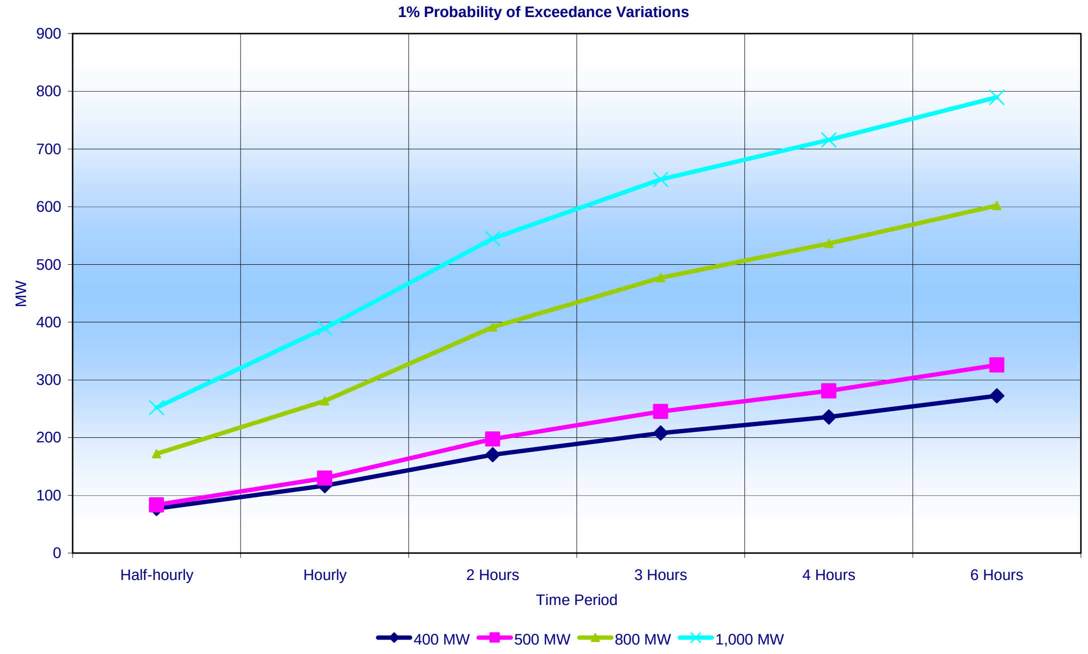


Figure 4-3 - 1% Probability of Exceedance Variations

EXTREME VARIATIONS IN HALF-HOUR AND LONGER TIMEFRAMES

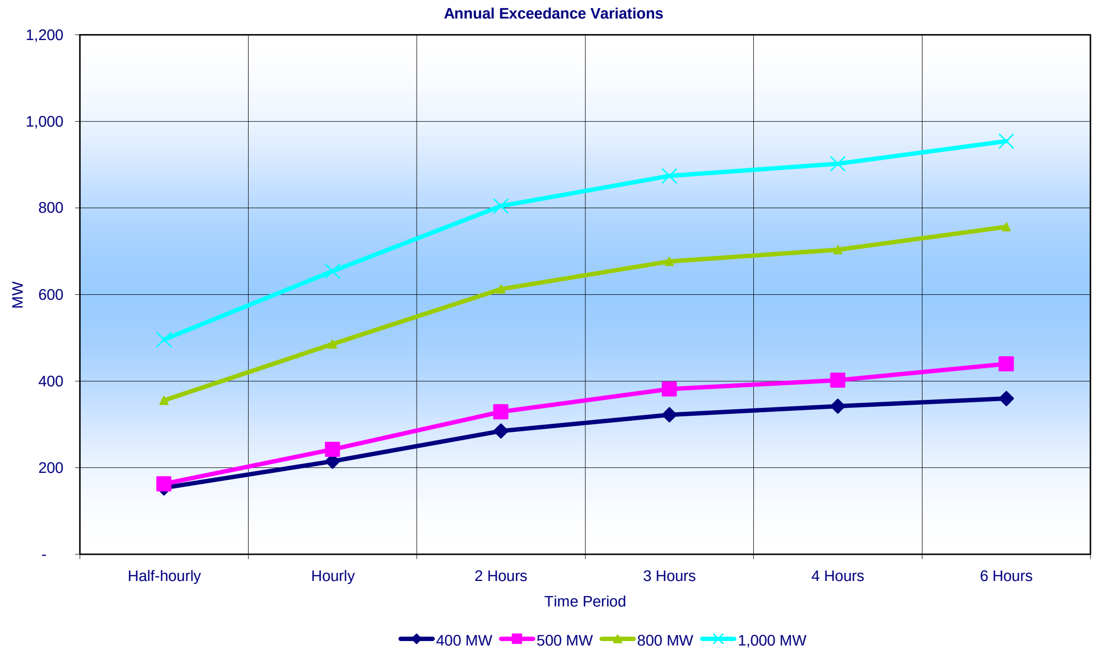


Figure 4-4 - Variations on a Once per Annum Basis

CASE	HALF-HOURLY	HOURLY	2 HOURS	3 HOURS	4 HOURS	6 HOURS
400 MW	153	215	285	322	342	360
500 MW	163	242	329	382	402	440
800 MW	356	486	613	677	704	756
1000 MW	496	654	804	874	902	954

Table 4-5 - Once per Annum Variability.

The variation in wind generation output from one period to the next has been calculated through the process described earlier. The variation in output which would be expected to occur, or be exceeded, once per annum is shown in *Table 4-5*.

The variation for the 400 and 500 MW cases is less than the current contingency margin of 260 MW over half an hour and hourly, but significantly greater than this level for the 800 and 1,000 MW cases. Over four to six hours the 400 and 500 MW cases show variations that are greater than one contingency however over these time-frames other slower start generation may have been able to be made operational even without comprehensive forecasting. In the 800 and 1,000 MW cases the hourly variabilty is significantly greater than two contingencies in the State. Without comprehsive forecasting of these events or additional constraints in the National Electricity Market to instruct other generators to be operaing, it may be difficult to ensure that sufficient generating capacity would be available.

SUB 30 MINUTES VARIABLITY

The Planning Council engaged Dr John Boland from the University of South Australia to assess the short term variability of wind generation. The work undertaken in association with Dr Boland adopted a different, statistical approach to assessing variability of wind generation using a time series analysis to extrapolate the output variability from a single wind-farm to estimate the expected variability for a range of wind generation across South Australia. A detailed explanation of the methodology used is given in *Appendix 5*.

This statistical analysis provides a comparison between the output variability of a single actual Starfish Hill and the aggregated output variability which could be expected in the 400 MW and 1,000 MW cases. The data quantifies the benefits of diversity for the 400 MW case with the 12 wind-farms having around half the variability per installed capacity as Starfish Hill by itself. These benefits are still clear with the 1,000 MW case although significantly reduced. The 1,000 MW case has less diversity benefits as it adds capacity at only two sites, one of which was already included in the 400 MW case.

	STARFISH HILL	400 MW CASE	1,000 MW CASE
Mean	1.7 MW	14 MW	29 MW
Standard Deviation	2.1 MW	15 MW	47 MW
10% PoE	4.1 MW	34 MW	83 MW
5% PoE	5.7 MW	45 MW	122 MW
1% PoE	10.3 MW	70 MW	221 MW

Table 4-6 – 30 Minute Output Variability

The results of this analysis, align favourably with the more detailed deterministic studies undertaken by the Planning Council. For example, the 1% Probability of Exceedance variation for the 400 MW case calculated here is 70 MW whereas our market modelling (PoE) work calculated 77 MW.

5 MINUTE VARIABILITY

It is important to understand the five minute variability from wind-farms as an input into the National Electricity Market dispatch process and the implications for the management of network constraints. In this time-frame the National Electricity Market dispatch process would be issuing instructions to the available generators to change their output to accommodate variations in wind and demand. This is frequently referred to as the Ramp Rate controls in the National Electricity Market.

Extending the statistical analysis performed for the half-hourly variability the Planning Council has calculated the following five minute variability.

	STARFISH HILL	400 MW CASE	1,000 MW CASE
Mean	0.75 MW	7.1 MW	14.8 MW
Standard Deviation	1.08 MW	4.03 MW	7.39 MW
10% PoE	1.78 MW	12.51 MW	24.68 MW
5% PoE	2.40 MW	14.76 MW	28.65 MW
1% PoE	4.42 MW	19.64 MW	37.13 MW

Table 4-7 - 5 Minute Output Variability

In this *Table*, the 1% PoE can be expected to be met or exceeded one in every hundred five minute periods or around three times per day.

3 SECOND VARIABILITY

The 3 second variability of the wind output can not be compensated for in the existing National Electricity Market dispatch instruction arrangements, relying instead on the automated governor controls (AGC) of the generators in the National Electricity Market. Currently this service is part of the existing Frequency Control Ancillary Service market arrangements.

Assuming that three second fluctuations in wind generation output will not be correlated even between adjacent wind-farms the Planning Council calculated the variability of the cases as follows.

	STARFISH HILL	400 MW CASE	1,000 MW CASE
10%	0.67 MW	2.93 MW	5.70 MW
5%	1.10 MW	3.55 MW	6.53 MW
1%	2.54 MW	4.94 MW	8.30 MW
0.01%	4.31 MW	8.68MW	12.75 MW
0.00167%	5.48 MW	10.1 MW	14.34 MW

Table 4-8 – 3 Second Output Variability

It is important to remember that on a three second basis, a 1%PoE could be expected to occur once every five minutes. Therefore some lower PoE *Figure*s have been included. The 0.01% PoE level would occur as often as one in every hundred five minute intervals or three times a day. While the 0.00167% PoE level would occur as often as one in every hundred 30 minute intervals or several times a week.

0-3 SECOND INERTIA TIME-FRAMES

Variation in either generation or load in these timeframes is not able to be managed by the regulating ancillary services. The regulating ancillary services are provided by generators through AGC on a four second time interval. Fluctuations in the 0 to 3 second timescale will directly impact on system frequency and are only mitigated by the inertia in the power system. The most important source of inertia is the mechanical momentum of the generators rotating in the market which is greatest in larger conventional generators. Some inertia is necessary to maintain the stability of the system. During a system disturbance or a very rapid change in demand on the power system, the inertia of the available generators provides the resistance required to maintain the system frequency. The variability of the wind-farm output in the 400 and 500 MW cases, because it is of a similar magnitude to that of the demand, is likely to be accommodated under existing arrangements. At higher levels of penetration the variability is significantly larger than the variation of South Australian demand and may have some affect on the normal operation of the network and market. The variability of wind in this very short time-frame is not able to be forecast, but the Planning Council notes that the latest technology wind turbines have significantly improved control systems that, to a large degree, should be able to smooth out these perturbations.

Summary

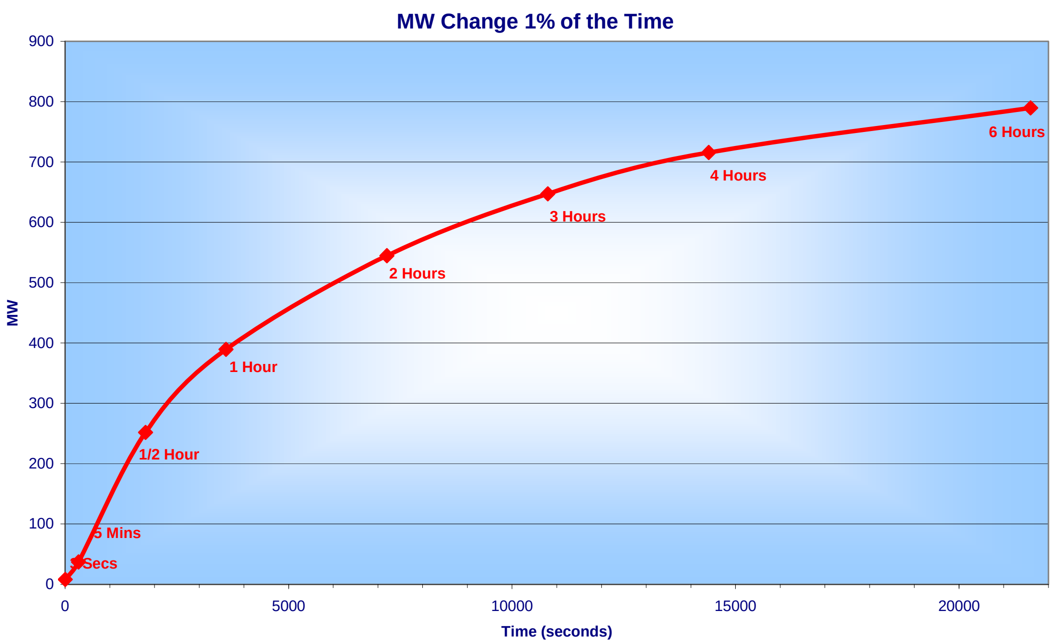
The following *Table* summarises the 1% PoE variations in output over and above any diurnal patterns for the studied timeframes:

	400 MW CASE	1,000 MW CASE
30 minutes	70 MW	221 MW
5 minutes	20 MW	37 MW
3 seconds	4.9 MW	8.3 MW

Table 4-9 - 1% PoE Output Variations

Given that the underlying diurnal pattern of wind has been removed, the above *Figure*s can be seen in one sense as the random variation around a predictable generation pattern. *Figure 4-5* shows graphically the 1% variation of wind energy over the range of time-frames examined for the 1,000MW case.

Figure 4-5 - MW Variation 1% of the time for the 1,000 MW case



5 POTENTIAL IMPACTS ON POWER QUALITY

One of the key aspects that ESCOSA asked the Planning Council to consider was whether increasing levels of wind energy are likely to have any impact on power quality.

It is vital to ensure that the quality of the power delivered to customers is maintained within standards as the performance and safe operation of electrical machines and appliances depends upon maintaining supply within specification. Not only customers but network service providers and other generators depend upon the quality of the power supply.

Recognising the importance of power quality, the *National Electricity Code* sets out system standards for:

- voltage;
- voltage fluctuations;
- harmonic distortion; and
- voltage imbalance.

Wind-farms can be connected to either the distribution or transmission networks. Those connected to the distribution system generally raise more issues with respect to power quality, as they are electrically closer to customers than generators connected to the transmission system. However, in certain cases, transmission connected generators could impact power quality to local customers especially where the transmission network is radial or where the wind-farm proposed is large relative to power flows in the area.

The management of power quality needs therefore to be undertaken on a case by case basis and is an important consideration for many proposed generators and customer loads. The Planning Council has examined the approach taken by ETSA Utilities and ElectraNet SA to ensure power quality issues are dealt with through the connection process.

Power quality issues are location specific and, in this respect, the proposed Myponga wind-farm is an example where higher standards would be expected of a connecting generator. The project is to connect to the Myponga sub-station which is part of ETSA Utilities' sub-transmission network for the southern suburbs and Fleurieu Peninsula. Myponga is located on a single circuit 66kV line and is some distance from the transmission backbone at Morphett Vale East.

The Planning Council review indicated that power quality issues are being managed under the current arrangements. Appropriate standards are in place and the utility is monitored to ensure these standards are met. The technical capabilities of today's wind turbines and the approaches available through the connection arrangements and supplementary plant ensure that any potential power quality issues can be managed. The Planning Council is satisfied that the combination of improving machine types and the commendably high quality of network agreements delivers adequate assurances that power quality will not be adversely affected by increased levels of wind generation. The Planning Council supports arrangements in more recent connection agreements to include power quality meters to further ensure standards are consistently met.

The details of the power quality assessment performed by the Planning Council can be found in *Appendix* 4.

6 POTENTIAL IMPACTS ON SYSTEM SECURITY AND RELIABILITY

The fluctuating nature of wind energy raises potential issues around the security and reliability of the power system, including:

- short term security and plant responsiveness;
- system stability;
- medium term plant commitment to support short term security; and
- longer term reliability.

Management of system security and reliability in the National Electricity Market relies upon:

- setting appropriate requirements on plant prior to allowing them to connect; and
- ongoing operation and management of the power system through:
    - market incentives;
    - market mechanisms; and
    - NEMMCO's powers.

Connection Arrangements and Technical Standards

The range of technical requirements which may be imposed on generators seeking to connect are set out in the *National Electricity Code* and the detailed standards to apply to a particular case are negotiated through the connection process. An over-riding objective of the negotiation of technical standards is to ensure that the power system can be managed and the system's stability and security can be maintained.

The negotiation of technical standards and connection arrangements for new generators is led by the Transmission Network Service Provider, in South Australia's case, ElectraNet SA. NEMMCO is involved in matters potentially relating to system security. The connection process for generators requires the application of the *National Electricity Code* requirements to the specific project and the assessment of a range of factors. The technical standards in the *National Electricity Code* were developed prior to the advent of large wind generation proposals in Australia and are not well adapted to be applied to such unscheduled and often asynchronous generation. The technical standards are not rigid and the connection process involves the setting of a number of "negotiated access standards". Negotiated standards are normally applied to wind generators' ability to ride through low voltage disturbances and to their ability to generate and absorb reactive power.

The connection of wind-farms to the South Australian network in each case includes an analysis of the transient stability of the generator. The analysis of all wind-farms, except Myponga, has been limited to examining whether the proposed generator is able to remain stable and connected to the system through the most severe credible contingency on the transmission system cleared in primary protection time. In general, this will require the wind-farm to remain stable and connected to the network despite it experiencing a severe drop in voltage at its connection point for up to 120 milliseconds. It is important that generators can "ride through" such disturbances such that individual faults or failures on the system do not cascade and lead to insecurity of the whole system.

This type of assessment is based on dynamic models of different types of wind turbines and concerns remain about the accuracy of such models and their wider applicability in studying system stability. The assessment of the negotiated standards also requires assumptions about other plant that will be on-line in the future and the critical contingencies that ought to be considered.

The "automatic access standard" in the *National Electricity Code* avoids this by specifying a particular form of low voltage event which a generator should be able to ride through. This more prescriptive approach, while more onerous, is typical of approaches being adopted internationally and will provide a more secure system. Myponga is an example of a wind-farm that meets the automatic access standard and, as such, is capable of "riding through" a more severe fault of 175 milliseconds at its connection point.

The arrangements for the provision of reactive power and voltage control within the network are occasionally unclear. The automatic access standard would require the ability to generate and absorb considerable quantities of reactive power. It allows, however, the amount provided to be negotiated down to zero and the Planning Council understands that wind-farms are normally required to provide limited or no reactive power. With wind generators potentially constituting a considerable proportion of generation at some times, this is likely to become a concern in the future. Even without state of the art turbines, wind-farms can meet connection point obligations by installing additional network support equipment. For example, several wind-farms in South Australia have employed static VAR compensators at their connection point to assist in fault ride through and voltage support.

Generators seeking to connect to the system also need to be able to remain connected and continue to generate through a severe disturbance to the system frequency. Each wind-farm developer has given undertakings that their plant will ride through the specified frequency disturbance, but no specific assessment process is undertaken. The range of frequencies experienced in the National Electricity Market and which generators must therefore be able to contend with is considerably wider than that encountered in Europe and the United States. The Planning Council has some concern about the ability of some of the wind turbine generators to ride through the necessary frequency events, but early experience in Western Australia suggests that at least some machines display adequate response to low frequency events. Wind proponents are clearly bound to comply given the terms in their connection agreement and this should be considered as a detail to be separately resolved.

The different challenges of wind generation may also introduce a need for new standards. The short term variability of wind generation means that power output can fluctuate very quickly, more quickly than correcting systems operate. This can be effectively managed by requiring wind generators to smooth their short term output, for example over periods of seconds up to perhaps one minute. The potential rate of change over five minute periods can also be effectively limited with current technology and provision of that capability could significantly improve the future management of system security. The more general provision of data on each wind-farms current output and provision for its remote control through market security systems will be imperative to maintaining system security with a larger proportion of wind energy on the system.

RECOMMENDED CHANGES TO TECHNICAL STANDARDS

The technical standards under the *National Electricity Code* are not drafted to deal with significant amounts of wind generation and should be reviewed and redrafted in this light. Despite the difficulties in interpretation, the application of these standards in practice by the South Australian network service providers has served the State well up to the current level of wind generation. As the proportion of wind generation increases in South Australia, higher standards will need to be imposed to ensure system security can be maintained. The Planning Council considers that all future wind-farms should be required to meet tighter standards including the ability to:

- ride through a prescriptive and more severe low voltage event;
- generate and absorb reactive power and control voltage;
- smooth short term fluctuations in output; and
- be remotely controlled and to curtail output where necessary.

The control of the wind-farms should provide the capability to manage their ramp rate of change. The requirements for the provision of communications and SCADA data currently imposed by NEMMCO should continue.

The review of international experience in *Chapter* 8 includes an assessment of general trends in the technical standards being required of generators in other markets. The technology to meet these international standards is now widely available and all three of the licence applications which include more technical detail are based on the application of state of the art technology. Each of these proposals would either be able to meet such new specifications as proposed or could do so with limited modification.

New standards with these sorts of capabilities ought to be developed which are consistent with emerging international best practice. While the Planning Council considers that new standards with these sorts of capabilities ought to be developed as a matter of priority, the application of the current “automatic access standards” in the *National Electricity Code* supplemented by NEMMCO’s remote data and control requirements provides a reasonable interim step. Further work by the Planning Council due to be published shortly provides an assessment of the emerging *National Electricity*

Code requirements in Alberta and Ireland and compares those with the automatic access standards under the National Electricity *National Electricity Code*.

Secure Dispatch and Market Operation

Appropriate connection arrangements and adherence to technical standards is a precursor to a secure and stable power system. System security then has to be assured by active management in real time.

This section considers the variability of wind generation in the context of the variability and uncertainty evident in power system and market operations already. This provides a background to assess the likely impact of wind generation on the task of managing system security.

This task is a responsibility of NEMMCO delivered through its market systems which are designed to deliver “security constrained optimised dispatch.” Security and reliability in a broader context though also depends upon market incentives. That is, generators in the National Electricity Market need to manage their resources to make themselves available at the right time and enable them to respond to customers demands.

The market mechanisms include markets for frequency control ancillary services. We therefore cannot assess the overall impact of wind generation on reliability and security without analysing its impact on the market. Our approach to assessment has been to model the National Electricity Market outcomes with different levels of wind generation and a range of assumptions as to generators’ market behaviour. The details of this approach and the various assumptions employed are set out in *Appendix* 3.

From this modelling we can:

- determine likely dispatch patterns;
- examine ramp rate adequacy to deal with variability;
- consider the demands on generators to effectively commit their plant in time; and
- share data with NEMMCO and seek their advice on security issues including:
    - system stability; and
    - adequacy of ancillary services.

Impact of Wind Generation on Demand Variability and Uncertainty

The variability of wind generation has been described in *Chapter* 4. This variability needs to be seen in context in that there are elements of variability and uncertainty inherent in the operation of any power system, both on the demand and supply side.

Customer demand is by its nature variable. The demand in a region follows a strong diurnal pattern with the general level of load highly influenced by the day of the week, the season and the temperature. Within those broad patterns though, demand varies as individual consumers turn plant or appliances on and off and as individual machines cycle through loading patterns.

Generation output also varies. A number of unscheduled generators start and stop operation at their own choice. While larger generators are centrally scheduled, they cannot exactly follow dispatch targets and most have a lower limit of safe operation. Most large generators, therefore, must commence generating and jump to this minimum level and cease generating by lowering to minimum generation levels before disconnecting.

The fluctuations of wind generation are generally uncorrelated to these fluctuations in demand and other generation. Therefore, the various fluctuations or probability distribution functions will add together in a probabilistic rather than an arithmetic manner.

Demand is routinely predicted by NEMMCO as part of its role as market and power system operator. The accuracy of those predictions varies and, on rare occasions, those predictions can diverge by several hundred megawatts from actual demand. The market must routinely deal with this level of uncertainty.

The outcome of this, seen in practice in power systems worldwide, is that the addition of modest amounts of wind energy will marginally increase the variability and uncertainty already inherent in the operation of the power system. As the concentration of wind generation in a power system increases, its variability will become more important and, at high levels, the dominant issue in the management of the power system. *Table 6-1* below shows the projected variability of wind generation in South Australia for each case on a half-hour to half-hour basis. Variability of the various cases is compared to the variability of demand and its predictability.

CASE	400 MW	500 MW	800 MW	1000 MW
Ave Half-hour variation	22.7 MW	26.4 MW	52.3 MW	71.5 MW

Table 6-1 Half-hour wind variability by case

By comparison with the half-hourly wind variability shown in the *Table 6-1*, the average variability of demand is in the order of 31.9 MW and the average demand forecast error one hour in the future is approximately 35 MW.

Table 6-1 shows that the average variability of wind generation in the 400 and 500 MW cases is of a similar magnitude or smaller than the average variation in demand and the average forecast error. This suggests that wind generation in these cases would increase overall variability by 20 to 30%. A similar deterioration could be expected in the average forecast accuracy. On average, while undesirable, this is unlikely to be a major concern.

In the two larger cases, the average variability in wind generation exceeds the average variability in the demand and demand forecast accuracy. In these cases we could expect variability in wind generation to be the dominant cause of variability and uncertainty in market operations. The diversity of wind generation across the power system and the size of individual wind-farms clearly influences the levels which can be accommodated and this can be seen in these cases. The 400 and 500 MW cases are well dispersed across South Australia maximising the benefits of diversity whereas the 800 and 1,000 MW cases add large new wind-farms at only two sites.

The accuracy of NEMMCO's demand forecasts for South Australia four hours ahead of dispatch has been analysed using data supplied by NECA. These forecasts had an average error of 50.1 MW over the year from September 2003 to September 2004. The average wind output variation for each case simulated is shown in *Table 6-2*.

CASE	400MW	500MW	800MW	1000MW
Average 4 hour variation	56.7 MW	68.4 MW	131.7 MW	177.5 MW

Table 6-2 - Average four hour wind variability

By comparison with the four hour wind variability shown in *Table 6-2*, the average four hour demand forecast error is in the order of 50 MW. The average change in wind generation in four hours for the 400 MW case is estimated at 56.7 MW. Even in this case, the variation in wind energy exceeds the current average forecast error. In all cases the variability in wind generation over a four hour time period will be larger than the current forecast errors and hence the major contributor to forecast inaccuracy. In the 1,000 MW case we could expect variability in generation to quadruple forecast errors over four hours. Without excellent wind generation forecasting we should expect a significant deterioration on the forward demand forecasts which are vital for other generators trying to make efficient plant commitment decisions. NECA's quarterly report and the latest information from the market indicate that we are already seeing a reduction in forecast accuracy in South Australia as a result of the wind generation now online.

Ramp Rate and Unit Commitment

The chronological model simulations highlight that the half-hourly variability and the potential for rapid changes in output from wind may have significant impact on the number of conventional generation units required to maintain a capability to compensate for these fluctuations. In the majority of simulations of the 400 and 500 MW cases the ramp rates, while challenging at times, did not appear be unmanageable as the variations were of a similar magnitude to that of the largest unit in South Australia.

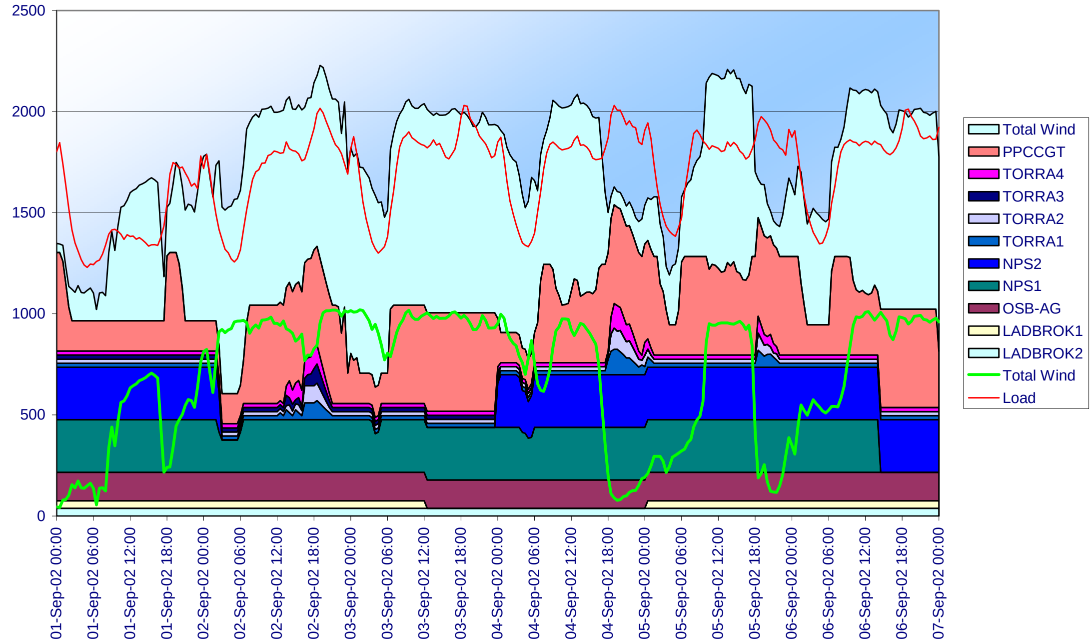


Figure 6-1- Example of Rapid Rate of Change of Wind-Farm Output (1,000 MW Case)

In the 800 MW and 1,000 MW cases, on the other hand, there were a number of periods where the ramp rate of the generation currently operating was insufficient and it was necessary to commit additional generation to provide the shortfall. *Figure 6-1* shows a situation where the currently committed generation was capable of covering the rapid change in output from the wind-farms. It should be noted in this example that the Torrens Island units are on their minimum generation levels for almost all periods other than those where the rapid change occurred. Currently in the National Electricity Market, some portion of this duty would typically be performed by a combination of peaking gas turbines or by short term overloading of the interconnector. Fortunately these large magnitude variations are not instantaneous; however they are relatively short with respect to the commitment

time-frame for major units in the State. The magnitude of these variations in the simulations triggered other generators to start and ramp rapidly to high loading levels. Depending on their state of preparation, this type of behaviour is potentially damaging and costly and may alter their behaviour. With accurate forecasts of these types of rapid rate of change events and appropriate dispatch optimisation mechanisms the generators and the market operator could more effectively optimise the dispatch of all of the generators in the network.

Alternatives and augmentations to existing market arrangements to manage rapid rate of change events could include:

- accurate, timely forecasting;
- the biasing of the offset point of the Murraylink interconnector;
- the creation of a network support service; and

- the inclusion of additional constraints on the interconnector, incorporating and optimising the output of the wind-farms.

Each of these alternatives has potential benefits and costs. Offsetting Murraylink to accommodate some of the variability in the wind would only have limited scope due to Murraylink's size, and may reduce the optimality of the price being set in South Australia. The key factors in addressing this issue are accurate forecasting and ensuring the visibility of the wind generation to the rest of the market.

Implications for Dispatch

There has been concern over the coincidence of low demand periods with periods of high wind output and the potential for the South Australian market to be insecure as a result of the predominance of wind. The Planning Council's analysis of this situation revealed a number of important outcomes.

A statistical analysis of wind power versus the South Australian demand shows the frequency analysis of wind-farm output in low demand periods.

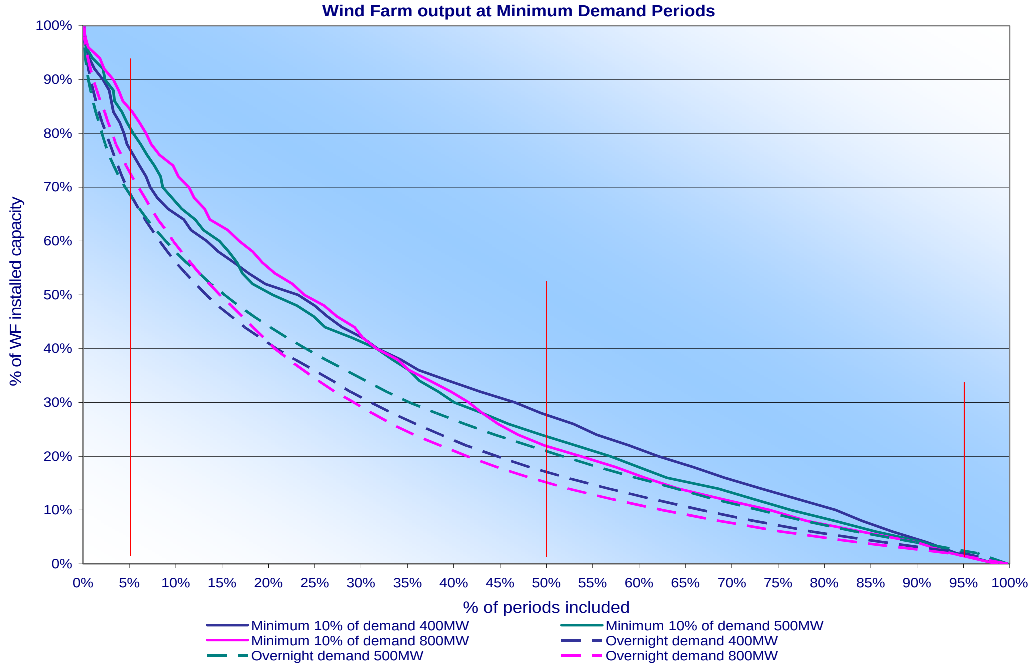


Figure 6-2 Minimum Demand periods vs wind-farm Output

Figure 6-2 indicates that for 50% of the periods of minimum demand, the output from the wind-farms is above 22% of their installed capacity. Significantly, for 5% of the minimum demand periods the output from wind-farms is above 75% of their installed capacity and for 2% of the minimum demand periods the output from wind-farms is above 85% of their installed capacity. This demonstrates that high levels of wind generation occur less frequently at times of low State demand. However, on those occasions where the two coincide, the security implications need to be managed.

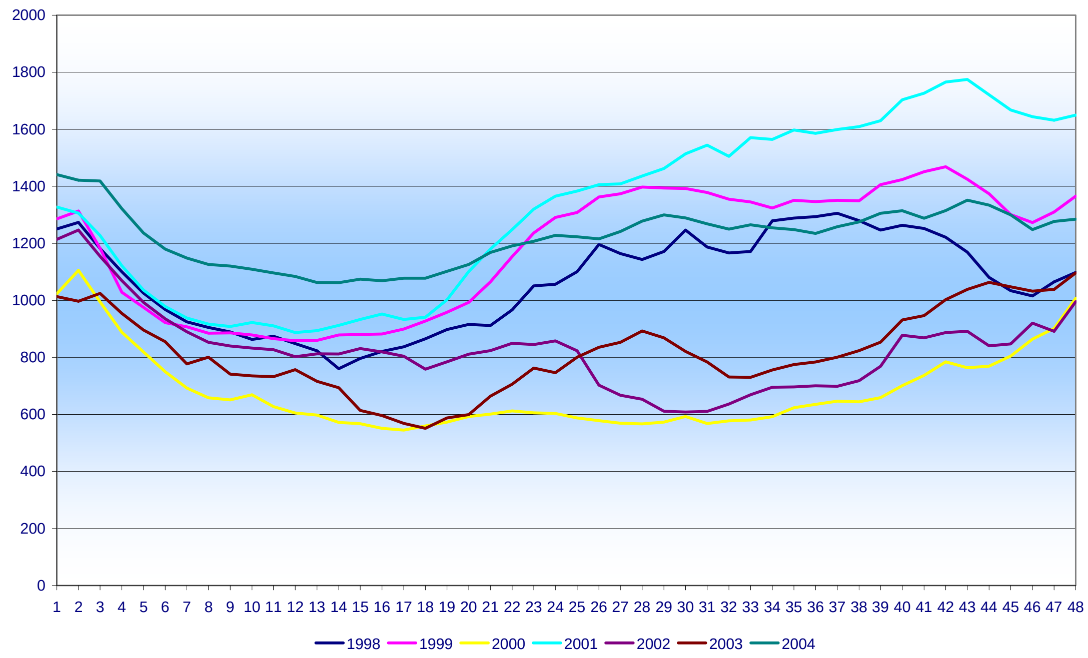


Figure 6-3 - January 1, SA Residual Electricity Demand after Wind generation has been removed (500 MW case)

Consistent with the graph of variability on January 1 of each year in the seven year wind dataset in *Figure 4-1*, *Figure 6-3* shows the residual South Australian demand that would need to have been supplied by the conventional generators and the interconnector at the same time. On some days the pattern of the wind generation negates the normal diurnal shape of the load. Based on the 500 MW case this shows that the impact of wind during marginal load periods will dominate the demand patterns in the State and are likely to be the major factor affecting the operational behaviour of the existing generators.

Figure 6-4 and *Figure 6-5* show modelled outcomes for a low demand period in South Australia; the Christmas – New Year period where most of the commercial and industrial demand is not present. Demand during these periods could be as low as 1,000 MW. In the 500 MW case, shown in *Figure 6-4,* South Australia is importing energy from the eastern states and there are still four or five units operating. In the 1,000 MW case, shown in *Figure 6-5* a significant portion of local demand is being satisfied by wind alone. South Australia is exporting energy to the eastern states and has only three or four conventional units operating at or near their full capacity.

This outcome is consistent with normal market theory that when significant levels of wind generation are available in the market at low demand periods, wholesale prices are also likely to be low with respect to the other interconnected regions. If this is the case then, depending on the level of wind penetration, South Australia may have a low level of imports or could be exporting power to the eastern states.

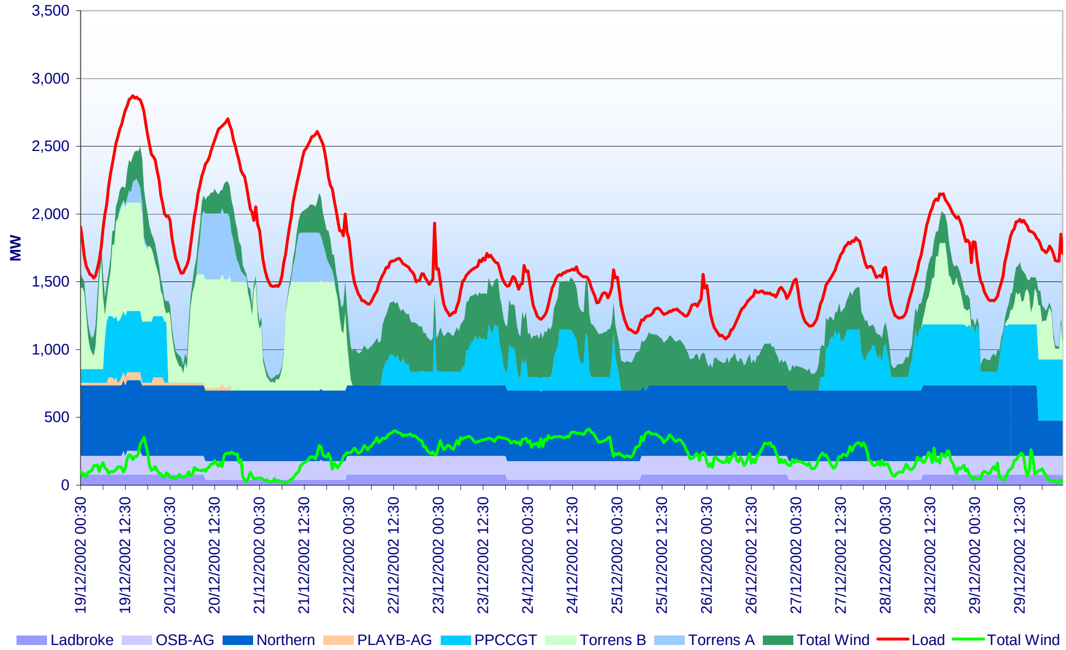


Figure 6-4 - Christmas - New Year Dispatch example (500 MW case)

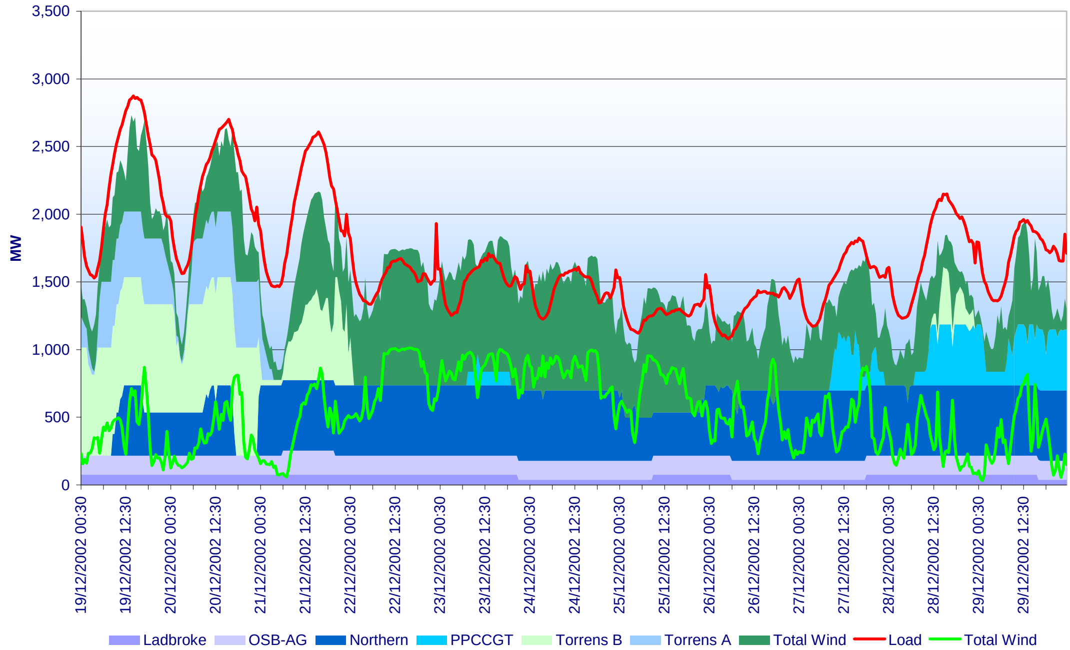


Figure 6-5 - Christmas - New Year Dispatch example (1,000 MW case)

The Planning Council's modelling shows that in most circumstances where the output from the wind-farms is significant with respect to demand, South Australia will be exporting power mitigating, to some degree, the risk of a credible contingency causing significant instability. The issue remains that under these circumstances the technical requirements for operating the network within its safe working envelope may require additional capacity from conventional generation beyond that which would be available on the basis of market offers to maintain system integrity during a forced outage.

Providing wind-farms are part of the economic optimisation of the National Electricity Market, there would be economic pressures on them such that there may be some self curtailment of wind output during low price periods, easing the pressure on enforcing system security.

The extreme variation for various timescales, or the variation we would expect to see matched or exceeded once per annum over that time period, is provided in *Chapter 4* and *Figure 4-4*. The extreme half - hourly and hourly variation for the 400 and 500 MW cases is less than the current contingency. Over 4 to 6 hours these variations are still less than two contingencies. As the power system is operated to maintain security through the failure of one of the largest units in South Australia (260 MW), the Planning Council considers that this situation is manageable. The ramp rate to deal with contingencies would initially be derived from operating plant in South Australia and interstate via the interconnector. For periods up to 30 minutes, the interconnector can be partially overloaded to meet such requirements. Gas turbines in the State can be started within 10 to 15 minutes and, over longer time-frames and subject to the flexibility of the fuel contracts, units at Pelican Point and Torrens Island could be started. This would imply that the commitment and ramp rate risks associated with these two cases are manageable.

The half-hourly variability in both the 800 and 1,000 MW cases exceeds the 260 MW contingency level. The variability over one to two hours exceeds two contingencies and the four to six hour variability is very high. Without adequate foreknowledge and planning it is likely that these cases could lead to insecurity.

Gas Utilisation

While not part of the primary concern of this study, the analysis shows that increased wind generation will reduce the average usage of gas in South Australia and increase the volatility of its usage. This confirms previous work and is to be expected given that gas is frequently the marginal fuel in the South Australian market.

Gas supply, particularly during times when either pipeline has reduced availability or capacity, is likely to be more challenging with higher penetrations of wind energy. The Planning Council is not in a position to assess the adequacy of the pressure and flow control arrangements on the gas supplies at each power station but notes that in previous periods where pipeline capacity has been severely curtailed, that these facilities have been hard pressed. The additional variability that wind may impose on these arrangements is likely to need further review.

The Planning Council notes that the results presented here are highly dependent on the assumptions used in the simulations. This analysis is particularly sensitive to the bidding behaviour of the participants. Under circumstances where the incumbent generators are more protective of their current operating regimes the affect could be reduced.

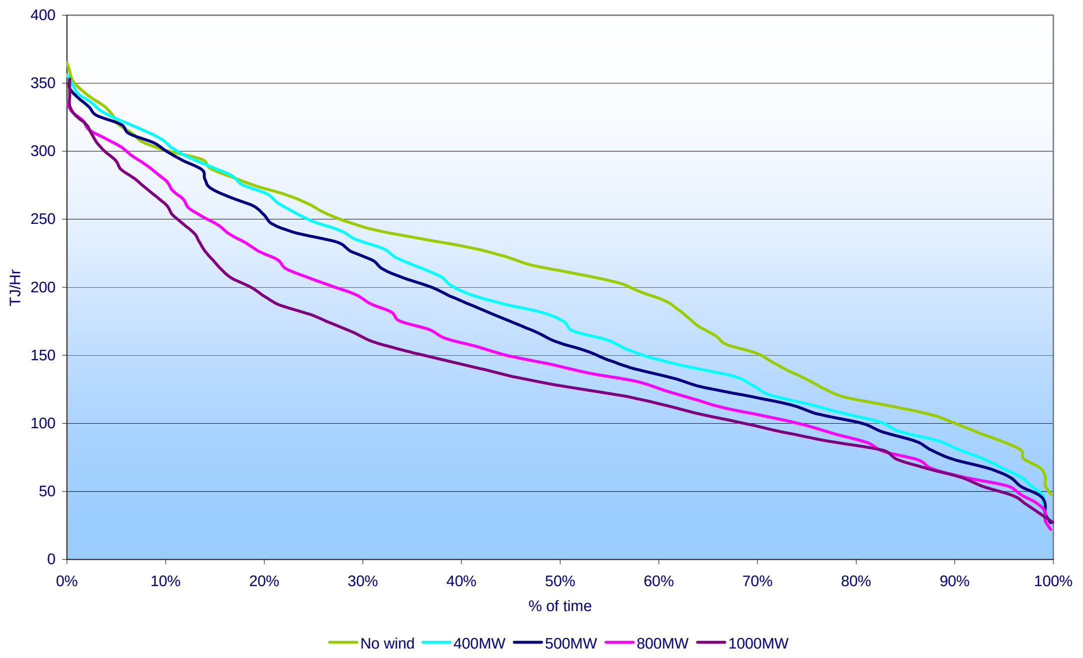


Figure 6-6 Typical MDQ duration curve (LRMC Case)

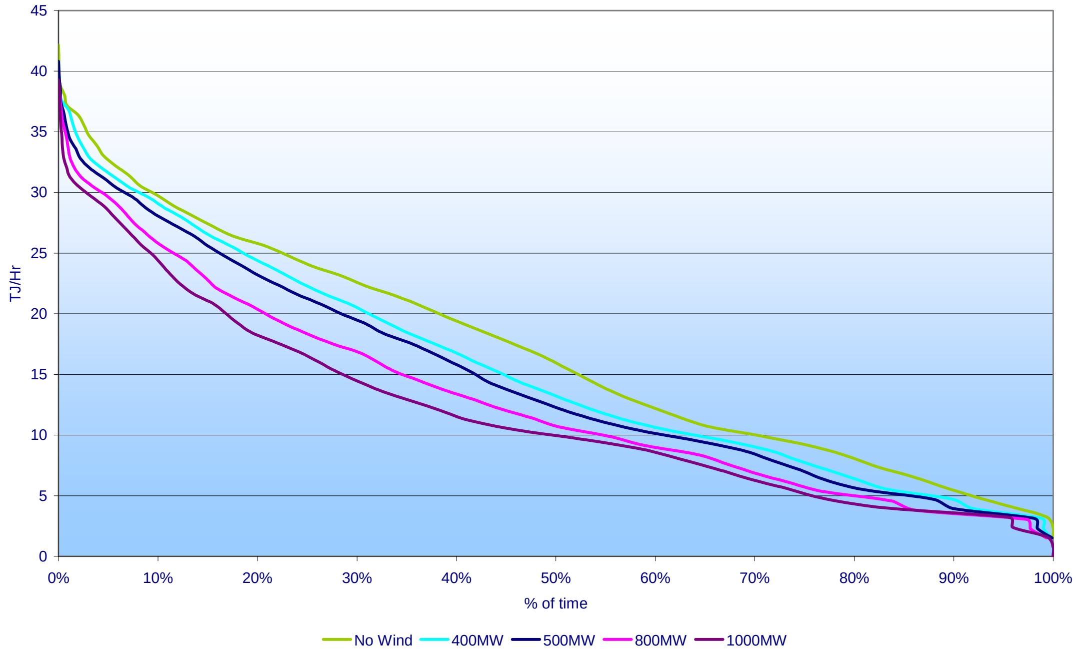


Figure 6-7 Typical MHQ duration curve (LRMC Case)

As can be seen from *Figure 6-6* and *Figure 6-7* the peak demand requirements are essentially unchanged, but the average and minimum requirements are significantly reduced. This increased volatility is to some degree mitigated by:

- the availability of alternative fuels for the Torrens Island and Hallett power stations;
- pipeline linepack; and
- the possibility of accurate wind forecasting.

However, this variability places increased importance on the management of pipeline linepack, the disposition of fuel in the pipeline and terminal pressures. If adequate instantaneous fuel reserves are not available then more expensive non-gas based generation is likely to be required, potentially increasing further the market price volatility. The Planning Council also notes that since the commissioning of the SEAGas pipeline the owner of the Moomba to Adelaide pipeline has indicated that it is reviewing the requirements for the current compressor arrangements. A reduction in the number of compressors available on the Moomba to Adelaide pipeline would reduce both its line pack and capacity and may increase the challenge of gas management as a result of high levels of wind penetration.

If the load factor of the pipelines is reduced as a result of the increased penetration of wind, as is indicated in the analysis, then this could increase pressure on the cost of gas transport. At this stage, the Planning Council has not attempted to calculate the potential cost impacts of this situation.

Market Participation Issues for Wind Generation

South Australia participates in the National Electricity Market and all the generators within the State are required to abide by the standards and rules that are contained in the *National Electricity Code*.

While wind generation was always envisaged as a part of the market, the rules were written at a time when the volumes of wind energy that are being proposed could not have been anticipated. As a result, the national market rules classify wind generators as non-scheduled. This classification has a number of implications for the operation of the market, some of which have the potential to lead to unacceptable market distortions as the quantum of wind energy increases:

Dispatch

Unlike other generators, wind generators do not participate in the normal market bidding process to determine which generators are allowed to operate to satisfy demand. Wind energy, therefore, never acts to set the wholesale pool price and is simply paid the going rate as determined by the bids of other generators. However, by lowering the overall volume of energy being bid for by those residual generators, wind will, in this circumstance, increase competition and create a downward pressure on pool price.

Stability and Market Optimisation

Under the current rules, NEMMCO has no power to manage the stability and security of the market by incorporating wind into its normal market optimisation techniques. Normally, NEMMCO would set certain tolerance levels expressed as constraint equations that would ensure that the system remained in a secure operating state. As a non-scheduled generator, wind does not participate in this process and NEMMCO must either rely on powers of manual intervention or must constrain other non-wind sections of the market if it is to control security. A manual scheme cannot provide the immediate response that is likely to be necessary, particularly in light of the variable output associated with wind and, in any event, is potentially inefficient and undesirable in a market context. Constraining other plant to deliver security also risks inefficient outcomes and undesirable price impacts.

Transparency

Currently, wind generation is treated as negative demand rather than as a source of supply. As the volume of energy supplied by wind grows, this treatment of wind in the market has the potential to cause confusion and certainly will make demand trends hard to interpret. It means that neither the forecast nor actual quantities of wind energy are visible to the market making it hard for participants to manage their involvement in the market.

Ancillary Services

A key consequence of wind being categorised as non-scheduled is that they do not participate in the markets for ancillary services. Ancillary services are an important part of the market design that allows NEMMCO to manage the market within secure limits. On the whole, the ancillary services operate on a causer-pays basis where the cost of providing the relevant service is paid for by the individual or group of market participants that create the requirement for the service. Conversely, those participants who can supply ancillary services are able to earn extra revenue in the market.

Under the current rules, wind energy will neither pay for the ancillary services that they cause nor be able to earn revenue from the provision of such services.

7 POTENTIAL IMPACT ON THE MARKET AND MARKET PRICES

The modelling described in *Appendix* 3 and used in the previous section to examine potential impacts of wind on the power system also provides insights into the market outcomes and price impacts that can be expected with a higher penetration of wind generation. The following commentary regarding the impacts that different levels of wind might have on the market is drawn from the Planning Council's extensive modelling results. No attempt has been made to present the specific results for all of the cases and scenarios considered; rather, the following section extracts examples from the modelling to draw general conclusions.

Interconnector Utilisation

The results of the chronological modelling indicate that as the level of wind penetration in South Australia increases, part of the wind energy offsets local generation and the rest comes off imports into the State.

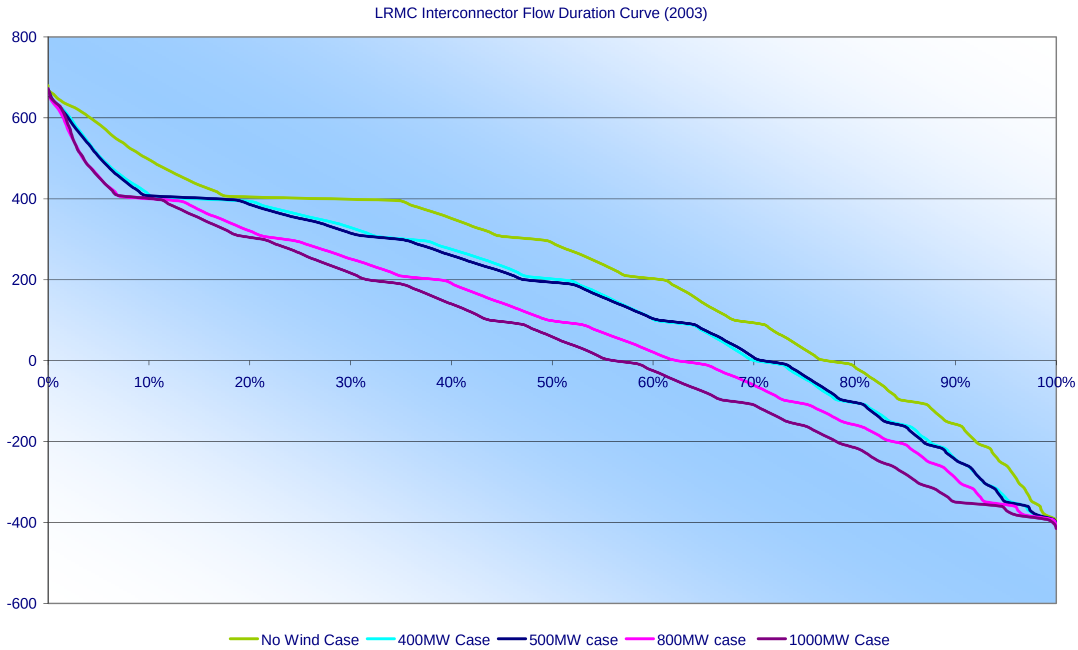


Figure 7-1 Interconnector Flow duration Curves for the LRMC analysis

Figure 7-1 shows that as the level of wind penetration in South Australia increases there is an increase in the level of energy exported and a decrease in the level of imports. Importantly, in all but one case, South Australia remains a net importer of energy from the Eastern States. This has implications on the local generation in the State. The results also indicate that where the import levels into South Australia remain high reducing the local generation, there are more occasions where the wind-farms in the South-East are also curtailed.

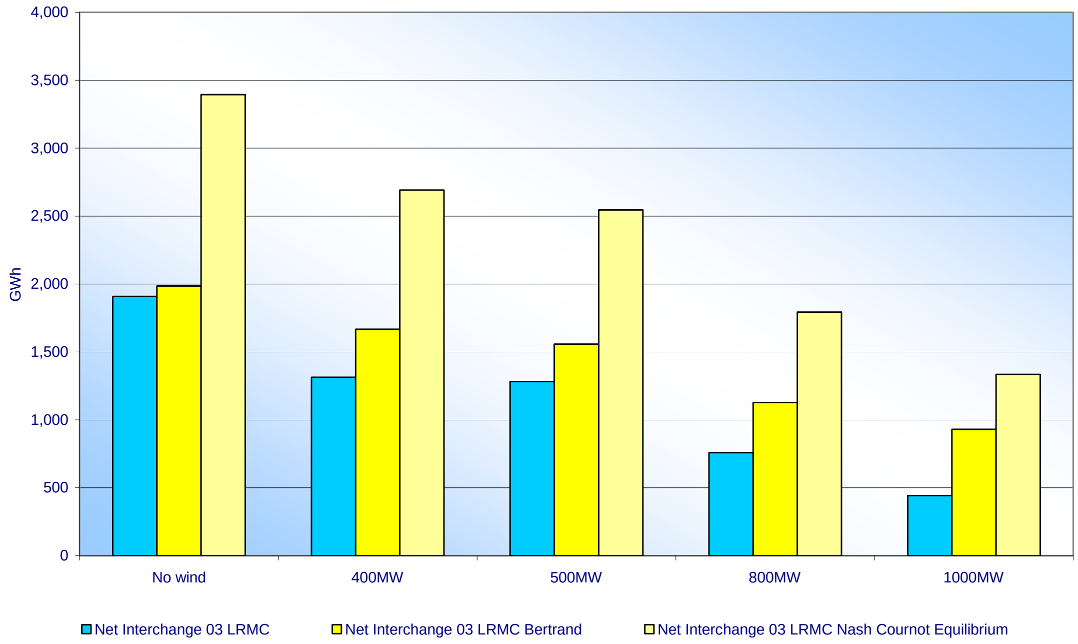


Figure 7-2 – Net Interchange - LRCM results for 2002-03

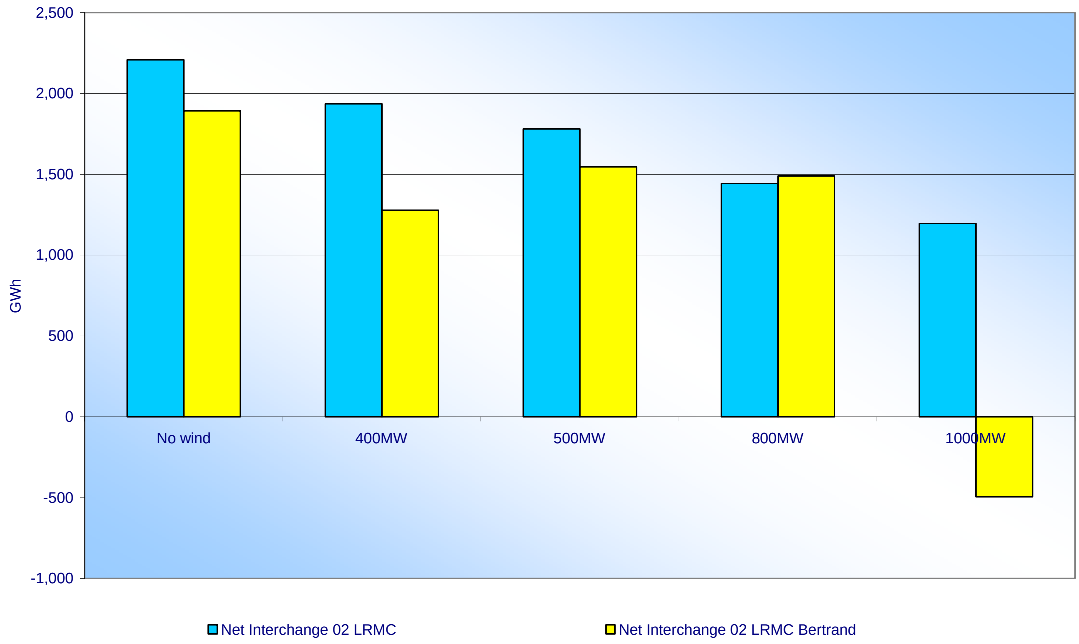


Figure 7-3 Net Interchange - LRMC results for 2001-02

Impact on the Incumbent South Australian Generators

Depending on the bidding strategy used the results indicate that about 50% of the energy generated by wind power displaced South Australian scheduled generation and principally gas generation.

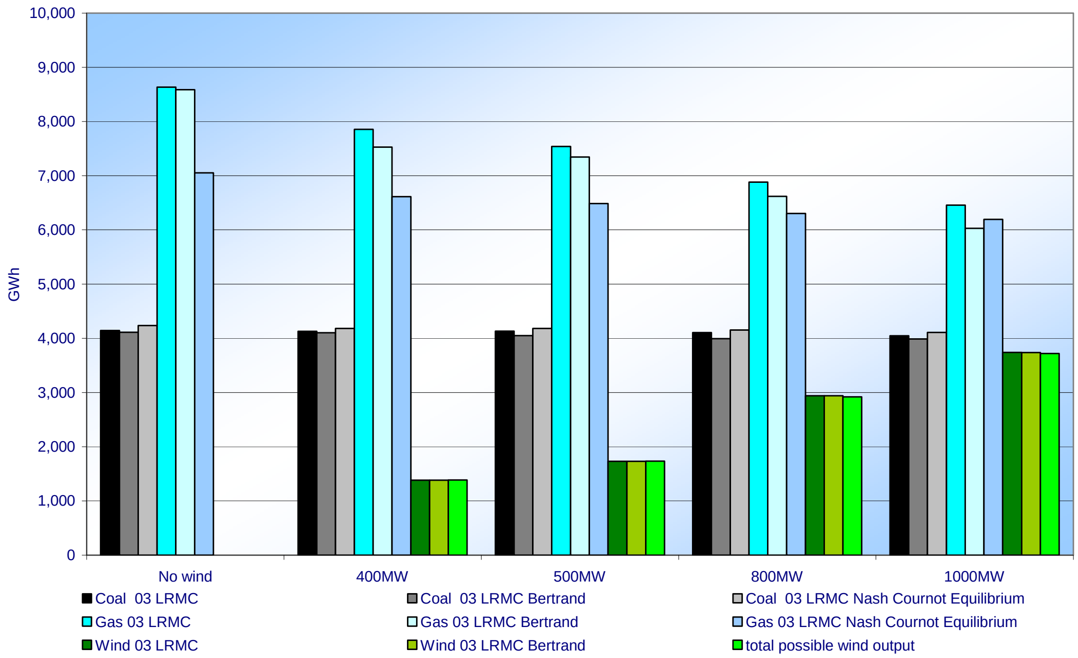


Figure 7-4 - Relative Generation Levels - LRMC results for 2002-03

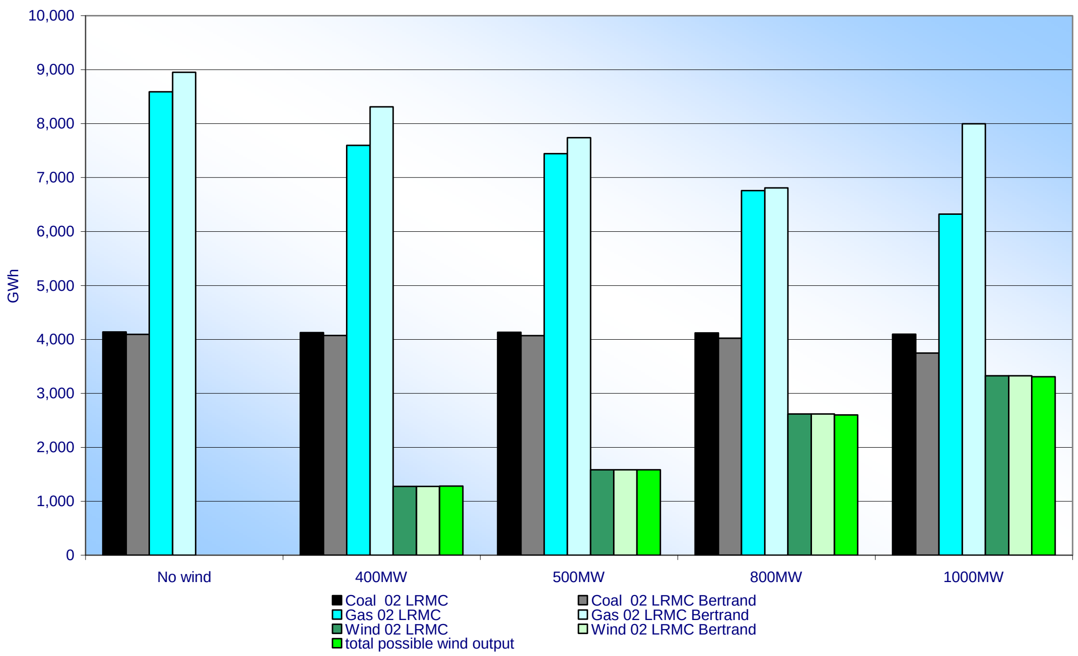


Figure 7-5- Relative Generation Levels - LRMC results for 2001-02

The response of the generators to the change in competition brought about by the increased penetration of wind in the State is difficult to predict.

Price Impacts

The spot price projections from any market modelling is highly dependent on the bidding assumptions and methodologies that are used. The Planning Council modelling considered four different bidding styles all of which are described in *Appendix 3*.

It is also important to differentiate between wholesale market effects and retail market effects. The market modelling done here simulates the operation of the wholesale market whereas prices to customers will be driven by prices in the associated financial contract markets.

The introduction of a significant quantity of generation into any region increases competition in some or all sectors of the market and, in an ideal market, will put downward pressure on price. The modelling of the outcome in one year for each of the four cases generally demonstrates that impact. The scale and nature of those impacts varies with the assumed bidding behaviour and is strongest in the simpler bidding models.

Increasing wind generation in South Australia also changes the utilisation of the interconnector, reducing imports and increasing exports. These changes will tend to bring prices in South Australia and Victoria closer together with more generation in South Australia. Under some scenarios prices in South Australia remain relatively constant while prices in Victoria and the rest of the market increase.

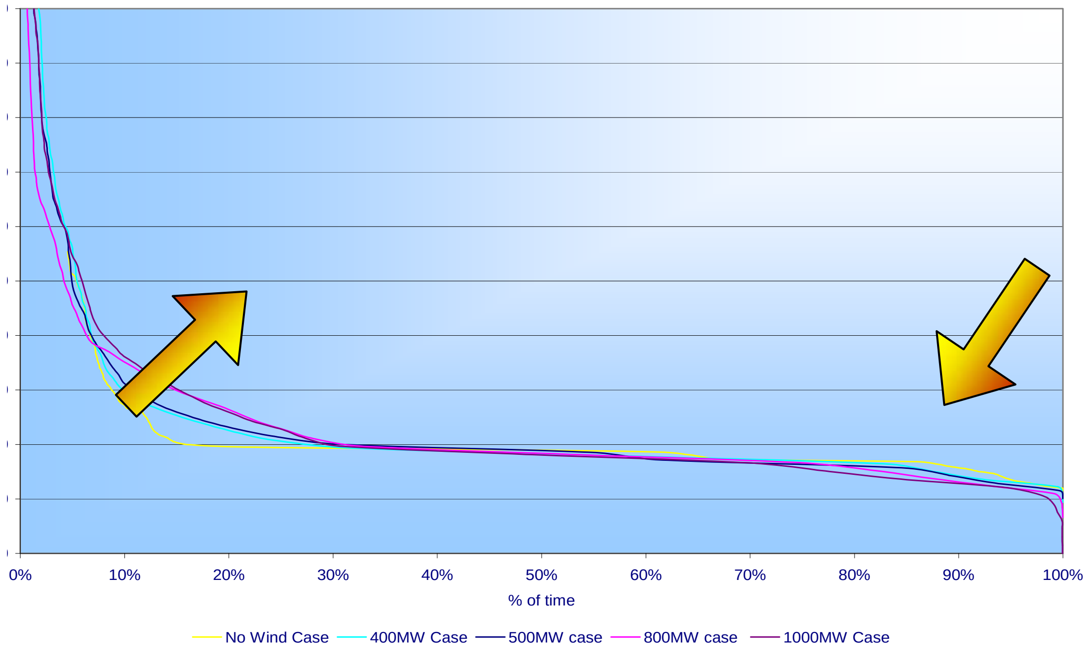


Figure 7-6 Indicative Price Duration Curve

In the simple SRMC bidding cases, prices in South Australia and the National Electricity Market fall. However, prices in these cases are unsustainable, being much lower and less volatile than real market prices. The LRMC cases are perhaps more representative of commercial reality, assuming participants seek to remain viable. These cases reveal wholesale market price volatility increasing with increased penetration from wind. More wind increases wholesale market competition and may decrease prices when the output from wind generators is high. However, when wind generation is low or in situations where there is a rapid fall in wind-farm output, the nature of competition changes and prices are likely to be driven higher.

While only indicative, *Figure 7-6* shows that as the level of wind generation increases the occurrence of low prices increases, but the incidence of higher prices also increases. It should be remembered that the market simulations performed by the Planning Council only cover a single year in the future (2005-06) and longer term studies will be heavily influenced by behavioural responses. It is certainly clear that if the price trends shown here were to continue that the timing of new entrants and the generation technology they might choose would be different than if prices were to simply rise as a result of load growth. Increasing wind generation shifts the investment decision away from the selection of what would normally be considered base load style of generation, to technologies that are more flexible.

The energy provided by the wind-farms for all cases considered is significant with respect to energy growth in South Australia. The Planning Council's 2004 *Annual Planning Report* projects average growth in energy demand at 250 GWhs per annum over the next five years. The 400 MW case generates sufficient energy to cover 5 years of growth and would result in several years of negative energy growth for the scheduled generators. The energy contribution from wind energy in South Australia will therefore have a considerable impact on other investment in the market.

While the Planning Council has not simulated the flow-on effects of increased price volatility on the retail market price it is possible, from fundamental economic theory, to link increased wholesale price volatility to increased retail price. This is primarily due to the increased cost of provision of cap contracts and other price insurance mechanisms. The end result on the average retail price would depend on whether the increased cost of cap contracts would be balanced by potential reductions in the base cost of other hedging instruments.

8 INTERNATIONAL EXPERIENCE

The Planning Council supplemented its analysis of the impacts of wind generation in South Australia with a review of international experience. This review has been undertaken in two parts:

- a review by Garrad Hassan of international experience in countries with significant levels of wind generation; and
- a Planning Council review of recent international developments in the integration of wind energy into power systems.

The following sections provide an overview of the development of wind generation internationally, a summary of the review by Garrad Hassan and the review by the Planning Council. The full version of the Garrad Hassan report is available on the Planning Council's website[2] and a comparison of technical standards by the Planning Council will be published shortly.

Development of Wind Energy

Windmills have been a source of energy around the world for centuries. The modern form of wind turbines for electricity generation began serial production around 1980 with the earliest markets being Denmark and California. These generators were very small, a popular model being 55 kW. The US market slowed after 1986 with adverse changes to the supporting regulations but growth continued in Europe with Germany and then Spain becoming major markets for the technology. By 1990, wind turbine generators had grown to typically 500 kW or ten fold in ten years.

Through the 1990's, wind generation continued to grow and the technology develop. In 1995 wind turbine generators in excess of 1 MW became available and the first offshore wind-farms were developed in Europe. The technology has continued to develop and wind turbines of 2 to 3 MW are widely available today with several 4.5 MW machines under test. The growth in the world's installed capacity and its disposition around the world is shown in Figure 8-1 and Figure 8-2[3]. In 2003 some 8,129 MW of new wind generation was commissioned worldwide and in 2004 a further 8,321 MW.

[2] www.esipc.sa.gov.au

[3] Information for these charts has been drawn from the World Wind Energy Association Press Release 7 March 2005

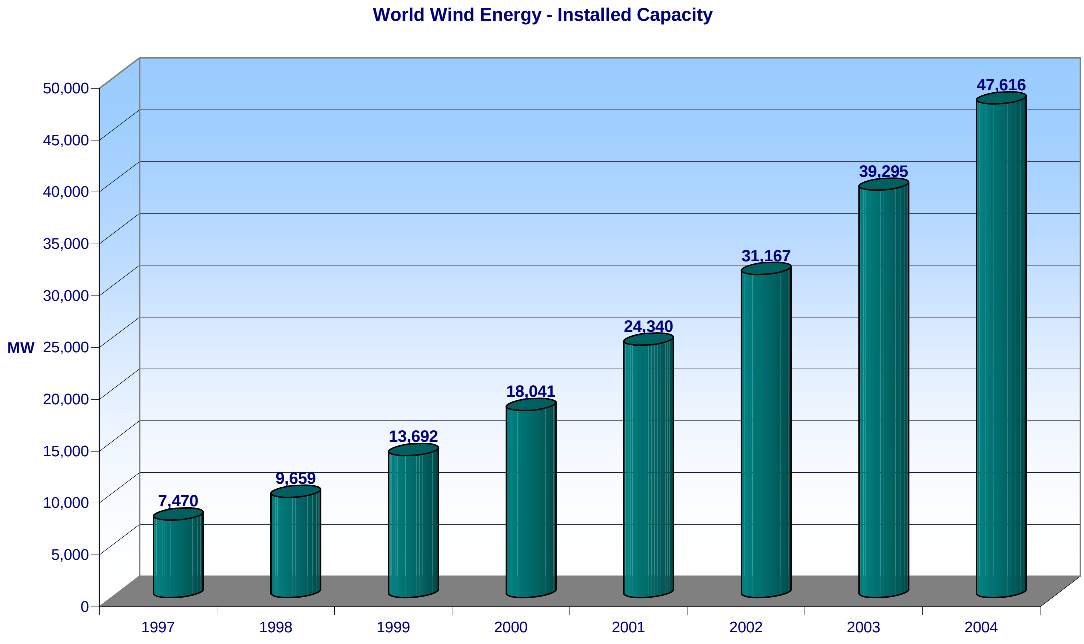


Figure 8-1 - World Wind Energy - Installed Capacity

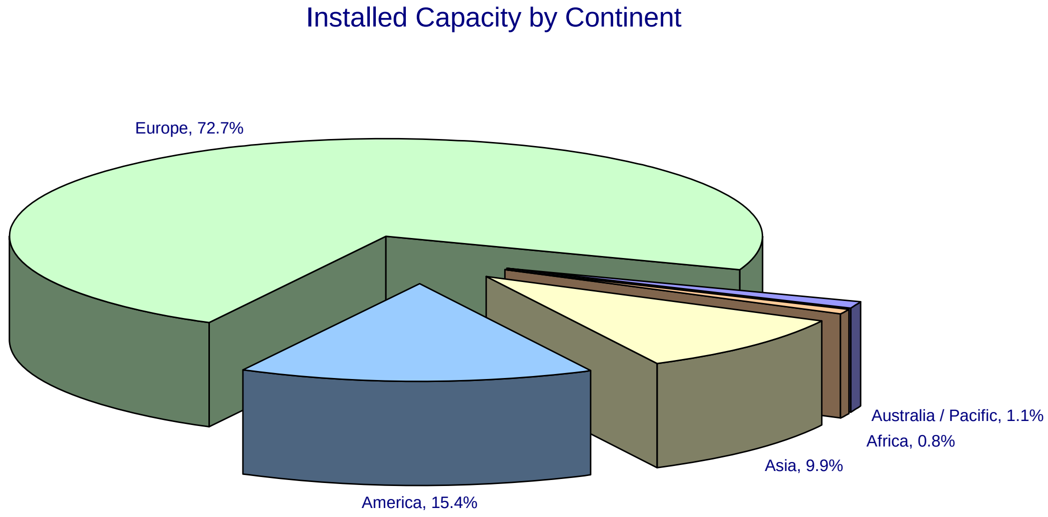


Figure 8-2 Installed Capacity by Continent

The world market for wind turbines is now very large and as a result there have been marked changes in the manufacturing industry. There has been some consolidation of participants including the takeover of NEG-Micon by Vestas and we have seen the entry of three of the biggest electrical equipment manufacturers (GE, Siemens & Mitsubishi) through their takeover of smaller players. The strength of the leading companies now manufacturing wind turbines is expected to continue the development of the technology leading, in the longer term, to lower production costs and better performance. Strong competition and new technical standards have already resulted in significant new products which address many of the technical concerns associated with earlier wind turbine designs.

Although the traditional European markets continue to have the highest installed capacity other markets such as the United States, Canada, Ireland, UK, Australia and New Zealand are now growing fast. The World Wind Energy Association has identified the Australia/Pacific region as the fastest growing in the world in 2004. The cost of wind generation has fallen considerably since the early 1980's but is still higher than conventional fossil fuel generation. The countries with a significant penetration of wind generation all have support schemes which may include direct subsidies, tax benefits, obligations on other parties to purchase a percentage of green energy and arrangements to subsidise the cost of connection.

Garrad Hassan Review of International Experience

Garrad Hassan was retained by the Planning Council to report on international experience in markets with significant levels of wind generation. The work was designed to learn from overseas experience, highlighting issues and solutions potentially relevant to South Australia.

The report reviewed experience in the following overseas markets:

- Denmark (Jutland and Funen);
- Eire;
- Germany (and particularly Lower Saxony and Schleswig-Holstein);
- Great Britain;
- Spain;
- Texas; and
- Canada (Alberta).

The report developed a set of market statistics which allow the preparation of "world-ranking" tables to identify the penetration of wind energy and compare it with possible levels of wind generation under consideration in South Australia. The following tables summarising that work rank the areas on the basis of the wind penetration by capacity and energy.

COUNTRY REGION	TNSP	SYSTEM MAX DEMAND (MW)	TOTAL GENERATION CAPACITY (MW)	INSTALLED WIND CAPACITY (MW)	WIND CAPACITY PENETRATION (%)
Western Denmark	Eltra	3,760	7,018	2,315	33.0
SA – 800 MW Case	***ElectraNet***	***3,296***	***4,246***	***800***	***18.8***
Germany	all	75,000	120,822	16,500	13.7
Spain	REE	37,212	59,866	8,000	13.4
SA – 400 MW Case	***ElectraNet***	***3,111***	***3,791***	***388***	***10.5***
Eire (ROI)	ESB NG	4,494	5,892	256	4.3
Scotland	SSE + SP	5,914	10,067	246	2.5
Alberta	AIES	7,880	11,900	255	2.1
Texas	ERCOT	59,080	82,320	1,396	1.7
Australia - 2006	all states	38,554	48,073	720	1.5
England/Wales/NI	NGT	55,400	64,000	698	1.1

Table 8-1- System Capacity and Wind Penetration – Summary (Overseas markets at end of 2004)

COUNTRY	TNSP	TOTAL CONSUMPTION (TWh)	GENERATION BY WIND TURBINES (TWh)	WIND ENERGY PENETRATION (%)
Western Denmark	Eltra	21	4.1	19.3
SA – 800 MW Case	***ElectraNet***	***13.5***	***2.5***	***18.5***
SA – 400 MW Case	***ElectraNet***	***12.9***	***1.2***	***9.3***
Spain	REE	224	17.5	7.8
Germany	all states	507	21.7	4.3
Eire (ROI)	ESB NG	29	1.3	4.5
Scotland	SSE + SP	36	0.9	2.4
Texas	ERCOT	280	4.3	1.5

COUNTRY	TNSP	TOTAL CONSUMPTION (TWh)	GENERATION BY WIND TURBINES (TWh)	WIND ENERGY PENETRATION (%)
Alberta	AIES	55	0.7	1.3
Australia (2006)	all states	226	2.1	0.9
UK	SSE+SP+NGT	400	2.7	0.7

Table 8-2 - System Energy and Wind Penetration – Summary (Overseas markets at end of 2004)

Table 8-1 and Table 8-2 indicate that South Australia will be world ranked by the end of 2005. The 800 and 1,000 MW cases would take South Australia to a world leading position on an energy basis confirming the importance of examining the market and technical challenges others have experienced and the solutions they are seeking to implement. The review focussed on those issues and solutions considered relevant to South Australia.

At the commencement of this study the wind capacity penetration in the National Electricity Market and in South Australia was less than one per cent. As a result no issues had been observed in the National Electricity Market nor would any be expected. There had, however, been work undertaken by the Planning Council, NEMMCO and the University of NSW (for the Australian Greenhouse Office) seeking to identify possible issues to enable the market to be better prepared for the future development of the wind industry. This background work and Garrad Hassan's experience highlighted a number of potential technical and market issues relating to the increasing contribution of wind generation to the National Electricity Market and the South Australian network in particular.

The report discusses the issues that may arise with increasing wind penetration and the mechanisms that are being employed to overcome them in the seven nominated markets including:

- frequency control;
- forecasting of wind-farm output;
- voltage control;
- system security and stability;
- connection costs;
- network constraints; and
- displacement of conventional plant and control/curtailment of wind generation.

Garrad Hassan observed that all of the potential technical issues that have been discussed have been encountered in at least one of the seven markets considered. The learnings from the review are summarised below.

Value of Diversity

Climatically and geographically diverse markets (such as Spain) benefit from lower variability in aggregate generation than areas of high concentration such as Western Denmark.

Forecasting

The review found that, of the seven countries or networks considered, significant experience with short-term forecasting of wind generation has been gained in Denmark, Germany and the Republic of Ireland.

In Denmark, Eltra has had limited success in forecasting wind generation. High forecast errors and several cases of problems caused by gross forecasting errors have been experienced by Eltra. Eltra considers that there is significant room for improvement and research is underway to reduce the average forecast error for the system.

In Germany, the transmission operator E.ON Netz uses a forecasting system developed by ISET (Institut für Solare Energieversorungstechnik). The error for a 24-hour-ahead forecast of wind generation is understood to be consistently within about 10%; however the accuracy of the forecast decreases rapidly with increasing time intervals.

In the Republic of Ireland, ESB National Grid has trialled forecasting systems but the review was unable to find any information regarding the accuracy of the different systems that it has trialled. However, it is notable that ESB National Grid does not use a short-term model, at least in part due to a lack of real-time generation signals from wind-farms but, it has concluded that such data will be necessary to its operations in future.

Spain and Great Britain are aware of the potential benefits of forecasting and have placed a high priority on developing and implementing forecasting.

Garrad Hassan considers that international experience points to the importance of forecasting as it can reduce the impacts of wind generation on the power system by:

- allowing better scheduling of the start-up and shutdown of conventional generators; and
- assisting in the management of system security.

Remote Monitoring

The development of the wind generation in Europe from small, often community owned turbines and small wind-farms, means that system operators in these areas often face a paucity of real time data on the output of wind generators. Work in the Republic of Ireland has identified this as a potential problem and ESB has concluded that real-time wind-farm operating data from wind-farms is necessary for both the:

- assessment of system security; and
- generation scheduling.

The current Scottish Grid Code requires real-time generation signals for wind-farms in excess of 5 MW and other operators are now requiring SCADA data on new larger wind-farms.

NEMMCO requires real-time generation data from all non-scheduled generators in excess of 30 MW. As the 30 MW criteria will include most wind-farm capacity Garrad Hassan considers that NEMMCO is in a good position with respect to the development of short-term wind generation forecasting and the real-time assessment of system security.

Control and Curtailment of Wind Generation

The Eltra system in Western Denmark includes a relatively large amount of wind generation and unscheduled cogeneration (or combined heat and power generation). As almost all of this generation is not capable of central control or curtailment (sometimes referred to as run-back capability) Eltra has experienced difficulties on occasions in managing power flows on its 150kV and 400kV internal lines, sub-stations and interconnectors to Germany and Scandinavia.

In other international examples, control or curtailment of wind generators has been routinely adopted to ensure secure network operation. For example, wind-farms on the Kintyre Peninsula connected to Scottish and Southern Energy are subject to routine curtailment to manage power flows on critical lines. Similarly, wind-farms in western Texas connected to ERCOT's system are subject to regular curtailment.

Recent studies in the Republic of Ireland have determined that curtailment will be necessary at the higher penetrations of wind energy expected to be installed in the future. Spain has also undertaken work contemplating central control and curtailment of wind generation under certain circumstances.

Garrad Hassan considers that, on the basis of international experience, South Australia will require control infrastructure for curtailment at some stage.

Technical Standards

The technical standards initially imposed on wind generators seeking to connect to the grids in the US and Europe were lenient. The technology employed in those early wind turbine generators usually had very poor electrical characteristics. High standards, however, were unnecessary when wind generation constituted a very small percentage of total generation on the power system and individual wind turbine generators were small.

As the number of generators increased and larger wind-farms were introduced, a number of problems became evident and security risks arose. As a result, new and more stringent requirements were developed.

In Germany, E.ON Netz developed and implemented a comprehensive "Grid Code" relevant to wind generation and including specific requirements such as the ability to:

- operate safely and remain connected over a prescribed range of voltages and frequencies;
- contribute toward voltage support; and
- ride through specified faults on the system.

A number of international markets with a growing contribution from wind energy have introduced, or are developing wind specific Grid Codes. Grid Codes with specific requirements relevant to wind-farms are now in-place in Ireland, Great Britain, Spain, Germany and Denmark. Proposals for such codes are well advanced in the US (FERC and NYPP)) and Canada (Alberta). Some of these codes are discussed further below.

The manufacturers of wind turbine generators have generally shown the ability to quickly enhance the performance of their product to comply with these emerging requirements. While the *National Electricity Code* specifies technical standards for all generators, many of the requirements do not apply well to wind-farms. Garrad Hassan considers that Australia should monitor international developments in this area.

Reactive Power and Voltage Control

There have been some issues with the management of voltage and power factor as a result of high local concentrations of wind generation. In the Texas system for example, there are significant distances between the load and the major source of wind generation. The system experienced large voltage swings due to changes in active and reactive power flows caused by:

- large generation capacity at the end of long transmission lines; and
- the displacement of conventional generation by wind-farms with lower reactive power and/or voltage control capabilities.

The situation has been solved in such cases by the installation of additional reactive capability to control voltage. Generally the speed and nature of switching required necessitates the use of solid state controls to produce or absorb reactive power.

Dynamic control of the reactive power output of wind-farms is technically feasible and increasingly necessary. In a number of international markets grid connection requirements have changed to oblige wind-farms to provide such a capability. Examples include the new requirements in the United Kingdom, Germany, Canada and the United States. Spain, on the other hand, has introduced regulations allowing wind-farms to vary their power factor with a bonus paid for supporting voltage control and penalties for not doing so. The bonus paid or penalty imposed varies by time of day and seeks to provide a market incentive for helping to maintain the system voltage within acceptable limits.

Garrad Hassan considers that the ability of modern wind generators to supply and absorb reactive power and contribute to voltage control will be useful for South Australia. The existing National Electricity Market arrangements pay for voltage control under some circumstances through the Network Control Ancillary Services (NCAS) arrangements. Garrad Hassan considers that these might eventually form the basis for commercial incentives for the supply of voltage support services in which modern wind-farms could participate.

Frequency Control

All power systems need generators with the ability to vary their output to balance supply and demand and to ensure that the system frequency remains in a tight and stable operating range. In the Australian market, these requirements are met by generators offering frequency control ancillary services. Supply and demand must be kept in balance as demand varies (regulating services) and as events occur such as plant failing (contingency services). Contingency services are required to act very quickly often through the inertia of larger conventional generators and to sustain changes over time. Traditionally wind turbine generators have little or no inertia and have not been able to modulate their generation with varying demand by responding to frequency variations on the system.

The advent of large concentrations of wind generation in some areas of Europe has lead to some difficulties with occasional shortages of appropriate generation online to provide frequency control services. Eltra in Denmark, for example, has had occasions when there was not sufficient local frequency control ancillary services available. However in many cases Eltra has been able to rely upon interconnectors with Sweden and Norway to supply such services.

Garrad Hassan notes that some wind turbine generators now available can assist with frequency control and that some grid codes under development are considering imposing such requirements on new generators. The requirement for any additional frequency control ancillary services support in the National Electricity Market as a result of wind generation needs to be further considered in conjunction with the potential role of interconnectors.

Power Quality

The variability in output inherent with wind generation and the nature of the technology employed, created the potential for issues with the maintenance of adequate power quality. International experience with wind integration has shown that local network issues such as power quality (harmonics, flicker and other effects) have been generally acceptable despite early concern from utilities.

Garrad Hassan considers that, on the basis of international experience, power quality issues associated with wind generation are well-understood and that mitigation, although not often necessary, is relatively straightforward.

Market Issues

Market issues raised by wind generation will vary with different market designs and, to date, there is only limited experience with high wind penetration in competitive markets other than Nordpool. The various market designs influence:

- pricing outcomes with wind generation;
- the need to participate in forward markets and hence for wind generation to forecast output; and
- arrangements with regard to ancillary services.

Increasing levels of wind generation in deregulated markets also raise issues associated with grid connection costs and the incentives and penalties driving investment into efficient locations.

GARRAD HASSAN CONCLUSIONS

Garrad Hassan concluded that there is no limit to the relative penetration of wind energy in a power system evident from international experience. However, it is clear that with increasing levels of wind generation action needs to be taken to:

- ensure technical standards are appropriate;
- introduce generation monitoring;
- implement wind generation forecasting; and
- manage congestion and potential security issues with schemes to curtail wind generation when necessary.

Garrad Hassan considers that at some higher level of wind energy penetration, there will be an incremental cost will exclude further investment in wind energy.

There are a number of common themes in all markets studied and solutions are being developed that will have application in Australia. While stricter grid connection requirements have been found necessary with increased wind energy penetration, wind turbine technology has evolved and manufacturers have responded to efficiently meet these requirements. South Australia is already receiving benefits from this evolution. Changes to standards will be necessary at some point in the National Electricity Market and when they do, attention should be given to a number of the newer international standards. The growth of the world market for wind turbines and the consolidation in the manufacturing industry should see further improvements in the capability of wind generators.

International Technical Standards for Wind Generators

The growth of wind generation in recent years has driven several electricity markets to develop new technical standards for wind-farms seeking to connect to their networks as those networks face a higher relative contribution of wind energy. In particular, the Planning Council has considered:

- the developing electricity market in the Republic of Ireland (Commission for Energy Regulation CER); and
- the Alberta Power Pool (Alberta Electric Supply Operator AESO).

A detailed review of comparative technical standards for wind will be published shortly on the Planning Council's website.

The Republic of Ireland

The Commission for Energy Regulation (CER) is the independent body responsible for overseeing the liberalisation of Ireland's energy sector. The introduction of competition into the Irish electricity market is proceeding on a phased basis, with a view to full market opening in 2005. The liberalisation of the market began on 19 February 2000 when major consumers of electricity were able to choose a supplier of their choice. All customers, irrespective of their electricity consumption level, can choose to be supplied from retailers that sell either renewable/sustainable/alternative ("green") or Combined Heat and Power (CHP) electricity.

Through 2003 there were rising concerns with the growth of wind energy on the system. With only 166 MW of wind generation connected at the time supplying just 2% of Ireland's electricity requirements the Commissioner for Electricity Regulation announced a moratorium on the connection of new wind-farms in December 2003. At the time some 700 MW of wind-farms were seeking connection. During 2004 the electricity bodies in Ireland worked to develop a new "Grid Code for Wind". The new requirements were to be inserted into the existing transmission and distribution Grid Codes and apply to wind generators above a threshold of 5 MW. The approved new Grid Code for Wind can be viewed on the CER's website in consultation paper CER/04/237.

In December 2004 the Commission directed ESB National Grid and ESB Networks to resume issuing connection offers to wind generator applicants in accordance with the new technical standards and a number of conditions. There is a considerable backlog in processing applications, verified wind generator models have been difficult to obtain and recent advice to the Planning Council is that progress in connecting new wind generators in Ireland will be slow. The new technical requirements applying to Ireland can therefore be seen as pre-empting any issues arising rather than being based on problematic experience. Never the less they do present a recent updated set of technical standards which may be relevant in South Australia.

Alberta

The Power Pool of Alberta has been in operation since 1996 and has operated as a competitive market since January 2001. With a peak load in 2004 of 9,092 MW and total generation of 64,900 GWh, the market in Alberta is over 3 times the peak load in South

Australia and around 5 times the generation. As of September 2004 Alberta had 210 MW of wind generation.

The Government of Alberta is supportive of wind generation and the AESO has moved forward with a major transmission enhancement proposal for south-western Alberta in order to accommodate proposed wind power developments in that area. They were concerned though with the rise of wind generation seeking to connect to the system early in 2004 and determined that:

> "Alberta needs wind power standards to ensure the safe, reliable, fair and economic operation of Alberta's interconnected electric system."

The AESO then embarked on a process to develop new technical standards to apply to wind-farms seeking to connect to the power grid in Alberta. Following a major study and recommendations by consultants ABB, the AESO worked in collaboration with industry stakeholders from May through November 2004 to those requirements. The result of that work was the "Wind Power Facility Technical Requirements" published in November 2004. These requirements were developed with considerable technical analysis and industry consultation but again they must be seen as foreshadowing issues and dealing with them in advance of any problems becoming evident. The AESO has stated that it continues to monitor developments of wind power standards and may make modifications in the future to be consistent with other emerging standards in North America's electric industry.

Other Jurisdictions

The growth of wind generation on electricity networks in many areas of the world has lead to a flurry of activity in developing new standards appropriate to the connection and operation of wind generation. During the period of our study there have been further developments in standards for the United Kingdom and the United States. While these have not been included in our more detailed analysis they have been considered in framing our advice.

The Federal Energy Regulatory Commission (FERC) has been considering standards for the connection of wind generation which would apply more consistently across the United States. FERC is the independent agency that regulates the interstate transmission of natural gas, oil, and electricity in the US. In January 2005 FERC released a set of proposed regulations that would "remove barriers to wind-generated electricity while helping to ensure continued reliability of the national power grid."

In releasing the proposed regulations FERC noted that the existing technical standards and rules for connection to the US power system are tailored to more traditional power generation sources. The proposed regulations would include certain technical requirements, in addition to the standard requirements, that would apply to wind generation plants. In its statement commencing consultation on the draft requirements it stated that:

"The Commission is proposing to require wind plants to demonstrate the ability to continue operation even if a low voltage condition is experienced on the grid, to stabilize voltage levels and help the transmission grid stay in balance. Wind-powered facilities further would be required to have supervisory control and data acquisition (SCADA) capability to ensure real-time communication with transmission providers."

In parallel to the work of FERC, the operator of the New York Power Pool (NYISO) has been undertaking a detailed technical analysis of the expected impact of greater quantities of wind generation on its power system. The New York power system has a peak load of around 32,500 MW although typical loads are around 25,000 MW and loads can fall to 14,500 MW at low load conditions. The New York system is strongly interconnected to other power systems in the area including PJM to the south and the Northeast ISO to the north. It even has links to Canadian generators in Ontario and Quebec. They currently have almost no wind generation in operation but have applications to connect from almost 2,000 MW of wind generation. The NYISO used General Electric as their expert consultants and undertook detailed modelling of a theoretical case of 3,300 MW of wind generation connected around their grid. General Electric characterised the wind resource in the State, modelled the expected output and performance of some 37 notional wind-farms and examined potential impacts on the grid and the operation of the Power Pool. The recommendations were that the New York state power system could reliably accommodate at least 10% penetration of wind energy (based on peak load) subject to:

- employing state of the art technology in the wind-farms;
- introducing state of the art forecasting;
- undertaking a system reliability impact study on each individual wind-farm as part of its connection process, and
- implementing procedures to manage network constraints which may arise from wind generation in certain areas.

On a comparative basis these recommendations would apply to only 250 MW (25% of low demand) to 280 MW (10% of peak load) of wind generation in South Australia.

APPENDIX 1: WIND DATA PREPARATION

Methodology for the Preparation of the Long Term Wind Data

Previous analysis by the Planning Council based the output for a wind-farm at any location on the performance of a single virtual turbine, representing a scaled version of a single turbine as chosen by the proponent. This simplification had the affect of reducing the operating range of the wind-farm and the overall contribution of wind energy.

Since many of the earlier wind turbines had a rapid change in output for a small change in wind speed this made output more variable. As a result of more recent developments in technology, many of the latest machines are capable of absorbing the additional energy from gusts as additional kinetic energy to be recovered over subsequent periods. This has the effect of smoothing the output and reducing the instantaneous variability.

In this latest analysis, the Planning Council used proponent information on the performance of the entire turbine array as proposed. Significantly this increases the range of wind speeds over that which a single turbine would operate and to a large extent further smooths the output response of the farm to small changes in wind speed.

The analysis performed by the Planning Council utilised wind data from both the wind-farm proponents and the Bureau of Meteorology.

As the Planning Council was seeking to develop an extended continuous half-hourly wind data set, representative of and chronologically consistent with numerous locations in the State, Bureau of Meteorology data was considered to be the most appropriate major source.

While close to many of the proposed wind-farms, all of the Automatic Weather Stations from which information was to be used were registering wind speeds at 10 meters or less above ground level and may have been subject to undocumented changes to their local environment and equipment alteration. The Planning Council recognised therefore that this data had numerous limitations and needed to be carefully verified and manipulated.

Proponent data was usually too limited in scope for use in the chronological model, but was used to provide both wind-farm output relationships and a benchmark against which the Bureau of Meteorology data could be re-developed.

Subsequent discussions with a number of wind industry consultants has revealed that the data manipulation process undertaken by the Planning Council is not inconsistent with that used in the industry.

The process for the conversion of the Bureau of Meteorology data to that required by the dispatch model was as follows:

- complete the Bureau of Meteorology Automatic Weather Station wind speed data sets with interpolated data for each location;

- develop wind duration curves for each Bureau of Meteorology Automatic Weather Station location;
- from proponent information develop wind duration curves for each wind-farm location at hub height;
- using the proponent wind speed and wind-farm power data generate a wind-farm power versus wind speed curve;
- mathematically translate the completed Bureau of Meteorology Automatic Weather Station wind speed duration curves to replicate those from the proponent data; and
- using the wind-farm power versus wind speed curve translate the modified Bureau of Meteorology Automatic Weather Station data to wind power and re-map the proponents target capacity factor with the result.

While this method does not account for variations in the efficiency of the wind-farm due to changes in wind direction the Planning Council examined the materiality that this additional level analysis would provide and was satisfied that for this analysis it was not warranted. This method incorporates benefits of the configuration and geographical layout of the turbines that will make up a wind-farm in total and variations that are likely to occur within the half-hour time-frames on which it is based.

This methodology does not account for potential reductions in wind-farm capacity due to temperature. While significant for the assessment of planning capacity, this aspect of the performance of wind-farms is less important to the generation of the long term dataset for the use in the chronological generation modelling.

APPENDIX 2: CALCULATION OF PLANNING CAPACITY

Statistical Analysis of the Planning Capacity

In its previous analysis the Planning Council examined the level of wind capacity that would assumed to be available at times of peak demand in the South Australian market. This analysis was repeated with the latest long term wind dataset. Without accounting for temperature de-ratings this planning capacity was found to be about 15% of installed capacity. It should be noted that the planning capacity is not to be confused with the "capacity credit" frequently referred to in other literature. The capacity credit refers more to the average contribution of wind power for a given period, where as the planning capacity analysis is specifically examining firm availability at times of peak demand.

The supply-demand balance for reliability analysis and forward planning is calculated based on the declared availability of the generators in the National Electricity Market for weather conditions that produce peak electricity demand. As the wind resource is neither storable nor predictable, the Planning Council believes that, consistent with the previous assessment performed in 2003, the available capacity from a given wind-farm distribution across the State should be calculated based on that which is available for at least 95% of the time. This provides the wind-farms with a comparable level of unavailability based on their "fuel" resource as the conventional generators would have from forced outages. That is, the Planning Council has assumed that the planning capacity of a wind-farm is that percentage of its installed capacity that is statistically available for at least 95% of the time during weather conditions that would produce peak electricity demand.

The analysis performed to establish the level of planning capacity considered the combined output from the wind-farms for each of the different wind development cases for the top 10% of demand in each year. For comparison, the Planning Council also calculated the wind-farm output for the summer daylight hours when peak demand is usually experienced and the average contribution for all seasons for the same daylight hours in the year.

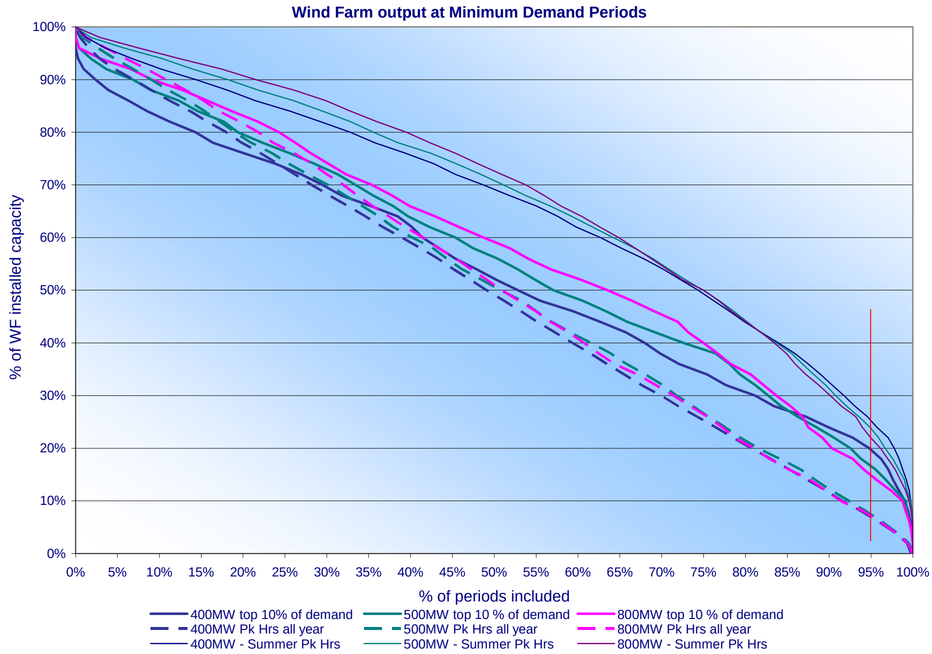


Figure A-1 - Planning Capacity Assessment

As can be seen from *Figure A-1 -* the planning capacity for the peak hours for the whole year is in the order of 8% and for the peak hours during the summer months the planning capacity is in the order of 23%. This outcome is consistent with results from the seasonal analysis where the average wind speed in the late afternoon in summer is higher than that of the other months.

The planning capacity from the wind output during the top 10% of peak demand periods lies between these other values, indicating that the wind is less strong during periods when South Australia is experiencing its peak electricity demand.

South Australia's peak electricity demand is highly dependent on the ambient temperature conditions in the State. Currently the 10% Probability of Exceedence (PoE) temperature conditions are based on an average of the daytime maximum and overnight minimum temperatures of 34.8°C. In the supply-demand balance the Planning Council requests that the generators provide their summer capacity estimates based on a 42°C ambient temperature. The Planning Council understands that many of the wind-farms have maximum ratings of 40°C, however it is unclear how the output of the machines varies above this temperature.

During recent hot periods the Planning Council has monitored the output of wind-farms with respect to ambient temperature and it is apparent that some of the existing wind-farms in the State are more sensitive to high ambient temperatures than others.

The Planning Council understands that this aspect of the performance of the wind-farms is highly dependent on the manufacturer and specification of the machines employed at each wind-farm and is in the process of gathering more information on the sensitivity of existing wind-farms, new farms under construction and the proposed new projects such that this *Figure* can be more rigorously determined.

Without this additional information the Planning Council believes that it is prudent to leave the current *Figure* of between 7% and 8% for the calculation of the supply-demand balance to accommodate for this currently unquantifiable reduction at peak load until more detailed operational information is obtained.

APPENDIX 3: CHRONOLOGICAL MODEL ASSUMPTIONS

Introduction

Using the seven year wind power data set generated for the statistical analysis, the Planning Council also performed a large number of electricity market simulations to examine the market impact of each wind penetration case.

This half-hourly chronological market analysis was performed using the PLEXOS Optimisation and Simulation tool from Drayton Analytics. In order to represent the National Electricity Market, this package needs a considerable amount of additional information to describe not only the physical performance of the network and the generators, but also the financial drivers on the participants.

The following section broadly describes the principle assumptions incorporated into the model.

Previous studies considered an extended modelling time-frame up to eight years into the future where each year of the four effective years of wind generation data, created from the Bureau of Meteorology data, was repeated twice. The latest modelling has approached the simulation slightly differently by basing all of the analysis on the 2005-06 financial year, growing the actual chronological demand traces for the years for which wind was available to the 2005-06 energy and peak demand targets. This approach has the advantage of enabling a comparison of different wind patterns on market simulations based on consistent market conditions. It does not, however, reveal anything about the impact of long term growth in the electricity demand in the State on the penetration of wind.

Three financial years from the long term wind dataset were chosen for the simulations; 2000-01, 2001-02 and 2002-03 providing a representation of hot, cool and mild summer conditions.

Electricity Industry Data

The seasonal capacity and availability of each generator in the National Electricity Market and levels of demand side participation used in this study are from the NEMMCO 2004 Statement of Opportunities (SOO). Other station performance parameters, reliability and transmission network constraints are consistent with those used in the 2004 NEMMCO reliability assessment and the 2004 Supply-Demand balance calculator.

Some additional behavioural constraints were also added to attempt to more accurately represent the true behaviour of the participants.

Only wind generation from South Australian wind-farms has been simulated in the Planning Council analysis.

DEMAND

The chronological modelling performed by the Planning Council simulated the behaviour of the National Electricity Market in the financial year 2005-06. That is, all of the demand forecasts were based on NEMMCO's regional 50% probability of exceedance peak demand forecasts for each region and the medium economic growth targets for energy growth. (*Table A-1*). It should be noted that the energy and peak demand forecasts for regions such as South Australia already contain an allowance for wind generation. This component has therefore been added back into the total *Figure*s.

REGION	ENERGY[4] (GWh)	PEAK SUMMER DEMAND (MW)	PEAK WINTER DEMAND (MW)
NSW	77,603	13,300	13,080
QLD	51,396	8,587	7,986
SA	13,484	3,111	2,408
VIC	51,326	9,274	8,182

Table A-1 Regional Energy and Peak Demand Growth

CONVENTIONAL GENERATION

Generator Ratings and Capabilities

Assumptions concerning specific station performance parameters not included in the NEMMCO 2004 SOO are based on information provided by the South Australian participants and general engineering knowledge, these assumptions cover station performance parameters including:

- heat rate data;
- in-house usage;
- heating and cooling rates;
- start up costs and fuel usage; and
- generator maintenance rates (based on those used for the NEMMCO reliability assessment).

4 Energy *Figure*s have been converted from the "as sent out" *Figure*s in the SOO to "as generated" in accordance with the published conversion rates.

Forced Outage Rates

Forced outage rates have not been included in this assessment. This investigation is primarily interested in the impact of wind under normal operating conditions in the market. The inclusion of forced outages in the simulations, while possibly more indicative of reality, would have required a significant increase in the computational burden without providing significant additional insight into the performance of the market as a result of the increased penetration of wind.

Hydro Generation

Hydro generation energy limitations were extracted from the information provided by NEMMCO as part of its 2004 Reliability Analysis. At this stage the hydro generation has not been based on a pond model, however the results from this form of modelling provide an adequate representation for the assessment of wind generation in South Australia.

Ramp Rates

The ramp rates ascribed to the conventional generators in the National Electricity Market are particularly important with respect to the assessment of the likely changes in behaviour as a result of the increased penetration of wind in South Australia. The Planning Council has extracted the typical ramp rates for each generator from each generator's market offers. This information was then benchmarked against information provide to the market in NEMMCO's latest market consultation for the 2005 Australian National Transmission Statement.

Fuel Considerations

No fuel restrictions were imposed on generators. This assumption may oversimplify the availability of fuel for generation in South Australia. Both the SEAGas and Moomba to Adelaide pipelines have been included in the simulations. The gas generators in South Australia submit a gas nomination to their respective fuel suppliers to ensure that their likely fuel requirements are available. The variability and potential unpredictability of wind may make this assumption less appropriate.

Generator Commitment

The replication of generator commitment decisions are of key importance to this analysis. Market modelling of this nature assumes perfect foresight with respect to the timing of the commitment of generation. In reality, forecasts are critical to the timing of unit commitment and any increase in forecast uncertainty as a result of wind will not be reflected in the model outcomes.

Bidding Behaviour

Bidding is probably one of the most difficult aspects of the market simulation. The analysis has considered a number of different approaches to bidding.

Short Run Marginal Cost where each unit in the National Electricity Market offers its capacity in accordance with its fuel cost and heat rate performance.

The Planning Council also considered a number of bidding scenarios loosely labelled as Long Run Marginal Cost. In these scenarios a number of the more commonly considered bidding strategies were considered where the offers for each generator in each portfolio operating in the National Electricity Market are optimised such that the generating company targets sufficient revenue to cover its financial requirements.

Three LRMC strategies were considered. The first of which is a simplified full cost recovery approach where the initial positions of the generators are based on their SRMC merit order. The algorithm then seeks to optimise the revenue of the generation portfolio by altering its bids to obtain a financially satisfactory outcome.

The second uses a Bertrand bidding approach as its starting position, offering each portfolio at a cost just below that of its nearest competitor while adhering to the transmission constraints which would control the access of that competitor to the regional reference node. Similar to the first LRMC approach the algorithm then seeks to optimise the revenue of the generation portfolio by altering its bids to obtain a financially satisfactory outcome.

The third uses a significantly more complex Nash-Cournot approach. The basic theory of Nash-Cournot is that it is a quantity game played against a set of demand functions. The demand functions describe the price responsiveness of demand in each region of the National Electricity Market (taken from NIEIR reports). However, in reality there is little demand response on the half-hour level so PLEXOS solves an annual game with aggregate generation, demand and transmission. The solution respects transmission limits.

The solution to the annual game provides annual generation and revenue targets for all of the generation companies in the National Electricity Market. The revenue recovery algorithm, which normally targets LRMC is then used to target the Cournot outcome, with bids working to replicate the annual Cournot prices and generation.

The result is half-hourly simulation that a) closely fits the annual optimal Cournot outcome for all players, and b) does not require half-hourly demand functions

Wind Generation

Data for wind generation in the PLEXOS modelling has been drawn directly from the Extended Wind Data Set and each wind-farm has been uniquely identified. The only additional information defined in PLEXOS for each wind-farm is an $8/MWh allowance for variable operating and maintenance costs and an implied 5% Used in House energy allowance to accommodate fouling losses, wake and turbulence losses and on-site electricity distribution losses.

TRANSMISSION

Interconnectors

In the National Electricity Market model, the notional interconnector provides a simple 'link' representation of the complex mesh of individual transmission lines that forms the actual, physical interconnection between two regions. Figure B-1 provides a notional, market representation of the existing regions and inter-regional links in the National Electricity Market; it is not a physical representation. Both the proposed South Australia–New South Wales Interconnector (SNI) and Basslink are excluded.

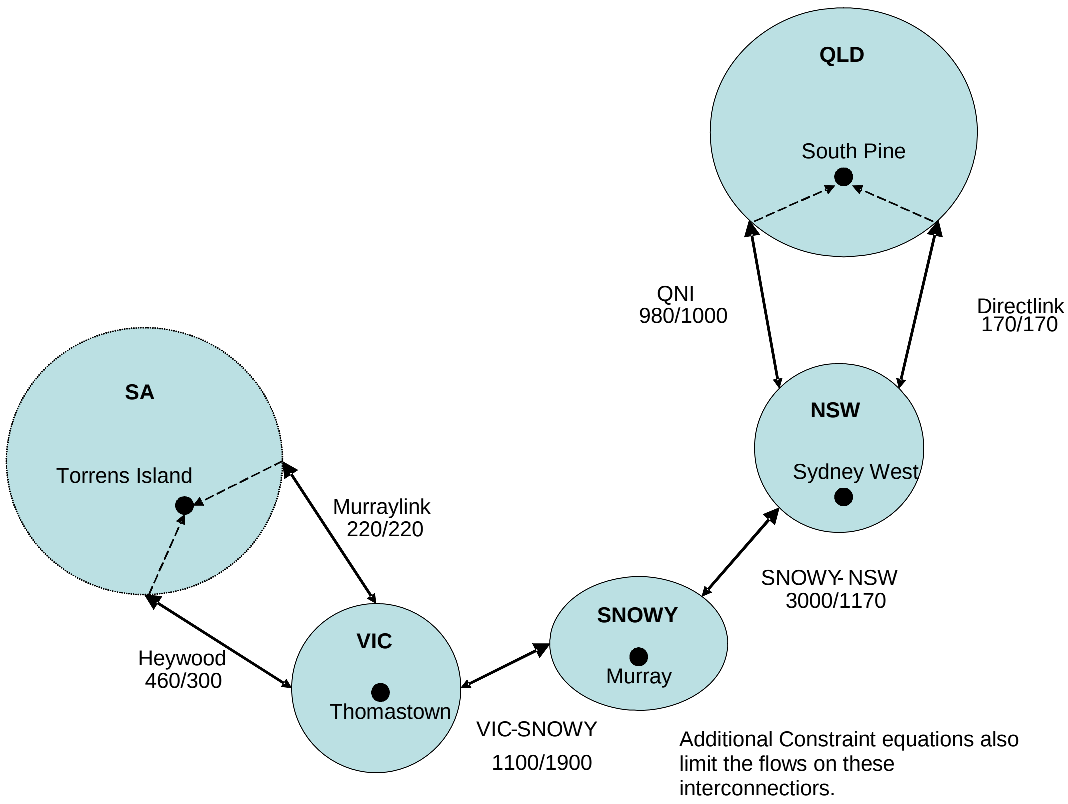


Figure B-1 Interconnector representation in the National Electricity Market

Interconnectors may carry flow in either direction, and in Figure B-1, the larger arrow on each interconnector indicates the direction of flow that the National Electricity Market model defines as notionally positive. For example, flow from Victoria to South Australia on V-SA is notionally positive, while flow in the reverse direction is notionally negative.

In Figure B-1, the rating of each line is given below the line name, with the rating for the positive direction of flow given first. For example, the rating of the Heywood interconnector is 460MW from Victoria to South Australia (positive) and 300MW from South Australia to Victoria (negative).

As can be seen from the diagram Basslink and Tasmania have not been included in the analysis.

Losses

Intra-regional losses are accounted for using static Marginal Loss Factors as published annually by NEMMCO.

Inter-regional losses are represented in accordance with the loss equations that represent the virtual interconnectors as described in the previous section. NEMMCO annually publish a full set of Marginal Loss Equations in conjunction with the Marginal Loss Factors

It should be recognised that the use of static Marginal Loss Factors and Marginal Loss Equations for determining losses for the study could over account for actual losses.

Constraints

In National Electricity Market dispatch systems there are in the order of 13,000 constraint equations that are designed to represent the constraints on the real transmission system under all circumstances and outage conditions. It is neither practical nor necessary to implement all of these constraints in the simulations, however it is important to use a subset of equations that can adequately describe the network performance under normal conditions. NEMMCO publish a subset of the market equations in the in the SOO supply-demand balance calculator that is designed to represent the typical system normal condition. This subset has been implemented in the PLEXOS model. Unlike the National Electricity Market dispatch engine PLEXOS will co-optimise the all of the inputs in a constraint equation.

Limitations to the Modelling

PRICING EFFECTS: HALF-HOUR TO FIVE MINUTE

In the National Electricity Market as it currently stands a market clearing price is issued every five minutes. Settlement pricing is calculated every half-hour based on the average of the six dispatch intervals in the preceding period. This averaging of price can lead to occasions where the market conditions may result in a high price period for some part of the settlement period and low prices in the rest of the period. The result is a settlement price that, because of averaging, may mask the dispatch difficulties that may have occurred. An example of this would be where a peaking generator may be called upon for a number of dispatch intervals within a settlement period to provide additional capacity during a rapid change in demand and the average settlement price received is significantly different than the prices in each dispatch interval. (1 dispatch interval with a price of $9,000/MWh averaged with 5 intervals of $30/MWh would result in a settlement price of $1,525/MWh). The variability of wind over short time-frames may make situations such as this more frequent, however, Planning Council analysis using a half-hourly model would not reflect this level of volatility.

FUEL AVAILABILITY / DAILY NOMINATIONS

As stated previously the model has both perfect foresight and fuel restrictions related to pipeline performance have not been simulated. While not a first order impact, the ability of the generators to accurately nominate their fuel requirements while maintaining the safe and secure operation of the gas transmission facilities may become more problematic as a result of increased uncertainty of wind.

PARTICIPANT BIDDING BEHAVIOUR

While PLEXOS provides a sophisticated mechanism for examining various bidding strategies it is still highly dependent on the validity of the assumptions on which it is based. In the National Electricity Market, the contractual positions for both the electricity and fuel requirements of the generation portfolios play a significant but unclear part in their behaviour.

MEDIUM TERM DECISIONS

The modelling undertaken by the Planning Council has only considered the results for the market for a single year, the 2005-06 financial year. It has not attempted, at this time, to examine the on going impact on generation, interconnector utilisation or price in the medium or long term. Variations over these longer time-frames would affect participant behaviour such as investment decisions and operational strategies.

APPENDIX 4: POWER QUALITY

Standards and Controls on Power Quality

It is vital that the quality of the power delivered to customers is maintained within standards. The performance and safe operation of electrical machines and appliances used by customers depends upon maintaining supply within specification. Not only customers but network service providers and other generators depend upon the quality of the power supply. In certain circumstances telecommunications and other industries can even be affected by poor quality of supply.

Recognising the importance of power quality, the *National Electricity Code* sets out system standards for:

- Voltage
- Voltage fluctuations
- Harmonic distortion
- Voltage imbalance

The standards in the *National Electricity Code* rely heavily on Australian standards with the standards for harmonic distortion and voltage fluctuations based on AS61000. The targets set in the system standards are supported by requirements on network service providers, generators and customers. The detailed standards individual generators seeking to connect to the network will be required to meet to ensure the system standards are met are determined through the connection processes.

The Electricity Distribution Code in South Australia sets out some general requirements which are consistent with the *National Electricity Code*. The *National Electricity Code* mentions limits on voltage imbalance, voltage fluctuation, harmonic content and interference. The *National Electricity Code* also requires embedded generators to advise ETSA Utilities when their machines change status or generating output.

The requirements to maintain power quality within specification is reinforced by ESCOSA's service standard which include the following:

1.2.3. Quality of Supply

1.2.3.1. Voltage

A *distributor* must ensure that its *distribution network* is designed, installed, operated and maintained so that:

(a) at the *customer's supply address*:

(i) the <u>voltage</u> is as set out in AS 60038;

(ii) the voltage fluctuations that occur are contained within the limits as set out in AS/NZS 61000 Parts 3.3 and 3.5 and AS2279 Part 4; and

(iii) the harmonic voltage distortions do not exceed the values in AS/NZS 61000 Part 3.2 and AS 2279 Part 2 and as set out in the schedule to the *standard connection and supply contract.*

(b) the voltage unbalance factor in 3 phase supplies does not exceed the values set out in the schedule to the *standard connection and supply contract.*

Potential Power Quality Issues

Wind-farms can be connected to either the distribution or transmission networks. Of the existing generators and those currently under construction:

- Starfish Hill and Canunda are classified as distribution connected; and
- Cathedral Rocks, Lake Bonney, Mt Millar and Wattle Point are transmission connected.

Those connected to the distribution system and referred to as embedded generators generally raise more issues with respect to power quality. As they are connected to the distribution system close to customers, they are more likely to have an impact on the quality of power in the area than remote generators connected to the transmission system. In certain cases though, transmission connected generators could impact on power quality to local customers especially where the transmission network is radial or where the wind-farm proposed is large relative to power flows in the area.

The management of power quality needs therefore to be undertaken on a case by case basis and is an important consideration for many proposed generators and customer loads. Issues which are potentially relevant to wind-farms include:

Voltage control: As the output from an individual wind-farm will vary widely and at times relatively quickly, the impact on local voltages needs to be managed within allowable ranges. Traditional tap changers on distribution transformers are generally too slow to compensate for output variability by wind-farms

Voltage fluctuations: At part load, and in rare cases full load, individual wind turbines within a wind-farm will be starting or stopping generation. Each start or stop can produce a small but sharp fluctuation in output and hence local voltage. Wind turbine generators, depending upon their specific design, can also create voltage spikes on changing the number of poles in the generator (analogous to changing gears) and where the turbine is a fixed speed design turbulence in the wind is reflected directly in generation output. There are also cases reported of output flicker in some cases due to a shadow effect as blades pass the tower.

Harmonics: The newer generation of wind turbine generators significantly improve their performance with respect to voltage control and voltage flicker. In doing so, however, they employ power electronics which, if not correctly specified, can lead to issues with harmonics.

Processes to Manage Potential Power Quality Issues

The Planning Council has examined the approach taken by ETSA Utilities and ElectraNet SA to ensure power quality issues are dealt with through the connection process. The Planning Council used the proposed Myponga wind-farm as a test case and examined the approach taken to power quality through the process of negotiating its provisional connection agreement with ETSA Utilities.

Power quality issues are location specific and in this respect the proposed Myponga wind-farm is an example where higher standards would be expected of a connecting generator. The project is to connect to the Myponga sub-station which is part of ETSA's sub-transmission network for the Southern suburbs and Fleurieu Peninsula. Myponga is located on a single circuit 66kV line and is some distance from the transmission backbone at Morphett Vale East.

The 20 wind turbine generators proposed are connected to each other at 33 kV (in two separate groups) and connect via a proposed new transformer and busbar to the Myponga 66kV. This arrangement ensures that ETSA's customers can expect at least two stages of transformation between the wind generators and their load. This arrangement aids meeting power quality standards.

Through the process of negotiating the connection agreement, power quality issues had been well addressed. ETSA Utilities have developed an engineering report which covered relevant aspects including:

- Steady state voltage and voltage control
- Steady state reactive compensation
- Voltage fluctuations including fluctuations on start-up
- Harmonics and interference
- Fault levels
- Operating constraints
- Protection
- Monitoring and control
- Operating arrangements
- Testing and commissioning

As a part of that assessment, ElectraNet SA was retained to analyse and provide a report on dynamic stability and response to system disturbances by the proposed wind-farm. The report considers a range of severe contingencies in the sub-transmission and transmission system under different load conditions. The work in this report is consistent with that undertaken by ElectraNet SA on wind-farms proposing to connect to the transmission system except that it also covers the more severe “automatic access standard”. The automatic access standard in the *National Electricity Code* for low voltage ride through is that a generator must be capable of continuous uninterrupted operation during the occurrence of a voltage dip at the connection point to zero Volts for 175 milliseconds in any one phase or combination of phases. This is a more stringent test than we are aware of being applied to any other wind-farm in Australia and is close to international best practice levels.

The connection process leads to the negotiation of a set of standards which in the case of Myponga include:

- connection to separate (sole use) bus
- ability to contribute to voltage control and provide and absorb reactive
- generation output smoothing and controlled ramp rates
- limitations on number of turbine starts;
- soft start and soft stop of generators;
- the provision of SCADA data to ETSA Utilities; and
- the provision of SCADA control to the network operating centre.

The provisional connection agreement includes requirements for commissioning and testing to ensure standards are met from commencement. They also require the installation of power quality meters.

APPENDIX 5: SHORT TERM VARIABILITY OF POWER OUTPUT

Variability in Power Output in 30 minute and Lower Timeframes

The Planning Council engaged Dr John Boland from the University of South Australia. Dr Boland is the leader of the Environmental modelling research group within the School of Mathematics and Statistics and has had an ongoing interest in the utilisation of renewable energy and, in particular, the time series analysis and forecasting of climate variables necessary for their efficient planning and utilisation.

The work undertaken in association with Dr Boland adopted a different statistical approach to assessing variability of wind generation. It does not at this stage extend to assessing the predictability of that variability but does provide a sound basis for such work. The approach adopted is based on taking detailed generation data from the Starfish Hill wind-farm and extrapolating the output variability to estimate the expected variability for a range of wind generation across South Australia.

The Starfish Hill wind-farm, owned by Tarong Energy, has been operating since October 2003 and has collected operating data since that time including the power output measured every 3 seconds. We have used some of that data to examine typical variability on the following timescales:

- half-hourly;
- 5 minutes; and
- 3 seconds.

The first of these provides an alternate view of the variability from that in the deterministic model over seven years discussed in section. The analysis of the other timeframes gives us a view of the aggregate impact of the variability of wind generation in timeframes that are vital to understanding the potential impacts of larger amounts of wind generation on the network, the power system and the market.

Half-hourly Variability

The half-hourly generation output from Starfish Hill for the first year of operation was used as the basis for the analysis of half-hour to half-hour variability of wind generation in aggregate across South Australia for two cases. First the variability in output has been separated from the general diurnal trend in wind generation across each day and a probability distribution fitted to the results.

The variability in output was shown to be broadly symmetrical; that is, the generation was equally likely to rise as fall a given amount and the absolute value of the variability was able to be modelled as a gamma distribution. Figure C-1 clearly shows that the data appears to reasonably fit the distribution chosen.

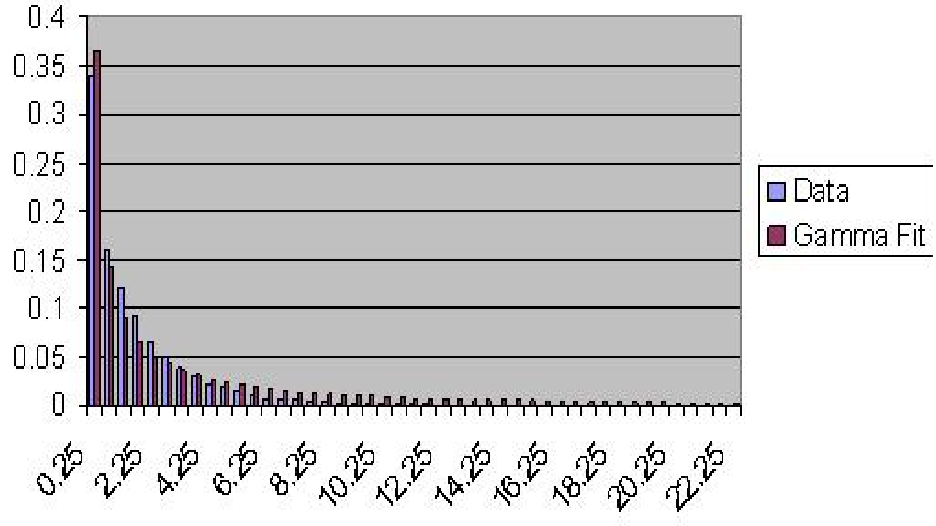


Figure C-1 Gamma Distribution match to Variability

Table C-1 summarises the probability that a given change in output will occur from one-half-hour to the next. For example, 5% of the time, the output will vary from half-hour to half-hour by 5.65 MW or more. In some international literature this variability is compared to the installed capacity

PROBABILITY OF EXCEEDANCE	HALF-HOURLY VARIATION IN GENERATION	
	MW	% OF INSTALLED CAPACITY
10%	4.14 MW	12%
5%	5.65 MW	16%
1%	10.31 MW	30%

Table C-1 - Exceedance levels for different probabilities for half-hourly output

Having characterised the generation variability, we need to extrapolate that to the variability we would expect for the aggregate generation output for a range of wind-farms across South Australia. In seeking to extend these results we have assumed that:

- the variability of wind generation can be calculated after removing normal variations associated with a regular diurnal pattern; and
- the resulting local variability in output of a wind-farm in any location is the same as that of Starfish Hill and can be characterised as a given number of Starfish Hills at that location.

The variability in output across the various locations in South Australia on a half-hourly basis can be expected to be at least partially correlated. The extent to which wind generation at various sites will be correlated or random will depend upon how close they are and the nature at the wind resource at the sites. The level of correlation has been captured in a correlation matrix relating wind speed at the different locations based on standard BoM data near those sites.

A method developed by Alouini et al[5] for finding the distribution of a sum of correlated gamma variates was adapted to estimate the correlation between the output variability's at the various sites.

While we do not have output for farms at the five sites, we do have wind data for those sites from the Bureau of Meteorology. Using this data, we can determine the correlation between the wind speeds at the sites nearest each proposed wind-farm. It should be noted that Parawa is the closest BoM site to Starfish Hill and that this calculation is the correlation after the deterministic diurnal pattern has been removed.

It is then assumed that the correlation between the output variability's will be similar to the variation in wind speed. The following *Table* sets out the correlations in wind speed measured each hour between the five sites. The *Table* shows that all sites are positively correlated; ie high wind speeds at one site will tend to correlate with high wind speeds at others. A factor close to zero would infer that two sites are not correlated but rather wind speed variations at the sites are random While a factor close to one would infer that they move in synchronism. The factors calculated lie in the middle of the range demonstrating some correlation but also considerable benefits from diversity. The diurnal patterns were closely correlated across the sites indicating similar drivers and reflecting the fact that the sites are all less than 20 minutes apart with respect to the sunrise and sunset time.

	PARAWA	COONAWARRA	PT LINCOLN	CLEVE	EDITHBURG
PARAWA	1	0.472	0.562	0.315	0.676
COONAWARRA	0.472	1	0.468	0.47	0.51
PT LINCOLN	0.562	0.468	1	0.543	0.654
CLEVE	0.315	0.47	0.543	1	0.499
EDITHBURG	0.676	0.51	0.654	0.499	1

Table C-2- Correlations in wind speeds measured half-hourly at the five sites

[5] M. S. Alouini, A. Abdi, and M. Kaveh, Sum of gamma variates and performance of wireless communication systems over Nakagami fading channels, *IEEE Transactions on Vehicular Technology*, Vol. 50, No. 6, pp. 1471-1480, November 2001.

The wind correlation matrix has been converted to a wind generation correlation matrix assuming:

- for the 400 MW case, 12 Starfish Hill wind-farms distributed amongst the five sites where farms are currently being constructed; and
- for the 1,000 MW case, 28 wind-farms distributed amongst 6 sites.

The following table summarises the outcomes of this work and gives a comparison between the statistics of the output variability of a single actual Starfish Hill and the aggregated output variability which could be expected in the 400 MW and 1,000 MW cases. The data quantifies the benefits of diversity for the 400 MW case with the 12 wind-farms having around half the variability per installed capacity as Starfish Hill by itself. These benefits are still clear with the 1,000 MW case although significantly reduced. The 1,000 MW case has less diversity benefits as it only adds capacity at two sites, one of which was included in the 400 MW case.

	STARFISH HILL	400 MW CASE	1,000 MW CASE
Mean	1.7 MW	14 MW	29 MW
Standard Deviation	2.1 MW	15 MW	47 MW
10% PoE	4.1 MW	34 MW	83 MW
5% PoE	5.7 MW	45 MW	122 MW
1% PoE	10.3 MW	70 MW	221 MW

Table C-3 - Output Variability Summary

Half-hour to Half-hour Variability

The statistical analysis provides confidence in the more detailed deterministic studies undertaken by the Planning Council. For example, the 1% probability of exceedance variation for the 400 MW case calculated here is 70 MW whereas our other market modelling work calculated 77 MW. Given this excludes the output variation due to diurnal patterns of generation, this is a very close match. This statistical work uses the best information available to us at this stage and is a valuable adjunct to the deterministic model.

Five Minute Variability

The correlation matrix calculated can be argued to be technically correct for half-hour variability as it is derived from half-hourly data. An objective of this work was also to build an understanding of variability at shorter time scales. Care needs to be used in adopting this approach because variability could be expected to be less correlated between sites in shorter timeframes. We do not have sufficient consistent data across all the sites at these shorter timeframes to develop a full new correlation matrix. We have, some data from the South East wind-farms as well as the detailed data for Starfish Hill and are able to use that to estimate a simpler correlation matrix. This would be expected to show lower correlation than the half-hour data to the extent that the correlation of the half-hourly variations ought to be seen as an upper bound estimate.

The five minute variability for the Starfish Hill farm over the smoothed diurnal pattern of generation was calculated. A gamma probability density function was fitted to the data and is shown in the Figure C-2.

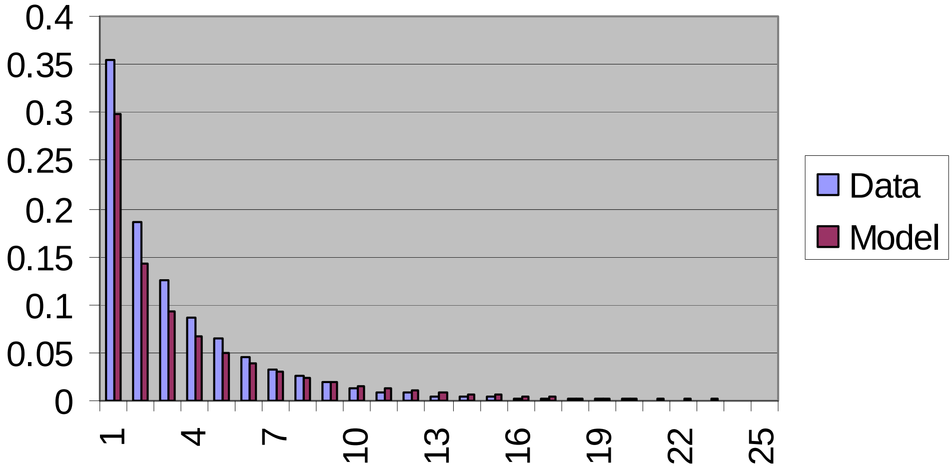


Figure C-2 five minute variability gamma probability density function comparison

The limited five minute generating data at other sites required a simplified approach to developing a correlation matrix similar to that used in the calculation of half-hourly variability. The approach adopted was to:

- calculate the correlation between Canunda 1 and 2 and use that as an estimate of the correlation between wind-farms at a single site, and
- calculate the correlation between Starfish Hill and the Canunda sites and use that as an estimate of the correlation between more distant sites.

The correlation between the outputs of Canunda and the Lake Bonney Stage 1 can be seen in Figure C-3. This example is based on 10 second data collected from meters at the ElectraNet SA and ETSA Utilities connection points

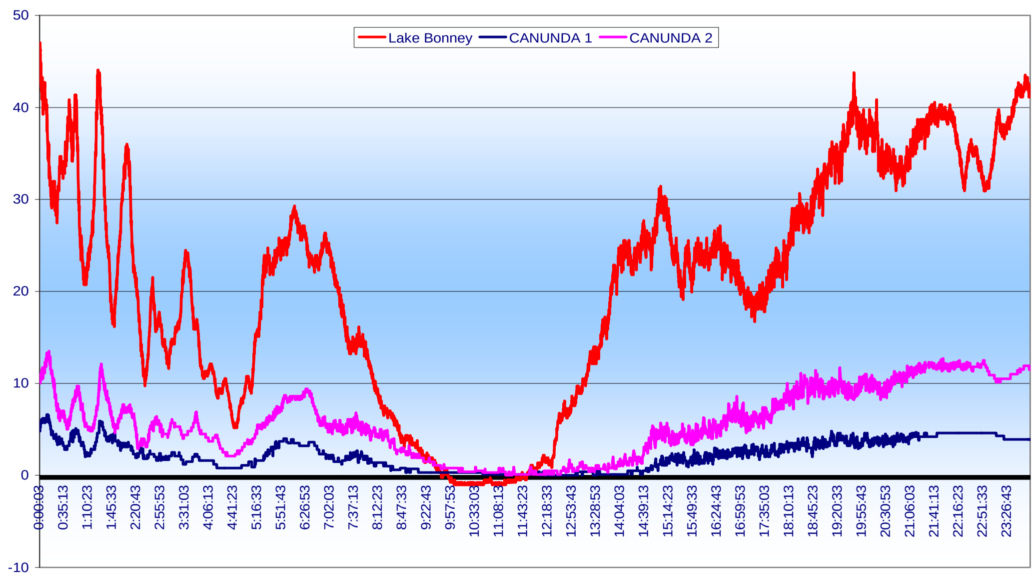


Figure C-3 Example of the correlation between the Wind-farms in the South East

From this analysis we calculated a correlation coefficient of 0.51 as an estimate of the correlation within sites, and 0.1 as an estimate of the correlation between sites at this time scale. Under these assumptions we can then proceed as before and calculate an overall correlation between the wind-farms in each case. The outcome of this work is as follows:

	STARFISH HILL	400 MW	1,000 MW
Mean	0.75 MW	7.1 MW	14.8 MW
Standard Deviation	1.08 MW	4.03 MW	7.39 MW
10% PoE	1.78 MW	12.51 MW	24.68 MW
5% PoE	2.40 MW	14.76 MW	28.65 MW
1% PoE	4.42 MW	19.64 MW	37.13 MW
0.162% PoE	7.76 MW	24.81 MW	46.01 MW

Table C-4 - Overall Correlation Between Wind-farms

The 1% probability of exceedance can be expected to be met or exceeded 1 in every 100 five minute periods or around 3 times per day.

Three Second Variability

For this analysis we selected one day of three second data. Figure C-4 shows the data for that day. The general profile of generation on that day was selected as it showed a general smooth trend across the generation range of the wind-farm. This should provide a reasonable basis for assessing the general short term variability in wind output excluding the possible complications of major weather or operational changes on the wind-farms output.

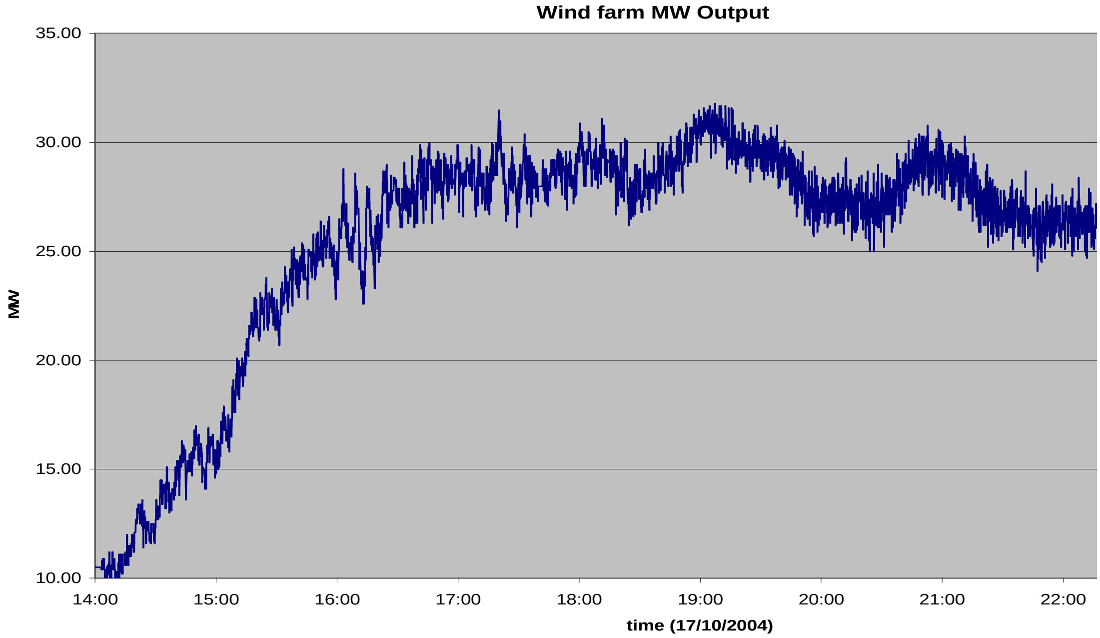


Figure C-4 3-Second Variability for a single day from Starfish Hill Wind-farm

The assumption adopted in this case is that three second fluctuations in wind generation output will not be correlated even between adjacent wind-farms. On this basis the three second variations in output are as follows:

	STARFISH HILL	400 MW	1,000 MW
10%	0.67 MW	2.93 MW	5.70 MW
5%	1.10 MW	3.55 MW	6.53 MW
1%	2.54 MW	4.94 MW	8.30 MW
0.01%	4.31 MW	8.68MW	12.75 MW
0.00167%	5.48 MW	10.1 MW	14.34 MW

Table C-5 - 3-Second Variations in Output

Again some lower probability of exceedance *Figure*s have been included as a three second PoE 1% level would be met or exceeded once every 5 minutes. The 0.01% PoE level would occur as often as the 1% PoE 5 minute level and the 0.00167% probability of exceedance level would occur as often as the 1% PoE 30 minute level.

Summary

The following *Table* summarises the 1% PoE variations in output over and above any diurnal patterns for the studied timeframes:

	400 MW	1,000 MW
30 minutes	70 MW	221 MW
5 minutes	20 MW	37 MW
3 seconds	4.9 MW	8.3 MW

Table C-6 - 1% PoE Variations in Output

The following *Table* takes an alternate approach and sets out the variations in each timeframe which would be exceeded around 170 times per annum:

	400 MW	1,000 MW
30 minutes	70 MW	221 MW
5 minutes	25 MW	46 MW
3 seconds	5.4 MW	14.2 MW

Table C-7 - Alternate Approach in Output

These *Figure*s do not include changes in output due to the underlying diurnal pattern of generation. They therefore might be seen in one sense as the random variation around a predictable generation pattern. Alternatively the gross changes in output would have to be increased. These *Figure*s represent the stochastic variation about a predictable generation pattern.

APPENDIX 6: NATIONAL WIND REFORM

WETAG / WEPWG

At its April 2004 meeting, the Ministerial Council on Energy (MCE) agreed to establish a project to consider issues concerning the entry of renewable energy generation (particularly intermittent and non-scheduled generation such as wind) into the National Electricity Market. Through the Standing Committee of Officials established the Wind Energy Policy Working Group (WEPWG) in mid 2004 to consider the range of policy level issues associated with the anticipated entry of large amounts of wind generation into the National Electricity Market in the coming years. The WEPWG requested that NEMMCO establish the Wind Energy Technical Advisory Group (WETAG), consisting of industry participants, to assist the WEPWG with the analysis of technical and policy aspects of wind penetration in the National Electricity Market.

The results of the investigation by the WETAG have been forwarded to the WEPWG and the SCO for their consideration. The WETAG considered that there are a number of issues that need to be considered, including:

- An urgent review of the technical standards for connection;
- Managing the impact of intermittent generation on network flows;
- Wind-farm modelling in respect of power system operational implications;
- Disclosure of appropriate information; and
- Cost recovery of Regulation Frequency Control Ancillary Services.

The Planning Council understands that, at the time of writing, the recommendations of the WETAG to the WEPWG are available for release and the recommendations of this group will address a number of the above market distortions.