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Wind Energy – How Much is Enough ?

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Introduction

This paper is concerned with the question of what might be the limiting share of generation that wind power might be expected to achieve in a thermal power system such as the South Australian region of the National Electricity Market (NEM).

There are many well documented technical issues associated with accepting a large installed capacity of wind power in a power system. With the exception of the requirement that thermal plant be available and committed to cover variations in wind power output, these are not considered in this paper.

Advocates of wind power development sometimes argue that spatial diversity in the locating of new installations promises to reduce substantially the intermittency and variability of wind generation solving many of its problems. The argument developed in this paper is that the diversification introduced by new wind farms may not be substantial. In this case the wholesale electricity spot market revenue earned by the wind generation sector can be expected to decline relative to the (time-weighted) average spot price as additional wind farms are added. If this is so, the final installed capacity of wind power may be determined by economic or prospective revenue considerations before serious technical limitations are encountered. The argument is supported by analysis which suggests that the projections of wind generation reported in the South Australian Annual Planning Report may be optimistic.

Rationale for wind power development

In the early eighties, wind power was advocated for small power grids on remote wind-swept islands on the grounds that wind generation could displace the use of expensive diesel fuel, but not the diesel generating sets themselves.

Nearly thirty years on, major power grids are experiencing rapid growth in wind power installations. In Australia, development of this “more mature” of the renewable energy technologies has been stimulated by the expanded Renewable Energy Target (RET) scheme, and the prospect of additional stimulus by means of a carbon cost uplifted wholesale electricity price when an emissions trading scheme eventually gets going.

Spot pricing under an energy only market

It is generally agreed that for an energy only market, such as the NEM, to be sustainable, it must provide for generators to recover their fixed (capacity) and

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variable (fuel) costs. Necessarily therefore, although for much of the time spot prices might reflect variable costs only, at other times, spot prices must be very high so that average spot prices, calculated over any extended time period, provide generators payments that match their total costs.

It could be argued that wind farms participating as market generators in the NEM are benefiting from the “energy only” NEM design which allows intermittent generation to access the “capacity component” of the electricity spot price even though the wind energy generator provides little or no capacity benefit to the market. Of course “capacity benefit” is a system rather than a market concept. The energy only market does not favour particular technologies on the basis of their alleged “capacity benefit” or lack thereof and pays for capacity only when it is required. At such times half-hourly spot prices spike to levels potentially hundreds of time higher than average spot prices and all generators irrespective of technology are rewarded for running.

Owing to intermittency, wind generators will miss some price spikes but while their output remains largely uncorrelated with spot prices, over any extended period of time, they will receive close to the average spot price.

This seems to have been the experience with the initial stage of wind power development in the NEM. With respect to the prospect of wind energy achieving an increasing share of generation we shall consider the following questions –

- Might diversification solve the problem of intermittency?
- Do the economics of incremental wind farm development depend on the amount of wind generation already present?
- What are the implications of the increased presence of wind for the economics of existing thermal plant and the reliability of the power system?

In attempting to answer these questions we’ll shift our attention from the NEM in general and focus on South Australia where “the volume of wind connecting or planning to connect to the South Australian network will make South Australia one of the most wind energy intensive power systems in the world.”[i]

Our approach to answering these questions will be analytical but high level and more concerned with elucidating market dynamics than any precise quantification of effects. Use will be made of wind power data already summarised for us. This will be combined with other readily accessible generation system and demand data using simple probabilistic techniques.

Opportunity for wind energy – displacement of thermal generation

We look at the opportunity for wind energy to displace thermal generation. Initially we consider the South Australian region (SA) in isolation, ignoring for the time being its interconnection with the other regions of the NEM.

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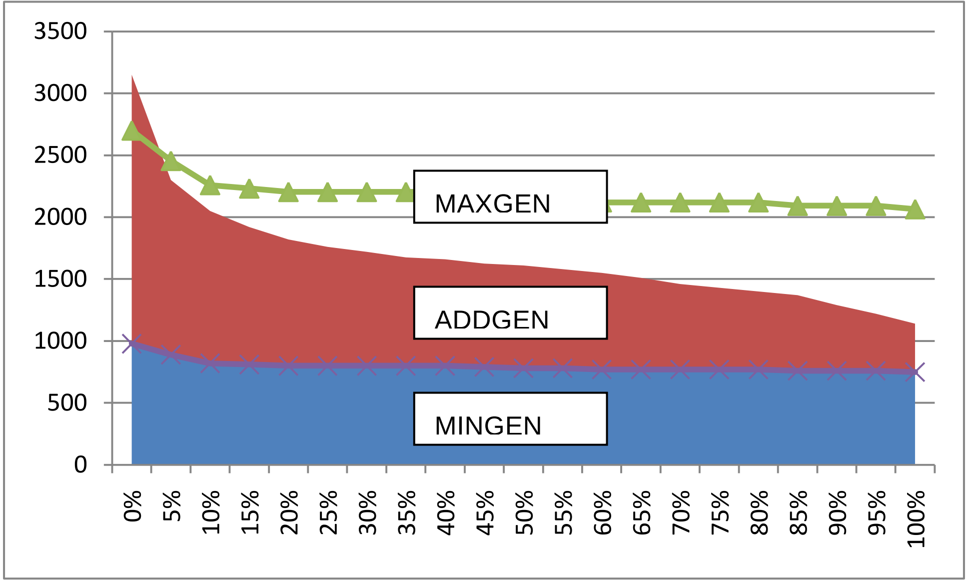
[i] Annual Planning Report, Electricity Supply Industry Planning Council, June 2009. It is also noted that the South Australian Government has set a new target of 33% of power generation coming from renewable energy in that State by 2030.

Figure 1 represents regional demand and thermal generation (excluding peaking plant)[ii] as duration curves in 2008-9.

Figure 1 SA demand and thermal generation 2008-9 (MW)



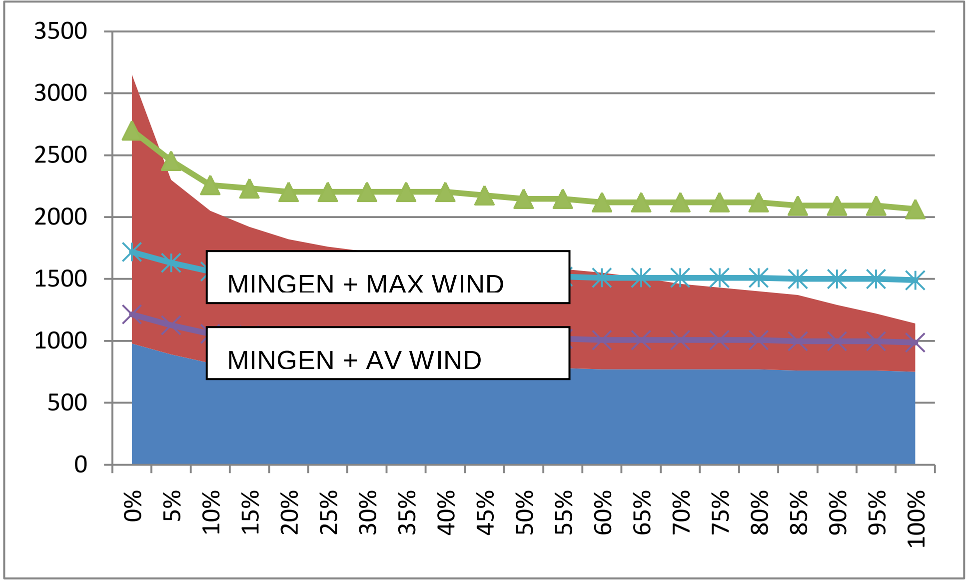
The blue area represents committed thermal generation in terms of the sum of unit minimum generation levels (MINGEN) and represents some 47% of the load. The red area represents the generation required above minimum generation to meet load (ADDGEN). It is also the area where there is an opportunity for the displacement of thermal generation by wind. This is because thermal plant must remain committed so that it can ramp up in the event that the wind stops blowing[iii]. The green line presents the maximum generation level of committed thermal generation (MAXGEN). For around 5% of the time the load is higher than MAXGEN and peaking plant must be dispatched to meet it. Based on these considerations, wind energy could displace up to 53% of thermal generation. However for this to be achieved, wind generation must correlate perfectly with load whereas in practice there is little or no such correlation.

In Figure 2 we overlay 740MW of installed wind capacity as MINGEN + MAX WIND and MINGEN + AV WIND (based on 32% capacity factor). It is clear that while the average wind output is absorbed without issue, at times of low demand and high wind generation, some wind generation will be spilt (or exported).

[ii] This includes the coal fired power stations – Northern (520MW) and Playford (240MW), and the gas fired power stations - Osborne (190MW), Torrens Island (1,280MW) and Pelican Point (487MW).

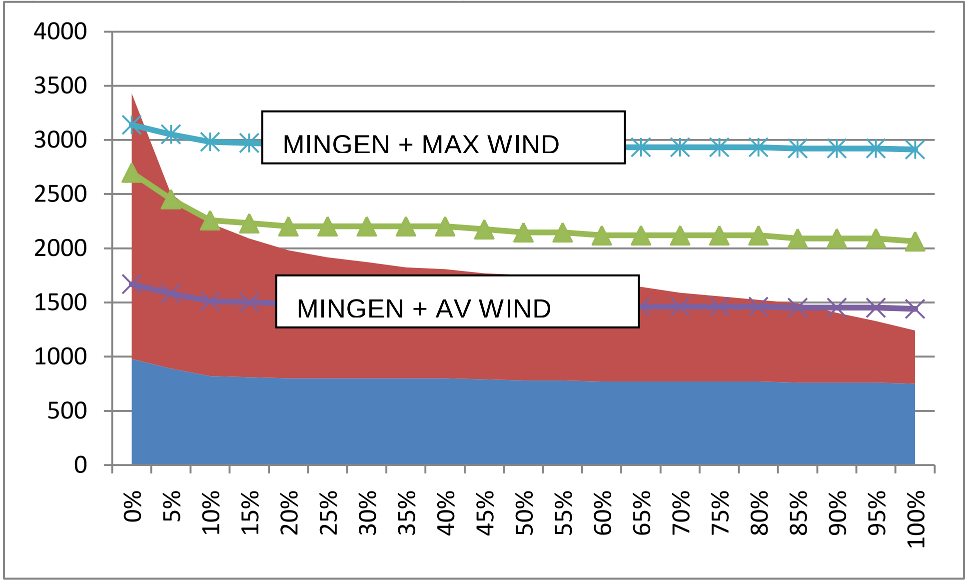
[iii] In this article we do not consider whether the ramp rates of committed units are sufficient to regulate the short term fluctuations of wind generation.

Figure 2 SA demand, thermal generation, and wind 2008-9 (MW)



The South Australian Annual Planning Review projects 2,162MW of installed wind capacity by 2012-13. In Figure 3 we grow the demand to the projected level in that year and redo the above analysis.

Figure 3 SA demand, thermal generation, and wind 2012-13(MW)



The analysis suggests that, even allowing for demand growth, with this level of installed capacity a large amount of wind will be potentially spilt if it cannot be exported to other NEM regions. We investigate this further by considering the issue of diversification.

Diversification and intermittency - of negative correlation (the good kind)

Just as the detractors of wind power are quick to point out the problems of its intermittency, its supporters appeal to diversification as ameliorating or even potentially solving these problems.

Typically, wind speed at any two sites will be positively correlated and the strength of the correlation will generally decline with the distance between the two sites. The development of wind farms at different sites will, as a consequence of spatial variability in wind speed profiles, make the sum of the profiles or equivalently[iv] the sum of the generation profiles of the wind farms less intermittent. This is analogous to the familiar financial portfolio theory which shows how the variance of financial return can be reduced by including investment classes which have low correlation with one another. This theory depends on a basic result from the mathematics of random variables.

If X and Y are two dependent random variables with a correlation coefficient of P then

$$VAR\ (X+Y) = VAR(X) + VAR(Y) + 2\ P\ (VAR(X)\ VAR(Y))\ \hat{}\ 0.5$$

where VAR is the variance.

The correlation coefficient has a value in the range -1 to 1. It is easy to see that the variance of the sum is maximised when P = 1 and minimised when P = -1.

We do not expect diversification to reduce intermittency significantly. The only way to achieve the desirable flat profile is to combine the portfolio of existing wind farms with a portfolio of new developments with a profile *perfectly* negatively correlated to the existing profile. In practice, the correlation between the profiles would be low positive or perhaps zero. Negative correlation, at least the good kind, is hard to find.

According to the Annual Planning Report (APR), in 2008-9 South Australia had 740MW of installed wind capacity exporting to the grid 2,078GWh (average capacity factor 32%). By 2011-12 this is projected to increase to 1,499MW installed exporting to the grid 4,201GWh and in 2012-13 further to 2,162MW and 6,061GWh by 2013-14. Roughly this represents a doubling of existing installed capacity and energy by 2012-13 and a trebling by 2013-14.

The APR (p.64) presents a normalised generation duration curve for wind in South Australia. We have approximated this as a discrete probability mass function. To get an indication of how the profile could improve as additional wind farms bringing spatial diversity are added we convolve this probability mass function with itself and then re-express the result as a normalised generation duration curve. This is equivalent to assuming that another equal sized “portfolio” of wind farms is added to the existing “portfolio” of wind farms and that while the normalised generation duration curves are the same, they are statistically independent (uncorrelated).

The probability mass functions of two wind portfolios (U and V) are combined as follows:

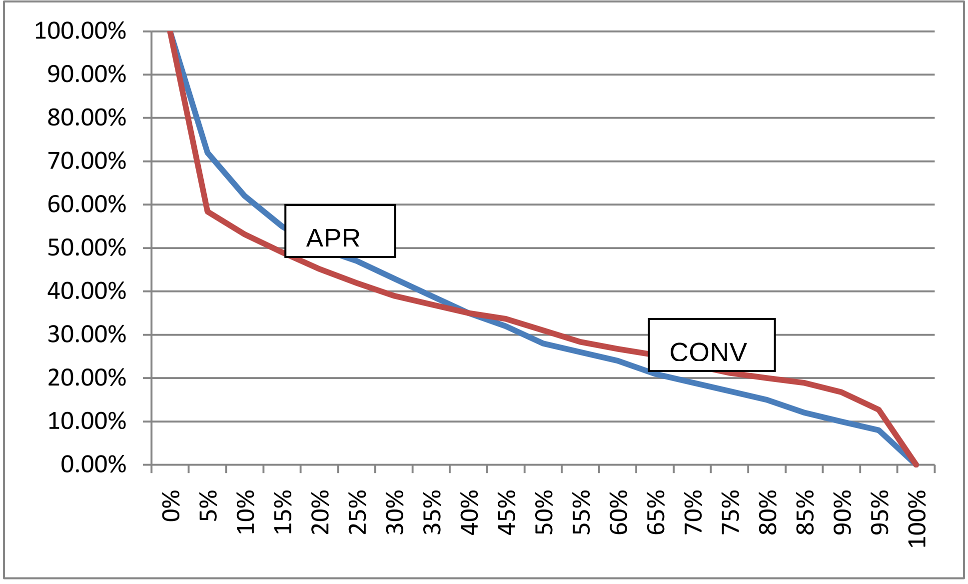
$$r(Wk) = \sum i{=}1..N\ \ p(Ui)\ q\ (Wk - Ui)$$

[iv] Wind farm power output is proportional to the cube of the speed of the wind and cuts out at a specified high wind speed.

where Wk is the output of the sum of the tranches (W = U + V) and r, p, and q are the probabilities for each of the N discrete levels of wind output.

Figure 4 shows the original normalised wind generation curve (APR) and the curve obtained by convolution (CONV).

Figure 4 Normalised wind generation duration curves



The figure shows that as long as additional installed capacity brings some spatial diversity, the normalised wind generation duration curve will experience some flattening. However the result is far from the equivalent of high availability base-load generation. In particular the probability of very low or zero generation remains significant.

Further, from our knowledge of the cross correlation structure of existing wind farm generation profiles, we do not expect the two "portfolios" to be independent. For this reason our convolution result will possibly overstate the diversity benefit.

Economics of incremental wind power development – of negative correlation (the bad kind)

The issue of diversification and intermittency has a significant bearing on the economics of incremental wind farm development.

This is because, if a flat profile of wind output could be achieved, wind output would remain uncorrelated with the spot price, and wind farms would earn the average spot price.

However if the profile of total wind farm output remains intermittent, albeit with some reduction in intermittency, at sufficiently large total installed capacity, wind will increasingly appear "at the margin" setting the spot price. This seems to have started to happen already with a large number of negative spot prices occurring in South Australia in September 2008.

As wind becomes increasingly “marginal” at negative spot prices[v], wind output will progressively become negatively correlated with spot price. In other words a wind farm’s dispatch weighted spot price will progressively reduce compared to the time-weighted spot price. Furthermore price spikes will tend to occur when total wind output is low as at such times there will be less competition for dispatch. It seems then the economics of incremental development deteriorates as the amount of the wind generation present increases, but the poorer revenue result is shared by the whole sector rather than the latest entrant. Other factors impacting negatively not only the business case of intending new entrants but also the profitability of the sector as a whole include:

1. deteriorating marginal loss factor and increased congestion on transmission lines;
2. increases in the cost of regulation frequency control ancillary service (FCAS) and the proportion allocated to wind farms through the causer pays mechanism; and
3. possible allocation of additional costs to wind on a causer pays basis in the event that thermal units require additional incentives (reserve or capacity payments) to remain committed.

We do not propose to discuss the first two here but will have something to say about the latter shortly.

Analysis of past generation and demand data shows a positive relationship between the capacity of committed thermal plant and the level of demand. For thermal plant to remain committed it needs to be running at least at its minimum generation. The opportunity for additional wind projects is provided by the difference between the half-hourly demand and the total minimum generation level of committed thermal plant.

The use of a detailed market simulation model such as PROPHET, would allow the deterioration in wind generation sector revenue relative to the time weighted average spot price to be observed directly. However in this article, we illustrate the projected deterioration in revenue indirectly by calculating “spilt wind” using a simple model based on wind generation and load duration curves and the assumption that wind generation and load are uncorrelated.

We calculate wind spill as the difference between wind generation capability and the wind generation accepted by the system defined as the minimum of the wind generation capability and difference between the regional demand and the sum of the minimum generations of committed thermal units.

Figure 5 shows average (AV) and incremental (INC) spill curves for 2012-13 projected demand for the levels of installed capacity (MW) shown. The curves are calculated for two normalised wind generation duration curves – APR and CONV. No allowance is made for the export of wind energy to other NEM regions.

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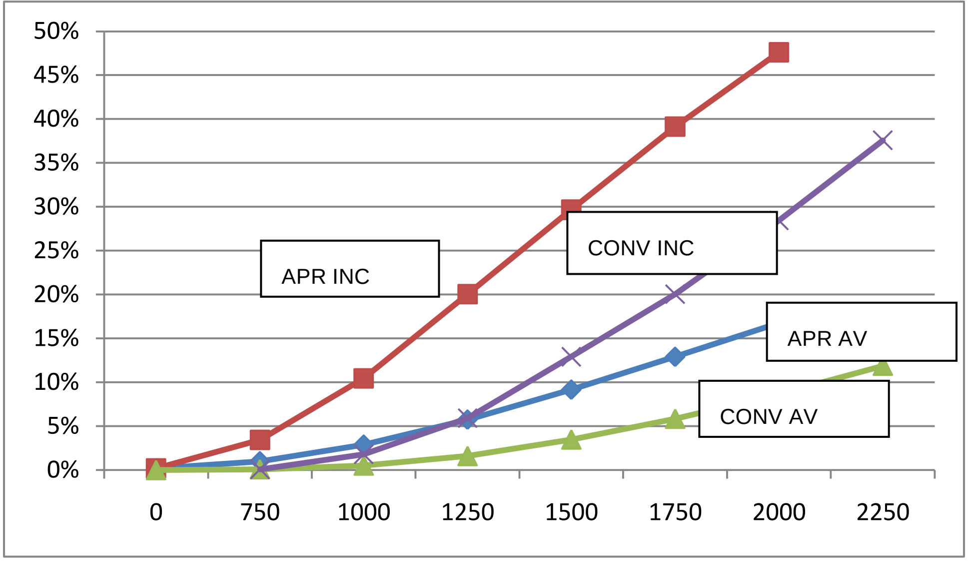
[v] Under RET, the wind generator’s effective short run marginal cost is in fact negative and equal to its foregone Renewable Energy Certificate (REC) revenue i.e the REC price.

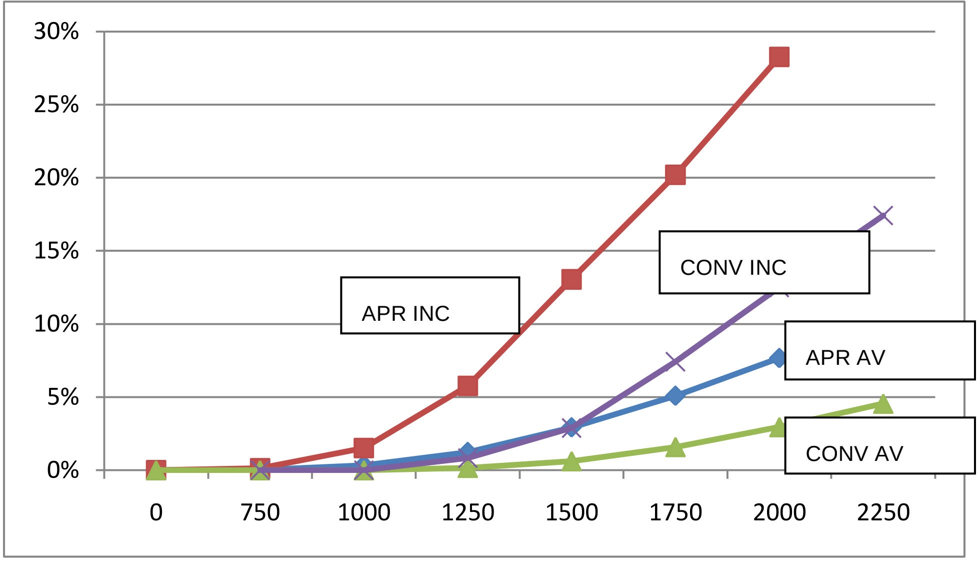
Figure 5 Wind energy spill curves – no export



In the absence of a diversification benefit from spatial variability, average and incremental wind energy spills increase with installed wind capacity so that for example, in moving from 1000MW to 1250MW, 20% of the energy generated by the incremental capacity is spilt. In the presence of diversification benefit, albeit somewhat greater than what we think likely to be achieved, 20% of the energy is spilt when taking the installed capacity from 1750MW to 2000MW. Of course these spills are reduced to the extent to which the excess energy can be exported to other NEM regions.

Figure 6 shows the results of repeating the analysis but allowing for 300MW export capability at all times. In this case, assuming no additional diversity benefit, the incremental wind energy spilt increases almost linearly by around 7% for every 250MW added from 1250MW. Allowing for diversity, incremental wind energy spill is considerably lower and the average spill remains under 5% even up to 2,250MW installed. However this case is considered optimistic.

Figure 6 Wind energy spill curves – 300MW export



On the basis of our consideration of the potential diversification of wind generation we have assessed, using simple techniques, the opportunity for wind power to displace existing thermal generation allowing for demand growth and subject to thermal units remaining committed at minimum generation. Our results suggest that the wind generation projected for the South Australian APR may be optimistic.

Existing thermal plant and system reliability

Finally we consider implications for existing thermal plant and power system reliability. There are two issues to address here. The first is the impact of an expanding wind generation sector on the profitability of the existing thermal plant. The second is its impact on power system reliability. A consideration of the incentives for existing thermal plant to support the reliability of the power system relates the two issues.

The reliability issue has been taken up by the Australian Energy Market Commission (AEMC) more broadly in its “Review of Energy Market Frameworks in light of Climate Change Policies” where expanded options for the Australian Energy Market Operator (AEMO) to procure reserve including short notice reserve contracting are canvassed. Notably the AEMC concluded in its first interim report that “there is a risk that the current frameworks will not enable the AEMO to manage an actual or anticipated transitory shortfall of capacity effectively or efficiently” and in the second “we remain of the view that the current frameworks would not adequately address the risk of capacity shortfalls in the short term following the introduction of the climate change policies. Given the potential for significant disruption and the costs incurred should the framework fail, there is a need to amend the existing mechanisms to strengthen the resilience of the arrangements to respond to such risks.” However in its final report released in October 2009, the AEMC decided not to progress a number of previously canvassed reserve contracting options.

The profitability of existing thermal plant has declined with the introduction of wind farms. This is a consequence of the wind farms receiving spot market revenue greater than the fuel cost of the thermal generation they have displaced. As argued previously, with a larger amount of wind generation, there is potential for this to be redressed through a change in the electricity spot market dynamics i.e., thermal generators setting high spot prices at times of low wind generation. But this is not a certain outcome, and it is possible that thermal generators will require additional and more certain compensation if they are to remain committed at minimum generation during extended periods of high wind generation and associated negative spot prices.

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