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High penetration wind generation impacts on spot prices in the Australian national electricity market

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ABSTRACT

This paper explores wind power integration issues for the South Australian (SA) region of the Australian National Electricity Market (NEM) by assessing the interaction of regional wind generation, electricity demand and spot prices over 2 recent years of market operation. SA's wind energy penetration has recently surpassed 20% and it has only a limited interconnection with other regions of the NEM. As such, it represents an interesting example of high wind penetration in a gross wholesale pool market electricity industry. Our findings suggest that while electricity demand continues to have the greatest influence on spot prices in SA, wind generation levels have become a significant secondary influence, and there is an inverse relationship between wind generation and price. No clear relationship between wind generation and demand has been identified although some periods of extremely high demand may coincide with lower wind generation. Periods of high wind output are associated with generally lower market prices, and also appear to contribute to extreme negative price events. The results highlight the importance of electricity market and renewable policy design in facilitating economically efficient high wind penetrations.

1. Introduction

Growing concerns about energy security and climate change have heightened interest in harnessing some abundant yet non-storable and variable renewable energy resources. Wind power is the first such renewable generation technology to reach significant penetrations in large power systems. Whilst it is now providing growing amounts of low-emission and locally sourced electricity in electricity industries around the world, wind energy's highly variable and partially predictable nature is also adding to the complexity of electricity industry operation.

Worldwide, a growing number of projects have been undertaken to facilitate wind power integration including the development of wind power forecasting and studies analyzing the operation of electricity markets with high wind penetrations. Baldick (in press) studied the interaction of wind power in the electricity market in Texas with some broadly similar outcomes to this investigation as will be referred to in Section 3.3. Two computer simulation projects have been recently completed in the US, each modeling the effects, costs and emissions reductions from 10%, 20% and 30% wind power in the US power systems (Milligan et al., 2009). They conclude that 20% penetration[1] is possible, with the assistance from wind forecasts, but that 30% penetration may be more difficult. Their simulation results also suggest that at times of high wind generation, electricity spot prices will fall. Many studies refer to wind penetration on a power system level, which is an appropriate level for analysis. However, the increasingly interconnected nature of electricity industries around the world can be problematic in this regard. In particular, wind penetration levels are often quoted on a country-by-country basis, which may only be appropriate when there are significant transmission constraints between countries or different electricity industry designs that discourage cross-border electricity trading. There are a few power system regions in the world where wind penetration is around 20%, but usually with interconnections to other power system regions to assist with wind variability. Denmark is currently the country with the highest wind power penetration with greater than 20% of electricity production from wind power in 2009 (Wiser et al., 2010). Within Denmark wind penetration reaches 25% in Western Denmark

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[1] Wind penetration is defined here as the percentage of wind power produced within a power system region with no, or only limited, interconnections, compared with the electricity demand for that region averaged over at least one year.

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(Grohnheit and Andersen, 2009). The Danish electricity transmission network is strongly interconnected with neighboring countries, which facilitates management of the technical implications of wind power fluctuations (Buckley et al., 2005). Denmark also participates in two multi-national electricity markets, which facilitate the management of the commercial implications of wind power fluctuations. More broadly, wind generation is required to formally participate in many of the electricity markets in Europe (Holttinen, 2005) and in other places there are plans to introduce rules to that effect (Botterup et al., 2009). Klessmann et al. (2008) shows how increasing wind penetration in countries like Denmark, Spain and Germany appears to be causing average electricity spot market prices to fall. Electricity market arrangements as well as renewable policy design are, therefore, playing an increasingly important role in facilitating wind integration into the electricity industry.

This paper explores the effect of increasing wind generation in the Australian National Electricity Market (NEM), with a particular focus on the South Australian region of the NEM. Wind generation capacity has been steadily growing in Australia since the Australian Government introduced the Mandatory Renewable Energy Target (MRET) in 2001. A large proportion of the wind farms to date have been built in the State of South Australia (SA), which has an excellent wind resource and attractive site access opportunities (Australian Energy Market Operator, 2010b). SA has a population of around 1.4 million and electricity demand typically ranging from around 1000 MW minimum to 3300 MW maximum. For September 2008 to August 2010, the total electricity produced by fossil-fuel generation in SA was equivalent to roughly 80% (45% from gas generation and 35% from coal generation[2]) of SA's electricity consumption. The South Australian power system has only two interconnections, both to its neighboring State of Victoria with a combined security-constrained export limit of 420 MW; flow across these interconnections contributed a net import of 3% of SA electricity consumption during the above 2-year period.

Wind penetration in SA is far higher than in any other region of the NEM. Wind power production in SA was equivalent to 16.1% of SA's electricity consumption over the 2-year period from September 2008 to August 2010, and 17.8% in the second 12 months of that period. This fraction is reported to be greater than 20% in 2010–11 (Australian Energy Market Operator, 2011) and it is projected to rise further as more wind farms are installed. This is among the highest levels of wind penetration in the world and thus SA presents an excellent opportunity to analyze the potential impacts of wind generation within the particular competitive electricity industry arrangements of the Australian NEM.

The Australian Government's recently enacted expanded Renewable Energy Target (RET) mandates an approximately four-fold increase in renewable generation by 2020 compared to that achieved by MRET to date (Australian Government, 2010). The RET is based on green certificate trading from eligible 'new' renewable generation that creates an additional cash flow to energy market revenue for renewable energy projects. Wind power is expected to play a significant role in achieving this target and there are important questions regarding the potential impact that additional wind generation may have on the operation of the NEM (MacGill, 2010; Outhred and Thorncraft, 2010).

The NEM is an energy-only gross pool market, in which energy prices are established 5-min ahead by a security-constrained dispatch of participating resources (known as scheduled resources in the NEM, and potentially including flexible load and reversible storage as well as generators) to meet 5-min demand forecasts. Eight frequency-control ancillary service markets are co-optimized with the energy market to acquire ancillary services that can manage supply–demand balance within the 5-min dispatch intervals. While scheduled resources are required to submit day-ahead bids and offers to the market operator expressing their price and quantity preferences, they are permitted to rebid their quantities at any time prior to the next 5 min dispatch.

The NEM is divided into five State-based regions, each with a Regional Reference Node (RRN) and flows between market regions are modeled as constrained arbitrage transactions between the regional reference nodes.

If no security constraints bind, there is a single marginal resource in the NEM dispatch market and the offer (or bid) of that resource determines the dispatch price at its node. Network loss factors are used to determine dispatch prices at all other nodes. If one or more security constraints bind, there will be additional marginal resources and price separation can occur between market regions. MacGill (2010) and Outhred and Thorncraft (2010) contain more information on NEM design and performance.

Commercial spot energy and ancillary service market transactions in the NEM are conducted on half-hourly trading intervals, for which prices are set at the average of the constituent 5-min dispatch prices. The analyses in this paper are based on half-hourly data.

A well-designed electricity market has the objective of translating much of the short-term physical risk in maintaining electricity supply into short-term commercial risk in the form of highly volatile electricity spot prices. In the Australian NEM, the spot price floor is set at –A$1000/MWh (–US$1000/MWh) and the ceiling at A$12,500/MWh (US$12,500/MWh).[3] Spot market participants use derivative trading to re-allocate spot price risks for a high proportion of their electricity production. Derivative contracts translate short-term commercial risks into long-term financial risk management arrangements, which in turn underpin long-term participant decision-making about fuel purchases, maintenance scheduling, hydro-reservoir management and investment in new supply and demand side resources. For more about the design philosophy of the Australian NEM, see AEMO (2010a).

In general, as the penetration of wind energy increases in an electricity market, market operation, market participant behavior and, in the longer-term, the electricity industry resource mix, are likely to evolve with it. The first few wind farms in the Australian NEM were small and considered to be non-dispatchable price-takers that had little influence on market outcomes. They were treated as negative load, classified as "intermittent" generators and not required to bid in the electricity spot market.

In 2005, the Essential Services Commission of South Australia introduced a license condition that required all new wind farms in SA with ratings greater than or equal to 30 MW to register as scheduled[4] generators in the Australian NEM. This required them to participate in the spot market and ancillary service cost allocation arrangements. The central dispatch process for scheduled generators is not particularly onerous for wind farms as the National Electricity Rules permit a scheduled generator to repeatedly update its forecast of electricity production during a particular 5-min dispatch interval until the start of that particular dispatch interval. In practice, scheduled wind farms commonly offer their forecast production into the dispatch process at a negative price that takes

[2] The proportion of coal generation is much higher in most of the other NEM regions.

[3] The price ceiling was recently increased from A$10,000/MWh to A$12,500/MWh on 1 July 2010 (http://www.aemo.com.au/) and the A$10,000/MWh figure is the relevant value for the results in this paper. The US dollar amounts provided assume that one Australian dollar equals US$1.00.

[4] Note that the definition of 'scheduled' within the NEM may be different in other electricity markets such as in the US where scheduled generators are typically those generators that are explicitly not offering their electricity into the wholesale spot market.