Renewable Energy 105 (2017) 96–105

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Wind power volatility and its impact on production failures in the Nordic electricity market

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A R T I C L E I N F O

Article history:
Received 2 March 2016
Received in revised form
1 November 2016
Accepted 12 December 2016
Available online 13 December 2016

Keywords:
Intermittent electricity production
Cycling costs
Nord Pool
UMMs
Failures

A B S T R A C T

Wind power generation of electricity has gained popular support because of its low environmental impact and its low costs relative to other renewable energy sources. However, concerns have been raised in the power sector that wind power generation will come at the price of increased damage to other power generators. Wind power generation is naturally volatile which requires other power sources to start up and shut down in accordance with weather conditions, which for instance coal or gas generators are in general not built to do. The previous literature has used simulations to show that the damage done and the associated costs can be substantial. We use a dataset containing all reported failures in the Nordic electricity market Nord Pool and data for Danish wind power generation. The analysis shows that for both Denmark and the rest of Nord Pool the short-term costs associated with the volatility of wind power generation are non-significant.

1. Introduction

The demand for renewable energy sources has increased due to environmental concerns. One of the most important options for meeting renewable energy targets has been wind power since it is clean and reasonably cost effective. However, since wind generation is volatile, the imbalances in the net demand (demand less intermittent generation) have to be complemented with large amounts of other capacity, often provided through coal, gas, oil or hydro. When wind power ceases to provide electricity, the other capacity is required to start up and conversely it needs to shut down when the winds are sufficiently strong. The frequent start-ups and shut-downs put a strain on the other generators which could potentially mean more frequent failures or increased needs for maintenance compared to when wind power is not part of the energy mix [28,30,31]. This may be a significant problem since failures and maintenance threaten supply security and can increase prices for consumers. Moreover, cycling can negatively impact plant lifetime and costs [31]. There have been various studies assessing the impact of large amounts of wind power on the operations of the power systems. However, to the best of our knowledge, there is no systematic empirical assessment of the effects intermittent power has on the cycling costs in the system and associated failure rates.

In this paper we empirically investigate how volatility in wind power production affects the failure rates of conventional power sources. We estimate effects for Denmark, which is part of Nord Pool, one of the largest European electricity markets, and for all of Nord Pool. A well-integrated electricity market with less congestion can balance the volatility of wind power production better through export or import, compared to a market with restricted export and import possibilities [14]. That is, if imbalances in net demand can seamlessly be met through export and import, cycling of own units can be expected to be less of a problem. This is especially true for Denmark since neighboring countries in Nord Pool have substantial amounts of hydro power, which can be argued to be naturally more flexible than for instance coal and gas. For this reason we estimate separate effects for when Denmark experiences congestion, and hence is import or export constrained, and when Denmark can freely export and import. We expect more failures in Denmark as a consequence of cycling when Denmark is export or import constrained.

The main analysis reported in this paper can have a causal interpretation as wind is naturally exogenous and moreover, due to the minimal marginal cost of wind power production, wind power units are utilized whenever it is windy [4]. Additionally, we provide

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http://dx.doi.org/10.1016/j.renene.2016.12.024
0960-1481/

some descriptive relations between wind power production in MW and the number of failures reported per week over the seven-year period 2006–2012. The purpose of these descriptive regressions is to verify whether there are any correlations between the number of failures in the system and a more compound effect of wind power, i.e., a continuous increased use of wind power over time and more sudden changes in wind production levels between different weeks in our sample.

In our analysis we use a unique dataset containing wind power utilization in Denmark and failures reported in Urgent Market Messages (UMMs) released in the Nordic electricity market Nord Pool for the years 2006–2012. Denmark has the largest share of wind power use in the world and in 2013 33.2% of the Danish electricity consumption was covered by wind, which makes the results for Denmark especially interesting [12]. The results in this paper will also have policy implications for other areas investing heavily in wind power generation, such as Texas or Spain.

The results show that there is no short-term effect of wind power volatility on production failures in Denmark or Nord Pool. Production failures do not seem to be affected by whether there is congestion or not. Descriptive regressions aimed to capture a more compound effect of wind power use on the power generation units show some significant effects for Nord Pool but only a weakly significant effect on oil power plants for Denmark. The insignificant effects for Denmark could however be due to increased market integration with Sweden and Norway, as a larger market can enable better balancing, especially with the use of hydro generation [24].[1] It is also possible that increased damage to units due to cycling was expected and hence the investment in maintenance increased in our sample over time. Our results provide evidence that in Nord Pool and Denmark, the inclusion of wind power in the market mix has an insignificant effect on the number of failures and associated costs in the short run. As such, it contributes by revealing new evidence in support of wind power.

There have been various studies assessing the impact of large amounts of wind power on the operations of the power systems. A study of integration of high levels of intermittent power into the western US electrical system revealed that a reduction of the value of wind and solar power due to cycling costs of thermal units in systems (were 30% of demand was supplied by this type of power) was between 0.1 and 2.4% [19]. Another study of European electricity systems indicated that cycling costs are more pronounced in systems with a lot of wind power. With larger variations of net load, the level of cycling costs impacts the competitiveness of generating units, i.e., “low cycling costs represent an increasingly relevant competitive advantage” [11]. The same author states also that “for systems in which the differences in cycling costs between the generation units are large but the differences in running costs are small, the impact on the capacity factors of the generation units will be evident already at low levels of wind-power penetration”. The cost of integrating wind power has been also discussed by Refs. [29] and [6]; who point out that already at the 10% level of wind power penetration the economic cost of the operation of power system as a whole will increase. Moreover, [21] and [6] conclude that cycling associated with the operation of units generating electricity at varying load levels puts pressure on the operating equipment resulting in higher plant operations and maintenance expenditures. It is increasingly difficult to put one number on the costs related with frequent start-ups and shut-downs of the conventional power plants. Therefore, as [31] points out “uncertainty surrounding cycling cots can lead to these costs being under-estimated by generators, which in turn can lead to increased cycling”. Some estimates of operation and maintenance (O&M) costs for a start and shut down cycle of certain units have been presented in the literature, for e.g. a gas unit has been found to range from $300 to $80,000 in the O&M costs. These costs represent the increased damage to plant equipment, lower fuel efficiencies and potentially shortened plant life [23].

The effects that integration of large amounts of wind power into the electricity grid has on the workings of the power sector have been studied in the literature. It has been pointed out that increased cycling can lead to deterioration of various components [22,31] and hence increased rates of forced outages. However, to the best of our knowledge, there is no systematic empirical assessment of the effects intermittent power has on the failure rates of conventional generators, which is the contribution of this paper.

The paper is structured as follows. The next section describes Danish wind power. Section 3 discusses consequences of increased wind production volatility and its effect on the power system. Section 4 describes data and Section 5 the empirical strategy. The results are discussed in Section 6. The last section concludes the paper.

2. Danish wind power penetration and market conditions

Development of wind power generation has been popular in Denmark since the 1970’s when the oil crises led to economic difficulties. The impact of coal power on the climate and the local environment, together with a popular distrust in nuclear power, paved the way for efforts to expand wind power [8]. Until 1973, 90% of the country’s energy supply was based on imported oil. At the beginning of the 1980’s subsidies for the construction and operation of wind turbines, taxes imposed on oil and coal and additional tax incentives aimed at Danish families for generating power for their communities, increased the interest in renewable power [18].

The subsidies for the wind power were canceled in 1988 and in 1993 feed-in tariffs for wind power were introduced, to be replaced in 1999 by a system of tradable green certificates. Since 2003 an environmental premium has instead been added to the market-clearing price for wind power generated electricity. The feed-in tariffs for turbines of all sizes were re-introduced in 2009. The initial drop of the feed-in tariff decreased the willingness to invest in new turbines as can be seen in Fig. 1 [18]. This can explain why capacity and the number of turbines have diverging time trends at the beginning of the 21 st century. At the same time the Danish government ordered additional offshore wind power to be installed at five different locations. The turbines scrapping system that was first introduced in 2001 and later had several follow-ups [2] can be another reason for the diverging trends. It was introduced in April 2001 by the Danish government in order to expand wind power and decommission old turbines [25].

Between 2004 and 2006, less than 40 MW of new wind capacity was added in Denmark. Local opposition to proposed wind projects grew and became an increasingly important political force. Most of the increase in Danish wind power capacity in the years after 2005 was due to the construction of large offshore wind farms. Denmark is the world-leading producer of commercial turbines and the domestic use of wind power has increased rapidly up until present numbers [2].

Since 2000 Denmark has been part of the integrated Nordic energy market Nord Pool. In 2006 Denmark had a nominal exporting capacity of 5220 MW and was using around 60% of this capacity [27]. Congestion between Denmark and other Nord Pool price areas is still a frequent phenomenon. Theoretically there is a

[1] Also [16] in their simulation study of western Denmark showed that after accounting for decreased fuel costs and higher cycling costs, a large part of the Danish wind generation and associated variations in net load were exported to the neighboring countries.