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Assessment of wind power predictability as a decision factor in the investment phase of wind farms

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HIGHLIGHTS

- ▶ We simulated two years of day ahead market participation of 182 Danish wind farms.
- ▶ We analyzed the case when cluster of wind farms participate in the day ahead market.
- ▶ We analyzed the relation between capacity factor, predictability and revenue.
- ▶ Predictability explains 0.015–0.02% of the revenues, capacity factor around 98%.
- ▶ Price settlement mechanism analysis shows the prospective value of the results.

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ABSTRACT

The ability to predict wind power production over the next few hours to days is prerequisites for the secure and economic operation of power systems with high wind power penetration. From the point of view of a producer participating in the day-ahead electricity market, lack of predictability at a wind power production site results in imbalance costs. This paper aims at quantifying the impact on market revenue of, respectively, the predictability and the capacity factor of a wind farm or a cluster of wind farms. This is done through a real-life case study in West Denmark, including wind farm production data and market data. Finally, we make a prospective analysis under the assumption that the imbalance price settlement mechanism will remain the same.

1. Introduction

The share of renewable energy sources in the energy mix of several countries worldwide is rapidly increasing. As regards the European Union (EU-27), the European Commission has set a target of 20% of EU-27 energy consumption to come from renewable sources. Wind energy is anticipated to be a major contributor to this target with an installed capacity that is expected to extend from 74.7 GW by end of 2010 in EU-27, to 230 GW by 2020 according to EWEA projections (see [1]).

Such large-scale integration of wind energy raises several challenges in operating and managing power systems. It is now recognized that accurate short-term forecasts of wind farms' power output over the next few hours to days are important factors for the secure and economic operation of power systems with high wind power penetration [2]. The future evolution of installed wind capacity entails building a significant number of new wind farms across Europe. As most windy sites are already occupied in certain countries (e.g. in Spain [3] and Germany [4]), wind farm developers will have to deal with more and more complex terrains in the future. Previous works, like the benchmarking exercise performed in [5] have shown to what extent predictability is dependent on terrain complexity; the higher the complexity, the lower the predictability. It was shown also in [6] that predictability tends to decrease when wind speeds increase. In such a case, a site's predictability is denoted by the level of accuracy of short-term wind power predictions that can be obtained for that site.

Today, significant R and D efforts are being undertaken to improve the performance of wind power prediction models and related weather forecast models. Increased overall wind power predictability is expected to be beneficial for several actors, such as transmission or distribution system operators, for efficiently performing functions such as estimating reserves, unit commitment, and congestion management. Independent power producers

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could benefit from increased predictability when they participate in an electricity market.

Since it is not possible to imagine a power system with unpredictable generating means, it is difficult to quantify the economic benefit of increasing predictability. A direct consequence of this is the difficulty in devising clear economic incentives aiming at greater predictability. However, when participating in the day-ahead market, deviations of the produced energy from the contracted energy (imbalance) due to forecast errors are exchanged at a different price called the imbalance price, resulting in imbalance costs from the wind power producer's point of view. This direct translation of wind power forecast errors into a financial cost, as well as strategies for the reduction of this cost, have already been studied (see e.g. in [7–10]).

The investment decision on the placement of wind turbines has been analyzed in previous works. Ref. [11] investigates to what extent optimal allocation of wind farms in Germany can reduce wind power fluctuations through aggregation while [12] proposes a model in the frequency domain to assess the power reduction induced by cut off in high wind conditions. These works have shown that the aggregation of wind farms can produce significant effects in terms of variability and cost reductions.

The aim of this paper is to quantitatively assess the role of predictability when expanding a wind farm portfolio, with real market data and real wind farm production data. Here predictability of a new wind farm is supposed to be determined by its location and by the aggregation effect with the rest of the portfolio. The actors concerned could be independent power producers, wind farm developers, aggregators or virtual power plant operators that need to decide where to install a new wind farm, or how to compose an optimal portfolio of wind farms for participating in an electricity market. In addition, penalties paid by producers that deviate from the day-ahead contract are settled by the transmission system operator and market operator, who will thus be concerned by the results of this paper.

These questions relate to a case where the revenue of a wind farm as an investment is generated by the wind farm's direct participation in an electricity market and not through a subsidy-based scheme, i.e. a feed-in tariff system. A large share of Europe's current installed capacity is supported by feed-in tariff schemes. However, as penetration increases, Member States are tending to switch to direct market participation mechanisms for wind farms. This means that a high share of wind farms will be developed under such mechanisms in the future.

In a subsidy-based supporting scheme, decisions on where to install a new wind farm are taken based on well-established "resource assessment" practices. Given the fixed remuneration per kW h, predictability does not play any role in decision-making. In contrast, when wind farms participate directly in an electricity market, wind farm revenue is generated from the market and is affected by the short-term predictability of wind farm production. Indeed, imbalance prices are applied to imbalances.

As mentioned above, well-established methodologies exist in the case where a decision has to be made based solely on a site's wind potential. In other words, the site with the highest potential tends to be chosen. However, this is not the case in the new electricity market context. This paper contributes to this tendency, by studying the new questions that are increasingly being posed by end-users: Can a compromise between resource potential and predictability be beneficial when choosing between two sites to install a wind farm?

When a wind farm participates in an electricity market, the revenue is a function of the contracted energy, the spot prices, the difference between the contracted energy and the produced energy and the imbalance prices. The induced imbalance costs reduce the revenue proportionally to forecast errors. One might then ask the question that, if some compromise has to be found when choosing between two sites, let us say one with high potential but low predictability (i.e. a complex terrain site) and one with lower potential but higher predictability (i.e. a flat terrain site), then such a compromise might lead to choosing the site with lower potential if the loss in revenue can be compensated by lower penalties. Taking this reasoning one step further, one might study how to optimally extend a portfolio of wind farms by adding new wind farms so that the ensemble has an optimal performance in the market.

Predictability here is seen from the producer's point of view. It is however a very important aspect as such for the power system and market operators, who may want to incite wind farm operators to adopt practices that increase predictability so that wind production is the source of less imbalances. The assessment in this work may contribute to defining incentives in this direction.

In this paper we propose a methodology to study the above questions, which is presented in Section 2 together with the test case of several hundred wind farms in Denmark and the market assumptions that we used. In Section 3 this methodology is applied to evaluate the importance of predictability versus that of the capacity factor on the revenue generated by a wind farm. Two cases are considered, one where a producer considers the installation of a single wind farm, and the second where a portfolio or aggregation of wind farms is extended. Before the conclusions, Section 4 proposes a prospective discussion of the results.

2. Methodology and description of the case study

2.1. Methodology overview

In our approach we consider the current performance level of state-of-the-art forecasting technology as being given. A reasonable range of possible levels of predictability is considered in the case study. Better levels of predictability may be achieved in the future through further research. This could include more collaboration with the meteorological community on how to better use meteorological models, elaboration of more accurate power prediction methods especially for extremes, and improved processes for checking data quality, a.o.

Here, however, we attempt to increase given levels of predictability through aggregating wind farms, which can be considered as a form of physical hedging. Previous works have studied the spatial smoothing effect that can be achieved in a wide area and can result in a substantial increase in the predictability of the aggregation compared to individual wind farms (see e.g. [13,14]). Other techniques for physical hedging could be based on coordinating wind farms with either storage devices or conventional generation physical hedging technique [8].

The methodology can be broken down into two steps. In the first step we simulate individual wind power producers' participation in the day-ahead electricity market. This results in quantified revenues per producer. In the second step we make a statistical analysis of the revenue, capacity factor (CF, produced MW h per year/ (8760 h $\times$ Pn)) and predictability at a wind farm (expressed by the NMAE defined in Section 2.4). This allows us to evaluate the relative importance of predictability w.r.t. the capacity factor for increasing revenue. This methodology is applied twice.

1. initially only with wind farms participating in a market independently;
2. then allowing clusters of wind farms of up to 16 in size to jointly participate in the market. This makes it possible to study the aggregation effect.

We consider realistic time series of wind power production and associated prediction errors through a real-life test case. These