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Evaluating risk-constrained bidding strategies in adjustment spot markets for wind power producers

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ABSTRACT

Participation of wind energy in the day-ahead electricity market implies large deviations from the initial schedule, which leads to costs for the wind farm owner. By means of short-term wind power prediction programs, the contracted energy can be updated in adjustment spot markets, reducing the power deviations and increasing the total revenue for wind power producers. Taking into account the different uncertainties involved in the problem, an optimal bidding strategy can be used to maximize the wind power producer revenues. As the strategy could be very risky due to all these uncertainties, a CVaR constraint for the bid that maximizes the expected revenue is proposed as a way of reducing the risk. A test-case using the Spanish market rules during a 10-month period has been used to check the potential benefits of the aforementioned strategies.

1. Introduction

Since the liberalization of the electricity markets, the integration of wind power in the electric energy systems has increased in many countries, and wind producers participate in electricity markets trying to maximize their benefits. This participation implies following the energy market rules and, in general, wind power producers commit a production level, which must be delivered in the settlement period [1]. As wind power is intermittent and un-dispatchable, the future production is estimated through a short-term wind power prediction tool, and there is always an imbalance between the scheduled and the actual production. The wind producer must then buy or sell the difference in the balancing markets, leading to economic losses, since this energy is traded in worse conditions than in the spot energy markets.

One way of reducing the error prediction costs is updating the bid made to the day-ahead market in adjustment markets, when predictions with shorter horizons, and thus higher accuracy, are available [2–7].

The losses can also be reduced considering the uncertainty of the forecasts, in an optimization strategy which bids a given power to the electricity market, trying to reduce the economic losses, and consequently, improve the revenues. Several approaches for the uncertainty estimation can be found in literature, such as in [5,8–13]. These optimization strategies are commonly used to foster the incomes of generation producers [14].

Another way of reducing the imbalance costs is the combination of wind energy with an Energy Storage Device [15,16] or hydro plants [17]. These methods optimize the benefits of a coordinated participation in the electricity market, decreasing the losses due to uncertain forecasts.

But market participants must also cope with uncertain market prices. Then, a prediction of the electricity prices is a goal in most optimization problems, as shown in [18–23]. Specially relevant is the estimate of the imbalance prices, because the deviations between committed and delivered power are paid according to these prices and lead to imbalance costs which must be borne by the wind power producers. A bad model of these prices may influence strongly the revenues obtained. Since it is not possible to know in advance the value of the imbalance prices, several authors deal with this issue using known prices [3], considering reserves prices [2,24] or employing average imbalance prices [6,22]. All these studies are based on simplifications of reality, because the uncertainty of the future imbalance prices and their high dispersion are not considered, so the results obtained may widely differ from those obtained with more realistic assumptions. Further advances in a more proper modeling considering actual imbalance prices were presented in [25].

A risk management restriction may be included in the optimization strategy in an effort to reduce the hazard of having extremely high imbalance losses. This kind of methods considers either the variability of imbalance prices [26,27], or the production uncertainty

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risk [28,22], or both [13,29], and handles them in order to increase the revenues obtained by the wind power producer with minimum risk.

This paper addresses the optimal participation of wind energy in adjustment *spot* markets[1], or intra-day markets, in order to increase the wind producer revenues, through a stochastic optimization process which considers the uncertainty of the random variables involved, namely short-term wind power prediction, intra-day market price prediction and imbalance price prediction. Historic market prices are used to forecast future prices in the adjustment markets and a probabilistic approach, also based on historic imbalance prices, is considered to estimate the future imbalance prices, taking into account their stochastic character. To deal with extremely high and no predictable imbalance prices, a management risk constraint is integrated in the optimization strategy aiming to maximize the profit and reduce the risk of high losses. The strategies presented in this paper are different from those of previous literature.

In order to evaluate the actual performance of the proposed trading strategies, the participation of a 21 MW wind farm in the Spanish electricity adjustment markets during a period of 10 months is considered. Results are compared with those obtained with bids based only on point forecasts.

Compared to previous works, this paper presents new contributions. It includes an estimate of imbalance prices based on real data and not hypothetical scenarios, and the wind power forecasts are produced with a prediction tool in comparison to theoretical models of wind scenarios presented in other works. In short, all data considered in this paper are based on actual data (market prices, power productions and wind power forecasts). Also, an approach to reduce the risk in the participation of wind traders in electricity markets has been developed. This analysis comprises both production volume and volatility prices risk which are computed in a very simple and efficient way. A wide range of different risk levels is also included in this paper, allowing us to model different attitudes towards risk. Furthermore, the method deals with an analysis for 10 months, which includes data affected by seasonality. This mathematical problem takes into account the participation in three electricity markets, namely, day-ahead, adjustment and imbalances, and involves the uncertainties of both wind power production and electricity prices. The solution is obtained by a simple procedure, which is easy to embed in a real time decision-making tool, because it simulates the standard procedure of wind traders in the Spanish electricity market. This paper also presents conclusions that could be useful for market participants, relative to risk-constrained optimization strategies.

Summarizing, the main contributions of this paper are to provide:

1. A probabilistic model of imbalance prices, which allows considering imbalance prices uncertainty in bidding strategies for wind power producers.
2. An effective and simple way to improve the profit of wind power producers through an optimization procedure.
3. A new strategy for the risk-constrained participation in adjustment markets, considering a CVaR value associated to both volume production and market prices variability. The attitude to the risk of wind traders is modeled in this work.
4. A thorough analysis for almost one year of data, so that the advantages of different strategies can be assessed.

The paper begins with a short introduction to wind power participation in electricity markets and short-term wind power prediction. Uncertainty of market prices is considered in Section 4 where a probabilistic approach for estimating imbalance prices is described. The optimal strategy for bidding in adjustment spot markets is formulated in Section 5 as an optimization problem, which aims at maximizing the expectation of the revenues for the wind power producer. The optimal risk-constrained strategy is included in Section 6. Section 7 describes the test-case used to check the performance of the new trading strategies and results are provided in Section 8 in comparison to a point forecast trading strategy. Finally, the main conclusions of the study are presented in Section 9.

2. Wind power in electricity markets

The electricity market is composed by a set of different submarkets, with several schedule horizons. Most of the energy negotiated in a pool is traded in the day-ahead market, or Daily Market (DM), where the commitment is made usually the day before the Operation Settlement Period (OSP). The Intra-day Market (IM) is an adjustment market with shorter time scheduling, which may be continuous, as the Elbas Market, or structured in several sessions, as the Spanish Market. Previous studies [30] have shown the advantages of the actual market design of the Spanish Market to enable the integration of wind energy into the power systems.

After every IM session, the system operator solves the real time deviations, making use of ancillary services and the following deviation management procedure.

If wind power producers participate in the electricity market, they must interact in such scheme. Consequently, trading wind energy in the day-ahead market requires forecasts of future wind generation for horizons up to typically 2 days ahead (for the next OSP) with an admissible reliability.

These forecasts may be updated in the intra-day markets, with shorter times between the gate closure and the start of the energy delivered period, and therefore, more accurately. In spite of this, forecasting errors do exist, and differences between contracted and actual energy production will be produced, causing imbalances for the power system. These differences have to be settled in the deviation market procedure at the imbalance prices, usually leading to important imbalance costs for wind power producers. For example, wind power is the technology causing the most imbalances in the Spanish system (about 28% of the overall imbalance in 2010), only exceeded by demand [31].

2.1. Imbalance pricing

Due to the importance of the imbalance prices for wind power producers, a short description of two existing pricing mechanisms are briefly described [32]:

- Dual imbalance pricing, where a different price is applied to positive imbalance volumes and negative imbalance volumes; or
- Single imbalance pricing, where a single imbalance price is used for all imbalance volumes.

Most pricing mechanism follow dual imbalance pricing, where the main price is applied to imbalance volumes in the same direction as the overall market, whereas the reverse price is applied to imbalance volumes opposite in direction to the overall market e.g. *short* when the market is *long*, or vice versa.

The two-price system scheme is represented in Table 1, where the main price is the day-ahead marginal price (*MP*) and the reverse prices are *BP* (buy price) or *SP* (sell price), depending on the sign both of the system imbalance and the producer imbalance.

[1] The European convention is adopted in this article; in the USA the term *forward markets* is used.