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Wind power bidding in electricity markets with high wind penetration

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HIGHLIGHTS

- We analyze the pricing systems and wind power trading in electricity markets.
- We propose a model that captures the relation between market prices and wind power.
- A probabilistic bidding model can increase profits for wind power producers.
- Profit maximizing bidding strategies carry risks for power system operators.
- We conclude that modifications of current market designs may be needed.

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ABSTRACT

Objective: The optimal day-ahead bidding strategy is studied for a wind power producer operating in an electricity market with high wind penetration.
Methods: A generalized electricity market is studied with minimal assumptions about the structure of the production, bidding, or consumption of electricity. Two electricity imbalance pricing schemes are investigated, the one price and the two price scheme. A stochastic market model is created to capture the price effects of wind power production and consumption. A bidding algorithm called SCOPES (Supply Curve One Price Estimation Strategy) is developed for the one price system. A bidding algorithm called MIMICS (Multivariate Interdependence Minimizing Imbalance Cost Strategy) is developed for the two price system.
Results: Both bidding strategies are shown to have advantages over the assumed "default" bidding strategy, the point forecast.
Conclusion: The success of these strategies even in the case of high deviation penalties in a one price system and the implicit deviation penalties of the two price system has substantial implications for power producers and system operators in electricity markets with a high level of wind penetration.
Practice implications: From an electricity market design perspective, the results indicate that further penalties or regulations may be needed to reduce system imbalance.

1. Introduction

1.1. Introduction to wind energy

Wind power is one of the fastest growing renewable sources of energy. However, with the rapid increase in wind power production has come a need for better integration of wind power into electricity markets. In particular, the fluctuating nature and limited predictability of wind power comes at a cost. Not only is there the practical problem of meeting consumer demands for power, but system operators often levy penalties when dispatched power level deviates from the schedule [1]. In general, the higher the share of wind power in the system, the more costly this uncertainty becomes, as high cost oil and gas fired power plants must be brought online or offline at short notice [2].

Western Denmark, for example, produced 20.3% of its power from wind in 2010 [3]. Denmark plans to increase its wind production to 50% of consumption by 2025 [2]. This high penetration of wind in the power market has led to a large correlation between hourly prices and the corresponding hourly wind levels. This effect of wind power production on prices affects the optimal bidding strategy for a wind farm producer. This change in bidding strategy, however, can also affect the system balance, as wind producer bids may deviate from the expected wind production, possibly leading to increased costs of balancing supply and demand.

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Nomenclature

D	is the set of all hours for which data is known
c	total electricity consumption
c_C	conventional consumption (total consumption – wind power produced)
w_{DA}	is the point forecast for wind power production (day-ahead wind production)
w_{RT}	is the realized wind power production (real-time wind production)
π	realized operating profit (DKK[1])
q_{DA}	quantity bid into day-ahead market (MW h)
q_{RT}	quantity produced in real-time market (MW h)
$\bar{q}_{RT}$	max potential quantity delivered (MW h) (in real-time)
p_{DA}	day-ahead price (DKK)
p_{RT}	real-time price (DKK)
$p_{\downarrow RT}$	down-regulating real-time price (DKK)
$p_{\uparrow RT}$	up-regulating real-time price (DKK)
r_{RT}	real-time regulation volume (MW h)
$W_{DA,H,t}$	historical day-ahead wind prediction data known before time t
$W_{RT,H,t}$	historical real-time wind production data known before time t
$R_{RT,H,t}$	historical real-time regulation volume data known before time t
$P_{DA-\uparrow RT,H,t}$	historical difference between day-ahead price and real-time up-regulation price data known before time t
$P_{DA-\downarrow RT,H,t}$	historical difference between day-ahead price and real-time down-regulation price data known before time t
$C_{H,t}$	historical electricity consumption data

1.2. Energy market standards of operation

Most power markets include both a day-ahead and a real-time exchange. In the day-ahead market, the system operator collects bids from all participating power producers. The system operator then schedules these bids in such a way as to maximize some objective function, typically either the minimization of cost or the maximization of "social welfare". The very short-term balancing of supply and demand takes place in the real-time market. When electricity consumption or production differs from the day-ahead schedule, the differences are settled at a real-time price that is adjusted to keep power generation equal to demand. Power producers may face lost profits from the difference between day-ahead and real-time prices as well as from potential deviation penalties. A general explanation of energy market standards of operations can be found in [4].

The bidding mechanism is used by system operators to set the price of electricity for the next day and to distribute the demand for electricity among the producers of electricity. In the most general version of power bidding, each producer submits both a price and a production level (in MW h) for each hour of the following day. The system operator matches these bids to the expected consumer demand for electricity and determines the price for each hour (usually the highest bidded price that is matched). Many electricity systems have slight variations, but most follow this basic bidding model.

Wind power and some other renewables (such as solar photovoltaic) have a unique place in these electricity markets both because of their low marginal cost of production and their limited predictability. The low marginal costs of these sources means that they can make bids at a low enough price that they will almost always be accepted. The production level is therefore the only bidding parameter a wind power producer needs to determine to maximize its profits. The uncertainty of these sources means that they will usually be a large contributor to system imbalances [5] (because they will not necessarily meet the production level that they bid). Minimizing deviation penalties is an obvious goal of wind power producers as long as it helps maximize their profits. From the system operator perspective, understanding wind power bidding strategies is important to designing appropriate penalty and pricing systems.

1.3. Market pricing structure

It is well known that electricity demand tends to be largely price inelastic in the short term due to the necessity of electricity for residential and commercial operations [6]. The electricity market can be described by a supply and demand graph where the supply curve has tiers based on generation technology [7]. Those sources of electricity with a low marginal cost (e.g. wind and solar) make up the lowest portion of the supply curve, whereas thermal generation technologies have higher marginal costs. A graphical example of this tiered supply graph can be seen in Fig. 1, where w represents the wind power produced. Demand is assumed to be entirely independent of price, a reasonable approximation in the short term.

As a result of this tiered supply system, the amount of wind energy produced during a given hour shifts the supply curve horizontally, either increasing (in the case of low wind) or decreasing (in the case of high wind) prices [2]. For the rest of this paper, the portion of the supply curve that does not include the wind will be referred to as the "conventional supply curve".

By scheduling supply resources one day ahead of the delivery time in the day-ahead market, the system operator is able to better plan for imbalances in the system and the power producers are able to better plan how much power they should produce (which is useful for power plants that have substantial start-up costs). For planning purposes, the system operator wants to keep day-ahead schedules and real-time deliveries as close as possible to the actual power delivered. System operators employ a variety of

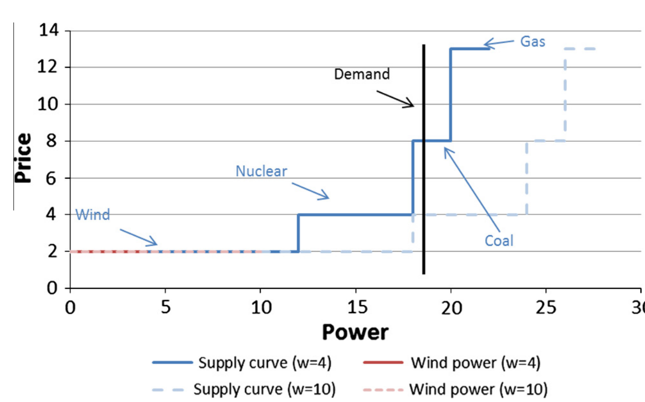

Fig. 1. Tiered structure of electricity markets.

[1] The average 2010 exchange rate was 1 EUR for 7.45 DKK.