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Potential of trading wind power as regulation services in the California short-term electricity market

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HIGHLIGHTS

- We design a wind power trading model and strategy in ancillary regulation service and energy markets.
- Revenue increases if wind power producers enter regulation service markets.
- Regulation down service market has greater market potential than regulation up service market.

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ABSTRACT

A short-term electricity market is usually composed of the energy market and ancillary service market. However, wind power is not allowed to be traded in ancillary service markets although it has been proven technically feasible to be regulation services. This paper aims to explore the market potential of trading wind power as regulation services in the California electricity market. A model for wind power trade in the day-ahead (DA) market is established considering the uncertainties of market prices and wind power. An optimal trading strategy for wind power producers is derived by using an analytical algorithm. Trading wind power as regulation is tested by using actual data and the impacts of market control on the market outcome are discussed. The results show that, based on the current framework of the California electricity market, wind power producers can earn much more money if they bid in the DA energy and regulation markets than if they only bid in the DA energy market. The results also show that the potential to enhance profit for wind power producers is larger in the regulation down market than in the regulation up market.

1. Introduction

In the past, owing to the small amount of wind energy production, many policies were enacted to stimulate the development of wind power industry all over the world. For example, numerous wind power producers were given a production-based subsidy so that they often would produce energy even if they were receiving negative energy payments for doing so. Another policy forced power system operators to purchase all the available wind energy. Consequently, the risk due to the variability and uncertainty of wind power was entirely taken by the existing power grid. However, this risk is gradually increasing with the rise in the penetration level of wind power and many countries aim at increasing the penetration level to 20% or even higher (GWEC, 2011). Nowadays, as wind power forecast and control technologies are improved and electricity markets are liberalized, wind power producers are expected to attend electricity market trade and power system operation as other market participants. This is particularly the case for producers who bid in short-term forward markets through electricity pools, rather than relying on long-term bilateral contracts. Notice that the markets discussed in the following content indicate the short-term markets.

In some energy markets of North America and Europe, wind energy is already traded today based on a policy where deviations from original bids/schedules of production are penalized. In the Texas nodal market of the USA, the Electric Reliability Council of Texas (ERCOT) shall charge a wind power plant if the metered generation is more than 10% above the scheduling base point (ERCOT, 2012). In the New Electricity Trading Arrangements (NETA) of the UK, there is a dual price mechanism for imbalance

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energy, i.e. the wind power plants who are under- or over-generating will receive lower revenues for their production than if they had been accurately generating (Bathurst et al., 2002). Wind power producers often face more pressure than other market participants because the considerable forecast errors of wind power may cause a large amount of imbalance penalties. To lower imbalance penalties, the wind energy trading strategies in some forward energy markets were designed in recent years. Matevosyan and Söder (2006) proposed an optimal day-ahead (DA) trading strategy for the wind power producers in the Nordic power market. The forecast error of wind power was represented by many scenarios which were generated based on an autoregressive moving average (ARMA) model for wind speeds and a power curve. Pinson et al. (2007) presented a DA wind energy trading strategy in the Dutch electricity pool. The uncertainties of wind power were represented by probabilistic forecasts, i.e. a point prediction with many prediction intervals whose confidence level ranges from 10% to 90%. Morales et al. (2010) derived a wind energy bidding strategy in the electricity market of Iberian Peninsula and proposed an effective way to restrain the risk of profit variability for wind power producers. The uncertainties of prices and wind were accurately represented by seasonal autoregressive integrated moving average (ARIMA) models. Dent et al. (2011) presented analytical results for determining optimal wind energy bidding strategies in the Great Britain electricity market. The authors also considered the correlation between real-time (RT) prices and RT wind power production and the risk attitude of producers. Zugno et al. (in press) proposed an optimal strategy for trading wind energy in Nord Pool. The probabilistic forecasts of wind generation and of market quantities were both taken into account by the authors. Most of the existing associated literature concentrated on the European electricity markets with similar market mechanisms. As supplementary, Botterud et al. (2012) presented a wind energy trading strategy based on the settlement mechanisms of the US electricity markets with locational marginal prices (LMPs). The correlation between DA and RT LMPs was involved in the trading model and the trade-off between risk and return was analyzed.

A short-term electricity market usually includes the energy market and ancillary service market. The participation of wind power producers in energy markets has been followed with many interests as claimed above, whereas the participation of wind power producers in ancillary service markets has been seldom discussed today. Modern wind turbines are based on the power electronic control technology so that they can adjust their active power output much faster than most of the non-wind generators. This creates a technical condition for wind power plants to provide some types of ancillary services, i.e. regulation services, spinning reserve services and non-spinning reserve services. The prices of regulation capacity are usually higher than those of spinning and non-spinning reserves and sometimes even comparable with those of electric energy (Kirby et al., 2010). This creates a potential economic condition for wind power plants to offer regulation services. Here comes one question: why not include wind power producers into regulation markets? Many scholars have proven it technically feasible to use wind power plants to assist power system frequency regulation (Sun et al., 2010, 2012; Zhang et al., 2011, 2012a). The wind turbines, newly produced by some manufacturers such as General Electric (GE) and Vestas, have already had the patent of frequency control technologies. Some grid codes, such as those in Spain, UK and Denmark, have stipulated that wind power plants must have the capability of supporting frequency regulation (Zhang et al., 2011, 2012a). However, the above efforts are all made from the technical aspect. It is actually a commercial issue as well to let wind power offer frequency regulation. Unlike other market participants, wind power producers mostly have not yet entered the existing regulation markets. Imagine that, if there is a policy that allows wind power producers to attend regulation markets, the main market stakeholders may hold different perspectives. Manufacturers may support the policy since they could sell their newly produced wind turbines and earn the royalties of their frequency control patents. System operators may also support the policy since the introduction of wind-provided regulation capacity could ease the operators' pressure caused by the declining system regulation capacity due to the rise of wind power penetration. By contrast, wind power producers may have perspective gaps as they are afraid of losing energy revenue if they sell wind power as regulation services (Ela and Brooks, 2011). Up till now, very few studies discussed the feasibility of wind power producers' participation in regulation markets. Liang et al. (2011) indicated that regulation prices will likely increase as system reserves become scarce, which creates incentives for wind power plants to provide regulation services. Sáiz-Marín et al. (2012) also proved that there are business opportunities for wind power producers to attend regulation markets, even based on the current regulatory policy and market prices of the Spanish electricity market. Therefore, if suitable market environment and supportive policies are given, market potentials may exist to fill the perspective gaps and mutual benefit may be obtained for each stakeholder.

This paper aims to explore the potential to trade wind power in regulation markets in addition to energy markets. The research ideas proceed as the following steps:

(a) Market access: based on the current framework of the California deregulated electricity market in the USA, wind power producers are allowed to participate in the regulation market;
(b) Trading strategy design: an optimal bidding strategy for wind power producers is designed to pursue profit maximization in the DA regulation and DA energy markets;
(c) Validation: whether wind power producers can make additional profit is tested compared with if they had only bid in the DA energy market. The impacts on the market outcome are investigated if market policy is changed.

Among the above steps, the core part is the trading strategy design. Liang et al. (2011) presented a strategy of trading wind power in the DA energy and up-regulation markets in Texas, USA. Nonetheless, the authors omitted the exchange of down-regulation, that is likely a more profitable regulation service due to its lower opportunity cost compared with up-regulation (Rose and Apt, 2010), and omitted the uncertainties of market prices. This paper follows the study of (Liang et al., 2011) and the main contributions are summarized as follows:

(a) Based on the framework of the California electricity market, a stochastic model is established to derive hourly DA energy and regulation (up and down) bids for wind power producers.
(b) The uncertainties of market prices are represented by scenarios and the uncertainties of wind power are represented by continuous probability distributions. By doing so, the objective function of the bidding model is converted to an expected form and the stochastic optimization problem is simplified to a deterministic one with analytical solutions.
(c) Trading wind power as regulation is tested by using realistic market data. It is found that there is a big potential to make profit in the regulation market for wind power producers.
(d) The impacts of policy and market control on the market outcome are further discussed. The results show that to trade wind power in the down-regulation market has a greater commercial potential than in the up-regulation market.

This paper is organized as follows: Section 2 introduces the structure of the California electricity market. Section 3 designs a