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Insurance strategy for mitigating power system operational risk introduced by wind power forecasting uncertainty

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ABSTRACT

The increasing penetration of wind power significantly affects the reliability of power systems due to its intrinsic intermittency. Wind generators participating in electricity markets will encounter operational risk (i.e. imbalance cost) under current trading mechanism. The imbalance cost arises from the service for mitigating supply-demand imbalance caused by inaccurate wind forecasts. In this paper, an insurance strategy is proposed to cover the possible imbalance cost that wind power producers may incur. First of all, a novel method based on Monte Carlo simulations is proposed to estimate insurance premiums. The impacts of insurance excesses on premiums are analyzed as well. Energy storage system (ESS) is then discussed as an alternative approach to balancing small wind power forecasting errors, whose loss claims would be blocked by insurance excesses. Finally, the ESS and insurance policy are combined together to mitigate the imbalance risks of trading wind power in real-time markets. With the proposed approach, the most economic power capacity of ESS can be determined under different excess scenarios. Case studies prove that the proposed ESS plus insurance strategy is a promising risk aversion approach for trading wind power in real-time electricity markets.

1. Introduction

Wind energy, one of the most appealing renewable energy sources for power generation, has become a mainstream alternative electricity source in energy industry. In the past five years, the average annual installed wind generation capacity increase around 30%. In the USA, wind energy has become the largest source of new electricity generation capacity, representing around 50% of all new electric additions. The European Wind Energy Association (EWEA) has set a target to satisfy 25% of European electricity needs with wind by 2030 [1]. In fact, some countries have already achieved high level of wind penetration. For instance, wind power accounts for around 30% of electricity production in Denmark. In Australia, wind market is benefiting from favorable tax treatment for wind generation and state mandates for renewable energy. It is expected that wind energy will provide the largest share of Australia's targeted 20% renewable energy by 2020 [2]. China has rapidly become a global leader in wind energy and now ranks second in the world in installed capacity [3]. By the end of 2013, the installed capacity of wind energy has reached 12.2 GW, which is about 0.4% of China's total electricity supply. Although wind energy plays an increasingly important role in energy sector worldwide, the ever-increasing level of wind energy with significant uncertainty brings potential risk to power system operations [4]. Furthermore, after direct participating in electricity market, the high volatility of electricity price will further intensify the risk of wind energy [5]. Therefore, accurate wind power forecast at various time-scales is essential for market trading and portfolio management [6,7].

Although forecasting techniques have been continually improved over the last decade, due to imperfect prediction models and inaccurate initial states, it is widely accepted that wind power output cannot be predicted at high accuracy at all times [8,9].

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Currently, spinning reserves are employed to compensate for the prediction errors, and the participation of wind power is investigated in electricity markets in order to maximize benefits and minimize impacts [6,10–12]. In Ref. [6], a probabilistic approach is applied to evaluate the impacts of wind forecasting errors when wind farms participate in day-ahead or hour-ahead energy markets. It is found that the cost for compensating forecast errors can reach as high as 10% of total energy trading income. In Ref. [13], the optimal forward strategy is studied to consider the opportunity costs of wind power in an electricity market. A bid curve is proposed for wind power, instead of the traditional fixed quantity bid. It is found that wind farms have to undertake high risk of wind power fluctuation. In Ref. [14], a model for optimal trading of wind power in day-ahead markets considering wind and price uncertainties is proposed. A deviation penalty is added to quantify the imbalance cost of wind power. In general, although wind energy promises a relatively cheap source of electricity, high penetration of wind power will cause high potential risk in power system operation [12]. For instance, trading wind power will cause increased system operation cost (generation cost, reserve cost) and extra cost (generation and load shedding cost) due to wind forecast uncertainty. One of the possible solutions is to provide sufficient reserves from other power sources all the time to assist wind farms in balancing power output and participating in market trading.

The advance in material [12] science and power electronic technologies has facilitated the effective employment of new energy storage devices. Energy storage system (ESS) can mitigate the impacts of wind power prediction errors and smooth the wind power output [15]. It is applicable to power system operation or energy trading, i.e. unit commitment and economic dispatch [4]. And the required size of ESS can be determined based on the forecast errors of wind power [9,13]. Nevertheless, ESS cannot eliminate the impacts of forecast errors, since the maximum size of these changes could reach 100% of the installed capacity in a very short time period [5]. Besides reserve and ESS, if participating in real-time markets, there are three kinds of measures to control the risk produced by the wind power forecast uncertainties [5,13]:

- Risk reduction: Adjust bidding strategies by considering power imbalance costs. The methodologies currently adopted for wind power forecasting should undergo continuous refinement in light of future operational experience.
- Risk avoidance: Indirectly participating in electricity markets. Renewable energy generators can choose to sell power to other market players who bid in real-time markets, i.e. thermal generators with enough spinning reserve.
- Risk transfer: Transferring the risk of imbalance costs to a third party. An agency is expected to pool funds from many insured renewable generators, so losses of an individual generator could be compensated from the funding pool. Insurance is a widely accepted mechanism to transfer risk to third parties.

The operation of wind power requires effective risk management and transferring tools, which can insure against the low-probability high-loss events and make up part of economic loss, thereby contributing to the sustainable development of wind industry [16]. However, wind insurance involves many factors and requires long-term historical data, and it offers a number of technical underwriting challenges. Therefore, the existing insurance market is still dominated by classic insurance products, including property insurance, damage insurance, and non-operational risks associated insurance. Many insurance companies refuse to participate in this market, preferring a wait-and-see attitude, which led to relatively high loss ratios for all types of insurance products. Compared with improving prediction accuracy, how to effectively address the contradiction between power system reliability and economy with insurance, reducing the impact of wind power prediction errors on system scheduling and control, becomes more important.

In this paper, insurance is used to mitigate the imbalance costs caused by trading wind power in electricity markets, aiming at improving system reliability and reducing power outage loss. A Monte Carlo (MC) simulation based approach is applied to determine the expected imbalance costs of wind power in real-time markets. A number of historical datasets are used in the simulation, which include wind forecasting errors, load forecast errors, and frequency regulation prices. Then, the feasibility of applying insurance to mitigate the financial risk caused by wind power forecasting error is discussed. Details regarding how to calculate insurance premiums from the perspective of an insurance company are also given.

This paper is organized as follows: the operational risk of power system by wind power forecast uncertainties is discussed in section 2. The basic concepts of the insurance strategy are introduced, followed by the derivation of the insurance premium calculation method in section 3. In section 4, case studies are conducted to validate the proposed insurance strategy. Conclusions are given in the last section.

2. Operational risk of power system by wind power forecasting uncertainties

2.1. Risk estimation of wind power forecast errors

Wind forecasting error risk refers to increased operational cost and extra cost due to the changes in wind power generation caused by grid-connected wind power generation equipment failures or wind speed fluctuations. In this paper, it refers to power system imbalance losses introduced by wind power prediction uncertainty. When a deviation occurs between the predicted and the actual wind power output, the spare capacity will be dispatched to make up the difference; when reserve capacity is insufficient to compensate the changes in wind power output, the load shedding will be applied. The wind power prediction error risk assessment process is shown in Fig. 1.

2.2. Risk quantification of wind power forecast errors

Trading wind power under long-term contracts is less risky, because the average power output over a long period of time is more predictable [13]. On the contrary, predicting wind power outputs over a short period of time is still a challenging task. It is widely accepted that wind speed is highly volatile and difficult to predict, because of wind speed fluctuations caused by thermal convection or vortices [5]. Furthermore, the current electricity markets were designed to deal with various forms of dispatchable generation and a predictable electric load pattern, trading wind power in the markets is still a relatively new topic. In general, real-time wind power trading is based on wind power forecasting and bidding strategy design [17]. With frequent real-time market clearing, wind power output can deviate from its forecasted value, due to its intermittency. The difference between the scheduled and actual power outputs has to be compensated by other generation sources in power systems, for example, the spinning reserve. These costs incurred by the reserve generation sources are defined as imbalance costs [6].

We calculate the imbalance costs after scheduling has been performed by the independent system operator (ISO), who is in charge of scheduling and settlement process based on forecasted demand and bidding information. The imbalance between supply and demand in power systems can be attributed to several factors, i.e. load and generation forecast errors, line faults, or sudden losses of generator. Renewable power forecast errors can be mitigated by