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Mitigating market risk for wind power providers via financial risk exchange

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ABSTRACT

When wind power producers (WPPs) participate in forward electricity markets, they become exposed to real-time (RT) market risks from uncertain generation outputs and highly volatile RT market prices. This joint volume-price risk causes a risk-averse WPP to sell less energy than the expected generation, which discourages the WPP from fully enjoying the benefits of participating in forward electricity markets. In order to mitigate volume-price risks from the RT market, this paper proposes a financial instrument referred to as a risk exchange (REX) that enables the WPPs to trade random net payments from uncertain prices and generation outputs, after the day-ahead market is cleared. A negotiation for the REX is modeled by a bargaining game based on a conflict of interest in determining the REX amounts. Both Nash and Rubinstein's bargaining game models are addressed to analyze the REX bargaining game. It is shown that there is a unique outcome of the game which can be achieved by using a pure strategy. Moreover, a central planner who aims to minimize the aggregated risks of the WPPs is explored. Numerical examples demonstrate that the REX is able to reduce RTM risks successfully and encourages the WPPs to sell more energy to the DAM. Since the REX is not limited by physical constraints in power systems, it can be traded by the WPPs exposed to different locational marginal prices (LMPs).

1. Introduction

Wind energy is regarded as one of the most sustainable resources that can provide electric power without emissions. Many countries around the world have adopted wind energy as an important energy source due to its abundance and ease of large-scale generation, and have provided production tax credits (PTC) and incentives for wind power generation to increase the growth of wind power capacity and, in some cases, have required that all wind production be accepted under "must take" rules. In U.S. electricity markets, those incentives have been successful in motivating wind power producers to invest in wind farm installation. Several markets, including the Electric Reliability Council of Texas (ERCOT) and the Midcontinent Independent System Operator (MISO) require wind power producers (WPPs) as a normal generator, without "must take" requirements.

In organized U.S. electricity markets, an ISO adopts a two-settlement system which typically consists of a day-ahead market (DAM) and a real-time market (RTM). On the one hand, the DAM is a financial market that clears energy supply and demand for the next day, where transactions in the market are generally financially binding. On the other hand, the RTM clears energy a short time prior to the operating time, and its transactions are subject to physical obligations. When a generator is financially obligated through the DAM to sell power, imbalances between the DA accepted volume and actual generation will be settled at the real-time (RT) market clearing price (MCP). In U.S. markets, generators are subject to a single real-time price (RTP) regardless of whether RT imbalance is short or long (Helman et al., 2008). In some European systems, such as Iberian and Great Britain, different regulation prices are applied to generators depending on whether they are short or long (Morales et al., 2010).

Real-time markets are expected to be volatile because the ability of adjusting supply to rapidly changing system load is restricted by the transmission constraints and physical limitations of the generators. Furthermore, the growing penetration of wind generation enlarges the RTP variance (Woo et al., 2011; Ketterer, 2014). So, the market participants who rely only on the RTM might not be able to achieve stable profits. Among various RTM risk hedging methods, participating in the DAM is a typical way for the market

Abbreviations: ISO, Independent System Operator; WPP, Wind Power Producer; DAM, Day-Ahead Market; RTM, Real-Time Market; DAP, Day-Ahead market Price; RTP, Real-Time market price; MCP, Market Clearing Price; LMP, Locational Marginal Price; REX, Risk Exchange.

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participants to hedge risks because the DAM, the short-term forward market for the RTM, is relatively independent from incidental transmission and generation outages and thus has more stable market prices than the RTM. In addition to risk-hedging, the DAM can be utilized to arbitrage with the RTM. Market participants can engage in “virtual bids” which are matched buy-sell and sell-buy positions between DA and RT markets. By exploiting arbitrage opportunities, such virtual bids tend to make the DAP equal to the expected RTP. However, the market participants' expectation of high RTM volatility might result in a violation of the no-arbitrage condition between the DAM and RTM (Potomac Economics, 2017; Parsons et al., 2015; Borenstein et al., 2008; Woo et al., 2015). There is nevertheless historical evidence that the average of day-ahead price (DAP) is higher than the average of RTP, including ERCOT (Potomac Economics, 2017), the PJM market (Longstaff and Wang, 2004), the New England market (Hadsell, 2008) , the Midwest market (Bowden et al., 2009), and the Iberian market (Ito and Reguant, 2016). Risk aversion (McAfee and Vincent, 1993) and market power (Ito and Reguant, 2016) of market participants are identified as the drivers of positive DAM premium.

However, those advantages of the DAM are not fully transferred to the WPPs because of their generation uncertainty. RT delivery of wind power can deviate significantly from DA commitment, which causes RT imbalance. This RT imbalance is settled by RT price in U.S. system or regulation prices in European system. So, the combination of volumetric risks and RT price risks could make the overall risks greater, which might cause financial crisis to the WPPs. This joint price-volume risks discourage the WPPs from selling energy to the DAM and taking advantage of DAM premium. Therefore, mitigating joint price-volume risk is a highly important task to WPPs.

Risk hedging strategies for electricity market participants have been widely studied. Pineda and Conejo (2012) showed that forward contract and options sufficiently hedge conventional power producers against risks relevant to market prices and unexpected failure of generating units. Retailers are exposed to volumetric risk in addition to market price risk due to uncertain demand of its customers. Boroumand et al. (2015) use intra-day portfolios consisting of options and forward contracts to reduce the joint price-volume risk. Demand response can be another instrument to hedge the risks Zugno et al. (2013). In order to reduce the risk for WPPs, a combination of wind and dispatchable power resources has been explored. The use of a pumped hydro storage plant (PHSP) is able to minimize the risk from an imbalance penalty for WPPs and increase profit (Bourry et al., 2009; Varkani et al., 2011). Alleviating wind trading risks via coordination with thermal generators is studied in Al-Awami and El-Sharkawi (2011). Some works (Broeer et al., 2014; Falsafi et al., 2014; Heydarian-Forushani et al., 2014) concentrate on the role of demand response that can be used for balancing uncertain and volatile wind generation.

There has been considerable literature that addresses the problem of optimizing an offer strategy for a WPP in a wholesale electricity market either by analytical (Pinson et al., 2007; Bitar et al., 2012; Dent et al., 2011) or computational (Morales et al., 2010; Matevosyan and Soder, 2006; Pousinho et al., 2011) approaches. The papers adopting the first approach address the problem with mathematical analysis to obtain a closed-form expression of optimal offer quantity for a given offer price. Pinson et al. showed the method to calculate the optimal offer quantity by using probabilistic characteristics of wind power (Pinson et al., 2007). Bitar et al. analyzed the influence of information about the future wind generation on a WPP's profits and risks (Bitar et al., 2012). In addition, the optimal offer strategy in case of correlated wind power and price is considered in Dent et al. (2011). From using a normal distribution, the paper showed that the optimal offer is affected by the correlation between wind power and price and their variances. Those papers use a simple market model to give a clear insight of how the offer strategy will be affected by probabilistic features of wind power and price. The papers adopting the second approach solve the problem with computational method to calculate the optimal offer quantity. In these papers, scenario generation is used to capture the stochasticity of wind power and price and the problem is addressed by using stochastic optimization. The problem of maximizing profits is addressed in Matevosyan and Soder (2006) and reducing risks with a small decrease in profits is explored in Morales et al. (2010), Pousinho et al. (2011) .

These works deal with European electricity markets and concentrate on minimizing the RT imbalance cost using probabilistic characteristics of wind generation and prices. There is another line of work focusing on the statistical diversity of wind generation from different wind farms. This diversity can be utilized if WPPs are aggregated, and helps to reduce RT imbalance cost of WPPs (Baeyens et al., 2011; Baeyens et al., 2013; Zhao et al., 2015, Zhang et al., 2015). References Baeyens et al. (2011) and Baeyens et al. (2013) show that coalitional aggregation of WPPs is able to increase expected profits. The authors also investigate a profit sharing mechanism for WPPs. Reference Zhao et al. (2015) proposes a non-cooperative risk power market where WPPs trade uncertain future generation outputs with each other. The authors prove that competitive equilibrium produces the same total profit as obtained by a grand coalition of WPPs. Reference Zhang et al. (2015) studies a large aggregation of WPPs and how its strategic actions influence the electricity market. The strategies in Morales et al. (2010); Pinson et al. (2007); Bitar et al. (2012); Dent et al. (2011); Matevosyan and Soder (2006); Pousinho et al. (2011); Baeyens et al. (2011); Baeyens et al. (2013); Zhao et al. (2015); Zhang et al. (2015) are relevant to “two-price market” in which different prices or penalties are imposed on RT imbalance depending on whether they have short or long positions, as in European electricity markets. However, recently, the European system is moving away from a two-price market, due to “imbalance netting” (Lorenz and Gerbaulet, 2014; Farahmand and Doorman, 2012). Furthermore, the papers related to the wind energy aggregation only consider a limited system condition where WPPs are subject to a single MCP. That is, WPPs pay or are paid at the same price even when they are located at different buses.

In this paper, we propose a financial instrument referred to as risk exchange (REX) for WPPs in U.S. electricity markets. The proposed strategy gives WPPs an opportunity to exchange joint price-volume risks composed of uncertain RT imbalances and RTP after the DAM is cleared. Thereby, the WPPs are able to diversify their financial portfolio as a consequence of trading the REX with others. The applicability of the REX is not limited by physical constraints so that it can be traded among the WPPs who are exposed to different LMPs. The objective of the instrument is to reduce the joint price-volume risk for WPPs caused from RTM uncertainty, rather than to maximize profit.

Before analyzing the REX, the term *“admissible policy”* is defined in order to clarify the conditions for a policy to be beneficial to risk-averse WPPs. Afterward, we show that there exists a conflict of interest among WPPs when determining the amount of REX trade. The negotiation process for resolving the conflict in the REX trade is modeled as a bargaining game. We first apply Nash's axiomatic approach to address negotiated outcomes reached by WPPs. We show that the outcome of the REX bargaining game is unique and can be achieved by using a pure strategy. Since Nash's approach does not construct the bargaining process explicitly, it is necessary to study how to implement the bargaining game in a non-cooperative fashion. To this end, we also investigate Rubinstein's non-cooperative game model and consider alternating offers for the REX trading. Finally, we consider a case in which a central planner determines the amount of the REX trade aimed at minimizing the total risk for the WPPs. Through numerical examples using data from the ERCOT market, we demonstrate that the REX successfully reduces RTM risk faced by the