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Wind farms participation in electricity markets considering uncertainties

Hamed Dehghani, Behrooz Vahidi*, Seyed Hossein Hosseinian

Department of Electrical Engineering, Amirkabir University of Technology, 424 Hafez Ave., Tehran, Iran

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ABSTRACT

Rising global temperature and environmental pollution as well as the demand for energy consumption have made finding new and affordable clean energy resources a serious challenge for governments. A possible solution could be renewable resources such as solar, wind or geothermal energies. Restructuring and deregulation have provided a competitive environment which makes analysis of these new energy sources necessary. Wind farms have been receiving more attention from governments because of their noticeable generation capability. The stochastic nature of the wind inflicts uncertainty on the output generation of wind farms which then causes some limitations for the participation of these farms in the electricity market. Thus, in this paper the effects of uncertainty in predicting the wind farm's power on locational marginal price in the market have been studied. According to the advantages and disadvantages of wind farm's power uncertainties, a procedure to maximize the social welfare **is** presented. The studies have been done on an 8-bus network for 24 h in a day-ahead electricity market. To do this, the farm power is predicted using Neural Network and Wavelet Transform and its uncertainties are calculated using the asymmetric Quantile Regression method.

1. Introduction

Environmental pollution, global temperature rise, fossil fuels shortage crisis and technology advancements have forced governments to consider using renewable resources such as solar, wind or geothermal energies. Moreover, restructuring and deregulation have produced a competitive economically opened environment which in turn has naturally increased the system efficiency. Therefore, of great importance is the investigating the economic effects of new equipment installed in the power network in this new environment [1]. Power generation using the wind, free and environment-friendly and having low repair and maintenance costs with quite high generation capability, has been increasing due to the growth in the use of wind farms in power networks. In spite of improvements in the generation and increased penetration in power systems, wind farm participation in the Electricity markets remains a real challenge because of their intermittent nature [2].

Market participants need to predict the power of wind farms for market closure. In doing so, There are several procedures including combining Fuzzy Logic and Neural Network, known as Fuzzy Logic-Neural Network methods [3,4], using Kolmogorov-Zurbenko filters, Markov-Chain model, and Wavelet Transform to eliminate temporal pulsations of the wind or wind farms power [5], combining adaptive wavelet neural network and feed-forward neural network [6], or using wavelet transform and Radial Basis Function network [7]. Moreover, the variation of the output power of wind turbines is a real challenge for the safe and economic performance of power systems; therefore, calculating uncertainty in the output power prediction is now inevitable for beneficiaries to making decisions.

One of the most common methods of uncertainty calculation is the Monte Carlo simulation. Unfortunately, since having a high program running rate and requiring the probabilistic distribution, this method is time consuming. The Point estimation technique is another method, unlike the Monte Carlo simulation, uses multiple points (one or two points), and thus reducing the number of calculations considerably [8,9]. Additional information about different methods of analyzing uncertainty in the predicting wind turbines can be found in Refs. [10–12]. Another important element in the calculation of uncertainty is prediction intervals (PIs) which, providing a lot of information about unknown uncertainties around the predicted points by defining specific Confidence intervals. Several methods have been offered for establishing prediction

* Corresponding author.
E-mail address: vahidi@aut.ac.ir (B. Vahidi).

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Nomenclature

Indices

I	Index for buses
J	Index for Generators

Sets (Variables)

P	Amount of active power
I_i	Injected power
P_d	Active power demand.
V_{t+k}	Velocity at time t + k
P_t	Wind farm's power at time t
P_{t+k}	Wind farm's power at time t + k
a,b,c	Cost functions' Coefficients
μ	Coefficient related to spot price.
Y_{ij}	the ith row and jth column of the admittance matrix
Θ_i	the angle of bus i
P_{ij}^{max}	the maximum power flow through the line i-j.

intervals using a Neural Network [13,14], the main drawbacks of these methods are again being highly time consuming, requiring a large amount of calculations and the necessity of specific probabilistic distributions. Attracting a lot of attention in recent years, Quantile Regression (QR) has been proven to be one of the most effective methods [15]. It features fast and easy calculations, having no need for probabilistic distributions, and not using the smart methods like Neural Network. Uncertainty in the power generation, risk of participating in the market and return of fund are other factors which effect the participation of wind farms in the market.

The need of wind farm owners and system operator to develop a strategy covering all above factors has been investigated in several studies. Many wind farm owners in the USA are selling their power through a long-term contract and with a fixed price [2]. In Ref. [16] the impact of different prediction methods on the wholesale price of wind power has been studied. In Ref. [17] reducing unbalanced price in short-term markets is investigated using a probabilistic Markov model. Research done in Ref. [18] used the Quantile Regression probabilistic power prediction method to discuss how wind farm performance can be used to maximize the acquired interest. In Ref. [19] the probabilistic distribution of unbalanced prices has been predicted and an optimized bidding procedure has been offered to participate in the market using the Kernel density estimation (KDE) method and the Conditional value at risk (CVAR) technique considering uncertainty. Wind energy trading in real-time and day-ahead markets have been studied in Ref. [20], and a balance between the risk and the recessive expenses of the wind farm was provided based on locational marginal price (LMP). Having considered the penalty factor and LMP [21], formulizes the wind farm contract optimization.

An important point that should be considered is that due to their rather high rate of generation, wind farms can affect the losses rate and increase congestion of the lines, affecting the generation capability of other units and the prices of the market. Power and uncertainty variations in the prediction complicate these affectations as well as decision making about the market. In the most recent studies in this area [22], an optimal bidding strategy is presented for a multi independent wind farm with the aim of maximizing 24 h social welfare in Oligopolistic Day-Ahead. Optimal bidding and generated scenarios for uncertainties in generated power were modeled by the Stochastic Cournot Model and Auto Regressive Moving Average (ARMA), respectively. This method requires a lot of computation; consequently, decreasing scenario methods are necessary for fewer calculations.

To the best of our knowledge most of the studies on wind power and its uncertainties in the electricity market are based on the point estimation (special value is allocated to the special value of wind) and the scenarios (dependent on many calculations) while the effects of the upper and lower bands and the probabilistic intervals (PI) created between the two bands in the context of the market price, profits and losses of participants and the optimal amount for wind power to maximize the social welfare are rarely considered [23].

Therefore, in this paper the impacts of uncertainty in predicting wind farms power on LMP in the market considering PIs has been studied, and a new method for an optimized amount provided by the wind farm in order to maximize producers and consumers profits (social welfare) has been offered. Optimal wind power tries to achieve the maximum possible profit for winners in every hour and the least amount of loss for the losers. In this study, the network was analyzed using DC optimal power flow (DCOPF) without considering the losses of the lines, and the wind farm modeled as a negative load without assuming a specific price for its power generation. To analyze LMP, the market has been run hourly and the electricity market is considered as a day-ahead market. As opposed to many references neglect the effect of network topology (such as congestion) on the issue, network topology has been considered in this paper since it has an effect on the process of the issue as well as the reality. The rest of the paper is organized as follows: in Section 3 wind farm power prediction methods are introduced and uncertainty in predicting the power of wind farms is studied. In Section 4 impacts of wind power and its uncertainties on LMPs are presented. In Section 5 the issue is formulized and a new strategy is provided so as to improve LMP and optimize social welfare. Finally, the conclusion is provided in the last section.

2. Wind farm power predicting and uncertainty analysis

2.1. Prediction

In this paper, the wavelet transform and radial basis function Neural network method has been used to predict wind speed [7]. The data set having been used for teaching purposes and testing the Neural Network includes speed, direction, humidity, and temperature. Considering contiguity of the turbines, locational characteristics, and the effects of the turbines site, in Ref. [24], the non-polynomial equations method is offered to calculate the output power of the turbines of Tetrapolis Kefalonia wind farm located in Greece with maximum capacity of 32.2 MW [24,25]. Using this method, the power of the turbines was calculated using Equation (1).

$$P_{t+k} = 403.51 \tanh\left(\frac{v_{t+k} - 9.1}{2.864}\right) + 0.025P_t + 407.6 \qquad (1)$$

Due to Tetrapolis wind farm's high generation capacity and more useful formula for calculating the power, this wind farm has been studied in this research. The wind speed is predicted by means of Wavelet- Neural Network method. Therefore, the power of the wind farm is calculated for a day using Equation (1) (11 May 2014). Power of wind farm based on the predicted speed is shown in Fig. 1.

2.2. Calculating uncertainty in predicting the power of wind farms using the Quantile Regression method

One of the most efficient methods for uncertainty calculations is the Quantile Regression method. It does not use a specific