Impacts of Strategic Behavior of Wind Power Plants on Electricity Markets: A Supply Function Equilibrium Approach

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Abstract- In this paper, the impacts of strategic behavior of wind power plants on electricity markets is studied both in mid and short-terms. To this end, the following schemes for participating wind power plants in electricity markets are proposed and compared: 1) wind power plant as a price-taker producer, and 2) wind power plant as a strategic producer which games in supply function. For this study, we need to know the bids of producers. To overcome this problem, it is assumed that the market has approached to its Nash equilibrium and the proposed schemes are compared at their Nash equilibrium. To consider uncertainty in wind power, different scenarios are considered for wind generation based on its probability density function. For mid-term study, it is assumed that the only available information about realization of wind power is the probability density of wind speed. For short-term study, it is assumed that wind power can be forecasted with a specified probability density function. Finally, to evaluate the strategic behavior of wind power plants, the proposed schemes are compared by applying them to a test system.

Keywords- electricity market, supply function equilibrium, wind power plant, support schema.

1. Introduction

Todays, wind energy is growing very fast around the world [1]. Up to now, it was not possible for wind power plants to have strategic behavior in the competitive electricity markets due to their high generation costs and intermittent nature of wind power generation [2]. A decade research on wind turbines and generators has developed the wind industry. Costs of wind power plants are decreasing and wind generation is going to get competitive with other power generation technologies. Governments are willing to reduce the considered subsidies for wind generation and are pushing wind power plants to participate in the market strategically and gain money [3]. In order to encourage wind power plants to participate in the market strategically, "feed-in tariff" support scheme that guarantees a fixed price for producing every MWh wind power generation is replacing with "feed-in premium". According to "feed-in premium", wind power plants receive a fixed price, which is less than the fixed price of "feed-in tariff", plus market price [4]. The "premium tariff" makes the wind power plant to follow the market and arouse their curiosity to have strategic behavior. On the other hand, power output of wind turbines has an **intermittent nature. Hence,** it is difficult to predict and control the wind turbines output. Therefore, power markets with large scale integration of wind power plants, usually, encounter with imbalance between generation and load. Up to now, the consumers were responsible to pay for the cost of power balancing. Recently in some power systems, in order to encourage wind power plants to reduce wind generation uncertainty, wind power plants get responsible to pay for imbalance cost [5]. This makes wind power plants to improve their forecasting tools and ready them to participate in the market strategically.

Studies about the integration of wind power plants into the electricity markets have appeared in literature recently. These investigations, mainly, try to find the optimal power bid or price bid for wind power plants in short-term, i.e., in day ahead and intra-day markets.

Optimal bidding strategy for wind power plants in day ahead and intra-day ahead markets is studied in [6]. In [7] a new method for pricing and utilizing of wind power in short-term is proposed. Risk management and optimal bidding for a wind power producer is studied in [8]. Paper [9] proposes a probabilistic methodology for estimating the energy costs in the market for wind generators associated with wind prediction errors. The optimal operation of a combined wind farm and pumped-storage facility in a market environment is investigated in [10]. In [11] wind power plants participates in both energy and regulation reserve market to increase their profit.

In [12] the impact of large scale integration of intermittent generation resources on electricity markets is studied through a supply function equilibrium model. In this paper, intermittent generation resources are considered as price taker producers. In [12] it is shown that adding a price taker wind power plant, in comparison to adding a strategic thermal power plant, changes the market price due to the following reasons. Due to reduction in competition market price increases, due to considering zero bid for wind generation market price decreases, and due to uncertainty in wind generation market price increases.

In this paper, the impacts of strategic behavior of wind power plants on electricity markets with supply function model and uniform pricing, is studied both in mid and short-terms. For this study, we need to know the bids of producers considering strategic behavior of wind power

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plants. To overcome this problem, it is assumed that the market has approached to its Nash equilibrium and the impacts are studied at the market Nash equilibrium.

The reminder of this paper is organized as follows: In Section 2, the paper is overviewed. Deterministic Supply Function Equilibrium (SFE) is reviewed in section 3. SFE considering the proposed schemes is modeled in section 4 for mid-term studies. Consideration for short-term studies is presented in section 5. The proposed schemes are compared by applying to a test system in section 6. Conclusion in section 7 closes the paper.

2. Paper Overview

In this paper the following schemes are proposed for participating of a wind farm in an electricity market:

A) Wind power plant is a price-taker producer

B) Wind power plant is a strategic producer and games in SF

The impacts of each scheme on the electricity price and profits of wind and non-wind strategic producers are studied in mid and short terms. To this end, we need to know the bid of each strategic player under each proposed scheme. To overcome this problem, it is assumed that in each scheme the market has approached to its SFE. Bids of strategic producers at SFE are used for the study. Uncertainty in wind generation depends on the error of wind generation forecasting. For mid-term study it is assumed that the only available information about wind speed is its probability density function. For short-term study it is assumed that wind speed can be forecasted with a specified pdf for the forecasting error.

3. Deterministic SFE Model

A SFE computing approach for an electricity market with only thermal units is presented in this section. This approach is developed in next sections to calculate SFE in presence of wind power plant for each scheme. Consider a uniform electricity market. Suppose the marginal cost of unit *i* is given by $MC_i = a_i + b_i P_{s_i}$ and the marginal utility of consumer j is given by$MU_j = c_j + d_j P_{D_j}$, where P_{s_i} and P_{D_j} are power output of unit i and consumption power of consumer j respectively. Assume that each unit i of firm f submits a linear supply function, $p_{bid}(P_{si}) = \alpha_i + \beta_i P_{s_i}$, to ISO. It is assumed that firm f can only change α_i of its units in order to increases its profit. The slop of linear supply function of unit i is assumed to be constant and equal to the slop of its marginal cost function ($\beta_i = b_i$). So, the goal of firm f is to strategically determines the parameters α_i of its units that maximizes its profit. The optimization problem of firm $f \in F$ can be modeled as follows [13]:

$$Max \quad \pi_f = \sum_{i \in s_f} \left(\lambda . P_{si} - a_i P_{si} - \tfrac{1}{2} b_i P_{si}^2 \right) \tag{1}$$

Where, F is the set of generating firms, π_f is the profit of firm f, s_f is the set of generation units of firm f, and λ is market clearing price (MCP). The objective of the Independent System Operator (ISO), on the other hand, is to find the MCP and quantities which maximize the social welfare. The ISO's social welfare optimization problem ignoring transmission constraints can be written as [13]:

$$Max\, J_{ISO} = \sum_{i \in D} \left(c_i P_{Di} - \tfrac{1}{2} d_i P_{Di}^2 \right) - \sum_{i \in S} \left(\alpha_i P_{si} + \tfrac{1}{2} b_i P_{si}^2 \right) \tag{2}$$

$$s.t.: \quad \sum_{i \in S} P_{si} - \sum_{i \in D} P_{Di} = 0 \tag{3}$$

$$P_{si}{}^{min} < P_{si} < P_{si}{}^{max} \qquad \forall\, i \in S \tag{4}$$

Where, J_{ISO} is social welfare, $P_{si}{}^{min}$ and $P_{si}{}^{max}$ are the capacity limits of unit i, S is the set of generation units, and D is the set of consumers. The SFE problem can be formulated as a bi-level optimization [13]. An approach to solve this bi-level optimization, is to add the Karush-Kuhn-Tucker (KKT) optimality conditions of the second-level optimization, problem (2)-(4), to the first-level optimization, problem of (1), as constraints, and then the KKT optimality conditions of the augmented optimization problem is solved for all firms together. By following the above mentioned approach, the SFE model can be simplified as follows [12]:

$$H(\alpha + \mu) + R + R' P_{D0} - U\mu = 0 \tag{5}$$

$$V P_{D0} + U(\alpha + \mu) \leq P_s^{max} \qquad \mu^{max} \tag{6}$$

$$V P_{D0} + U(\alpha + \mu) \geq P_s^{min} \qquad \mu^{min} \tag{7}$$

Where, the elements of matrices $H_{n_g \times n_g}$ ،$R_{n_g \times 1}$ ،$R'{}_{n_g \times 1}$ ، $V_{n_g \times 1}$ and $U_{n_g \times 1}$ depend on the coefficients of marginal cost functions of units and marginal utility of consumers and are defined in [12].

By solving (5)-(7) $\alpha_i^* \ \forall\, i \in S$ is computed. In order to solve (5)-(7) we need to know which generation limits are active at SFE. In [12], it is shown that the optimal strategy of firm f at SFE of the proposed electricity market model does not depend on the bids of bounded units at SFE. A bounded unit at SFE is a unit that one of its generation limits are active in SFE. So, first of all, bounded units at SFE must be identified and eliminated from SFE model, i.e. (5)-(7). An algorithm for computing probabilistic SFE is presented in [12]. The algorithm can be used for computing deterministic SFE assuming there is only one scenario for uncertainty. At each stage of this algorithm, (5)-(7) are solved and the unit with the largest dual variable associated with its generation limits is identified and omitted. Omitting a unit means fixing the output power of it at its active limit, subtracting power of the active generation limit from the load. This process continues until all bounded units are identified, omitted, and SFE is computed.

4. Mid-term study

Consider the electricity market described in section 3, and suppose a wind farm with zero generation cost and uncertain power output is added to this system. In this paper, in mid-term study, the focused is on an hour after a mid-term. The goal is to determine the optimal strategy of wind power plant for the study hour assuming the only available information about the wind at the study hour is its speed pdf. The second goal is to determine the impacts of strategic behavior of the wind farm on the electricity market. In order to consider wind generation uncertainty, different scenarios are defined for the wind generation. Future scenarios of wind generation and the associated probabilities are determined based on the pdf of wind speed and wind turbine power curve [12]. Suppose $P_{w_1}, P_{w_2}, \dots P_{w_k}, \dots, P_{w_{n_k}}$ are the future scenarios of wind generation with probabilities $s_1, s_2, \dots s_k, \dots, s_{n_k}$. These scenarios are referred to as mid-term scenarios.

4.1 Wind Power Plant as a Price Taker Unit

In this scheme, the wind power plant does not participate in electricity market strategically and receives market price for every MWh energy generation. So, wind power plant can be modeled as a negative load in SFE calculations. It is assumed that ISO considers average output of wind power plant for scheduling units in social maximization (2)-(4). In real time when the ISO's schedule is executed, wind power generation is different with the considered value in scheduling. It is assumed that ISO covers the imbalance using regulation reserves. For inelastic loads, P_{D0} represents total load in (5)-(7). Hence SFE can be calculated by replacing P_{D0} with $P_{D0} - P_{w_{mean}}$ in (5)-(7) and using the proposed algorithm for computing deterministic SFE in [12], where $P_{w_{mean}}$ is the average generated power of wind power plant. Average reserve cost is calculated as below:

$$average\ reserve\ cost = \sum_{k \in K} s_k (reserve\ cost)_k \tag{8}$$

$$(reserve\ cost)_k = \begin{cases} f_{up}\left(P_{w_{mean}} - P_{w_k}\right) & P_{w_k} > P_{w_{mean}} \\ f_{down}\left(P_{w_{mean}} - P_{w_k}\right) & P_{w_k} \le P_{w_{mean}} \end{cases} \tag{9}$$

where, f_{up} and f_{down} are positive and negative imbalance cost prices. A SFE model for a uniform electricity market with a price taker wind power plant is present in [12]. In the presented model in [12], the uncertainty in wind generation is covered by other strategic producers. While, in the presented model in this paper the uncertainty in wind generation is covered by regulation reserve.

4.2 Wind Power Plant as a Strategic Producer

In this scheme, wind power plant takes part in electricity market as a strategic market player by submitting a supply function to ISO. The ISO determines the power output of each unit including wind power plant by maximizing social welfare. Suppose P_{sw} is power output of wind power plant that is determined by ISO. It is assumed that wind power plant is responsible for imbalance cost. Therefore, the expected profit of wind power plant over different scenarios can be formulated as below:

$$\bar{\pi}_w = \sum_{k \in K} s_k \left(\lambda P_{sw} - (Imbalance\ cost)_k\right) \tag{10}$$

$$(Imbalance\ cost)_k = \begin{cases} f_{up}\left(P_{sw} - P_{w_k}\right) & P_{w_k} > P_{sw} \\ f_{down}\left(P_{sw} - P_{w_k}\right) & P_{w_k} \le P_{sw} \end{cases} \tag{11}$$

Since the uncertainty in wind generation is covered by reserves, the profits of other strategic producers are constant in different scenarios. The profit of firm *f* can be written as follows:

$$\bar{\pi}_f = \sum_{k \in K} s_k \sum_{i \in s_f} \left(\lambda . P_{si} - a_i P_{si} - \tfrac{1}{2} b_i P_{si}^2\right), \forall f \in F \tag{12}$$

Using step function, expected profit of wind power plant can be rewritten as below:

$$\bar{\pi}_w = \sum_{k \in K} p_k \left(\lambda P_{sw} - a_{w_k} P_{s_w}\right) + C \tag{13}$$

where:

$$a_{w_k} = f_{up} u\left(P_{w_k} - P_{s_w}\right) + f_{down} u(P_{s_w} - P_{w_k}) \tag{14}$$

$$C = \sum_{k \in K} s_k \left(f_{up} u\left(P_{w_k} - P_{s_w}\right) + f_{down} u(P_{s_w} - P_{w_k})\right) P_{w_k} \tag{15}$$

Comparing equations (12) and (13) shows that, the wind power plant can be modeled as a non-wind power plant which has a linear cost function with zero slope, $b_w = 0$, and variable interception in different scenarios as given in equation (14). In order to model the wind power plant as a non-wind power plant in the presented SFE model it is assumed that b_w is a very small positive real number, say 0.0001 \$/MW^{2}h. Therefore, in the presence of a strategic wind power plant the presented deterministic SFE model in (5)-(7) can be rewritten as follows:

$$H(\alpha + \mu) + R'(P_{D0}) - U\mu = -\sum_{k \in K} s_k (R_k) \tag{16}$$

$$VP_{D0} + U(\alpha + \mu_i) \le P_s^{max} \perp \mu^{max} \tag{17}$$

$$VP_{D0} + U(\alpha + \mu_i) \ge P_s^{min} \perp \mu^{min} \tag{18}$$

$$a_{w_k} = f_{up} u\left(P_{w_k} - P_{s_w}\right) + f_{down} u\left(P_{s_w} - P_{w_k}\right) \quad \forall k \in K \tag{19}$$

SFE can be computed by solving (16)-(19) using the proposed algorithm for computing deterministic SFE in section 3, which is a simplified version of the proposed algorithm for computing probabilistic SFE in [12].

By computing SFE, market price, optimal strategy of market players, expected profit of the wind power plant, cost of providing regulation reserve, and electricity price for consumers are determined. More attention is paid to these issues in section 6 by applying the proposed to a test system. Moreover, a supporting tariff for the wind power plant in is proposed in this section.

5. Short-term Study

In recent years, wind power forecasting softwares have been improved noticeably. In short-term ISO and market players forecast wind power plant output with appropriate degree of accuracy. This section focuses on the short-term study, i.e, an hour of tomorrow. Despite of mid-term study that wind power is a random variable with a wide pdf which can be zero to its maximum capacity, in short-term study wind power is modeled with a narrow pdf. In short-term wind power is modeled with a beta pdf [9]. Suppose p and σ^2 are the normalized predicted value of wind power and its variance for the study hour. The pdf of the normalized value of wind power is given by:

$$f_p(P_w) = x^{\alpha - 1} (1 - P_w)^{\beta - 1}\, n \tag{20}$$

where, P_w is wind power, α and β are distribution function shape parameters, and n is the normalization factor. Parameters α and β of a beta pdf are related to its mean and its variance as follows:

$$p = \frac{\alpha}{\alpha + \beta} \tag{21}$$

$$\sigma^2 = \frac{\alpha\beta}{(\alpha + \beta)^2 (\alpha + \beta + 1)} \tag{22}$$

Value of σ depends on p, the forecast horizon, and the size of the region where the wind farm is distributed [9]. Fig. 1 shows the dependency of σ to p. For illustrative purpose, two beta pdfs for p=0.1 pu and p=0.7 pu and the corresponded standard deviations determined from Fig. 1 are drawn in Fig. 2. In order to compute SFE considering uncertainty in predicted value of wind power, different scenarios and the associated probabilities are defined for the predicted value of wind power based on its beta pdf, say $P_{pred_{m_1}}, P_{pred_{m_2}}, \ldots, P_{pred_{m_e}}, \ldots, P_{pred_{m_{ne}}}$,these scenarios are referred to as short-term scenarios. Then, the presented algorithms in section 4 for computing SFE considering wind power plant as price taker and strategic producer are used to compute SFE for the proposed schemes.

In order to determine how wind power forecasting affects the strategic behavior of the wind power plant, mid and short-term studies should be compared. For the purpose of providing a fair comparison between mid-term and short term results, it is assumed that all mid-term scenarios, which are defined based on mid-term pdf of wind speed, happen. For each mid-term scenario, the pdf of the predicted value of wind power is specified and the respected short-term scenarios are defined. Then, the presented algorithms in section 4 are used to compute the short-term SFE for different mid-term scenarios and for the proposed schemes. After that, the average of MCP and firms' profits, are computed over different mid-term scenarios and are compared with the respected values which are computed in mid-term study. More attention is paid to these issues in section 6 by applying the proposed to a test system.

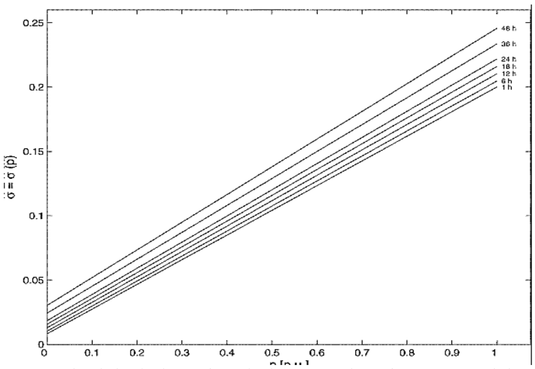

Fig. 1. Standard deviation of a wind power plant forecast model as a function of the normalized predicted power [9]

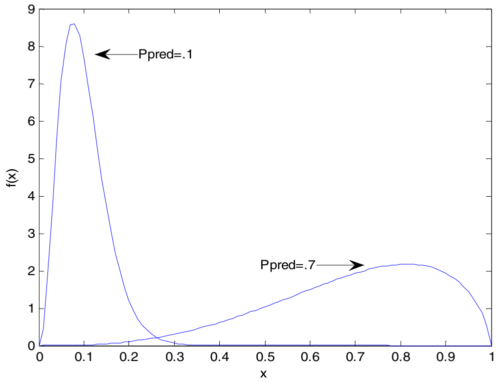

Fig. 2. Beta pdf for $p = 0.1$ & 0.7 and $t_{pred} = 24\ h$

6. Case Studies and Numerical Results

In this section, the proposed schemes for participating wind power plant in electricity markets are applied to a test system. The test system is a uniform electricity market with 6 strategic generation firms. Each generating firm has a generating unit. The generating units are the same as generating units of IEEE 30-bus test system. Transmission constraints are ignored. Parameters of generating units are given in table I. Total demand of the market is 250 MW, which is inelastic. It's assumed that a new generating firm with a 60 MW wind power plant is added to the system. It is assumed that wind speed at the location of the wind power plant has a Weibull probability distribution function (pdf) with scale parameter equal to 10 m/s and shape parameter equal to 1.8 [12]. Wind farm has an overall turbine power curve as presented in Fig. 3. In order to define mid-tem scenarios, a simple sampling method using pdf of the wind speed and the wind turbine power curve is presented in Fig. 3. In order to have n_s mid-term wind power scenarios, or n_s wind power samples, one sample is taken from the zero power section of wind turbine power curve, one from the maximum wind power, and $n_s - 2$ samples between this two values. The probability of each mid-term scenario is computed using wind speed pdf. In Fig. 3, the probability of each mid-term scenario is specified with the related hatched area [12]. Based on the presented sampling method, 20 mid-term scenarios are defined for modeling wind power plant. In order to consider the impacts of imbalance in the study, three sets of imbalance costs are considered as presented in table II. The imbalance costs are chosen based on the fact that $f_{down} > \lambda > f_{up}$ and based on the estimation of λ, which varies form 33 $\$/MWh$ to 35 $\$/MWh$ in the test system.

TABLE I. Parameters of generating units [12]

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
a	20	17.5	10	32.5	30	30
b	0.2	0.175	0.0625	0.084	0.25	0.25
P_s^{min}	0	0	0	0	0	0
P_s^{max}	80	80	50	55	30	40

TABLE II. Different sets of imbalance prices

	1st set	2nd set	3rd set
f_{up} $(\$/MWh)$	30	25	25
f_{down} $(\$/MWh)$	40	45	50

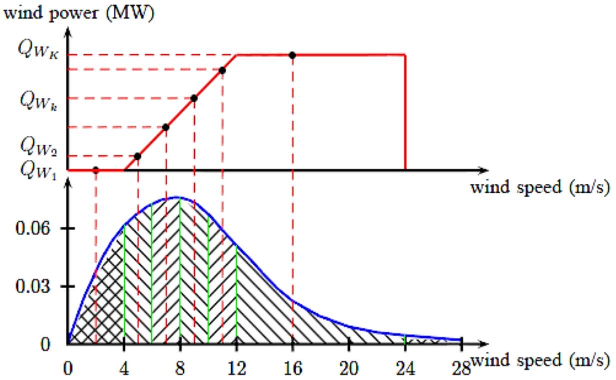

Fig. 3. Sampling wind power

6.1 Mid-term study

a) Wind power plant as a price taker unit

In order to determine the impacts of strategic wind power plants, first a non-strategic price taker power plant is considered. For this purpose, SFE is computed for this scheme. The bid of generation units, their power output, and their profits at the computed SFE are given in table III. The values that are given for power output and profit of wind power plant are the expected values over the 20 defined mid-term scenarios. MCP at SFE of this scheme is equal to 34.26 $\$/\mathrm{MWh}$.

TABLE III. Bids, power outputs, and profits at SFE of the price taker scheme

	Bid, α_i, ($/MWh)	Power output (MW)	Profit ($/h)
Unit 1	22.20	60.27	496
Unit 2	20.46	78.84	777
Unit 3	11.20	36.9	469
Unit 4	33.15	13.29	16
Unit 5	30.52	14.94	35
Unit 6	30.52	14.94	35
Wind	---	0~60	1055

Total payment to generating firms, total reserve cost, total cost of consumers, and consumer price at SFE for different imbalance costs are given in table IV. In this scheme, consumers are responsible for reserve cost. Hence, total cost of consumers is equal to sum of total payment to generating firms and total reserve cost.

TABLE IV. MCP, total payment to generating firms, total reserve cost, total consumers cost, and consumer price at SFE for different imbalance costs

	f_{up} =25 f_{down} =50	f_{up} =25 f_{down} =45	f_{up} =30 f_{down} =40
MCP ($/MWh)	34.26	34.26	34.26
Total payment to firms ($/h)	8565	8565	8565
Total reserve cost ($/h)	263	210	105
Total consumers cost ($/h)	8828	8775	8670
Consumer price ($/MWh)	35.31	35.10	34.68

As table IV shows, as the imbalance price increases, total reserve cost and consequently, consumer price increases.

b) Wind power plant as a strategic producer

Now suppose wind power plant is a strategic producer which changes its supply function to maximize its profits. In this scheme the power plant is responsible for reserve cost. SFE is computed for this scheme. The bid of generation units, their power output, and their profits at the computed SFE are given in table V.

TABLE V. Bids, power outputs, and profits at SFE of strategic wind power plant scheme ($\mathbf{f_{up} = 25\,\$/MWh}$, $\mathbf{f_{down} = 45\,\$/MWh}$)

	Bid, α_i, (MW)	Power output (MW)	Profit ($/h)
Unit 1	22.03	68.1	464
Unit 2	17.5	80	730
Unit 3	10.002	37.8	446
Unit 4	32.501	13.47	7.5
Unit 5	30.001	14.5	3.26
Unit 6	30.001	14.5	3.26
Wind	33.62	21.64	830

Positive and negative imbalance costs are assumed to be 25 and 45 $\$/\mathrm{MWh}$ respectively. The value that is given for profit of wind power plant is it's the expected profit over the 20 defined mid-term scenarios. MCP at SFE of this scheme is equal to 33.63 $\$/\mathrm{MWh}$.

MCP, expected profit of the wind power plant, total payment to generating firms, total reserve cost, total cost of consumers, and consumer price at SFE for different imbalance costs are given in table VI. Comparing tables IV and VI shows that MCP in strategic scheme is less than MCP in price taker plan. Since in strategic scheme the wind power plant is responsible for reserve cost not consumers, consumer price is equal to MCP, which is much less than consumer price in price taker scheme. Comparing tables IV and VI also shows the expected profit of the wind power plant in strategic scheme is lower than its value in price taker scheme. Therefore, the wind power plant is not willing to participate in strategic scheme, although the strategic scheme reduces the consumer price. In order to encourage the wind power plant to participate in strategic plan, a supporting tariff is defined for the wind power plant to compensate its loss in strategic plan in comparison to price taker scheme. In this supporting tariff the difference between the expected profit of wind power plant in price taker scheme and strategic scheme is paid to the power plant by consumer, this value is referred to as wind support tariff cost. By considering this supporting tariff, total cost of consumers is equal to total payment to generating firms plus wind support tariff cost. Consumer price considering the wind support tariff is given in table VI.

TABLE VI. Market price, wind power plant profit and consumers electricity price for different imbalance prices in supply function bid plan

	f_{up} =25 f_{down} =50	f_{up} =25 f_{down} =45	f_{up} =30 f_{down} =40
MCP ($/MWh)	33.88	33.63	33.87
Expected profit of wind ($/h)	806	830	943
Total payment to firms ($/h)	8470	8407	8467
Wind support cost ($/h)	249	225	112
Consumer price ($/MWh)	34.88	34.52	34.32

Table VI shows that MCP increases by increasing imbalance cost, i.e., increasing negative and deceasing positive imbalance cost. Expected profit of wind power plant for positive imbalance cost of 30 $/MWh and negative imbalance cost of 40 $/MWh is bigger than other cases. Since in this case the imbalance cost is less than other cases. Table VI shows that even after considering wind support tariff, consumer price is less than consumer price in price taker scheme.

6.2 Short-term study

In this section it is assumed that every mid-term scenario happens. For every mid-term scenario wind power is forecasted. The forecasted wind power is modeled by a beta pdf. For every mid-term scenario, short-term scenarios are defined using the beta pdf. Mean of the beta pdf associated with a mid-term scenario is equal to wind power of that scenario, and its standard deviation is determined based on Fig. 1. SFE is computed for each mid-term scenario considering the respected short-term scenario. Expected value of MCP, profit of power plant, total payment to generating firms, total reserve cost, wind support tariff cost, total cost of consumers, and consumer price over different mid-term scenario for price taker and strategic schemes are given in table VII. Positive and negative imbalance prices are assumed to be 25 and 45 $/MWh respectively.

TABLE VII. Short-term analysis results for price taker and strategic schemes

	Supply function bid	Price taker
Expected MCP ($/MWh)	34.44	34.49
Expected profit of Wind power plant ($/h)	944	1033
Expected payment to generating firm ($/h)	8610	8623
Expected reserve cost ($/h)	113	---
Expected wind support tariff cost ($/h)	---	119
Expected price of consumers ($/MWh)	34.89	34.97

Comparing table VII, VI, and IV shows that profit of generating firms including wind power plant increase in short-term. Increasing the profit of wind power plant at strategic scheme in short-term has two reasons. The first reason is reducing uncertainty in wind power generation and consequently reducing reserve and imbalance costs in short-term. The second reason is increasing the bids of generating firms due to reducing risk and consequently increasing MCP. In short-term, profit of wind power plant in strategic scheme is less than price taker scheme, like the mid-term study. In order to encourage the wind power plant to participate in the market strategically, wind support tariff is defined similarly. The results show that in both mid and short-term analysis consumer price decreases even after considering wind support tariff, while keep the profit of power plant as price taker scheme.

7. Conclusion

In this paper, the impacts of strategic behavior of wind power plants on electricity markets is studied both in mid and short-terms. To this end, the proposed price taker scheme and strategic scheme are compared at Nash equilibrium of the market. The simulation result shows that strategic behavior of the wind power plant reduces the market clearing price, price of consumers, and profit of the wind power plant both in mid and short terms. To encourage wind power plants to participate in the market strategically, a wind support tariff is defined to keep their profit as price taker scheme. Consumers are responsible to pay for the wind support tariff cost. The simulation result shows that even after considering the wind support tariff, both in mid and short terms, strategic behavior of the wind power plant reduces the price of consumers, while keep the profit of the power plants as its value in price taker scheme.

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