Impact of Imbalance Price Mechanism on Bidding Strategy of Wind Power Producers

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***Abstract*—This paper presents a game theoretic bidding strategy approach is proposed for the assessment of bidding strategy of WPPs in a uniform price based day-ahead oligopolistic electricity market considering rival behavior. Strategic interaction between WPPs is modeled through stochastic Cournot model. Wind power uncertainty is represented through scenarios, which are generated and reduced using scenario generation & reduction algorithms. Payoff of each WPP is calculated considering market clearing price (MCP) and imbalance charges obtained using inverse demand curve and imbalance price mechanisms, respectively. Single and dual imbalance price mechanisms are used in the evolving electricity markets. Nash equilibrium is the solution of the proposed approach that provides optimal bids for strategic WPPs considering rival behavior. The proposed approach is illustrated through a practical case study of WPPs. The influence of the different type of imbalance price mechanisms and increasing wind power penetration on WPPs' profit is analyzed.**

***Index Terms*—Wind Power Producers, Imbalance Price Mechanism, Stochastic Cournot model, Nash Equilibrium, Wind Uncertainty.**

I. INTRODUCTION

As a result of various support schemes and subsidies, installed capacity of WPPs is increasing rapidly over the last decade. Therefore, they are trending towards attaining dominating position in evolving electricity markets, to trade their generated power as price-makers without any subsidies or regulatory benefits [1-5]. Price-maker WPPs increase their profit through strategic bidding with an aim of altering market clearing prices [6]. However, power generated by WPPs is highly random, which may result into heavy imbalance charges. Therefore, WPPs are required to offer their bids strategically, as compared to CPPs [7].

Based on recent studies, price-taker WPPs can maximize their profit by using bidding strategy to minimize imbalance cost. Imbalance cost can be minimized using stochastic programming approach [5, 8-12, 14]. Due to growing penetration of wind power in electricity markets, WPPs have become price-makers and gain significant market power to alter MCPs [5]. Consideration of price-maker WPPs for energy trading is necessary to reflect the evolving market realities. Due to oligopolistic nature of electricity markets, profit of each strategic participant depends on behavior of other strategic participants [1,2, 5, 15]. Therefore, as price-maker WPPs, consideration of rival behavior is necessary to formulate their offering strategy in oligopolistic electricity markets. Game theory is an acceptable approach to model rival behavior in electricity markets [3, 5, 15, 16]. Incorporating rival behavior in decision-making is a major advantage of these approaches over stochastic programming approaches. However, Nash equilibrium solution of game theoretic models cannot be obtained easily for games with large number of strategic power producers and uncertain parameters [13].

In this paper, a game theoretic bidding strategy approach is proposed for strategic WPPs in a uniform price based day-ahead oligopolistic electricity market considering rival behavior. Strategic interaction between WPPs is modeled through stochastic Cournot model. Wind power uncertainty is represented through scenarios. Payoff of each WPP is calculated considering MCP and imbalance charges obtained using inverse demand curve and DIP mechanism, respectively. Nash equilibrium is the solution of proposed approach that provides optimal bids for strategic WPPs considering rival behavior. To obtain Nash equilibrium, MILP based Payoff Matrix approach is developed. The proposed approach is illustrated through a practical case study of WPPs located at Massachusetts, USA. Finally, the influence of different type of imbalance price mechanisms and increasing wind power penetration on WPPs' profit is analyzed.

II. WPPS'BIDDING STRATEGY PROBLEM

A. *Market Structure*

WPPs participate as price-makers in pool based, network unconstrained, day-ahead electricity market, cleared several hours prior to actual power delivery. Real-time balance between supply and demand is maintained by balancing market, few minutes prior to power delivery [1,2]. Imbalance charges resulting from the balancing market are charged to market participants (*i.e.* power producers and consumers) causing that system imbalance. In this work, DIP mechanism is generally used for imbalance charging, and is well adopted in European markets such as UK's NETA, Nord Pool and Iberian Peninsula [8,11]. Presented work focuses on formulation of WPPs' strategic bidding in wind dominated electricity markets. To highlight the fact of wind domination, participation of Conventional Power Producers (CPPs) and large consumers in competitive electricity market is not modeled in this chapter. It is assumed that the entire load is supplied by WPPs, and system imbalance is caused by wind generation only. However, CPPs and large consumers are assumed to be price-takers in ISO's market clearing problem, while considering the presence of other generators.

B. WPPs' Profit

In uniform price based day-ahead electricity market, the profit earned by WPPs at time t is a summation of their revenue and imbalance charges IC_t . The revenue of WPPs is a product of day-ahead MCP λ_t and their contracted power $V_{c,t}$. Considering imbalance charges, the hourly profit earned by WPPs can be expressed as [12]:

$$Profit_t = \lambda_t V_{c,t} + IC_t \tag{1}$$

All variables in (1) are uncertain at the time of bidding for day-ahead electricity market. Hourly imbalance charges of WPPs are calculated using imbalance price mechanism. Mathematically, hourly imbalance charge is expressed as:

$$IC_t = \left(V_{d,t} - V_{c,t}\right) C_{R,t} \tag{2}$$

Imbalance charges expressed in (2) are the product of charge rate and the difference between delivered $V_{d,t}$ and contracted $V_{c,t}$ power. Charge rate $C_{R,t}$ is calculated by the imbalance price mechanism explained in the next section.

III. Imbalance Price Mechanisms

In competitive electricity markets, imbalance price mechanism has been adopted by the ISO to penalize the market participants who deviate from their commitment schedules in real time. According to market design, imbalance price mechanism may be DIP and SIP. In SIP mechanism, imbalance price depends only on size of system imbalance while in DIP mechanism it depends on both size and direction of system imbalance.

A. Dual Imbalance Price Mechanism

In DIP mechanism, market participants are charged for their positive and negative deviation, according to system imbalance. For positive system imbalance, consumers would like to purchase the excess energy at a downward price λ_t^{DN}, lower than MCP λ_t . In this case, power producers producing excess power than scheduled, get a downward payment for their overproduction. On the other hand, power producers producing lower than their scheduled production are penalized according to the MCP. Positive Imbalance Price (PIP) λ_t^{+} and Negative Imbalance Price (NIP) λ_t^{-} , during system surplus, are mathematically expressed as:

$$\lambda_t^{+} = min\left(\lambda_t, \lambda_t^{DN}\right) \tag{3}$$

$$\lambda_t^{-} = \lambda_t \tag{4}$$

With negative system imbalance, power producers are willing to provide the energy needed to cover negative imbalance at MCP. In this case, power producers producing excess power than scheduled get payment for this overproduction according to MCP. On the other hand, power producers responsible for negative imbalance are penalized with upward price λ_t^{UP} . The PIP and NIP during system deficit are mathematically expressed as:

$$\lambda_t^{+} = \lambda_t \tag{5}$$

$$\lambda_t^{-} = max\left(\lambda_t, \lambda_t^{UP}\right) \tag{6}$$

B. Single Imbalance Price Mechanism

In SIP mechanism, market participants are charged for their positive and negative deviations from scheduled delivery according to real-time market price. Additionally, market participants may be discouraged by the imbalance penalty for their deviations to prevent gaming in real-time market. In this work, imbalance penalty is assumed to be a flat value per MW [2-3].

IV. Stochastic Cournot Model

Cournot game theory is a general approach to represent strategic behavior of power producers in oligopolistic electricity markets. Power producers make decisions independently and simultaneously, without cooperating with each other. With an aim to maximize profit, each power producer chooses quantity bids to be offered, considering rival behavior. Nash equilibrium is a solution of Cournot model; this is a standoff condition where no power producer can unilaterally increase its profit by changing its production level. In a deterministic Cournot model, input variables are scalar and independent, while in a stochastic Cournot model, input variables are stochastic in nature or dependent on other stochastic variables [3, 5, 16]. In this work, stochastic Cournot model with complete information is used to formulate bidding strategy of WPPs in oligopolistic day-ahead electricity market. Each WPP has complete information about their rival types, payoff function, location and installed capacity. Due to zero marginal cost and generation uncertainty, stochastic Cournot model is most suitable game theoretic approach for optimal decision-making of strategic WPPs in oligopolistic electricity markets.

A. Mathematical Formulation

Consider $i \in \Omega^w$ WPPs participating strategically in an oligopolistic day-ahead electricity market. Each WPP aims to maximize its own profit or payoff by offering a certain quantity bid. The profit maximization problem of i^{th} WPP in a day-ahead electricity market is formulated as follows:

$$\underset{Pof_{i,t}}{Max}\ U\left(Pof_{i,t}, Pof_{-i,t}\right) = \sum_{\omega \in \Omega^{\omega}} porb_{\omega,t}\left(\lambda_t Pof_{i,t} + IC_{i,\omega,t}\right), \quad \forall i, \forall \omega, \forall t \tag{7}$$

Subject to

$$0 \le Pof_{i,t} \le P_i^{\max}, \quad \forall i, \forall t \tag{8}$$

$$\Delta_{i,\omega,t} = P_{i,\omega,t} - Pof_{i,t}, \ \forall i, \forall \omega, \forall t \quad (9)$$

$$IC_{i,\omega,t} = \begin{cases} \lambda^{+}_{\omega,t}\Delta_{i,\omega,t}, & \Delta_{i,\omega,t} > 0 \\ \lambda^{-}_{\omega,t}\Delta_{i,\omega,t}, & \Delta_{i,\omega,t} < 0 \quad \forall i, \forall \omega, \forall t \\ 0 & \Delta_{i,\omega,t} = 0 \end{cases} \quad (10)$$

The objective function (7) has two components: revenue and imbalance charges. Revenue at any time t is defined as multiplication of MCP and offered power $Pof_{i,t}$. Imbalance charges $IC_{i,\omega,t}$ for each scenario ω_i may be positive or negative depending upon power produced $P_{i,\omega,t}$ in such scenario and imbalance prices. The occurrence probability $Prob_{\omega,t}$ is multiplied with the sum of revenue and imbalance charges for obtaining resultant payoff. For sake of simplicity, it is assumed that WPPs' generation cost is zero and they individually participate in the market without any control strategy. Each WPP selects offered power $Pof_{i,t}$, which maximizes its expected profit, considering imbalance cost. Constraint (8) limits the strategic WPPs' offered bids in day-ahead electricity market. The maximum power is equal to the installed capacity of WPPs, while the minimum power production is considered to be zero. WPPs do not generate any power when wind speed is below cut-in or above cut-out speed of the installed turbines. Constraint (9) defines the deviation $\Delta_{i,\omega,t}$ for each WPP in each scenario and time. Expression (10) reflects per scenario imbalance charges at particular time interval for each strategic WPP in electricity market.

Day-ahead MCP at time t is determined by inverse linear demand curve (5.12). Demand is the sum of power contracted by WPPs,

$$\lambda_t = \lambda^{\max} - KP_{d,t} \quad (11)$$

where, K is the ratio of maximum value of MCP $\lambda^{\max}$ to demand $P_d^{\max}$. This decision-making problem is formulated as a Cournot model, where all WPPs try to maximize their profit by optimizing their offered quantities. In mathematical terms, Cournot Nash equilibrium is a vector, which solves a collection of profit maximization problems of the form

$$U\left(Pof_i^*, Pof_{-i}^*, \omega_i\right) \geq U\left(Pof_i, Pof_{-i}^*, \omega_i\right), \ \forall i \in \Omega^w \quad (12)$$

Cournot Nash equilibrium provides optimal offered bids, considering rival behavior. During the selection of optimal offered power for i^{th} WPP, rivals' offered power $Pof_{-i,t}$ is kept fixed. Since the aim of proposed work is formulation of optimal bids for WPPs in wind dominated electricity markets, the CPPs are assumed to be price-takers. Thus, behavior of CPPs is assumed not to affect market equilibrium. The consideration of CPPs as rivals of WPPs is out of scope of proposed work. Nash equilibrium is obtained using MILP based payoff matrix approach, described in the next section.

B. MILP Based Payoff Matrix Approach

Payoff matrix approach is suitable to find Nash equilibrium of normal form matrix games [13]. Therefore, proposed Cournot Nash equilibrium problem needs to be defined in the form of matrix game. Let $N = \{1, \ldots\ldots n\}$ be the set of strategic players (*i.e.* strategic WPPs), who want to maximize their payoff and interact strategically in oligopolistic electricity markets. Each player $i \in N$ has its own set of continuous strategies $S_i = \left\{s_i^1, \ldots\ldots s_i^{m_i}\right\}$ with $|S_i| = m_i$. These strategies reflect their possible offering bids (*i.e.* $Pof_{i,t}$). In Nash game, players select the optimal strategy to be offered in the market, which gives them maximum payoff or profit, depending on other players' strategies. To find optimal strategy, each player formulates its payoff matrix for all possible combinations of his and rivals' strategies. If player i selects his strategy s_i^k while its rival player j selects his strategy s_j^1, the payoff matrix of player i can be defined as:

$$A_i\left(s_1^k, \ldots s_n^l\right) = \sum_{j \neq i} a_{ij}\left(s_i^k, s_j^l\right) \quad (13)$$

Similarly, payoff matrix for all strategic players can be formulated. The elements of payoff matrix are the profit obtained by strategic players for all possible combinations of his and rivals' strategies [13]. To solve Nash equilibrium problem using any optimization algorithm, payoff function of each player needs to be redefined in term of new probability vector X. For player i, the probability vector X_i can be defined corresponding to its strategy vector S_i. Now payoff matrix of this player is defined as

$$A_i(X) = (X_i)^T \sum_{j \neq i} A_{ij} X_j = \sum_{j \neq i} \sum_{k=1}^{m_i} a_{ij}^{kl} x_i^k x_j^l \quad (14)$$

where, x_i^k and x_j^l are the variables corresponding to player strategies s_i^k and s_j^l. The value of these variables provides players' Nash equilibrium strategy. In terms of these variables, the Nash equilibrium problem is defined as:

$$\left(X_i^*\right)^T \sum_{j \neq i} A_{ij} X_j^* \geq (X_i)^T \sum_{j \neq i} A_{ij} X_j^*, \quad \forall i \in N \quad (15)$$

Mathematically, this problem is a non-linear problem due to multiplication of variables x_i and x_j. Therefore, it is difficult to solve with high degree of accuracy using commercially available optimization solvers. Thus, Nash equilibrium problem needs to be transposed into MILP problem by incorporating binary variables through linearization techniques [38, 39].

The final optimization problem to find Nash equilibrium can be formulated as follows:

$$\min_{\gamma_i, X_i} \sum_{i \in N} \gamma_i \tag{16}$$

Subject to

$$\sum_{i \in N} e_i^t X_i = 1 \tag{17}$$

$$\gamma_i e_i - \sum_{j \in N: j \neq i} A_{ij} X_j - M_i U_i \leq 0 \tag{18}$$

$$X_i + U_i \leq e_i \tag{19}$$

$$X_i, X_j \geq 0, U_i = \{0,1\} \tag{20}$$

Objective function (16) is equal to the sum of players' expected payoff. To avoid non-convexity, payoff maximization objective of player i can be solved as a linear minimization objective using strong duality theory. This theory states that if a problem is convex, objective functions of primal problems have same value at the optimum. Therefore, dual objective γ_i of player i is equal to its primal objective $\gamma_i = (X_i)^T \sum_{j \neq i} A_{ij} X_j$. Constraint (17) ensures that sum of probability variables is always equal to one. Equation (18) constitutes the complementarity slackness conditions of objective. In this condition, M_i is constant a nd should be large enough, as constrained by the expression:

$$M_i = \left(\max_{i,j \in I: i \neq j} a_{ij} \right) - \left(\min_{i,j \in I: i \neq j} a_{ij} \right) \tag{21}$$

Inequality constraint (19) shows that the sum of probability variable and binary variable is always less than unity. The solution of formulated MILP problem in (16)-(21) may have multiple equilibrium solutions. To find meaningful equilibrium solution, eliminate constraints are added on formulated MILP problem.

$$\sum_{i=1}^{N} 1 + U_i\{1\} - U_i\{0\} \leq L \quad \forall i \in N \tag{22}$$

$$L = \frac{\sum_{i=1}^{N} M_i}{N+1} \tag{23}$$

This constraint eliminates the binary variable combinations found in initial equilibrium solution. To find local Nash equilibrium called meaningful Nash equilibrium, the formulated problem is repeatedly solved by adding elimination constraints. These constraints are used in the next iteration to fix the values of integer variables obtained in previous iteration. The iterations are repeated until similar Nash equilibrium is obtained in consecutive iteration.

C. *Simulation Procedure*

1. Model initialization: Define the number of WPPs that participate as strategic players in electricity market. Collect their parameters and respective demand benefit coefficients.
2. Time Counter Initialization: Initialize time counter to obtain optimal hourly offers of WPPs. Time counter starts with $t = 1$.
3. Scenario Generation and Reduction: Initialize the strategic WPPs' expected outcome by generation of scenarios. For scenario generation and reduction, algorithms proposed in [17].
4. Define Strategy Set: Continuous pure strategy set of players is defined between their maximum and minimum capacity. Using discretization, continuous strategy set transform into discrete strategy set.
5. Payoff Matrix Construction: Each WPP has discrete set of possible offering outputs. They select only one offer among possible offers, which maximizes their expected profit. To obtain Nash equilibrium, resultant payoff matrix is constructed having probabilistic information about each scenario. For each combination in payoff matrix, MCP is calculated using (11).
6. MILP Formulation: When all players' payoff matrix is constructed, then transpose equilibrium problem into MILP using (16)-(20).
7. Nash Equilibrium: Solution of MILP using any commercial MILP solver provides Nash equilibrium. Nash equilibrium is obtained by MILP based payoff matrix approach. This equilibrium gives optimal power output that can be offered by the WPPs.
8. Add Elimination Constraints: To check whether obtained Nash equilibrium is meaningful or meaningless equilibrium, add elimination constraints (22)-(23) on formulated MILP in (16)-(21). Again, run MILP solver to obtain new Nash equilibrium.
9. Check Meaningful Equilibrium: If new Nash equilibrium obtained in Step 8 is equal to old Nash equilibrium obtained in Step 7, this means meaningful equilibrium is achieved, then go to next Step 10. If new Nash equilibrium differs from old Nash equilibrium, it means solution is meaningless equilibrium, then go to Step 8.
10. Check Time Counter: For each considered hour, offer for each WPP is obtained. In the next step, update time counter by $t+1$ and go step 3.
11. End

V. Case Study

The present section considers a pool-based day-ahead electricity market, where three WPPs interact strategically. The results illustrate effectiveness of the proposed model for bidding strategy formulation of WPPs.

A. *Data*

The present study considers three WPPs, with an installed capacity of 100 MW each. These WPPs are situated at three different locations Barnstable, Savoy and Kingston of Massachusetts State, USA. Each WPP has 40 wind turbines, with commercial 2.5 MW, VENSYS100 turbine installed at 100 m hub height. Air density and temperature conditions are assumed to be same for each installed wind turbine. The used turbine model and its power curve are detailed in manufacturer database [19]. For all these WPPs, the actual wind speed data of August 2005 is taken, publically available at Wind Energy Center, University of Massachusetts, USA [20].

B. WPP's Stratgic Bidding under DIP Mechnism

WPPs are behave strategically and consider rival behavior for their offer selection. They offer power as per Nash equilibrium solution of the proposed stochastic Cournot model.

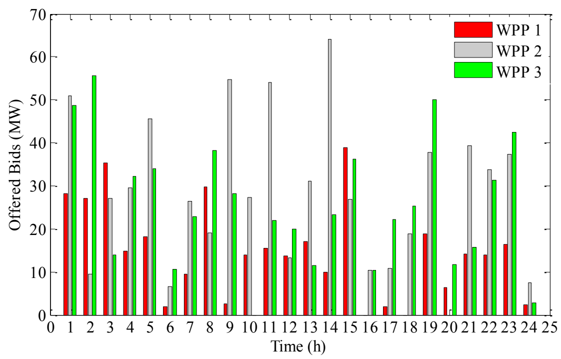

Figure 1. Bids Offered by Strategic WPPs.

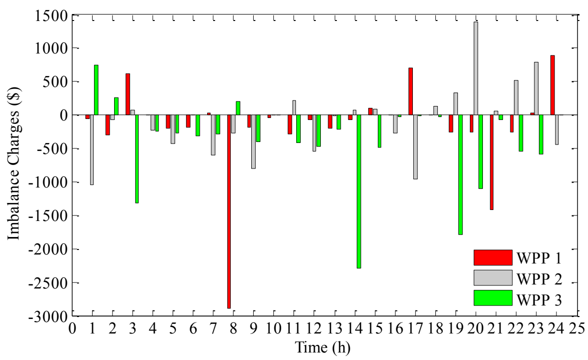

Figure 2. Imbalance Charges for each Strategic WPPs

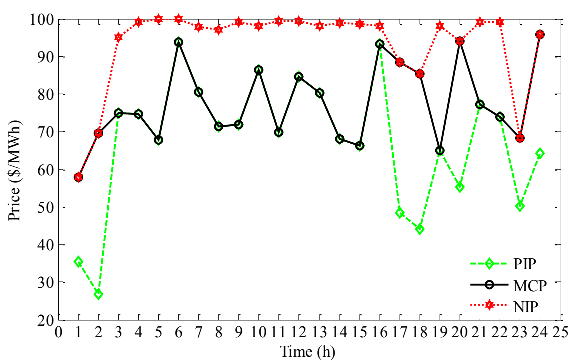

Figure 3. MCP and Imbalance Prices.

Hourly profile of the power offered by different WPPs is shown in Figure 1. At the first hour, power offered by WPP 1, WPP 2 and WPP 3 are 28.1260 MW, 51.0613 MW and 48.8089 MW, respectively. Actual generated power for both cases is equal to reduced scenarios. Imbalance charges for the

WPPs arise due to deviation between offered and generated power, as shown in Figure 2. For the first hour, power generated by WPP 3 is more than that originally offered, and hence it earns revenue corresponding to this positive imbalance. However, power generated by WPPs 1 and 2 is less than their offered power, and hence have to pay negative imbalance prices.

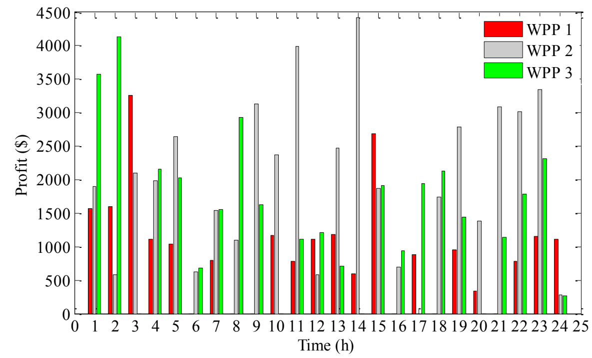

Figure 4. Expected Profit Profile of Strategic WPPs.

Figure 3 shows hourly imbalance charges for each WPP. From these figures, it is evident that at the first hour, positive imbalance price is lower than both MCP and negative imbalance price, due to system demand being less than generation. Hourly profile of the expected profits, for different strategic WPPs is shown in Figure 4. At the first hour, profit earned by WPP 1, WPP 2 and WPP 3 are \$1565.01, \$1899.12 and \$3571.92, respectively.

C. WPP's Stratgic Bidding under SIP Mechnism

In this study, 1000 real-time market price scenarios are generated using the algorithms proposed in [18]. Then generated scenarios are reduced to 10. Historical data of year 2000 of PJM electricity market is used for real-time market scenario generation and reduction [21]. The imbalance penalty is assumed to be \$15/ MWh. Similar to earlier dual imbalance price mechanism based study, both cases are considered and simulated using proposed simulation procedure. The obtained results for base case reflect a similar pattern as that from DIP mechanism. However, in this case, the offered bids, imbalances charges, imbalance prices and expected profits have been modified according to new imbalance mechanism and uncertain real-time market price.

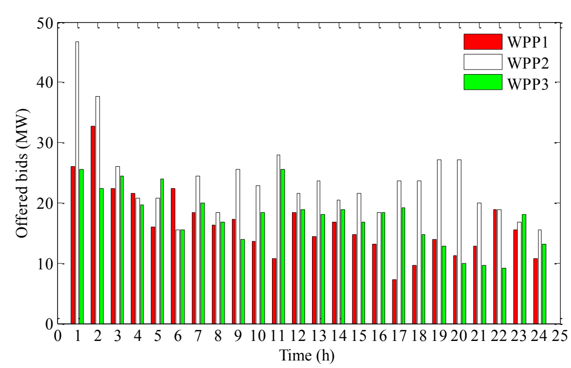

Figure 5. Bid Offered by WPPs.

The hourly bids offered by strategic WPPs using the proposed stochastic Cournot model are shown in Figure 6. At first hour, power offered by WPP1, WPP2 and WPP3 are 26.00 MW, 46.80 MW and 25.60 MW, respectively. Hourly imbalance charges and imbalance penalties of strategic WPPs are given in Figure 7 and 8 respectively. At the first hour, WPPs aggregated offer bids in day-ahead electricity market are higher than their actual generation, therefore they get negative imbalance charges and penalties for deficit generation. Hourly profit earned by WPPs is shown in Figure 8. From this figure, it is evident that proposed approach is helpful to maximize profit of strategic WPPs in single imbalance price based electricity markets.

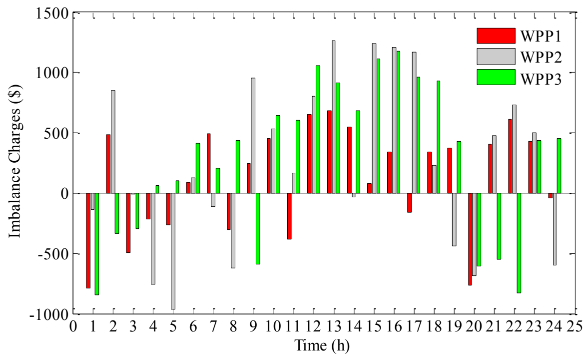

Figure 6. Imbalance Charges for each WPPs.

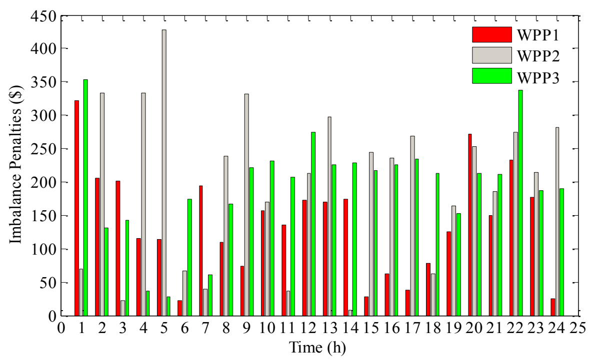

Figure 7. Imbalance Penalties for WPPs

D. *Impact of Increasing Wind Power Penetration Level on WPPs' Profits under DIP and SIP mechanism*

In this study, along with three WPPs with an installed capacity of 100 MW each, three CPPs are considered. Installed capacity and fuel type of CPPs are 350 MW coal, 250 MW oil and 150 MW gas, respectively. Thus, total capacity of CPPs is 750 MW. The coal, gas and oil CPPs can offer their generation at analytically assumed marginal costs of 40, 50 and 60 $/MWh respectively [5]. Wind power's share is 28.57% of total installed capacity.

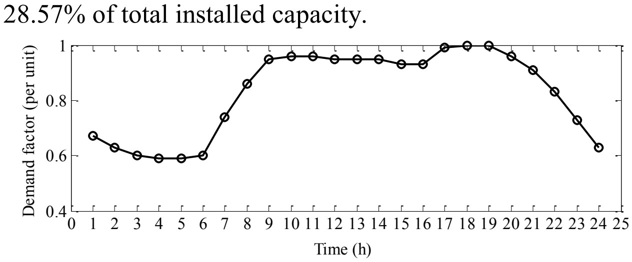

Figure 8. Hourly Demand Factor.

A single demand with peak value of 684 MW is considered. Hourly demand profile can be obtained by using multiplication of peak demand to hourly demand factor profile, as shown in Figure 9. The demand is assumed to be elastic, with 70% bids at 70 $/MWh and 30% bids at 80 $/MWh.

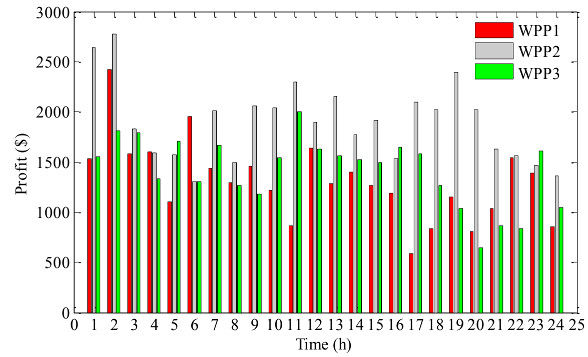

Figure 9. Expected Profit of WPPs.

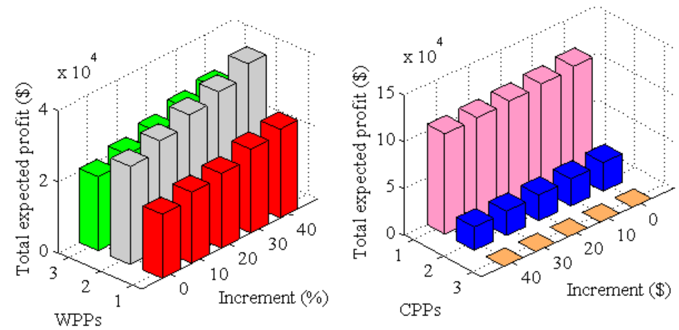

Figure 10. Influence of Wind Penetration on Daily Profit ($): DIP Mechanism.

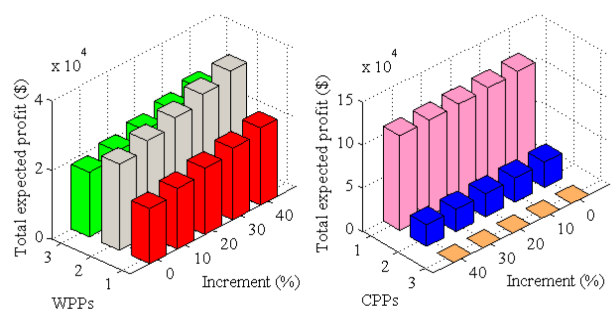

Figure 11. Influence of Wind Penetration on Daily Profit ($): SIP Mechanism.

To evaluate the influence of increasing wind power penetration on WPPs' daily profit, installed capacity of each WPP is increased up to 40% of its total capacity in steps of 10%. Additionally, with each step, system peak demand also increases by 2.5% of initially considered peak demand.
The obtained results for single and dual imbalance price mechanism are shown in Figures 11 and 12. From these

figures, it is visualized that daily profit of WPPs increases continuously while CPPs' profits decrease in both DIP and SIP mechanism. Due to increment in installed capacity, WPPs' daily profit increases and imbalance charges decrease. On the other hand, increasing wind power penetration in electricity markets would decrease the volume of CPPs' dispatched power as well as MCP. Due to zero marginal cost of wind power generation, bids submitted by WPPs are always accepted. Thus, MCP and CPPs' dispatched power is decreased.

VI. CONCLUSION

In an uniform price based day-ahead oligopolistic electricity market, strategic behavior of WPPs is modeled by a Stochastic Cournot model. Wind power uncertainty is represented through scenarios. Nash equilibrium solution of stochastic Cournot model gives the optimal strategic bids for WPPs considering rivals behavior. The impact of imbalance price mechanism on the strategic bidding has been evaluated. Obtained results shows that DIP mechanism is better than SIP mechanism for imbalance pricing due to consideration of system imbalance. The impact of growing penetration of wind generation on WPPs' profits shows that the profit of WPPs are increased and CPPs profits are decreased. Participation of WPPs in intraday markets could be be incorporated in proposed work. The MILP based payoff matrix approach can be enhanced to find unique Nash equilibrium for multiple asymmetric player stochastic games.

REFERENCES

[1] M. Zugno, J. M. Morales, P. Pinson and H. Madsen, "Pool strategy of a price-maker wind power producer," *IEEE Trans. Power Syst*., vol. 28, no. 3, pp. 3440–3450, 2013.

[2] L. Baringo and A. J. Conejo, "Strategic offering for a wind power producer," *IEEE Trans. Power Syst.,* vol. 28, no. 4, pp. 4645–4654, 2013.

[3] D. Chattopadhyay and T. Alpcan, "A game-theoretic analysis of wind generation variability on electricity markets," *IEEE Trans. Power Syst.,* vol. 29, no. 5, pp. 2069–2077, 2014.

[4] A. A. Sanchez de la Nieta, J. Contreras, J. I. Munoz and M. O'Malley, "Modeling the impact of a wind power producer as a price-maker," *IEEE Trans. Power Syst.,* vol. 29, no. 6, pp. 2723–2732, 2014.

[5] K. C. Sharma, R. Bhakar, H.P. Tiwari, "Strategic bidding for wind power producers in electricity markets" *Energy Conversion and Management,* vol. 86, pp. 259-267, Oct. 2014.

[6] P. Twomey and K. Neuhoff, "Wind power and market power in competitive markets," *Energ. Policy*, vol. 38, pp. 3198–3210, 2010.

[7] N. Troy and S. Twohig, "Wind as a price-maker and ancillary services provider in competitive electricity markets," Proc. *IEEE PES Gen. Meet.*, Minneapolis, MN, USA, Jul. 25–29, 2010.

[8] G. N. Bathurst, J. Weatherill and G. Strbac, "Trading wind generation in short term markets," *IEEE Trans. Power Syst.,* vol. 17, no. 3, pp. 782–789, 2002.

[9] J. Matevosyan and L. Soder, "Minimization of imbalance cost trading wind power on the short-term power market," *IEEE Trans. Power Syst.,* vol. 21, no. 3, pp. 1396–1404, 2006.

[10] P. Pinson, C. Chevallier and G. N. Kariniotakis, "Trading wind generation from short term probabilistic forecasts of wind power," *IEEE Trans. Power Syst.,* vol. 22, no. 3, pp. 1148–1156, 2007.

[11] J. M. Morales, A. J. Conejo and J. P. Ruiz, "Short term trading for a wind power producer," *IEEE Trans. Power Syst.,* vol. 25, no. 1, pp. 554–564, 2010.

[12] C. J. Dent, J. W. Bialek and B. F. Hobbs, "Opportunity cost bidding by wind generators in forward markets: Analytical results," *IEEE Trans. Power Syst.,* vol. 26, no. 3, pp. 1600–1608, 2011.

[13] K. C. Sharma, R. Bhakar, H. P. Tiwari, "Extreme Nash equilibrium of polymatrix game in electricity market" in Proc. *IEEE Int. Conf. on Recent Advances and Innovations in Engineering*, Jaipur, May 9-11, 2014.

[14] A. Botterud, Z. Zhou, J. Wang, R. J. Bessa, H. Keko, J. Sumaili and V. Miranda, "Wind power trading under uncertainty in LMP markets," *IEEE Trans. Power Syst.,* vol. 27, no. 2 894–903, 2012.

[15] M. Vilim and A. Botterud, "Wind power bidding in electricity markets with high wind penetration," *Appl. Energ.,* vol.118, pp. 141–155, 2014.

[16] T. Dai and W. Qiao, "Trading wind power in a competitive electricity market using stochastic programing and game theory," *IEEE Trans. Sustain. Energy*, vol. 4, no. 3, pp. 805–815, 2013.

[17] K. C. Sharma, P. Jain, R. Bhakar, "Wind power scenario generation and reduction in stochastic programming framework", *Electric Power Comp and Syst.,* vol. 41, no. 3, pp. 271-285, Jan. 2013.

[18] K. C. Sharma, R. Bhakar, H. P. Tiwari and Sandeep Chawda, "Scenario based uncertainty modeling of electricity market prices," in *Porc. 6th IEEE Int. Conf. on Computer Application in Electrical Engineering-Recent Advances* , Oct. 5-7, 2017, IIT Roorkee.

[19] Wind Energy Center, University of Massachusetts USA. [Online]. Available: http://www.umass.edu/windenergy/resoursedata.php/.

[20] PJM Electricity Market [Online] Available: http://www.pjm.com

[21] VENSYS Wind Turbines, Wellesweiler, Germany. [Online]. Available:http://www.vensys.de/energy-en/.