A Mechanism of Intraday Market Design for Promoting Wind Power Integration

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Abstract—**Wind power generation has been developing rapidly in recent years. Therefore, the mechanism for promoting wind power integration becomes increasingly important. In this paper, a novel mechanism of intraday market is proposed, which can utilize updating information of wind power and effectively exploit the shiftable load. The mechanism is compatible with the existing market framework, and promotes wind power producers (WPPs) to be more competitive in the market. Thus, the WPPs could make decisions for multiple market transactions in various trading timescales according to the market price. Moreover, the WPPs can optimize their decisions continuously in the intraday market at different time points in the model. The case study on IEEE-RTS verifies the proposed method is valid and feasible. It can support wind power integration and increase the benefit of the whole system as well.**

Index Terms—**Benefit analysis, electricity market, intraday market, shiftable load, wind power.**

I. INTRODUCTION

WIND power generation as an momentous mature form of renewable energy which has been growing rapidly in recent years, and represents one of the most important forms of renewable generation. With the increasing penetration of wind power, trading electricity supporting wind power integration is becoming more and more important [1]. In order to incorporate more wind power, a new market mechanism needs to be flexible enough to accommodate short-term forecasts and quick turn transactions. The flexibility is particularly valuable with respect to wind generation. Therefore, the markets of intraday and balancing need to be adjusted to make full use of the flexibility of the trading system to effectively respond to the increasing uncertainty in the market.

In most electricity markets, wind power is processed for different imbalance penalties as a preferential integration power source and its settled in feed-in price or price containing subsidy results in no deviating penalty [2]-[4]. The existing trading methods may promote the development of wind generation to some extent. However, they may not effectively promote wind power to actively take part in the market. Thus, new mechanisms for wind power transactions are essential for reflecting WPPs' willingness to participate in the new environments of the market.

It is known to all that a significant proportion of time shiftable loads exist in modern power systems. For instance: air conditioning, heating, thermostats, ventilation, electric vehicles, controllable lighting, and agricultural pumping, and so on. Their power consuming demands are flexible with just a fixed window of time. With appropriate interflow and control, the shiftable load can be manipulated as controllable demand-side resources in much the same way that generation producers are actively controlled today. The shiftable load can change their consuming manners according to the fluctuation of wind power output in order to counterbalance the resulting supply variations [5], [6].

A great deal of literature studies wind power integration from the perspective of demand-side resources. A direct load control by Independent System Operator (ISO) has been proposed, which can determine the proper amount of demand response (DR) load to be shifted from peak hours to off peaks [7]. Moreover, demand load shifting is further researched in [8]. The demand shifting is modeled in two different ways. First, the ISO controls the shiftable demand; secondly, each consumer decides its reaction to price elasticity. Furthermore, a robust optimization approach to derive an optimal unit commitment decision by ISO is proposed [9]. DR programs represent another reserve resource to mitigate the uncertainty of wind power output. The objective is maximizing total social welfare under the joint worst-case wind power output and demand response scenario.

On the whole, the existing works have realized the significance of shiftable load in the environment of wind power integration. Generally, the ISO makes overall decisions by taking into account wind power randomness and load flexibility. From the perspective of system operation, it can promote wind power consumption to some extent. However, there are some disadvantages: 1) large numbers of complex tasks are added on the scheduling algorithm and with the increasing number of wind farms, computation increases exponentially. 2) The generation and demand resources cope with the random output, but how to subsidize the contributions of these flexible resources and motivate them to actively participate in the market are still not sufficiently resolved. 3) The characteristics of fair treatment for each market participant are not sufficiently reflected. The random energy is given special treatment, which

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is not conducive to fair market competition. To the authors' knowledge, very few works study WPPs response with consideration of the shiftable load in multiple timescales.

This paper proposes a mechanism of intraday markets under the framework of the standard market. The trading models of concentrated and bilateral in markets of day-ahead, intraday, and real-time are analyzed in detail. Through the flexible transactions between the WPPs and the shiftable load, WPPs can choose more trading approaches, and actively take part in the concentrated market. The mechanism can not only increase the revenue of WPPs, but also bring more benefits to the whole system.

The main innovations of this paper are as follows: 1) This paper turns a centralized complex scheduling program by ISO into a decentralized optimization by WPPs through the response of market price. 2) The trading mechanism proposed in this paper effectively exploits shiftable load, which helps to increase the integration of wind power through the flexible contract. 3) The WPPs can utilize the rolling updated information and make decisions in intraday transactions, which better reflect the physical characteristics of wind power.

The objective intent of the paper is motivating WPPs to actively participate in the market, and giving full play to the shiftable load's advantages of flexible consumption. Through multiple optimizations in different timescales, it could further increase the revenues of WPPs, reduce wind spillage, enhance competitiveness of wind generation, and increase social benefits. The performance of the proposed model is simulated and demonstrated that it is compatible with existing technology and achievable.

The rest of the paper is organized as follows. The trading mechanism model is formulated in Section II, and decomposed in detail in Section III. Section IV provides the method and procedure of the calculating process. The case studies and conclusions are presented in Section V and VI, respectively.

II. TRANSACTION MECHANISM MODEL

In this paper, a trading mechanism for supporting wind power in multi-markets with considering load shifting, centralized market, punishment cost (imbalance punishment in balance market), and updated decision is proposed.

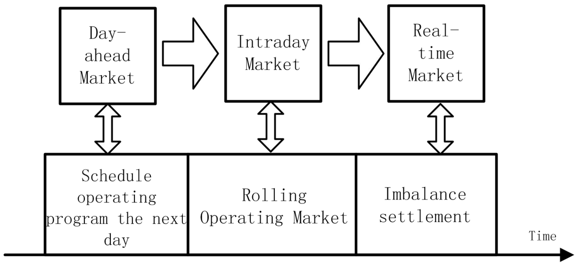

Fig. 1. Decisions making by WPPs in multiple market transactions over time.

As shown in Fig. 1, with the increasing of wind power, the uncertainty of power systems becomes increasingly stronger. The importance of short-term markets is analyzed [10], [11]. The literature proves that short-term markets enable the system operator to take advantages of reducing the uncertainty of wind power when new information becomes available. In the proposed mechanism in this paper, the WPPs respond to the market price in the day-ahead market, and trade with the shiftable load through the flexible contracts in the intraday market. The decision making by WPPs in multiple markets transactions over time include day-ahead and intraday. The specific trading contents are analyzed as *A*, *B*, *C*, and *D*.

A. Transaction in Day-ahead Market

In the proposed mechanism, the WPPs should first make the trading decision in day-ahead according to the predicted price. Then they determine the quantity of trading energy in both the centralized and bilateral markets during the next day. In this paper, the offered power of WPPs are optimized themselves instead of making whole complex decisions by the ISO. The ISO is just responsible for the matching of supply and demand as an agency, which makes market transactions fairer. The amounts of energy to be offered are decision variables which need to be determined by the optimizing program. We can get the offered energy of the WPPs through maximizing revenue, which is trading in the day-ahead market. The processes of decision making are bound by the large adjusting ability of markets and the total energy of flexible contracts.

B. Imbalance Settlement in the Balance Market

Due to the fluctuation of the wind generation, the WPPs participating in the balance market are subject to the penalties related to regulating costs. The imbalance punishment issue is analyzed in literature [12], [13].

The balance market closes 15 mins before the delivery, which ensures the balance of the system. The imbalance price is from the settlement mechanism of the balance market. Therefore, the deviations of market entities are settled in the imbalance price according to the balance mechanism. This allows the system to be equal between supply and demand. Due to the stochastic characteristics of wind output, the actual delivery and the declaring may be quite different, which would cause lots of imbalance costs. Although the specific codices vary in existing electricity markets, the general principles are similar.

C. Transactions in Intraday Markets

Generally, the actual output and the predicted are somewhat different for wind power. If the deviations are traded in the balance market, some conditions may occur as follows: 1) the actual output can't be completely consumed, so that spillage happens; 2) As the punishment mechanism exists in the market, some losses of WPPs happen [14], [15]. However, the intraday market managed by the ISO can relieve the deviations between supply and demand. In order to avoid unnecessary punishment and spillage, the intraday market is vital. There are primarily two forms of trading ways including centralized and bilateral transactions.

In the intraday centralized market, the participants can trade as time goes on. After the day-ahead market closing, the remaining longest time is up to 36h from the delivery time. The prediction of wind power decreases gradually. The participants, especially the WPPs, have requirements of further adjustments, and the intraday market is designed for this reason. They can bid and offer continually in the future hour. The trading system is similar to the day-ahead market.

In the intraday bilateral market, the WPPs and shiftable loads can trade effectively through flexible bilateral contracts with a discounted lower price. The purpose is resolving unscheduled deviations and promoting random energy integration. The discounted price should be less than the average market price. The welfare would increase through the flexible contract of wind producers and shiftable loads with designing appropriate contractual agreements.

D. Rolling Scheduling Process

The mechanism proposed in this paper allows WPPs to make adjustments based on the updated predictive information. The autoregressive integrated moving average model is utilized to generate scenarios of random energy outputs [16]. Each branch of the scenario tree represents a series of forecasting output, and corresponds to a certain probability of occurrence. Then a fast-forward scenario-reduction algorithm is used to obtain a reduced scenario set with a sufficiently small number of scenarios from an iterative process [17].

As the forecast of wind power output is in various timescales and multi-scenarios, the optimal energy quantity for transactions need to be calculated by solving in intraday timescale with updated forecasting information. The rolling schedule further promotes the integration of wind power, owing to the fact that updated predicting information is utilized.

III. MATH PROBLEM FORMULATION

We assume here that the WPPs are price-takers, and the day-ahead clearing price is defined as λ_t^{D} . According to the predicted price, WPPs can respond and make the decisions for the transactions. Electricity price forecasting is a mature technology. There are many methods in the field like the artificial neural network, ARMA method, and so on. After obtaining the predicted prices, the revenue of the WPPs is as follows:

$$R_{\mathrm{D}} = \sum_{t=1}^{24} \lambda_t^{\mathrm{D}} Q_t^{\mathrm{D,offer}} \tag{1}$$

where R_{D} is the revenue of the WPPs in day-ahead market, and $Q_t^{\mathrm{D,offer}}$ is the decision variable determined by optimizing the day-ahead scheduling program. In the intraday centralized market, the revenue of the WPPs can be expressed as:

$$R_{\mathrm{IB}} = \sum_{t=1}^{T} \lambda_t^{\mathrm{I}} Q_t^{\mathrm{I,offer}} \tag{2}$$

where R_{IB} is the revenue in the intraday centralized market, λ_t^I is the predicted price of intraday market, $Q_t^{\mathrm{I,offer}}$ is the offered quantity of the WPPs.

The flexible contracts are also proposed in this paper. In the intraday bilateral contracts market, the revenue of the WPPs can be expressed as:

$$R_{\mathrm{C}} = \lambda_{\mathrm{C}} \sum_{l=1}^{L} \sum_{t=T_{\mathrm{s}}(l)}^{T_{\mathrm{e}}(l)} C_{l,\omega,t} \tag{3}$$

where R_{C} is the revenue in the intraday bilateral contracts market, λ_{C} is contract price, and it is supposed to be less than the average value of the clearing price in the day-ahead market. The price is therefore the economic incentives for the shiftable load. $T_{\mathrm{s}}(l)$ and $T_{\mathrm{e}}(l)$ are the time of starting and ending of the consuming window of the l^{th} load, $C_{l,\omega,t}$ is the contract quantity.

The constraints of the contracts are as follows:

$$\sum_{t=T_{\mathrm{s}}(l)}^{T_{\mathrm{e}}(l)} C_{l,\omega,t} = E_l \ , \forall \omega \tag{4}$$

$$C_{l,\omega,t} = 0, \text{ if } t < T_{\mathrm{s}}(l) \text{ or } t > T_{\mathrm{e}}(l) \tag{5}$$

$$C_{l,\omega,t} \le C_{\max}, \qquad \forall l, \omega, t. \tag{6}$$

where E_l is the engaged contract energy of the lth contract. Eq. (5) describes the constraint consumption out of the time window. And (6) describes the constraint of the maximal volume of the shiftable load. Here, $C_{l,\omega,t}$ is modeled as the flexible load, and the difference value between the flexible load and rigid load is the shifting demand.

According to the analysis above, we define the total revenue of the intraday market as R_I , which can be expressed as:

$$R_{\mathrm{I}} = R_{\mathrm{IB}} + R_{\mathrm{C}} \tag{7}$$

Wind power deviation punishment is considered. We can get the revenue of the wind power in the balance market as follows:

$$R_{\mathrm{R}} = \sum_{\omega} prob(\omega) \sum_{t=1}^{24} r_{\omega,t} \tag{8}$$

where R_{R} is the expected revenue in the balance market. ω is the index of the scenario, and $prob(\omega)$ is the corresponding probability. $r_{\omega,t}$ is the penalty term, and the penalty coefficient is different in various situations. Although the imbalance tariffs depend on the specific regulation mechanism, the criteria are generally the same. Here the Spain mode is adopted as (9) described in [12]:

$$r_{\omega,t} = \begin{cases} K^{\mathrm{U}} \lambda_t^{\mathrm{D}} \Delta Q_{\omega,t} & , \Delta Q_{\omega,t} \ge 0 \\ K^{\mathrm{D}} \lambda_t^{\mathrm{D}} \Delta Q_{\omega,t} & , \Delta Q_{\omega,t} < 0 \end{cases} \quad , \forall \omega, t \tag{9}$$

where $\Delta Q_{\omega,t}$ represents the difference between the actual powers to market for delivery and the offering in centralized trading. It of course should be in a certain range for the limited capacity. K^U and K^D are penalty coefficients, K^U is less than 1, and K^D is generally greater than 1.

$$Q_t^{\mathrm{offer}} = Q_t^{\mathrm{D,offer}} + Q_t^{\mathrm{I,offer}}, \qquad \forall t \tag{10}$$

$$\Delta Q_{\omega,t} = Q_{\omega,t} - Q_t^{\mathrm{offer}}, \qquad \forall \omega, t \tag{11}$$

where $Q_{\omega,t}$ is the actual trading quantity in the centralized trading, and it can be described in (12) as:

$$Q_{\omega,t} = W_{\omega,t} - \sum_{l=1}^{L} C_{l,\omega,t} - S_{\omega,t}, \quad \forall \omega, t. \tag{12}$$

where $W_{\omega,t}$ is the actual output of the WPP. l is the index of the contract. $C_{l,\omega,t}$ is the trading volume of the flexible contract. $S_{\omega,t}$ is the wind spillage. It is known that the shiftable load can use the electricity flexibly in a certain time window.

In the day-ahead market, the objective function is maximizing the revenue of the WPPs. The function is expressed as follows:

$$\text{Max} \quad R = R_{\text{D}} + R_{\text{I}} + R_{\text{R}} \tag{13}$$

Solving this optimization problem can obtain $Q_t^{\text{D,offer*}}$. It is the realization of $Q_t^{\text{D,offer}}$, which is taken as the quantity of the bidding power of wind in the day-ahead market.

With the ending of the day-ahead market, the intraday market starts. The prediction of wind power will be more accurate with the delivery time drawing near. More frequent scheduling means that rolling updated information is used, which can better allocate wind power output in order to reducing imbalance punishments, promoting consumption of wind power, and increasing the profit of the WPPs. With the approaching of the delivery time, updated forecasts can be obtained by the WPPs. The objective function is as follows:

$$\text{Max} \;\; R_{\text{I}} + R_{\text{R}} \tag{14}$$

The main relationship is expressed in Eq. (15)~(18):

$$\begin{aligned} & W_{\omega,t}^{\text{new}} - Q_t^{\text{D,offer*}} - Q_t^{\text{I,offer}} - \sum_{l=1}^{L} C_{l,\omega,t} \\ & -S_{\omega,t} = \Delta Q_{\omega,t}^{\text{market}}, \quad \forall\, \omega,t \end{aligned} \tag{15}$$

$$r_{\omega,t}^{'} = \begin{cases} K^{\text{U}} \lambda_t^{\text{D*}} \Delta Q_{\omega,t}^{\text{market}}, \Delta Q_{\omega,t}^{\text{market}} \geq 0 \\ K^{\text{D}} \lambda_t^{\text{D*}} \Delta Q_{\omega,t}^{\text{market}}, \Delta Q_{\omega,t}^{\text{market}} < 0 \end{cases}, \forall\, \omega,t \tag{16}$$

$$Q_t^{\text{I,offer}} \leq Q_I^{\text{risk}}, \forall t \tag{17}$$

$$\Delta Q_{\omega,t}^{\text{market}} \leq Q_{\text{R}}^{\text{risk}}, \forall\, \omega,t \tag{18}$$

where $W_{\omega,t}^{\text{new}}$ is the new forecast wind power by updating data, $\Delta Q_{\omega,t}^{\text{market}}$ is the adjusted quantity of the WPPs. $r_{\omega,t}^{'}$ is the imbalance revenue. $Q_{\text{R}}^{\text{risk}}$ and $Q_{\text{I}}^{\text{risk}}$ are the risk thresholds of the markets both in real-time and intraday. The other constraints about the contract can be referenced by the day-ahead market.

IV. METHODOLOGY

The analysis of transactions, especially in the intraday markets, is introduced above. The specific procedures of the mechanism can be summarized as follows:

1)The WPPs predict electricity price of the day-ahead and intraday markets by using the technology of the artificial neural network, ARMA methods, and so on.

2)The WPPs respond to the market price and make transaction decisions through solving the maximizing revenue issues, and obtain the quantity of the bidding quantities in the day-ahead market.

3)The WPPs trade both in the centralized and bilateral intraday markets. The forms include concentrated transactions and flexible contracts. Specific provisions are primarilyh as follows: shiftable load should consume energy according to the instructions of the WPPs. The shiftable load can obtain the contract energy during certain time periods. Moreover, the arranged price must be preferential.

4)As time goes on, the WPPs can further optimize their results in the intraday market. They make the decisions of regulated energy, and the process is optimizing the trading quantity between the centralized market and flexible contract market according to the updated prediction.

5)The part of energy $Q_t^{\text{D,offer}}$ is settled according to the day-ahead optimization scheduling. The adjustments are treated on the basis of the punishment mechanism. The trading energy of the contract is settled by the agreed discounted price. $Q_t^{\text{I,offer}}$ and $C_{l,\omega,t}$ are settled according to the intraday optimization scheduling after obtaining the solution in the day-ahead market.

V. CASE STUDY

In this paper, a case study under a general market framework is considered. The proposed model is applied over a 24-h horizon to the IEEE-RTS 24-bus and 26 conventional generations. A wind farm of 300MW is introduced. The installed generation capacity is 3,675MW. The rigid demand is shown in Table I, and the max load reaches 2,385.45MW. Scenarios of wind power forecast are cut to 5 by utilizing the technique of scenario-reduction. K^U and K^D are 0.75 and 1.25, respectively. The discounted price of the flexible contract is deemed to 0.9, and the quantity is 480MWh. The consuming time window is deemed to be 08:00-20:00. In order to show the merits of the proposed method, three comparative cases are analyzed: 1) Without considering the intraday market. 2) Considering the intraday market but no bilateral transactions. 3) Considering both the intraday market and bilateral transactions. The Generic Algebraic Modeling System (GAMS) is used to solve the problem using mixed integer programming [20]. Three cases were analyzed in detail as follows. Fig. 2 shows the predicted price in hour.

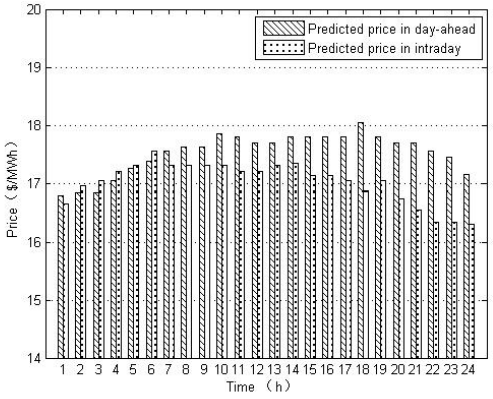

Fig. 2. Predicted price both in the day-ahead and intraday markets.

In order to analyze the profits of the WPPs and system, the results are calculated. The revenues of the WPPs in the three cases are shown in Fig. 3 (a), and the operational costs of the system are shown in Fig. 3 (b).

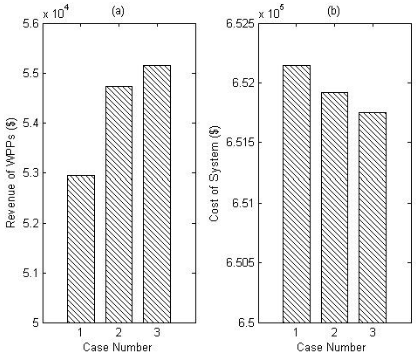

Fig. 3. Benefits analysis of revenue of the WPPs and operational cost of the system.

TABLE I
LOAD PROFILE

Time(h)	Demand(MW)	Time(h)	Demand(MW)
1	1598.25	13	2266.18
2	1502.83	14	2266.18
3	1431.27	15	2218.47
4	1407.42	16	2218.47
5	1407.42	17	2361.60
6	1431.27	18	2385.45
7	1765.23	19	2385.45
8	2051.49	20	2290.03
9	2266.18	21	2170.76
10	2290.03	22	1979.92
11	2290.03	23	1741.38
12	2266.18	24	1502.83

Because of the application of rolling scheduling in the intraday market, the revenue of the WPPs increases. The system operational costs become lower with meeting all the requirements. The main reason is the role of peak load shifting, so that more wind power can be integrated. Thus, we can see that the transactions of the intraday market can not only increase the WPPs' profit, but also be beneficial to the entire system.

Fig. 4 shows the quantity of wind power offered in the day-ahead market. Generally speaking, it does not consider intraday market trading in Case 1, so that there is more power in the day-ahead market to trade. In comparison, it considers intraday market trading in Case 2 and Case 3, and the bidding power in day-ahead is shown to be decreasing. The difference in day-ahead bidding can directly cause the diversity in benefits of the WPPs and system, and wind power spillage.

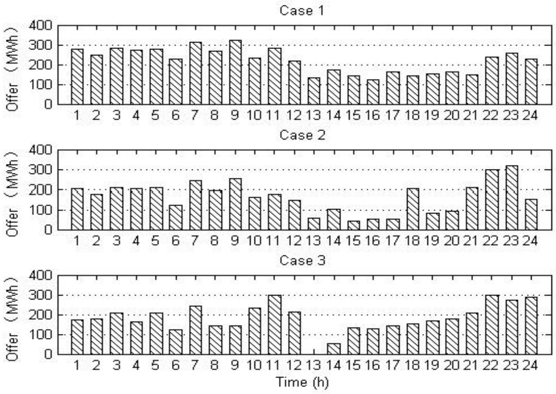

Fig. 4. The quantity of wind power offered in the day-ahead market.

The shiftable load consuming in time window is shown in Fig. 5. Two cases of not considering shiftable load and considering shiftable load are simulated. In the first case, it's assumed that the quantity of shiftable load is consumed on average in a time shifting window. In the second case, the consuming time and quantity of shiftable load is determined by the optimizing issue of the WPPs. Thus, the WPPs could sell more energy to the shiftable load in a lower spot price so that they can get more revenue. This result also displays the vital advantages of the flexible contract.

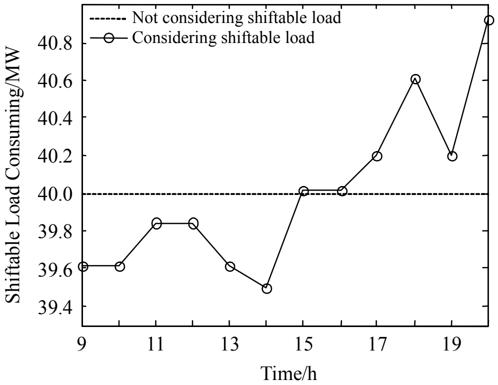

Fig. 5. The shiftable load consuming in time window.

The total spillage of the WPPs is shown in Table II. The maximum value reaches 31.38 MWh in Case 1, and the minimum value reaches 24.14 MWh in Case 3. The results further prove that the intraday market contributes to decreasing the spillage. In this regard, the WPPs get more benefits from the electricity sold to the system.

TABLE II
THE TOTAL WIND SPILLAGE IN THREE CASES

Case	1	2	3
Spill quantity(MWh)	31.38	27.08	24.14

TABLE III
THE REVENUE OF WIND POWER IN EACH MARKET

Revenue($)	Case 1	Case 2	*Case 3*
Day-ahead	91346	68998	75772
Intraday centralized	0	8476	−1050
Intraday bilateral	0	8280	8280
Imbalance cost	−10450	−3238	−184
Total	79894	82420	82810

Table III further validates the role in promoting the WPPs integration through the revenue analysis in different markets. It can be seen that the total revenue in Case 3 is maximum, which reaches $ 82810. On the contrary, the total revenue in Case 1 is minimum, which reaches $ 79894. The main reason of maximum revenue in Case 3 is the small imbalance cost in the balance market. In Case 1, the WPPs do not participate in the intraday market, in which the forecasting errors cannot be relieved by rolling regulating in the intraday market.

VI. CONCLUSION

This paper proposes a novel intraday market mechanism, in which WPPs can trade in various timescales and multiple markets. The intraday market transaction model for supporting wind power better utilizes shiftable loads and updated information. The proposed trading approaches are compatible with the existing market framework.

In the mechanism, The WPPs first predict electricity prices in the day-ahead and intraday markets by using the predicted technology. Then the WPPs and shiftable load agents would make optimal transactions internally, which make market participants more equal. The rolling scheduling programs better utilize updated information and regulate wind energy allocation in different market transactions. The results of the case study prove the rationality of the model and demonstrate that the mechanism improves the WPPs' competitiveness, and provides more profits. The proposed model creates a novel way for the WPPs to actively participate in market competition.

References

[1] Juan Rivier Abbad, "Electricity market participation of wind farms: the success story of the spanish pragmatism," *Energ. Policy*, vol. 38, no. 7, pp. 3174-3179, Jul. 2010.

[2] J.P. Chaves, R.A. Hakvoort, A. Ramos, "The impact of European balancing rules on wind power economics and on short-term bidding strategies", *Energy Policy*. vol. 68, pp. 383-393, May. 2014.

[3] Juan Rivier Abbad, "Electricity market participation of wind farms: the success story of the Spanish pragmatism," *Energy. Policy*, vol. 38, no. 7, pp. 3174-3179, Jul. 2010.

[4] European Wind Energy Association (EWEA), Wind Energy—The Facts: A Guide to the Technology, Economics and Future of Wind Power. London, UK: Earthscan. [Online]. Available: http://www.ewea.org/.

[5] S. A. Pourmousavi, S. N. Patrick, M. H. Nehrir, "Real-time demand response through aggregate electric water heaters for load shifting and balancing wind generation," *Smart Grid, IEEE Transactions on*, vol. 5, no. 2, pp. 769-778, 2014.

[6] Vlot, M.C., Knigge, J.D., Slootweg, J.G., "Economical Regulation Power Through Load Shifting With Smart Energy Appliances," *Smart Grid, IEEE Transactions on*, vol. 4, no. 3, pp. 1705-1712 , 2013.

[7] Zhao Zhechong, Wu Lei, "Impacts of high penetration wind generation and demand response on lmps in day-ahead market," *Smart Grid, IEEE Transactions on*, vol. 5, no. 1, pp. 220-229, 2014.

[8] K. Dietrich, J. M. Latorre,L. Olmos, *et al.* "Demand response in an isolated system with high wind integration," *Power Systems, IEEE Transactions on*, vol. 27, no. 1, pp. 20-29, 2012.

[9] Zhao Chaoyue, Wang Jianhui, J. P. Watson, et al. "Multi-stage robust unit commitment considering wind and demand response uncertainties," *Power Systems, IEEE Transactions on*, vol. 28, no. 3, pp. 2708-17, 2013.

[10] Jafari, A.M., Zareipour, H., Schellenberg, A., *et al.* "The Value of Intraday Markets in Power Systems With High Wind Power Penetration," *Power Systems, IEEE Transactions on*, vol. 29, no. 3, pp. 1121-1132, 2014.

[11] Chao Du, Xifan Wang, Chengcheng Shao, *et al.* "Flexible Consumption of Wind Power in Short-Term Market," *Power System Technology, International Conference on*, pp.257 – 262, 2014.

[12] P. Pinson, C. Chevallier, G. N. Kariniotakis, "Trading wind generation from short-term probabilistic forecasts of wind power," *Power Systems, IEEE Transactions on*, vol. 22, no. 3, pp. 1148-1156, 2007.

[13] J.P. Chaves, European short-term electricity market designs under high penetration of wind power. Delft University of Technology. http://xueshu.baidu.com/s?wd=paperuri%3A%2860c267b49bd0a1cf76a6bafb359d6f67%29&filter=sc_long_sign&tn=SE_xueshusource_2kduw22v&sc_vurl=http%3A%2F%2Fdx.doi.org%2F10.4233%2Fuuid%3Acbc2c7bd-d65e-4f4c-9f88-2ab55c11def8&ie=utf-8, 2014.

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

[15] P. Pinson, C. Chevallier, G. N. Kariniotakis, "Trading wind generation from short-term probabilistic forecasts of wind power," *Power Systems, IEEE Transactions on*, vol. 22, no. 3, pp. 1148-1156, 2007.

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

[17] J. M. Morales, S. Pineda, A. J. Conejo, and M. Carrión, "Scenario reduction for futures market trading in electricity markets," *IEEE Trans. Power Syst.*, vol. 24, no. 2, pp. 878–888, May 2009.

[18] Morales J.M., Conejo A.J., Kai Liu, *et al.* "Pricing Electricity in Pools With Wind Producers," Power Systems, IEEE Transactions on, vol. 27 no. 3, pp. 1366–1376, 2012.

[19] A. Ott, "Experience with PJM market operation, system design, and implementation," IEEE Trans. Power Syst., vol. 18, no. 2, pp. 528–534, May 2003.

[20] Richard E. R. "GAMS-a user's guide", Washington D.C.: GAMS Development Corporation, pp. 71-77, 2007.

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