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Optimal Bidding Strategy for Offshore Wind Farms Equipped with Energy Storage in the Electricity Markets

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***Abstract*—This paper tackles the challenges of offshore wind farm owners participating in the electricity market, aiming at maximizing their profit. Decreasing the subsidies, which used to support the wind farm owners in increasing the penetration of wind-based generation, resulted in new challenges. The owners need to compete not only with each other but also with the existing conventional producers in the electricity market. In this work, in order to have a more practical model, the day-ahead and balancing markets are considered. Moreover, the impact of energy storage devices on the profit of wind farm owners is also investigated. The stochastic programming approach is used to handle the existing uncertainties in the output power of the wind farm, and the day-ahead and balancing market prices. Four different case studies are conducted to analyze the potential of the proposed model. Results show the effectiveness of considering the day-ahead and balancing markets jointly by increasing the profit of windfarms owners. Moreover, the storage device highly increases the degree of freedom in participating in different electricity markets.**

***Keywords*—Offshore wind farm, Energy storage device, day-ahead market, balancing market.**

NOMENCLATURE

A. Indices

t	Index of time periods, $t \in 1..N_T$.
ω	Index of scenarios, $\omega \in 1..N_\omega$.

B. Parameters

ρ_ω	Probability of occurrence of the scenario ω
$\lambda_{t,\omega}^{DA}$	Electricity price in the day-ahead market for period t in scenario ω
$\lambda_{t,\omega}^{op}$	Electricity price in the balancing market in case of overproduction for period t and scenario ω
$\lambda_{t,\omega}^{up}$	Electricity price in the balancing market in case of underproduction for period t and scenario ω
P	Capacity of offshore wind farm [Mwh]
C	Cost of generation for offshore wind farm [€/Mwh]
C_s	Cost of operation for energy storage [€/Mwh]
η_c	Charging efficiency of energy storage
η_d	Discharging efficiency of energy storage

C. Variables

$P_{t,\omega}^{DA}$	Bidding power of offshore wind farm to the day-ahead market in period t and scenario ω
$P_{t,\omega}^{b,op}$	Bidding power of offshore wind farm to the balancing market in case of overproduction in period t and scenario ω
$P_{t,\omega}^{b,up}$	Bidding power of offshore wind farm to the balancing market in case of underproduction in period t and scenario ω
$P_{t,\omega}^{r,op}$	Remained unbalance power in case of overproduction in period t and scenario ω
$P_{t,\omega}^{r,up}$	Remained unbalance power in case of underproduction in period t and scenario ω
$P_{t,\omega}^{unb}$	Total unbalance power in period t and scenario ω.
$P_{t,\omega}^{op}$	Total overproduction in period t and scenario ω
$P_{t,\omega}^{up}$	Total underproduction in period t and scenario ω
$g_{t,\omega}$	Predicted generation power of offshore wind farm in period t and scenario ω
$G_{t,\omega}^{actual}$	Actual generation of the offshore wind farm in period t and scenario ω
$E_{t,\omega}^{s}$	Energy level of energy storage in period t and scenario ω
$E_{t,\omega}^{s,min}$	Minimum energy level of energy storage in period t and scenario ω
$E_{t,\omega}^{s,max}$	Maximum energy level of energy storage in period t and scenario ω
$P_{t,\omega}^{ch}$	Charging power of energy storage in period t and scenario ω
$P_{t,\omega}^{ch,max}$	Maximum charging power of energy storage in period t and scenario ω
$P_{t,\omega}^{dis}$	Discharging power of energy storage in period t and scenario ω
$P_{t,\omega}^{dis,max}$	Maximum discharging power of energy storage in period t and scenario ω
$u_{t,\omega}$, $\delta_{t,\omega}^{c}$, $\delta_{t,\omega}^{d}$	Binary variables

I. INTRODUCTION

The increasing concerns of climate change and the aggressive goals toward a carbon-free society resulted in growing the share of renewable energy (RE) sources in electricity generation. Among the RE-based technologies, wind farms have received greater attention, especially in countries with large coastal areas [1]. By facing such a huge increase, the governments decided to decrease the subsidies that used to support the wind producers by buying their generation at fixed prices no matter how much they produce. On the other hand, this transition brought new challenges to wind farm owners. These owners need to participate in the electricity markets and compete not only with each other but also with those existing cheap conventional fuel-based producers. To do this, they have to offer appropriate powers to the electricity markets based on their production and market prices, aiming at maximizing their profits [1].

Different electricity markets are available for the participation of wind farms, which has been considered in several studies [1]–[5]. In [1] and [2], both the day-ahead and balancing markets were considered as the target markets. Participating in the balancing market provides the opportunity for wind farm owners to decrease their disadvantages due to the differences between the committed power to the day-ahead market and actual production. In [3], the authors proposed a model that provides the possibility of bidding in the day-ahead market to wind farm owners aiming at maximizing their profit. Intraday, day-ahead, and balancing markets were considered in [4] for the participation of a wind power aggregator equipped with compressed air energy storage aggregator to maximize their profit. Maximizing the profit of a wind power producer by bidding in day-ahead and real-time markets were investigated in [5].

On the other hand, the biding strategy problem of the wind farm owners in the electricity markets is subject to uncertainty. Neglecting the existing uncertainties results in an unpractical outcome that highly endangers the profit of the wind farm producer. Considering these uncertainties, make the problem stochastic and more difficult to solve. Some of the commonly used approaches to handle the uncertainty are stochastic programming and adaptive robust programming. Authors in [6] used the Monte Carlo method to generate appropriate scenarios as the input of the stochastic programming. This method needs a large number of scenarios to result in a proper outcome, which in turn increases the size of the problem and makes it intractable. To address this issue and to enhance the computation efficiency without loss of generality, scenario reduction techniques have been used in some studies [1], [4]. A stochastic programming method was implemented in [7] to handle the uncertainties of a wind farm-based problem. The authors considered the uncertainties of wind generation and balancing prices; however, the uncertainty of the day-ahead market price was neglected.

Pairing a wind farm with an energy storage system may increase the profit of wind farm owners by providing adequate flexibility to participate in different electricity markets. In [3], [4] and [8] storage has been considered in the problem, which has been coupled with wind farms. The impacts of using storage devices on the profit of wind farm owners participating in the day-ahead market were studied in [3]. However, the balancing market was neglected. Authors in [4] considered a hybrid power plant, consisting of a wind farm and storage, to bid in different electricity markets. The wind farm considered in [4] was a small-scale one, which is not the real case that an electricity market may face with. In [8], a wind farm equipped with battery storage was considered to participate in the frequency regulation market effectively. Results showed an increase in their profit when they cooperate compared to the time when they worked independently.

The main contributions of this paper are to investigate a) the effectiveness of considering both the day-ahead and balancing electricity markets on the profits of the offshore wind farm owner and b) the capability of energy storage to increase the profit of an offshore wind farm owner by facilitating its participation in electricity markets. This work considers the decision-making problem for a large-scale wind farm while the impacts of the storage device are also studied. A stochastic programming methodology has been considered to take into account the uncertainties related to the wind farm generation and electricity market prices. The problem is formulated as a stochastic mixed-integer linear programming (MILP) model. The global solution of the MILP can be obtained either via conventional solution approaches or by utilizing appropriate commercial solvers. For the sake of practicality, historical data collected from the offshore wind farm site and Nordpool [9] are used in the proposed model. To examine the potential of the proposed model under different circumstances, different case studies are conducted, and the results are compared.

The remainder of this paper is organized as follows. The problem description is presented in section II. Section III display and discuss simulation results for different case studies. Section IV includes the conclusion of the paper and further work.

II. Problem Description

A. Market Structure

In this paper, two main markets, namely the day-ahead and balancing markets, are considered. The wind farm owner can bid in both of the aforementioned markets. The day-ahead market is usually closed a day before the actual delivery and the balancing market will be open a few minutes before the power delivery. Therefore, wind farms have to make their offers to the day-ahead market well before knowing their actual production. This is one of the primary sources of uncertainty that makes our problem stochastic. Wind farms will have the opportunity to amend the difference between the commitment power to the day-ahead market and their actual production through the balancing market. In the case of overproduction, i.e., production higher than what has been offered to the day-ahead market, they have the chance of either selling it in the balancing market to avoid wasting the power or, if equipped with the storage devices, it can be stored. On the other hand, for the underproduction condition in which the wind farm production is lower than what has been committed to the day-ahead market, the deficit power can either be bought from the balancing market to avoid the penalties, if the balancing market price is lower than the penalty, or compensated by discharging the storage device.

B. Uncertainty Modeling

The market model, in general, is uncertain due to the uncertainty in several primary parameters, such as the generation of the offshore wind farm and the day-ahead and balancing electricity market prices. Therefore, the deterministic approach will not result in a practical outcome and indeterministic models such as stochastic programming, robust optimization, etc., are the most suitable approaches to be used. In this paper, the stochastic programming is used while a Monte Carlo simulation method is used to predict the behavior of random variables. Typically, this method generates many scenarios to appropriately predict the values of random variables. Although considering a higher number of scenarios results in a more precise outcome, the problem may become intractable. To prevent intractability and increase computational efficiency, more often than not, scenario reduction techniques are implemented to reduce the size of the problem. In this paper, first, historical data of random variables is analyzed, and then, the normal (for electricity market prices) and Weibull (for wind farm generation) probability density functions are used to generate 1000 scenarios through the Monte Carlo simulation method. For the sake of tractability, a fast forward scenario reduction technique is applied to keep the 10 most possible scenarios [10].

C. Case studies

This work considers four different case studies to investigate the participation of the offshore wind farm in different electricity markets.

a. Case I: Participating in the Day-ahead Market

In this case, the offshore wind farm only participates in the day-ahead market without considering any storage devices. The objective is to maximize the profit of the offshore wind farm while bidding in the day-ahead market. This can be modeled by four different terms in (1) where the first term presents the profit obtained from selling power to the day-ahead market; the second and third terms stand for the costs caused by the difference between committed power to the day-ahead market and the actual generation of the wind farm, and the last term is the cost of generation for the wind farm. Here, the total profit, which is defined as the selling of generated power to the day-ahead market minus the deviation penalty and the generation cost, is maximized. The deviation penalty refers to the overproduction (producing more than the scheduled delivery) or underproduction (producing less than the scheduled delivery) [6]. In (1), $P_{t,\omega}^{DA}$, which represents the bidding power to the day-ahead market is limited to the predicted power of offshore wind farm for the coming day as shown in (2). Total power unbalance is calculated via (3) as the difference between the actual generated power and the power that has been bid in the day-ahead market, while (4) determines the type of the unbalance (overproduction or underproduction). To ensure that the wind farm either has an overproduction or underproduction at each t and ω, (5) and (6) are used.

$$\max\{\sum_{\omega}\rho_{\omega}\sum_{t}(\lambda_{t,\omega}^{DA}\cdot P_{t,\omega}^{DA}-c_1\cdot\lambda_{t,\omega}^{DA}\cdot P_{t,\omega}^{r,op} - c_2\cdot\lambda_{t,\omega}^{DA}\cdot P_{t,\omega}^{r,up}-c.g_{t,\omega})\} \tag{1}$$

s.t.

$$0\le P_{t,\omega}^{DA}\le g_{t,\omega} \tag{2}$$

$$\mathrm{P}_{t,\omega}^{unb}=G_{t,\omega}^{actual}-P_{t,\omega}^{DA} \tag{3}$$

$$\mathrm{P}_{t,\omega}^{unb}=P_{t,\omega}^{op}-P_{t,\omega}^{up} \tag{4}$$

$$\mathrm{P}_{t,\omega}^{\mathrm{op}}\le P\cdot(1-u_{t,\omega}) \tag{5}$$

$$\mathrm{P}_{t,\omega}^{up}\le P\cdot u_{t,\omega} \tag{6}$$

b. Case II: Participating in the Day-ahead and Balancing Markets

This case considers the bidding of the offshore wind farm in both the day-ahead and balancing markets. Therefore, compared to the objective function of Case *I*, two more terms are considered to take into account the profits of selling the overproduction and the cost of buying underproduction from the balancing electricity market. The problem is formulated as (7)-(11). The total overproduction is presented in (8) that can be partly compensated through selling to the balancing market, while the other extra portion causes a penalty to the wind farm producer. Moreover, (9) stands for the underproduction where a part of that can be bought from the balancing market, and the other part (deficit) is subject to a penalty. The overproduction and underproduction bidding powers are subject to a limit, defined as a percentage of the power prediction in the day-ahead market, see (10) and (11), respectively.

$$\max\{\sum_{\omega}\rho_{\omega}\sum_{t}(\lambda_{t,\omega}^{DA}\cdot P_{t,\omega}^{DA}+\lambda_{t,\omega}^{op}\cdot P_{t,\omega}^{b,op} - \lambda_{t,\omega}^{up}\cdot P_{t,\omega}^{b,\mathrm{up}}-c_1\cdot\lambda_{t,\omega}^{DA}\cdot P_{t,\omega}^{r,op} - c_2\cdot\lambda_{t,\omega}^{DA}\cdot P_{t,\omega}^{r,\mathrm{up}}-c\cdot g_{t,\omega})\} \tag{7}$$

s.t.

$$(2)-(6)$$

$$\mathrm{P}_{t,\omega}^{\mathrm{op}}=P_{t,\omega}^{b,op}+P_{t,\omega}^{r,op} \tag{8}$$

$$\mathrm{P}_{t,\omega}^{up}=P_{t,\omega}^{b,up}+P_{t,\omega}^{r,up} \tag{9}$$

$$0\le\mathrm{P}_{t,\omega}^{\mathrm{b,op}}\le 0.05\cdot g_{t,\omega} \tag{10}$$

$$0\le\mathrm{P}_{t,\omega}^{\mathrm{b},up}\le 0.05\cdot g_{t,\omega} \tag{11}$$

c. Case III: Participating in the Day-ahead Market in the Presence of Storage Device

This case investigates the profits of the offshore wind farm participating in only the day-ahead market in the presence of the storage device. The appropriate objective function (12) is obtained by adding a term corresponding to the operating cost of the storage device into (1). In (13), a part of overproduction charges the energy storage, while the surplus causes a penalty to the wind farm owner. In the case of underproduction, (14) states that a part of it can be compensated by the storage device, while the remained deficit causes a penalty. Charging and discharging power of energy storage are limited to the nominal power of the device via (15) and (16), while (17) ensures that at each time t and ω, the storage device can only be charged or discharged. The lower and upper energy levels of the energy storage device are presented in (18), where the energy level at each t and ω, can be calculated via (19). To prevent any unwanted biasing to the model, the initial and final level of energy storage during the operation horizon is kept the same via (20).

$$\max\{\sum_{\omega}\rho_{\omega}\sum_{t}(\lambda_{t,\omega}^{DA}.P_{t,\omega}^{DA}-c_1\cdot\lambda_{t,\omega}^{DA}\cdot P_{t,\omega}^{r,op} - c_2\cdot\lambda_{t,\omega}^{DA}\cdot P_{t,\omega}^{r,\mathrm{up}}-c\cdot g_{t,\omega}-c_s\cdot E_{t,\omega}^{s})\} \tag{12}$$

s.t.

$$(2)-(6)$$

$$\mathrm{P}_{t,\omega}^{\mathrm{op}}=P_{t,\omega}^{ch}+P_{t,\omega}^{r,op} \tag{13}$$

$$\mathrm{P}_{t,\omega}^{up}=P_{t,\omega}^{dis}+P_{t,\omega}^{r,\mathrm{up}} \tag{14}$$

$$0\le\mathrm{P}_{t,\omega}^{ch}\le P_{t,\omega}^{ch,\max}\cdot\delta_{t,\omega}^{c} \tag{15}$$

$$0\le\mathrm{P}_{t,\omega}^{dis}\le P_{t,\omega}^{dis,\max}\cdot\delta_{t,\omega}^{d} \tag{16}$$

$$\delta_{t,\omega}^{c}+\delta_{t,\omega}^{d}\le 1 \tag{17}$$

$$\mathrm{E}_{t,\omega}^{s,\min}\le E_{t,\omega}^{s}\le E_{t,\omega}^{s,\max} \tag{18}$$

$$\mathrm{E}_{t,\omega}^{s}=E_{t-1,\omega}^{s}+(\eta_c\cdot P_{t,\omega}^{ch})-(P_{t,\omega}^{dis}/\eta_d) \tag{19}$$

$$\mathrm{E}_{initial}^{s}=E_{final}^{s} \tag{20}$$

d. Case IV: Participating in the Day-ahead and Balancing Markets in the Presence of Storage Device

This case considers all the options such as bidding in both the day-ahead and balancing markets as well as the storage devices. The objective function in (21) has two more terms, namely terms two and three, compared to Case III, which stand for the income from bidding overproduction and the cost of bidding underproduction in the balancing market, respectively. In (22), total overproduction will be partly compensated through the charging of energy storage, bidding in balancing market and the remainder will cause a penalty to wind farm producer. Equation (23) states that the total underproduction will be compensated partly by discharging energy storage and bidding in the balancing market, and the remainder causes a penalty to the wind farm producer.

$$\max\{\sum_{\omega}\rho_{\omega}\sum_{t}(\lambda_{t,\omega}^{DA}\cdot P_{t,\omega}^{DA}+\lambda_{t,\omega}^{op}\cdot P_{t,\omega}^{b,op}-\lambda_{t,\omega}^{up}\cdot P_{t,\omega}^{b,\text{up}} -c_1\cdot\lambda_{t,\omega}^{DA}\cdot P_{t,\omega}^{r,op}-c_2\cdot\lambda_{t,\omega}^{DA}\cdot P_{t,\omega}^{r,\text{up}} -c\cdot g_{t,\omega}-c_s\cdot E_{t,\omega}^{s})\} \quad (21)$$

s.t.

$$(2)-(6)$$
$$(10)-(11)$$
$$(15)-(20)$$

$$\text{P}_{t,\omega}^{\text{op}}=P_{t,\omega}^{ch}+P_{t,\omega}^{b,op}+P_{t,\omega}^{r,op} \quad (22)$$

$$\text{P}_{t,\omega}^{up}=P_{t,\omega}^{dis}+P_{t,\omega}^{b,up}+P_{t,\omega}^{r,\text{up}} \quad (23)$$

D. Assumptions

The main assumptions in finding the optimal bidding strategies for offshore wind farm producers participating in different electricity markets with or without considering the storage devices are as followed.

- The installed capacity of the offshore wind farm is 760 MW.
- The capacity of the storage device paired with offshore wind farms is limited to 5 percent of the wind farm capacity, i.e., 38 MW.
- Furthermore, Table I provides the quantity of the parameters used in the problem formulations.

Table I. Problem parameters

Parameter	Value
P	760
C	0.01
C_S	0.01
C_1	0.1
C_2	1.1
η_C	0.95
η_d	0.95
$E_{t,\omega}^{s,min}$	1.9
$E_{t,\omega}^{s,max}$	36.1
$P_{t,\omega}^{ch,max}$	10
$P_{t,\omega}^{dis,max}$	10

III. Simulation Results and Discussion

In this section, the simulation results for the mentioned case studies are presented. The proposed model is implemented in GAMS software and the Cplex is used to handle the model. The simulation times for cases I, II, III, and IV are 0.24, 0.21, 0.25 and 0.18 second, respectively. The total profit of offshore wind farm by participating in the day-ahead and balancing markets is presented in Fig.1. In Case II, compared to Case I, the total profit has increased by 1.14%, which is the positive result of participating in the balancing market. This is due to the flexibility of the offshore wind farm, in Case II, to amend the deviation between the actual generation and the amount committed to the day-ahead market. The wind farm owner has the opportunity of selling its overproduction to the balancing market to make some profit and purchasing a part of its underproduction from this market to prevent higher penalties. In Case III, the total profit has increased by 0.76%, compared to Case I. In this case, the offshore wind farm producers can charge the energy storage

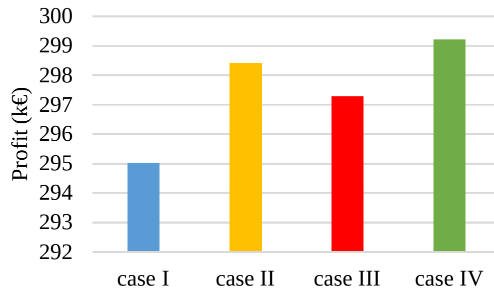

Fig.1. Profit for different case studies

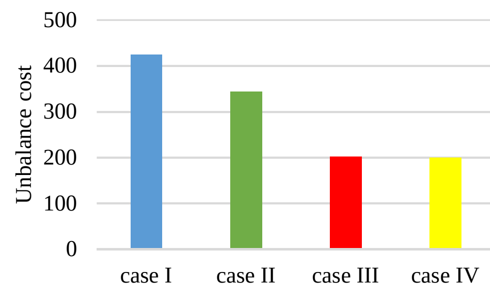

Fig.2. Unbalance cost for different case studies

during the overproduction condition and discharge the energy storage in underproduction situation to decrease the amount of unbalance. Therefore, penalties pertaining to the unbalanced periods in Case I has been decreased, and as a result, the total profit of the wind farm is increased. In Case IV, a 1.41% rise in the value of total profit, compared to Case I, has been resulted. The main reason is the higher flexibility of the wind farm equipped with a storage device that can participate in both the balancing and day-ahead market.

Fig. 2 displays the total costs that wind farm producer needs to pay when there is a difference between the actual generation and bidding in the day-ahead market. This includes the penalty due to the remainder of the overproduction (neither sold to market nor stored in the storage device), the penalty related to the remainder of the underproduction (neither bought from the market nor drawn from the storage device) and the costs of purchasing electricity from the balancing market to compensate for the underproduction. It can be seen in this figure that bidding in both the day-ahead and balancing markets at the presence of energy storage decreases the costs related to the unbalance. The unbalance cost in cases II, III, and IV, compared to Case I, has decreased by 18.72%, 52.38%, and 52.76%, respectively.

Table II displays the results of the simulation for Case IV, for one of the scenarios. This table can be used for validating the model. As can be seen from this table, the battery is either charging or discharging during the period. Moreover, whenever there is an overproduction, there is no underproduction that confirms the model is working properly. As an example, in hour 4, the total unbalance is 37.63 MW and a part of that is used to charge the battery, 10 MW, and 18.02 MW has been bid in the balancing market, while the remainder (9.61 MW) causes a penalty.

Fig. 3 shows the average of some of the variables in Case IV during the simulation period. These variables consist of total unbalance power, charging and discharging power of energy storage and bidding in the balancing market in case of overproduction and underproduction. The energy level of the storage of Case III and Case IV for different scenarios during

Table II. Result of simulation in Case IV

var	Time (hour)																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
$G^{actual}_{t,\omega}$	94.6	236.9	123.2	398.1	285.6	398	595.2	285.6	655	595.2	655	462.7	745.2	745.6	743.9	655	529.3	595.2	398.1	194.4	123.2	236.9	156.2	339
$P^{DA}_{t,\omega}$	94.6	234.23	133.2	360.47	278.75	408	588.13	277.2	636.6	605.2	623.35	450.71	753.70	708.3	751.8	656.9	539.3	566.4	401.4	170.9	123.2	225.3	156.2	330.9
$P^{unb}_{t,\omega}$	0	2.67	-10	37.63	6.85	-10	7.072	8.41	18.40	-10	31.65	11.99	-8.50	37.3	-7.9	-1.9	-10	28.8	-3.3	23.5	0	11.6	0	8.1
$P^{ch}_{t,\omega}$	0	0	0	10	0	0	7.072	8.41	10	0	4.71	10	0	0	0	0	0	0	0	10	0	0	0	8.1
$P^{dis}_{t,\omega}$	0	0	10	0	0	10	0	0	0	10	0	0	8.504	0	7.9	1.9	10	0	3.3	0	0	0	0	0
$P^{b,op}_{t,\omega}$	0	2.67	0	18.02	6.85	0	0	0	8.40	0	26.94	1.99	0	37.3	0	0	0	28.8	0	8.5	0	11.6	0	0
$P^{b,up}_{t,\omega}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

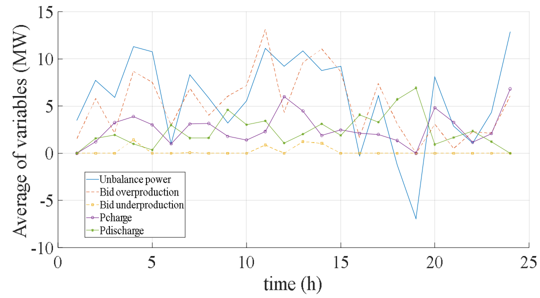

Fig.3. Average of some variables in case IV

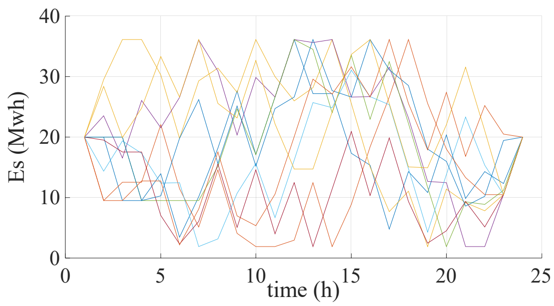

Fig.4. The energy level of storage for all the scenarios in case III

the simulation period are presented in Fig. 4 and Fig. 5. It can be seen in these figures that the energy level of the storage is always between its limits, which satisfy the constraint (18). Moreover, the initial and final energy level of storage for both cases are the same, which satisfy the constraint (20). Charging the energy storage, which increases its energy level, occurs when offshore wind farm producer faces overproduction. Furthermore, discharging energy storage which decreases its energy level, will happen when the wind farm has to deal with underproduction. In this way, the deviation between committed power to the day-ahead market and actual generation of the offshore wind farm will decrease, which subsequently reduces the penalty costs related to the unbalance for the wind farm.

IV. Conclusion

This paper has investigated the bidding strategy of wind farm producers in different electricity markets. Four different cases have been investigated, and the results have been compared. To address the existing uncertainties of the wind-based generation and market prices, the problem has been formulated via a stochastic mixed-integer linear programming model. Simulation results demonstrate that the benefit of the wind farm owner is proportional to the degree of freedom, which can be enhanced by considering different options such as participating not only in the day-ahead market but also in the balancing market as well as taking the advantages of the storage device. For instance, compared to the case with the only day-ahead option, the benefit of the wind farm owner participating in both the markets has increased by 1.14%. For the case in which the owner was equipped with the storage

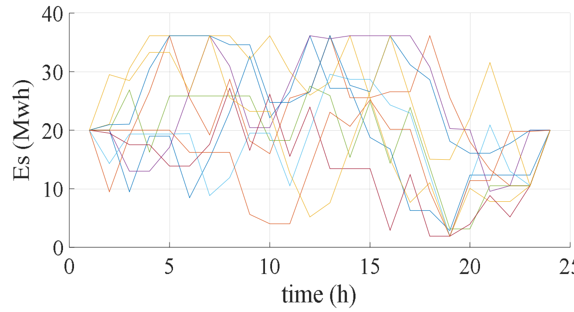

Fig.5. The energy level of storage for all the scenarios in case IV

device and only participating in the day-ahead market, the benefit has increased by 0.76%. The best condition has been observed when the owner decided to participate in both the aforementioned markets while equipped with the storage device where the benefit has increased by 1.41%. Considering that the results are for only one day, it can be deduced that the wind farm owners can make a huge benefit in a year.

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