A novel order type for storage units in day-ahead electricity auctions

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***Abstract*— The active market participation of storage units may catalize the integration process of renewable sources. However, the involvement of battery or other storage units in portfolio-bidding day-ahead markets is not straightforward. If one considers a charge-discharge process in multiple periods, buy and sell bids must be simultaneously submitted, and the possible rejection of buy bids in the case of non-price-taker bids may imply the non-deliverability of sell bids. On the other hand, using price-taker bids may not ensure the profitability of the participating storage unit. In this paper we propose a new potential order type for day-ahead markets, which on the one hand ensures that the physical constraints of the storage unit are respected in the bid-acceptance process, and on the other hand has the potential to ensure profitability for the storage-type market participant. We analyze how such orders affect market dynamics via simple market simulations.**

***Index Terms*-- Day-ahead electricity markets, dedicated order types, storage units.**

I. INTRODUCTION

Electricity demand and production of weather-dependent renewable sources are both fluctuating during the day. As the balance of consumption and production must be maintained for every instance in the power system, controlled energy sources have to be operated according to a schedule, which fits the time-dependent nature of these components. Implied by the recent investments in renewable production, the number of occasions when the extent of production by these sources exceeds the local demand is increasing. Nevertheless, assuming continuous increase in renewable production capacities, further decarbonization of production will be extremely challenging without storing the energy produced in renewable-rich peridos [1]. Although the efficient storage of electrical energy still poses a significant challenge, it is more and more likely that the total capacity of storage units involved in the daily operation of the integrated power system will increase in the near future [2].

Periods with increased renewable production and periods with high consumer demand are clearly reflected in the hourly (or quarter-hourly) prices of day-ahead electricity markets. Periods with high demand and low renewble supply require the activation of controllable production units with higher marginal cost, thus imply price-peaks, while periods with high production of weather-dependent renewable sources decrease the market clearing price. In Europe, the algorithm EUPHEMIA [3] is used for the clearing of coupled day-ahead markets. EUPHEMIA includes special order types tailored for thermal power plats which are characterized by significant start-up costs and inertia (block orders and complex orders), but currently there are no such dedicated order types matching the needs arising in the case of day-ahead market participation of storage type units. The reasons behind this are mostly historical – although at the time when the special orders of EUPHEMIA have been defined, the participation rate of storage type units in day-ahead markets was negligible, there is an increasing research trend which suggests the integration of electric vehichles [4] and other storage type units in day-ahead markets. Considering e.g. a battery type storage unit, which aims to fully market its charge-discharge cycle inside a one-day period of the day-ahead market, there are several factors, which must be reflected in the submitted bids: (1) the charge and discharge rate of the unit must be respected, (2) the quantity available for discharge (sell) depends on the quantity previously obtained by

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charging (corresponding to previous buy bids), (3) the actual state of charge must never exceed the maximal capacity of the storage unit and (4) the losses during charging and discharging have to be accounted for. While the aspect (1) may be easily reflected via the quantity of the submitted (hourly) bids, the consideration of the further facors is not trivial. The current framework of EUPHEMIA allows only one order type, which may be more or less fitted to these requirements: the linked block order (https://www.nordpoolgroup.com/en/trading/Day-ahead-trading/Order-types/Block-bid/), but these orders do not allow partial acceptance, thus they lack flexibility. In this paper we aim to propose an alternative order form, which allows partial acceptance of its components, and moreover it is explicitly tailored for the characteristic parameters of storage units.

II. Model

We consider a simple, multiperiod day-ahead market model in the paper, with 4 periods, where only two types of bids are present: standard bids and storage orders.

A. Standard bids

Standard bids are single-period stepwise bids, each such bid is characterized by the index of the respective period and a quantity-price pair. In case the resulting market clearing price (MCP) of the corresponding period is strictly appropriate (e.g. higher than the bid price in the case of supply bids or lower than the bid price in the case of demand bids), these bids must be fully accepted, and if the MCP is strictly inappropriate, they must be fully rejected. If the MCP equals the bid price, any rate of acceptance is possible. Positive and negative quantites correspond to demand and supply bids respectively. Table I summarizes the set of standard bids considered in market model, using the notations t for the relevant time period, q for the bid quantity and p for the bid price (per unit). We assume price taker (renewable) supply bids for periods 1 and 2.

TABLE I. STANDARD BIDS

ID	t	q	p	ID	t	q	p
1	1	69	50	13	1	-56	0
2	1	42	45	14	1	-45	20
3	1	41	30	15	1	-50	33
4	2	74	51	16	1	-32	42
5	2	54	41	17	2	-32	0
6	2	24	35	18	2	-42	22
7	3	72	55	19	2	-50	36
8	3	48	49	20	2	-32	44
9	3	25	37	21	3	-51	24
10	4	76	54	22	3	-37	39
11	4	58	52	23	3	-43	46
12	4	35	32	24	4	-47	24
				25	4	-40	41
				26	4	-39	47

B. Storage orders

In this paper we consider battery type storage units, and use the corresponding terminology, but the concept may be applied for other storage types as well. First, we define charge-discharge (CD) type storage orders (see the Discussion for generalization possibilities). In addition, for the aim of simplicity, let us assume that only one storage order is present in the market model (thus we can avoid the indexing of storage orders to improve readability). CD orders are parametrized by a quadruple $(Q_{init}, Q_{max}, \eta_c, \eta_d)$ and a set (or package) of m single-period stepwise bids. Q_{init} denotes the initial charge level of the storage unit (at the beginning of the trading day), Q_{max} stands for its maximal capacity, while η_c and η_d denote the efficiency of charging and discharging respectively. The package of single-period stepwise bids holds m component bids, each of which is described by t_i^s, q_i^s and p_i^s $(i = 1, \dots, m)$, denoting the time period, the quantity and the price of the component bid i respectively. We assume that $t_i^s \geq t_j^s$ if $i \geq j$, and (since we are talking about a CD) that buy orders $(q_i^s > 0)$ preceed sell orders $(q_i^s < 0)$. In the case of full or partial acceptance of a component bid of a storage order, the MCP of the respective period must be appropriate, but no vice-versa relation is assumed (i.e. component bids of SOs may be rejected even in the case of strictly appropriate MCPs, thus paradox rejection is allowed). Equations (1 – 4) describe the constraints of the CD type storage order.

$$\frac{1}{\eta_d} Q_{sell} \leq Q_{init} + \eta_c Q_{buy} \tag{1}$$

$$Q_{init} + \eta_c Q_{buy} \leq Q_{max} \tag{2}$$

$$Q_{buy} = \sum x_i^S q_i^S \quad \text{for } i: q_i^S > 0 \tag{3}$$

$$Q_{sell} = -\sum x_i^S q_i^S \quad \text{for } i: q_i^S < 0 \tag{4}$$

Eq. (1) ensures that the sold quantity can not exceed the available quantity, which is the sum of Q_{init} and the quantity obtained by trading (Q_{buy}), considering charge– and discarge–related losses. Eq. (2) describes that the sum of the initial quantity (Q_{init}) and the quantity obtained by trading (Q_{buy}) can not exceed the maximal capacity of the storage unit, considering also the losses related to charging.

III. Results

A. Reference market clearing

We consider only the standard bids of Table 1 in the reference market clearing, i.e. no storage orders are present inthis case. The clearing results in the MCP values 33, 41, 46 and 52 for periods 1, 2, 3 and 4 respectively, with bids 15, 5, 23 and 11 being the price-setter bids.

B. Market clearing with storage orders

First, we analyze the possible market outcomes from the perspective of the participant submitting the storage type bid.

Let us assume in this case that the parameters Q_{init}, Q_{max}, η_c and η_d are invariant with the values summarized in Table II.

TABLE II. PARAMETERS OF THE STORAGE BID I

Q_{init}	Q_{max}	η_c	η_d
0	50	0.97	0.98

In addition, we assume 4 component bids, corresponding for the 4 trading periods, for which we consider 4 possible parametrizations (i.e. scenarios) for the component bids. Buy bids are submitted in periods 1 and 2 with bid price 42 and sell bids in periods 3 and 4 with bid price 45. The bid quantity parameters are summarized in Table III.

TABLE III. PARAMETERS OF THE STORAGE BID II

scenario index	q_1^S	q_2^S	q_3^S	q_4^S
1	25	25	-22	-22
2	25	25	-25	-25
3	27	27	-22	-22
4	27	27	-25	-25

In the case of scenario 1, the clearing results in the full acceptance of all component bids of the storage order. This implies that the storage will be charged to the value of 48.5 units at the end of period 2, and the remaining charge after period 4 is 3.602 units (i.e. in this case there is no full discharge).

In the case of scenario 2, inequality (1) becomes active and the 3rd component bid (the sell bid corresponding to period 3) is only accepted at the rate of 0.9012 – the remaning component bids are fully accepted. In this case, at the end of period 4, the remaining charge is 0. The clearing algorithm limits the acceptance of the sell bid in the third period, since its welfare contribution is less compared to the sell bid in the last period.

Scenario 3 demonstrates a case, when the maximal capacity of the storage unit limits the acceptance rate of the buy bids in the first two periods via inequanlity (2). Buy bid of period 2 contributes less to the total welfare, thus its acceptance is limited to 0.909 (the remaining component bids are fully accepted). The remaining charge is 5.102 in this case.

In scenario 4, both inequalities (1) and (2) are active. The acceptance rate of the buy and sell component bids corresponding to 2 and 3 are limited to 0.909 and 0.96 respectively. Full discharge is reached at the end of period 4.

We may compare some market outcomes of the 4 scenarios to the reference case without storage bid. Table IV summarizes the total quantity traded in the market (QTT), the income of the storage unit (IS) and the vector of market clearing prices for the 4 periods. Let us note that the storage unit does not fully discharges in the case of scenarios 1 and 3 and does not fully charges in the case of scenarios 1 and 2. We can see that the presence of the storage order attenuates the price peak at period 4 in every case of the analyzed scenarios.

TABLE IV. PARAMETERS OF THE STORAGE BID II

scenario index	Q_{TT}	I_S	MCP
ref	481	-	[33, 41, 46, 52]
1	514	196	[33, 41, 46, 47]
2	514	361	[33, 41, 46, 47]
3	516	148	[33, 41, 46, 47]
4	516	381	[33, 41, 46, 47]

As one may expect, this trend increases as the market share of the storage unit becomes more significant. If we increase the capacity of our hypthetical storage unit to $Q_{max} = 110$, and assume that the quantity parameter of all component bids is 60 units (with price parameters unchanged), the order is cleared with the acceptance ratios [1, 0.833, 0.533, 0.7833] for the single bids respectively, resulting the MCP vector [42 41 46 45], where not only the value of the price peak is attenuated more, but due to the large amount of charge in the first period, the former price valley is also disappearing.

IV. DISCUSSION

Let us first note that the proposed approach may be easily fitted to discharge-charge orders as well instead of charge-discharge orders, using the inequalities (4) and (5) instead of (1) and (2).

$$\frac{1}{\eta_d} Q_{sell} \leq Q_{init} \tag{4}$$

$$Q_{init} - \frac{1}{\eta_d} Q_{sell} + \eta_c Q_{buy} \leq Q_{max} \tag{5}$$

The profitability of the proposed order for a single charged and discharged unit may be ensured by the appropriate bid prices for buy and sell bids. If inequality (6) holds for any pair of buy and sell bids, every unit of charged and discharged energy will be profitable.

$$p_{buy} < \eta_c \eta_d p_{sell} \tag{6}$$

The approach may be extended for muliple charge-discharge (or, as We have seen before discharge-charge) cycles in a trading day as well. In this case, it is possible to introduce an auxilliary variable Q_{I1} to account for the state of charge of the storage unit after the first charge-discharge cycle as

$$Q_{I1} = Q_{init} + \eta_c Q_{buy1} - \frac{1}{\eta_d} Q_{sell1}, \tag{7}$$

and use the inequalities (8-11) instead of (1-2), where Q_{buy1}, Q_{sell1}, Q_{buy2} and Q_{sell2} stand for the bought and sold energy quantites in charge-discharge cycles 1 and 2 respectively, and they may be determined following the approach formalized by eqs (3-4).

$$\frac{1}{\eta_d}Q_{sell1} \leq Q_{init} + \eta_c Q_{buy1} \quad (8)$$

$$\frac{1}{\eta_d}Q_{sel} \quad \leq Q_{I1} + \eta_c Q_{buy2} \quad (9)$$

$$Q_{init} + \eta_c Q_{buy1} \leq Q_{max} \quad (10)$$

$$Q_{I1} + \eta_c Q_{buy2} \leq Q_{max} \quad (11)$$

This approach may be easily extended for even further number of charge-discharge cycles is necessary.

The proposed storage order implicitly requires that the participant submitting such an order is able to (at least partially) predict the price valleys and peaks in order to properly determine the period indices of buy and sell bids. Although recent results [5] show that such predictions are possible in the case of data from the last decade, the price-profiles of day-ahead markets may be subject to change, and such prediction methods have to be re-evaluated in the face of recent datasets.

V. CONCLUSIONS AND FUTURE WORK

In this work we proposed a novel order type dedicated for storage type units, which could facilitate their participation in day-ahead markets. The proposed order explicitly considers important parametrs of the storage units, as maximal capacity and loss ratios of the charge and discharge processes, may be applied to one or multiple charge-discharge or discharge-charge cycles and allows partial acceptance of the component bids. The proposed formulation is fully compatible with the EUPHEMIA framework and introduces only linear equations and inequalities (no additional integer variables are needed). The profitability of the order may be ensured by the appropriate choice of price parameters. As the adequate use of the proposed order is only possible if the submitting participant is able to at least approximately predict the high- and lowprice periods, the statistical characteristics of market data have to be analyzed in order to fully evaluate the applicability of the proposed order format. In addition, further work is required to analyze the possibility of similar storage-oriented special orders, which avoid the allowance of paradox rejection of the component bids.

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