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VALUATION OF PARALLEL OPERATION OF BATTERIES IN SPOT AND BALNCING ELECTRICITY MARKETS

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ABSTRACT

Although integration of higher shares of renewable energy sources in the energy mix improves sustainability, it has profound consequences for the electricity markets. The uncertainty and variability of renewables escalates the need for cost-effective ways to balance supply and demand in real-time. Energy storage systems are considered a viable solution to hedge against the intermittency of supply. However, most prior studies suggest marginal or even negative profitability of batteries when participating in one stage of the electricity market. Given the physical characteristics of batteries which make it suitable for in multiple market stages, we investigate the profitability of batteries when simultaneously participating in the day-ahead and balancing markets. We formulate a stochastic programming framework to choose optimal market position, optimal bidding strategy, and optimal capacity split between the two markets. Our results show that participation of batteries in multiple stages of the electricity markets generates additional profit for the battery. The optimal strategy is to participate in the day-ahead market with full capacity as a seller and with full-capacity in the down-regulation secondary balancing power market as a buyer.

Keywords: Energy storage, Stochastic optimization, Energy and regulation markets

1. INTRODUCTION

Due to sustainability concerns, several countries plan to keep increasing the share of renewables in their energy mix [1]. Among all renewables, the expansion in solar and wind power installation seem to be the most promising as sustainable solutions. Especially with their ever-decreasing prices of these two technologies and their small marginal costs, the world-wide capacity of solar and wind increases exponentially fast. The replacement of reliable fossil fuel generators with less predictable solar and wind power generation, however, brings challenges to the elements of the energy systems, one of which being electricity markets.

Initially designed for mostly predictable energy sources, existing electricity systems can only handle a moderate share of renewables, as the dominant energy sources are the predictable and reliable fossil fuel energy sources. However, as the share of renewables increases, the uncertainty of supply increases and this might lead to market manipulations, inefficiency, or increased carbon emissions [2].

One approach to address the challenges of renewables is battery storage. Batteries are compatible to respond instantaneously when wind and solar output is low. Furthermore, batteries are well-suited to store energy when there is peak in supply and release it when energy is of greatest value.

Batteries can be used in several energy applications including, incentivizing demand response for cost reduction and reliability, together with renewable energy generation to reduce power curtailment and pay back periods of solar PV-panels/wind-turbines, and in electricity markets to make profit. Electricity markets are evolved mostly since the beginning of this century, to provide a competitive environment (moving away from traditional monopolies) for electricity trading at national level [3]. The application of batteries in electricity markets can be vital for balancing out electricity and guaranteeing reliability and avoiding congestion and

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outages. Electricity markets are structured in multiple time stages and a battery agent can independently participate in one or multiple of such markets. While most prior studies focus on participation in one market (typically day-ahead), simultaneous participation in multiple stages might make batteries more financially attractive.

Inspired to improve the financial viability of batteries in electricity markets, in this paper we investigate the optimal market position, bidding strategies, and capacity split of the battery capacity between two markets (day-ahead and balancing).

In section 2 we explain our approach and problem formulation. Section 3, represents the results of the case study followed by conclusion in the last section.

2. APPROACH

While electricity markets in all locations typically follow a similar pattern in their sequential structure (see Fig 1), there are also some variations in the detail designs [4]. In this paper, our focus is on the common European market design and in particular, the case of Germany's electricity markets.

Due to different reaction times of the energy suppliers in the electricity mix and the uncertainty of demand/supply, electricity markets allow trading in multiple time stages before the time of operation (see Fig 1). This includes forward markets (year-ahead, month-ahead, week-ahead), spot market (day-ahead, intra-day), and balancing market (aka, real-time market) (few minutes ahead of the operation time). In this study, we focus on battery participation in two stages of the market: day-ahead (DA) market and balancing market, as these two are known to be the best fit for batteries.

Day-ahead markets are merit-order auction-based markets. Bulk energy suppliers and consumers submit their asks and bids to the auction-based day-ahead market for the following day, a few hours before the start of the operating day. Based on the cleared prices and quantities of the market, the bids and asks determine the energy commitment of suppliers as well as the prices that they will receive.

To account for mis-predictions of electricity supply-demand in earlier stages of the market and potential unknown failures, there is a need for balancing markets close to the time of operation [5]. Balancing market ensures the continuous reliable operation of the power system. In the German liberalized power market, the transmission system operator (TSO) organizes the procurement of the balancing power through public auctions. The procurement of balancing is provided through public auctions.

In the balancing power market, suppliers can participate in three different market places with separate auctions, the primary balancing power market (PBP), the secondary balancing power market (SBP), and the tertiary balancing power market (TBP). These markets are distinguished by the reaction time of the balancing power being available to the grid

There are two types of balancing power: positive balancing power which needs to be activated when there is shortage of supply, and negative balancing power activated in case of oversupply. Therefore, a power plant that provides negative balancing power in case of call needs to decrease its load, while a power plant providing positive balancing power typically increases its load.

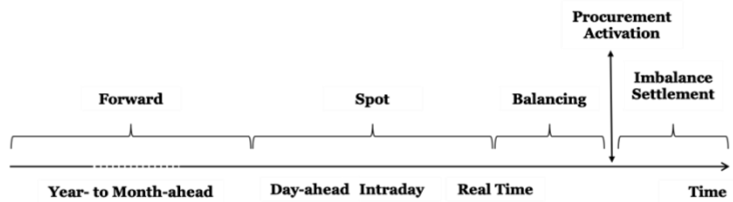

Fig 1 Electricity wholesale market stages

Among the three balancing markets, the SBP is reportedly a good fit for battery storage devices; hence, in our study, we choose to focus on this market in combination with the DA market.

2.1 Problem Formulation

In this section, we formulate the overall profit of a battery agent, when participating in both the DA and the SBP markets. The optimal market position, capacity split of the battery between the two markets, as well as the optimal bidding strategies are considered as the decision variables.

In each time period of the DA market t, the battery agent bids to get discharged (sell) with E_t^d energy units and charged (buy) by E_t^c energy units. The agent will receive (pay) the clearing price λ_t of the DA for every unit of energy it sells (buys). In addition, charging (discharging) battery incurs depreciation cost C^d per unit of energy, which affects the profit of battery agents.

The market structure in the SBP is more complicated than the DA market. Bidding in the German balancing market consists of 3 components: the power offer, the power bid, and the energy bid. The power offer [MW] represents the amount of balancing power offered, the power bid encompasses the offered price [EUR/MW] for keeping the balancing power available, and finally, the energy bid [EUR/MWh] compensates the offered price for actual delivery of balancing energy.

The up-regulation (down-regulation) power offer P_t^U (P_t^D), which is the selling (buying) power with the power price offer γ_t^U (γ_t^D), is rewarded based on the pay-as-bid rule. If the power bid is accepted, suppliers make profit with the energy bid (φ_t^U, φ_t^D) as well. This is the case when the offered power is actually called for stabilizing the grid frequency. The energy bids of suppliers with awarded power bids are arranged in increasing order in the up-regulation SBP market and decreasing order in the down-regulation SBP market. Thus, the lowest (highest) energy bid is cleared first in the up-regulation (down-regulation) market.

The overall profit of the battery agent can be expressed as the following non-linear stochastic optimization program:

$$
\begin{aligned}
Maximize\ \pi = & \sum_{t=1}^{T}\left[P_t\,(E_t^d - E_t^c) - C^d(\,\eta^c E_t^c + \frac{E_t^d}{\eta^d})\right] \\
& + \sum_{t=1}^{T} \omega_t^U \gamma_t^U P_t^U + \omega_t^D \gamma_t^D P_t^D \\
& + \sum_{t=1}^{T} \omega_t^U \pi_t^U \left(\varphi_t^U E_t^U - C^d \frac{E_t^U}{\eta^d}\right) \\
& + \omega_t^D \pi_t^D (\varphi_t^D E_t^D - C^d \eta^c E_t^D)
\end{aligned}
$$

The first term in the objective function, represents the profit made in the DA market, while the second and third lines represent the profit of battery agent from bidding in the SBP market. In the above equation ω_t^U and ω_t^D, represent the probability of winning in the auction for up and down regulation, which are functions of the offered capacity prices. Finally, π_t^U and π_t^D, represent the probability of being called for up and down regulation, which are functions of the offered energy prices.

This optimization problem is restricted by multiple constraints. Physical constraints of operation of battery naming battery charge and discharge efficiency, maximum depth of discharge, the bound of energy flowing in/out of the storage, have been considered.

RESULTS

To compare the profitability of battery in different market stages we solve the above optimization and obtain the best market position accordingly. We assume that the battery unit can produce up to 50 MW power. The price values for the day-ahead energy and balancing markets are obtained from the system operators for the year 2018, which are available through (www.epexspot.com) and (www.regelleistung.net).

We undertake the price of Li-ion batteries in 2019, which is 158 \$/kWh (www.statista.com).

There are three possible scenarios: only day-ahead market participation, only balancing market participation, and simultaneous participation in the day-ahead and balancing market. Table compares the profitability of these scenarios. According to this table, the most profitable scenario is when battery participates in the two markets in parallel and therefore it can arbitrage between the two markets.

Scenario	**Profit (EUR)**
Day-ahead market	2228
Balancing market	30540
Day-ahead and balancing market	49038

Figure 2 shows the normalized profit of battery from participating in the DA market and SBP market (for down regulation) for different capacity devotion in SBP. It also details on the break-down of the profit made through DA trading and SBP trading. Even though the share of SBP profit is limited compared to the down-regulation, according to this figure, it is still beneficial to stay active in both markets. Indeed, while Fig 2 only focuses on financial trading and benefit, our analysis shows that in terms of the amount of energy traded in the optimal scenario, DA trading and SBP trading are comparable. As a second observation, Fig 2 shows that the more capacity is devoted to the down-regulation SBP, the higher the profit. Given this observation and back-tracking the energy trading, we find that the optimal strategy is to participate in the DA with full capacity as a seller and with full-capacity in the down-regulation SBP as a buyer. We also find battery agent often act as an arbitrager between the two markets in the optimal scenario.

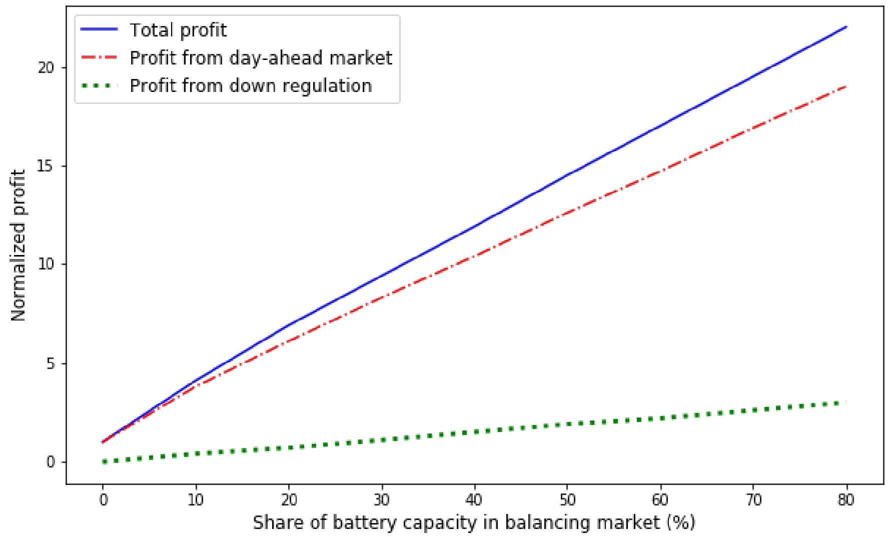

Fig 2 Profit of battery from day-ahead and down regulation

CONCLUSION

Profitability of battery agents is pivotal to unleash the great potentials of batteries to provide the extensive energy flexibility needed in power systems. Due to high costs of batteries and complicated operations of electricity markets there are still pessimistic views on whether or not batteries could be financially viable as a major flexibility option. In this paper, we develop a novel approach for optimal operation of such storage systems run by private investors.

Our methodology proposes an optimal market participation and bidding for batteries to offer in both day-ahead energy as well as balancing market when significant fluctuations in electricity supply and market prices exist due to high penetration of intermittent renewable sources.

Our model was based on a stochastic optimization framework to calculate bidding components and best market to participate. Our results showed that the optimal strategy is to participate in the DA with full capacity as a seller and with full-capacity in the down-regulation SBP as a buyer.

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