Integrating power and reserve trade in electricity networks

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Abstract

As power markets become liberalised and include more intermittent generation, the trade of reserve energy will become more important. We propose a novel bidding mechanism to integrate power and reserve markets. It facilitates planning for bidding in both markets and adds expressivity to reserve bids[1].

1 Introduction

The currently most popular power market design is to conduct two separate ahead-markets for each hour of the following day - one market to trade binding commitments to transfer power (the *day-ahead market*), and one market to trade optional intervals of power (the *reserve market*). In a real-time balancing phase, the differences between the outcome of the day-ahead market and actual demand are settled by executing parts of the intervals sold in the reserve market. The System Operator (SO) most often functions as the market maker, who, in our case, clears both markets simultaneously. Formally, during the day-ahead phase, a generator g, with a capacity $\in [P_g^L, P_g^U]$ and a convex cost function $c_g(P)$, sells a default amount of power P_g^{def} and offers an optional interval $[0, P_g^{opt}]$. During balancing, the SO can execute $P_g^{exe} \in [0, P_g^{opt}]$ per generator g. In both phases combined, g will sell at least P_g^{def} and at most $P_g^{max} = P_g^{def} + P_g^{opt} \leq P_g^U$.

The trade volume of reserve power is expected to grow: We are faced with decreasing certainty of supply caused by the advent of intermittent generation, i.e. renewables like solar and wind, and hope to use technologies like storage systems and Demand Response to manage this problem. This paper explores this new research challenge, beginning with the standard use case of reserve capacity offered by supply.

Although there is in fact only one product (power capacity) which can be offered in both markets, the bids for fixed power and reserves are currently made separately. This causes several problems for bidders. First, the success in one market depends strongly on the accuracy of assumptions made about the outcomes in the other market - this includes, but is not limited to, the problem of calculating opportunity costs for unsold parts of P_g^{opt}. It would simplify this planning problem if g could make assumptions about the outcome for P_g^{opt} while constructing the bid for P_g^{def}, and vice versa. Second, one convex cost function cannot be represented by two convex bid functions - therefore, the bid for reserves are currently restricted to only a constant price for each activated unit in P_g^{exe}. As the costs to produce P_g^{exe} are convex, this leads to imprecise bids by design, which increases the volatility of prices.

We propose a novel, bundled bid format for generators and an associated clearing mechanism for an integrated power- and reserve market. The bid format helps g with the problem of bidding in two dependent markets by allowing to include an assumption about the ratio between P_g^{def} and P_g^{opt}. It also allows to offer P_g^{opt} with a convex price function, which allows for a constant per-unit profit, independent of P_g^{exe}. The profit maximisation problem which g faces becomes less complex and its outcomes can be more stable against uncertainty and misconceptions about market outcomes. We formulate the two-stage clearing process of the SO as a Strictly Convex Quadratic Programming problem [1], which we have successfully implemented in the well-known electricity network simulation framework AMES [3] (which incorporates transmission constraints into power pricing).

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2 The bid format

Generator g maps amounts of power to total prices via a quadratic bid function. Quadratic functions are widely used to model bids in power markets because they are sufficiently realistic and their derivatives are continuous, and thus marginal prices are well-defined. To also express bidding for reserve capacity P_g^{opt} within these supply functions, we propose that g fixes the ratio $r = P_g^{opt}/P_g^{max}$ for each bid, such that knowing P_g^{def} determines $P_g^{opt} = P_g^{def}\frac{r}{1-r}$. For example, with $r = \frac{1}{3}$ we denote that P_g^{def} will certainly be sold and $[0, P_g^{opt}] = [0, (\frac{1}{3}P_g^{def})/\frac{2}{3}]$ is the optional interval. Thus, the market clearing determines the two intervals $[0, P_g^{def}]$ and $[P_g^{def}, P_g^{max}]$, allowing g to price P_g^{def} and P_g^{exe} on the same function.

At $r = 0$, no flexibility is offered and the generator has full certainty how much he sells ($P_g^{def} = P_g^{max}, P_g^{opt} = 0$). This resembles traditional bid functions with no reserve offer. At $r = 1$, everything is flexible and the SO will assume full flexibility over P_g^{exe} in the balancing phase ($P_g^{def} = 0, P_g^{opt} = P_g^{max}$). Generator g can place several bids $b_{g,r}$, each using a different $r \in [0, 1]$.

With values for $r > 0$, g will want to account for costs of (potentially) lost opportunity in the bid. He can increase the slope of the bid function, such that the expected total revenue, when taking an expected probability distribution over P_g^{exe} into account, compensates these costs.

3 The market mechanism

We now formulate a Constraint Satisfaction Problem for the day-ahead phase. The SO conducts a one-shot auction. Demand is modelled by agents $l \in L$, where L stands for Load-serving-entities (LSE), who only submit the requested amounts for fixed power P_l^{def} and reserve power P_l^{opt}. The SO chooses one bid b_{g,r_g} per generator g and announces a market clearing price γ_{def}, which defines how much each unit in $\sum_g^G P_g^{def}$ will be paid for. The marginal clearing price of the balancing phase γ_{exe} will be higher - its theoretical maximum is known as it will also be determined from the winning bids b_{g,r_g}. Via γ_{def}, each generator can look up on b_{g,r_g} how much power P_g^{def} he is committed to supply and this also tells him how much reserve capacity P_g^{opt} he needs to keep available. The optimisation goal of the SO is to minimise generation costs. One approach is to only minimise the costs which are known for sure in this phase ($\sum_g^G P_g^{def}\gamma_{def}$), another is to include an estimation of the costs of the balancing phase ($\sum_g^G P_g^{exe}\gamma_{exe}$). The first constraint to this optimisation requires that demand is satisfied: $\sum_g^G P_g^{def} = \sum_l^L P_l^{def}$. Secondly, the SO needs to make sure that each generator will stay within his generation limits: $P_g^L \leq P_g^{def} \leq P_g^U(1 - r_g)$. Each generator agrees to hold back reserve capacity $P_g^{opt} = P_g^{def}\frac{r}{1-r}$. The overall reserve capacity needs to match the demand for reserves. Hence, we add the third constraint $\sum_g^G P_g^{opt} \geq \sum_l^L P_l^{opt}$.

The number of functions each generator can bid is a parameter of the mechanism. This is a trade-off between the time complexity of finding a solution and the freedom of the generators to bid on many r.

During the balancing phase, LSEs announce their balancing requirements $P_l^{exe} \in [0, P_l^{opt}]$. In order to find γ_{exe} and thereby allocate each generator a value for $P_g^{exe} \in [0, P_g^{opt}]$, the SO translates the interval $[P_g^{def}, P_g^{max}]$ of each successful bid b_{g,r_g} from the day-ahead phase into a new bid function b_g^{bal} in the interval $[0, P_g^{opt}]$. These translated bids are then used to minimise $\sum_g^G P_g^{exe}\gamma_{exe}$.

References

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