

Micro-market Operation Strategy Based on Two-way Bidding of Electric Vehicles and Battery Energy Storage

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Abstract. To solve the problem that charging is constrained by the capacity of distribution facilities under high penetration of electric vehicles (EVs), this paper proposes to improve EV charging capacity through battery energy storage (BES) and presents the design of a locally organized market, namely micro-market, that manages the energy transactions between EVs and the BES. When the load of a distribution system approaches its limit, additional EV charging demand is met by the BES, and the price is determined in an automated two-way bidding process. This mechanism can increase EV charging capacity as well as provide an additional revenue stream for the BES in distribution systems. The presented micro-market design ensures the balance between revenue and expenditure of market participants. The organization and settlement process of the micro-market are demonstrated using an example case, and the effectiveness of the design is proved.

1 Introduction

Because of the cost-saving advantages and environmental benefits, electric vehicles (EVs) have received extensive attention and seen rapid growth. With the increasing number of EVs, the charging demand of EVs has brought obvious impact on the stable operation of the power grid, especially in peak load period [1,2]. Orderly charging of EVs is of great importance to reduce the impact of EV charging on the power grid [3,4].

In residential areas with old distribution systems, it is difficult to install charging facilities due to capacity limitation [5], and the economic benefits of expanding the power distribution system are low. Battery energy storage (BES) can be used to power delivering capability of these systems. However, most revenues of the demand-side energy storage projects come from energy arbitrage, i.e., profiting from the energy price difference between peak and valley periods, and the business model is hardly viable in residential areas due to the high installation cost and limited price differential.

A locally organized energy market design, namely micro-market, is proposed to solve the above problem. In the micro-market, EVs charging demand are met by the BES, which is compensated based on the market clearing price determined through a two-way bidding process. Using this approach, the number of EV charging facilities installed in old residential areas can be increased and the EV charging demand can be better met. Additionally, the BES in the residential areas can have another revenue stream by supplying energy to EVs.

2 Micro-market operation strategy

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2.1 Market bid

2.1.1 Electric vehicle bid

EV users that connect their vehicles to charging facilities need to submit a charging price for each scheduling period. The charging price can be updated in real time according to its own charging demand and power supply availability.

2.1.2 BES bid

BES needs to submit the default discharging price for each scheduling period. The discharging price can be updated in real time according to the BES's state of charge (SOC) and EV charging demand.

2.1.3 Power company bid

Although the power company does not need to bid into the micro-market, the normal electricity price can be considered as the bidding price for the remaining capacity of the transformer.

2.1.4 Bid limit

To ensure the reasonableness of the market clearing price, the upper and lower limits of the bidding price of the EV and the BES are set. Usually, the minimum bidding price is higher than the normal electricity price.

2.2 Market organization

If the remaining capacity of the transformer cannot meet the charging demand, the micro-market operation strategy is needed. The following content describes the micro-market design.

Based on market bidding, the bidding prices of EVs (buyers) are sorted from high to low, and the bidding prices of the power company and the BES (sellers) are sorted from low to high. Then, the market is cleared according to the principle of high-low matching. The market process is shown in Figure 1.

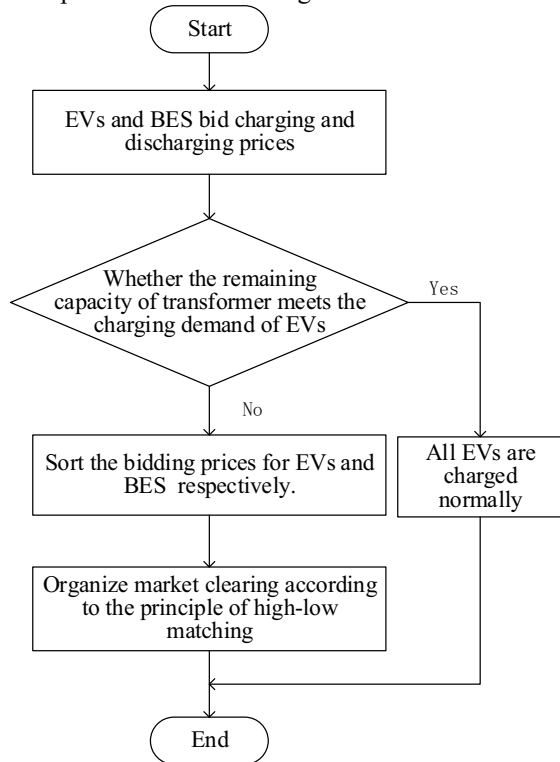


Figure 1. The market organization process.

The high-low matching method first compares the highest charging price with the lowest discharging price, if the charging price is higher than the discharging price, match the transaction; then in the remaining unmatched charging and discharging prices, match the transaction in the same way as above until there is no comparable bidding prices or the highest charging price is lower than the lowest discharging price. Since the bidding price of the power company is equivalent to the normal electricity price, and the bidding price of BES is higher than the normal electricity price, it is guaranteed that the remaining capacity of the transformer is cleared first. The diagram of high-low matching is shown in Figure 2.

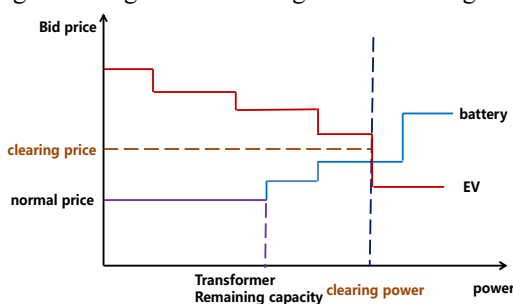


Figure 2. The diagram of high-low matching.

If the bidding prices of EVs or BES in the last transaction pair are equivalent, the trading energy will be distributed according to the proportion of rated charging or discharging power.

2.3 Market settlement

The average value of charging price and discharging price of the last set of matching transaction pairs is the market clearing price. The settlement price of the power company is the normal electricity price. The settlement price of EVs and BES is the market clearing price.

However, there will be an imbalance in market revenue and payment. The charging payment of EVs is higher than the power supply revenue of the power grid company and BES. The market surplus is the difference between charging payment of EVs and the power supply revenue of the power grid company and BES. The formula of the market surplus for a time interval is as follows:

$$C_{sur} = \sum_{i=1}^n \alpha_i \cdot p_i^c \cdot t_i^c \cdot P_c - \sum_{j=1}^m \beta_j \cdot p_j^d \cdot t_j^d \cdot P_c - p^r \cdot t^r \cdot P_0 \quad (1)$$

$$= p^r \cdot t^r \cdot (P_c - P_0)$$

Where, n and m are the number of EVs and BES in the market, respectively. α_i and β_j are 0-1 variables, which indicate whether EV i and BES j have won the bid. $\alpha_i=1$ means that the EV can be charged, $\alpha_i=0$ means that it cannot be charged. The same is true for BES. p_i^c and p_j^d are charging power of the EV and discharging power of the BES, respectively. t_i^c is the charging time of the EV in the time interval, t_j^d , and t^r are the energy supply time of the BES and the transformer in the time interval. P_c and P_0 are the market clearing price and normal electricity price. p^r is the remaining capacity of the transformer.

The market surplus needs to be returned to EVs and BES in proportion to the amount of charging energy and discharging energy.

The final payment of the EV is the difference between charging payment and market return part. The final revenue of the BES is the sum of discharging revenue and market return part.

The market settlement process is shown in Figure 3.

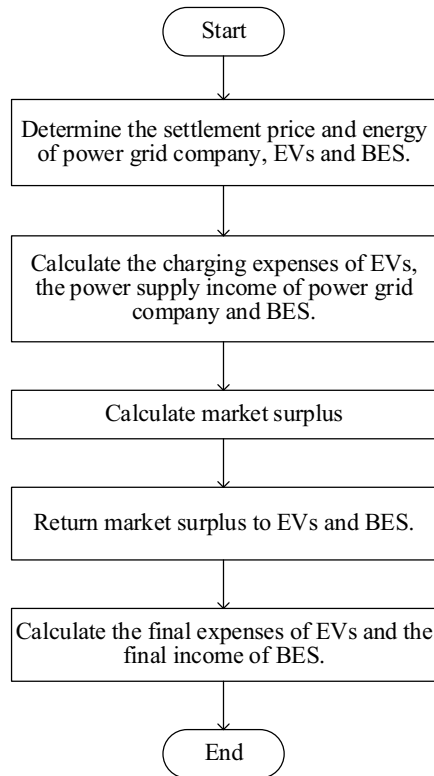


Figure 3. The market settlement process.

3 Example analysis

3.1 Scene and parameter setting

To explain the operation method of market organization and market settlement more clearly, the corresponding scene is set up for an example analysis. Suppose a residential area is equipped with a 630kVA transformer, twenty 7kW AC charging piles and five BES. The total power of the charging piles is greater than the difference between the transformer capacity and the peak load of other loads except EVs.

In this paper, the time interval of micro-market is set to 1 hour. The normal electricity price is \$0.52. The upper and lower limits of bid price of the EV and the energy storage battery are both \$0.52 and \$1.25 respectively.

If the other load is 560 kW in one hour, assuming that the twenty charging piles are connected by EVs during this period, it is obvious that the remaining capacity of the transformer cannot meet the charging demand, so the micro-market trading mechanism needs to be activated.

The charging prices confirmed by the users of the twenty EVs in this period are shown in Table 1. The battery capacity and current stage of charge (SOC) of the twenty EVs are shown in Table 2.

Table 1. Charging prices of EVs.

No.	Charging price (\$/kWh)	No.	Charging price (\$/kWh)
1	0.77	11	0.73
2	1.12	12	1.00
3	0.75	13	0.76

4	0.83	14	1.16
5	1.25	15	0.85
6	0.60	16	0.53
7	0.83	17	0.69
8	0.78	18	0.97
9	0.71	19	0.76
10	0.77	20	0.80

Table 2. Battery capacity and SOC of EVs.

No.	Battery capacity (kWh)	SOC (%)	No.	Battery capacity (kWh)	SOC (%)
1	52	50	11	20.3	45
2	25.6	33	12	41.4	40
3	41.4	66	13	62	58
4	52	41	14	25.6	38
5	82	55	15	82	54
6	20.3	65	16	41.4	70
7	25.6	44	17	52	60
8	82	49	18	62	45
9	62	57	19	25.6	57
10	41.4	40	20	20.3	32

The discharging prices of BES are shown in Table 3. The rated discharging power of the five BES are shown in Table 4.

Table 3. Discharging prices of BES.

No.	Discharging price (\$/kWh)
1	0.62
2	0.79
3	0.58
4	0.68
5	0.55

Table 4. Rated discharging power of BES.

No.	Rated discharging power (kW)
1	16
2	10
3	20
4	18
5	10

3.2 Clearing and settlement results

The high-low matching process of micro-market is shown in Figure 4. It can be seen that the last group of deals is the No. 17 EV and the No. 4 BES. Therefore, all EVs except No.6 and No.16 and all BES except No.2 win the bid.

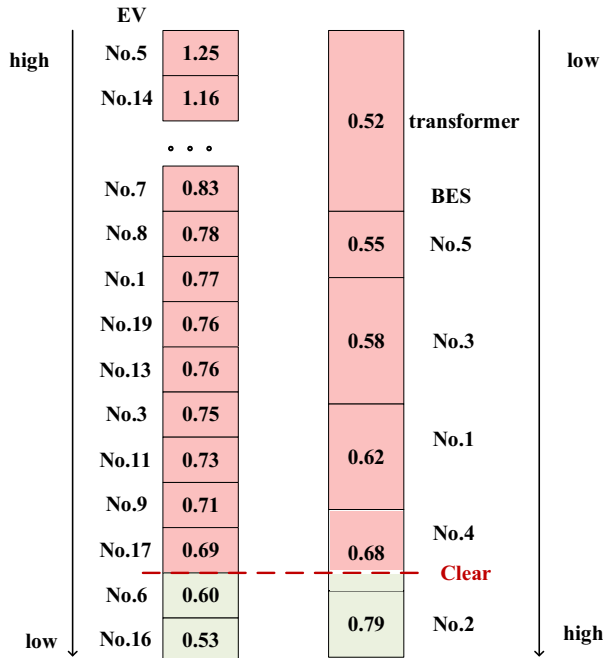


Figure 4. The high-low matching process of micro-market.

The micro-market clearing price is 0.685\$/kWh. The settlement prices of the power grid company, the EV and the BES are 0.52\$/kWh, 0.685\$/kWh and 0.685\$/kWh, respectively.

The remaining capacity of the transformer is 70kW, and the total revenue of the grid company is \$36.4.

It can be seen from table 2 that it takes more than 1 hour for each EV to be fully charged. So, the charging energy of each EV is 7kWh. The charging payment of each EVs is \$4.79, and the market return part is \$0.44. The final expenditure of each EVs is \$4.35.

The settlement result of BES is shown in Table 5.

Table 5. Settlement of BES.

No.	Discharging energy (kWh)	Discharging revenue (\$)	Market return (\$)	Final revenue (\$)
1	16	10.96	1.01	11.97
2	0	0	0	0
3	20	13.7	1.26	14.96
4	10	6.85	0.63	7.48
5	10	6.85	0.63	7.48

Finally, the total payment of EVs is \$78.3, the total revenue of power companies is \$36.4, and the total revenue of BES is \$41.9. The whole market is in balance.

If there is no micro-market mechanism, the remaining capacity of the transformer in this hour can only meet the

charging demand of seven EVs. Under the proposed micro-market, eighteen EVs are charged. EV users can meet their own charging demand through reasonable bidding prices.

4 Conclusion

To solve the problem of insufficient EV charging facilities due to limited transformer capacity, a micro-market design with market bid, market organization and market settlement mechanism is proposed. The basis of the market is the two-way bidding of EVs and BES. EVs submit charging prices and BES submit discharging prices. The market clearing is completed by matching the high and low bidding prices of both parties.

A scene of residential area is set up to explain the operation method of market organization and market settlement. The effectiveness of the micro-market operation strategy is proved by simulation results. More EV users' charging demand are met, and the BES realizes benefits through the business model of energy supply for EVs.

It should be pointed out that the effective operation of the micro-market is based on the reasonable bidding prices of the EVs and the BES. If the bidding price of the EVs is too low or the bidding price of the BES is too high, the market may not be able to match and clear.

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