Research on Discharging Price of Electric Vehicle Participating in Power Grid Dispatching Considering Reverse Cost

Feng Tingting¹, Zhang Junqi¹, Peng Guangjin², Xie Wenrui²,
¹Grid Chongqing Economic Research Institute, 401120, China State
²State Key Laboratory of Power Transmission Equipment and System Security (Chongqing University), Chongqing, 400044, China
Corresponding author e-mail: pengguangjin@cqu.edu.cn

Abstract. As a controllable load and distributed energy storage unit, electric vehicle (EV) can use electric vehicle with vehicle-to-grid (V2G) technology to realize peak load shifting. In order to study the maximum bearing price of the grid in the discharge behaviour of electric vehicles, the paper takes the lowest operating cost of the grid as the objective function, establishes the optimal unit combination model of the standby unit during the peak load. The maximum bearing price of the grid is applied to the maximum cost of scheduling electric vehicle. Then the relationship between the maximum acceptable price and the power of the electric vehicle can be obtained. With the day-ahead load forecast, the upper limit of the electric vehicle acceptable discharge price is obtained. Finally, the simulation and analysis of the proposed method are carried out by numerical examples, and the feasibility and effectiveness of the proposed method are verified.

1. Introduction
The interaction between EVs (EV) and power grids is one of the key technologies for smart grid construction in the future. EVs are discharged to the grid during the peak load period through charging facilities, which not only provide peaking and frequency regulation services, but also can create considerable revenue for grid and EV owners [1].

In recent years, with the popularization of EVs in developed countries, the economic benefits of ancillary services have received extensive attention [2]. The application of V2G technology to adjust the grid load requires the positive response of the EV owner, and the discharging price is the key factor affecting the enthusiasm of the EV owners. Therefore, the electricity market price mechanism, as an important basis for V2G implementation, has important research value [3].

At present, most scholars are studying the charging price of EVs [4-6], while the research on discharging price is rare. In [7], aiming at the randomness and particularity of charging behaviour of EVs, a charging and discharging game model of distributed EVs is established, and the optimal scheduling strategy is obtained by Nash Equilibrium. In [8], genetic algorithm is used to solve the optimal real-time electricity price and the battery-changing behaviour of EVs is guided through the electricity price. Literature [9] established a model for maximizing the charge and discharge revenue of EVs, reflecting the impact of real-time electricity prices on the distribution of EVs and the operating costs. Literature [10] studied the discharge behaviour of EVs in the Denmark electricity market. According to the existing electricity market mechanism in Denmark, the monthly income of EVs participating in V2G secondary frequency regulation service is 49.8-1327.4 yuan. In [11], the
optimization algorithm is proposed. The objective function is the minimum peak-to-valley difference and the maximum benefit of the EV owners, then the charge and discharging price are obtained. At present, most of the research on discharge electricity price pursues the greatest benefit for EV owners but ignores whether the grid can receive the price. Therefore, considering the standby cost of the grid has an especially key role in studying the discharging price.

From the perspective of grid economic operation, the paper firstly studies the optimal units’ combination model of power grid dispatching standby units during load peak period and analyses the objective function and constraint conditions of V2G unit combination model. Then, the lowest cost of electricity purchase is the objective function. By continuously changing the power of the EV into the network, the relationship between the maximum discharging price of the EV and the grid-connected power of the EV can be obtained by the grid; then, compared with the grid load forecast, the standby power that needs to be dispatched at each time of the day is obtained. Therefore, the limits of the acceptable electricity price of the grid in each period are obtained. Finally, the simulation method is used to verify the proposed method.

2. Model of standby units cost on peak time

In this paper, the standby units dispatching cost on the peak load is taken as the maximum limit of the grid's acceptable cost for the same capacity of EVs, so as to obtain the relationship between the maximum discharging price that the grid can accept and the power consumption of the EV. For different standby dispatch requirements, with the minimum power generation cost as the objective function, the corresponding power generation cost is obtained by the model, which is the highest cost of EV discharging price acceptable to the grid. However, during the peak load period, the EV may not be able to meet the standby dispatch requirements of the system and can only partially replace the standby units. But even if the EV cannot completely replace the standby units, it is economically feasible as long as the cost of dispatching the standby units can be reduced. The calculation process of the relationship between the highest price of the EV participating in the power system dispatching and the power needed is shown in Figure 1. The main steps are as follows:

![Figure 1. Calculation flow chart of relationship between price and power of EV](image)

3. Objective function and solution algorithm

In this paper, the grid with EVs is taken as the research object. The objective function is to minimize the operating costs and power generation costs of the power system, thereby establishing a V2G-units combination model.

3.1. Objective function
The cost of the traditional unit is mainly the fuel cost, and the fuel cost of each conventional unit is described in the form of a polynomial, as shown in equation (1).

\[
\min TC = \min \sum_{i=1}^{n} (FC_i P_i(t))
\]

Where, \( FC_i(P_i(t)) \) is the fuel cost function:

\[
FC_i(P_i(t)) = a_i + b_i P_i(t) + c_i P_i^2(t)
\]

Where, \( P_i(t) \) is the output of the \( i \)-th generator set (MW), \( a_i, b_i, c_i \) are the fuel cost factors.

3.2. Constraints

3.2.1. EV constraints
The number of EVs participating in the discharge in each period should be less than the number of EVs currently able to participate in the grid dispatch, and the SOC of the EV battery has upper and lower limits.

\[
N_e(t) \leq N_e^{\text{max}}(t)
\]

\[
SOC_{\text{min}} \leq SOC(t) \leq SOC_{\text{max}}
\]

Where, \( N_e(t) \) refers to the number of EVs discharging the period \( t \), \( N_e^{\text{max}}(t) \) refers to the maximum number of EVs that can participate in the discharge during the period \( t \); \( SOC(t) \) refers to the state of charge of EVs, and \( SOC_{\text{max}} \) refers to the upper limit of the state of charge of EVs, \( SOC_{\text{min}} \) refers to the lower limit of the state of charge of EVs

3.2.2. System power balance constraint
At any one time, the output of the generator sets in the grid plus the power provided by the EV should meet the load demand plus the system power loss.

\[
\sum_{i=1}^{N} P_i(t) + P_e N_e(t) = D(t) + P_{\text{loss}}
\]

Where, \( P_i \) is the discharge power of EVs; \( D(t) \) is the load demand during the period \( t \); \( P_{\text{loss}} \) refers to the network loss.

3.2.3. Rotating spare constraint
In order to keep the power system safe and reliable, the rotation reserve must be sufficient.

\[
\sum_{i=1}^{N} P_i^{\text{max}}(t) + P_e N_e^{\text{max}}(t) \geq D(t) + R(t) + P_{\text{loss}}
\]

Where, \( P_i^{\text{max}}(t) \) refers to the maximum output power of the \( i \)-th generator set at period \( t \); \( R(t) \) refers to the system’s rotating standby demand at period \( t \).

3.3. Solution algorithm
In this paper, optimal power flow calculation is combined with the particle swarm optimization algorithm [12]. The number of EVs in each node is used as the particle in the algorithm, and iteratively proceeds to the optimal power flow for the target. Compare the optimal solution and finally solve the function.
Yes

Initialize SAPSO parameters and N initial solutions are given randomly

Execute SAPSO search

Perform SA sampling process on N initial solutions

Let $g_{\text{best}}$ be the optimal solution in $P_{\text{best}}(i)$

Update SAPSO parameters

End of iteration?

No

Yes

Output optimal solution

Figure 2. Flow chart of PSO Algorithm

4. Case study

In this paper, six standby units under the A city power system are used for case study. It is assumed that only 8, 10-13, 20 of the daily time need spare unit output, the power is 100, 100, 150, 200, 100, 100, 100 MW, respectively. Due to the characteristics of EVs, EVs may not completely replace the standby units during the peak load period. This paper analyses the situation that the EV is completely replaced and cannot completely replace the standby units.

When the EVs can completely replace the standby units, according to the algorithm of this paper, the cost curve of the standby units (When require 10-200 MW power) can be calculated, so the relationship between the maximum discharging price and dispatched power of the EV can be obtained. As show in Figure 3. As can be seen from Figure 3, the unit power generation cost decreases as the power increases. When the power continues to increase beyond the upper limit of the unit's output, the new unit will be activated (the turning points in the figure). In general, the greater the power that EVs can provide, the lower the maximum acceptable discharging price for the grid, which is the maximum discharging price for the EV to completely replace the standby units.

![Figure 3. Power-price relationship curve of standby units](image1)

![Figure 4. Power-price relationship curve of EVs under different standby units power output](image2)

EVs may not completely replace the standby units output during peak load period. Assume that the power of the standby units is 100MW, 150MW and 200MW respectively, the EV can only partially replace the output of the standby units. Calculate the relationship between the power of the EV and the maximum discharging price in these three cases, as shown in Figure 4.

Assuming that EVs can only provide 30MW, 50MW and 80MW power on the same day, the period that need to dispatch standby units and electricity price are shown in Table 1. Finally, the relationship between the output power of the EVs and the maximum acceptable discharging is show in Figure 5. The
maximum acceptable discharging price of the grid under the different power output of EVs are shown in Figure 6.

Table 1. The price of the standby units under different output power of EV (yuan/kWh).

|       | T8 | T10 | T11 | T12 | T13 | T20 |
|-------|----|-----|-----|-----|-----|-----|
| 30MW  | 2.28 | 2.28 | 2.40 | 2.42 | 2.28 | 2.28 |
| 50MW  | 2.14 | 2.14 | 2.28 | 2.39 | 2.14 | 2.14 |
| 80MW  | 2.14 | 2.14 | 2.22 | 2.30 | 2.14 | 2.14 |

Figure 5. The relationship between the power of EVs and the maximum discharging price acceptable to the grid in each period

Figure 6. The maximum acceptable discharging price to the grid of three kinds of EVs

5. Conclusion
This paper studies the relationship between the grid-connected EVs discharging power and the maximum acceptable discharging price to the grid under the condition of different standby demand. In fact, it is difficult for EVs to completely replace the standby units during peak hours, so this article discusses the complete replacement and the partial replacement of standby units by EVs. Finally, based on the actual dispatch power of the EVs, calculate the maximum acceptable discharging price to the grid. According to the simulation analysis results, the following conclusions can be drawn:

1) There is a huge difference between the standby units dispatching cost and the traditional units dispatching cost. Therefore, when the grid chooses to dispatch the EV instead of the standby units, it could be a win-win choice.
2) When EVs completely replace the standby units, the power that the EV can provide is negatively correlated with the maximum discharging price that the grid can accept.

3) When the EV can only partially replace the standby units. When the standby power that the grid needs to dispatch is determined, the more power EVs can provide, the lower the maximum power price that the grid can accept; when the power that the EV can provide is determined, the more standby power the grid needs to dispatch, the higher the maximum acceptable discharging price to the grid.

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