Dividend Transmission Method for V2G Aggregators to Participate in Market Transactions

Li Tao[1, 2], Xin Du[1, 2*], Pengfei Zhao[3], Lin Zhang[1, 2], Ke Zhao[3] and Zhiqiang Zhao[3]
[1]*State Grid Electric Power Research Institute Co., Ltd., Nanjing, 211106, China*
[2]*Beijing Kedong Electric Power Control System Co., Ltd., Beijing, 100194, China*
[3]*State Grid Shanghai Electric Power Company, Shanghai, 200122, China*
[4]*State Grid Chongqing Electric Power Company, Chongqing, 400014, China*

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Abstract: Driven by the current goal of "carbon peak, carbon neutral", the penetration rate of electric vehicles will accelerate, and electric vehicles will become an important energy storage support for the development of renewable energy. By the end of 2020, the number of new energy vehicles in China will reach 4.92 million, of which 4 million are pure electric vehicles, accounting for 81.32% of the total number of new energy vehicles. The increment of new energy vehicles has exceeded 1 million for three consecutive years, showing a sustained high-speed growth trend. With the continuous progress of power electronics technology, the electric vehicle as a new type of energy storage facilities, through the V2G mode (vehicle to grid) to realize the two-way flow of electric energy with the grid, can become an important way to improve the power grid regulation ability and power supply reliability. This paper combs the services provided by V2G for power system, and based on the current electricity trading market and the cost of power battery, puts forward a method of electric vehicle V2G aggregator dividend transmission, which will help to encourage electric vehicle owners to participate in grid interaction more fully.

1 INTRODUCTION

Electric vehicle V2G technology (Liu, 2012) refers to the technology of electric vehicle power transmission to the grid, and its core idea is to use a large number of electric vehicle energy storage as the buffer of grid and renewable energy. When the electric vehicle is not in use, the power of the on-board battery is sold to the grid system. If the vehicle battery needs to be charged, the current flows from the grid to the vehicle. Because most of the vehicles are stopped 95% of the time, the vehicle battery can be used as a distributed energy storage unit. Electric vehicles (EV) have the property of energy storage, which can quickly adjust the power in a short time (Sarker, 2016). Through V2G, the problems of low grid efficiency and renewable energy fluctuations can not only be alleviated to a great extent, but also can create benefits for electric vehicle users.

The schedulable capacity of a single EV is limited. A large number of EV in the charging station can be aggregated, and the aggregator manager can participate in the market and schedule as an agent, so as to improve the overall responsive capacity of the EV cluster (Renewable and unstainable Energy Reviews, 2016). However, on the one hand, the uncertainty of EV's charging demand and charging behaviour makes it difficult to evaluate the reserve capacity and response ability of EV participating in the power market (Xing, 2020); on the other hand, the charging power optimization for power response and the compensation mechanism for EV users are also lack of mature operation framework.

In terms of charging cost and transaction income settlement, the price mechanism can encourage users to respond to the system demand. From the perspective of day ahead, the more EV charging, the greater the adjustment margin; from the perspective of real-time scheduling, EVs can also support each other in a short time. Therefore, we can establish a cost / benefit settlement framework for EV aggregators from the perspective of cooperative game (Ma, 2020). From the perspective of Sharpley value generation (Zhao, 2013), we can evaluate the

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marginal cost and marginal benefit of EV access, so as to reasonably allocate charging cost and transaction revenue.

2 SERVICES PROVIDED BY V2G FOR POWER SYSTEM

2.1 Peak Shaving

Through V2G, the idle energy of electric vehicles is sent back to the grid during peak load period, which can reduce the demand of the grid for peak load regulation resources and increase the income of electric vehicle users. In foreign mature power markets such as the United States and Europe, the role of peak shaving is realized through the price mechanism in the spot market of electric energy. Peak shaving is a unique auxiliary service in China. From the perspective of power grid companies, peak shaving through V2G mode requires additional investment to upgrade the power grid. From the perspective of electric vehicle users, the shortening of battery life caused by the new charge discharge cycle due to peak shaving is also an important factor affecting users' willingness to participate.

2.2 Frequency Modulation

The power battery of electric vehicle can be used as shunt active power filter through V2G to improve the power quality of distributed renewable energy grid connected generation. Reactive power regulation is often needed during the operation of power system, and the reactive power is usually provided by capacitor banks or other reactive compensators. If there is an electric vehicle charging station in the distribution network, it can be used as the source of reactive power in the power system.

2.3 Standby

In order to deal with potential accidents, the grid has prepared a lot of standby units to deal with emergency. Although the power of these standby units is not large, the cost is high due to the harsh response time requirements (less than 1 minute). It is a potential application for electric vehicles to provide rotating reserve capacity. As long as the charger is connected and the battery has the remaining power, the electric vehicle can provide the standby capacity to the grid. The number of times that the rotating spare capacity is actually called by the grid is relatively small, about 20 times in a year, so that the electric vehicle can only obtain the profit through the spare capacity cost in most of the parking time of the year.

In V2G mode, electric vehicles can adjust charging time and charging power according to the needs of the grid, and discharge through V2G terminals when the vehicle is stopped. The interaction between electric vehicles and the grid is shown below.

3 COST AND BENEFIT ANALYSIS OF V2G

The total energy cost for aggregators to participate in electricity trading is $C_{E,i}$

$$C_{E,i} = \pi_{E,i} P_{E,i} t_{E,i} \quad (1)$$

Among them, $\pi_{E,i}$ represents energy market price, $P_{E,i}$ represents energy market power, $t_{E,i}$ represents energy market time.

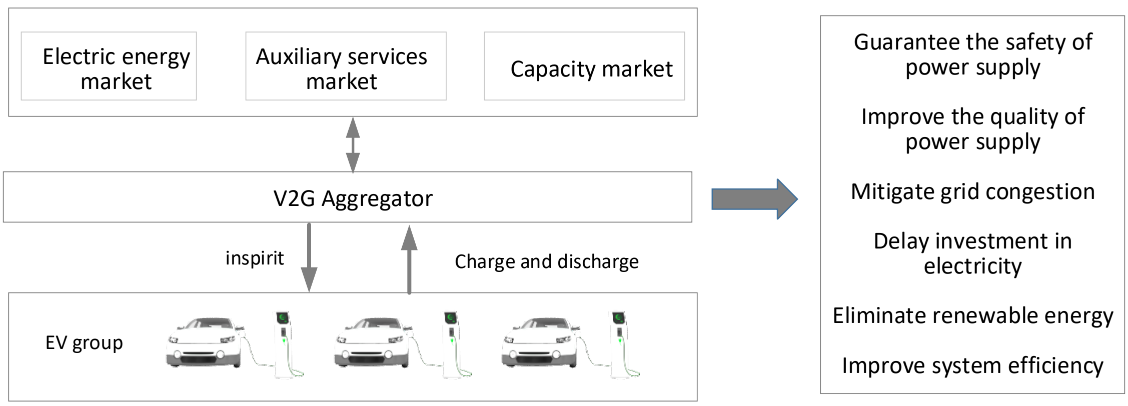

Figure 1: The interactive diagram of electric vehicles and the grid.

For EV with charging record, its charging cost in period i can be recorded as $c_{i,j}$,

$$C_{E,i} = \sum_{j=1}^{x_i} c_{i,j} \quad (2)$$

Through the "peak cutting and valley filling" mode, the electric vehicle aggregator can directly trade electric energy, and can choose to purchase electricity from the power grid when the price is low; when the price of electricity is high, the electricity is sold to the power grid, thus obtaining certain benefits. The income from electric vehicles is deducted from the income allocated to the aggregators.

$$Y_{PV,i} = \pi_{up,i} Q_{up,i} \quad (3)$$

$$(1-\alpha) Y_{PV,i} = \sum_{j=1}^{x_i} Y_{PV,i,j} \quad (4)$$

In the power market environment, electric vehicles participate in demand response, and make comprehensive planning of the resources on the power supply side and demand side, which can improve the security, reliability and power quality of the system.

$$Y_{DR,i} = \pi_{up,i} Q_{up,i} K_i \quad (5)$$

Among them, K_i is the peak adjustment contribution rate.

$$(1-\alpha) Y_{DR,i} = \sum_{j=1}^{x_i} Y_{DR,i,j} \quad (6)$$

When participating in adjusting the frequency, the aggregator shall report its standby capacity in different periods before the day, and the power that the aggregator can up / down regulate in each period will not exceed the capacity. $R_{up,i}$ and $R_{down,i}$ are the uplink and downlink Reserve reported to the reserve market, η_i and M_i represents the accuracy and mileage in the process of real-time response adjustment signal.

$$Y_{R,i} = \pi_{up,i} R_{up,i} + \pi_{down,i} R_{down,i} \quad (7)$$

$$Y_{M,i} = \pi_{M,i} \eta_i M_i \quad (8)$$

For EV with charging record, the regulation frequency gain can be recorded as $y_{i,j}$

$$(1-\alpha)\left(Y_{R,i} + Y_{M,i}\right) = \sum_{j=1}^{x_i} Y_{R,i,j} + \sum_{j=1}^{x_i} Y_{M,i,j} \quad (9)$$

4 COST AND INCOME DISTRIBUTION OF V2G AGGREGATORS

As a manager, EV aggregators need to distribute the total cost and total revenue fairly to each EV and calculate $c_{i,j}$ and $y_{i,j}$. Within the aggregator, from the perspective of a single EV, because it only accepts the charging power allocated by the EV aggregator, there is no explicit boundary between the reference power for planned charging and the power for peak shaving and frequency modulation. Therefore, within the aggregator, the settlement of each eV by the aggregator should be treated as a cooperative game problem. Based on the Shapley value theory, the energy resource occupation of EV should be considered in the energy cost allocation, and the contribution of EV should be considered in the transaction income, so as to distribute the energy cost and transaction income fairly. The basic equation of Shapley value of energy cost and benefit of the j-th EV is given by equation (10), where Xi is the set of all Xi EV, Γ represents one of all nonempty subsets of X_i that does not contain the j-th ev. v(Γ) is the utility function of the independent variable set as Γ. Then the essence of equation (10) is to calculate the marginal cost or marginal benefit of the EV, that is, the difference between the cost or benefit generated when the EV is charged and not charged.

$$\varphi_j(v) = \sum_{\Gamma \subseteq X_i \setminus \{j\}} \frac{|\Gamma|!(X_i - |\Gamma| - 1)!}{x_i!} \Big(v\big((\Gamma \cup \{j\})\big) - v(\Gamma) \Big) \quad (10)$$

After the Shapley value is obtained, the total cost or total income is allocated according to the proportion.

$$c_{i,j} = \frac{\varphi_{C,i,j}}{\sum_{j=1}^{x_i} \varphi_{C,i,j}} C_i \quad (11)$$

$$y_{i,j} = \frac{\varphi_{Y,i,j}}{\sum_{j=1}^{x_i} \varphi_{Y,i,j}} (1-\alpha) Y_i \quad (12)$$

$\varphi_{C,i,j}$ represents the Shapley value of charging cost of the j-th EV in period i. $\varphi_{Y,i,j}$ represents the Shapley value of benefit of the j-th EV in period i.

Equation (10) expresses the general situation in the allocation of cooperative games, that is, the marginal effects of the participants may be coupled with each other and do not have monotonic additivity, so it is necessary to traverse all subsets Γ without J. The final Shapley value can be obtained by calculating the marginal effect. For the aggregator which involves scheduling problem and contains a large number of EVs, the calculation of traversing all EV combinations to derive Shapley value is too large, so this paper will give the calculation method combined with EV characteristics.

- Distribution of charging cost

Since the charging of each EV does not interfere with each other, the charging demand of different EV is monotonous and additive. Therefore, equation

(10) can be reduced. The charging cost of each EV can be allocated proportionally according to their marginal cost:

$$c_{i,j} = \frac{Q_{i,j}}{\sum_{j=1}^{x_i} Q_{i,j}} C_i \tag{13}$$

- EV revenue distribution of electric vehicles

The essence of the marginal effect of a single EV on revenue: when the EV participates in power trading, it shares the change of the power margin of the rest of the EV by changing its own power margin. The physical meaning of power margin is: compared with the minimum power to meet the user's demand, the EV has more spare power.

Demand response income distribution:

$$y_{DR,i,j} = \sum_{t\in T_i} \frac{\Delta\varphi_{j,t}}{\sum_{j=1}^{X_j} \Delta\varphi_{j,t}} Y_{DR,i,j} \tag{14}$$

Income distribution of peak cutting and valley filling:

$$y_{PV,i,j} = \sum_{t\in T_i} \frac{\Delta\varphi_{j,t}}{\sum_{j=1}^{X_j} \Delta\varphi_{j,t}} Y_{PV,i,j} \tag{15}$$

Adjusting the income distribution of frequency assisted services:

In the real-time phase, the more EV charging, the more available capacity. Therefore, this part of revenue can be directly based on the allocation of EV capacity and charging time in this period.

$$y_{i,j} = \frac{T_{total,j} R_j}{\sum_{j=1}^{Xi} T_{total,j} R_j} Y_{R,i} \tag{16}$$

$$y_{M,i,j} = \sum_{t\in T_i} \frac{\Delta\varphi_{j,t}}{\sum_{j=1}^{X_j} \Delta\varphi_{j,t}} Y_{M,i,j} \tag{17}$$

5 CONCLUSION

As a highly flexible distributed energy storage method, V2G can participate in peak regulation, frequency modulation, standby and other services through bidirectional power flow between electric vehicle and power grid during non driving period, and support safe and stable operation of power grid. With the increasing of the total number of electric vehicles in the whole society, large-scale electric vehicle V2G is a potential resource for grid flexibility regulation.

This paper analyzes the cost and benefit of EV aggregators participating in grid services, and proposes the internal cost and benefit allocation method of EV aggregators. The revenue of V2G service providers is closely related to the electricity price policy and whether there is a mature electricity spot market and supporting service market. From the actual situation of our country, the spot market and auxiliary service market are still in the stage of construction and trial operation, which is far from mature operation.

In the current market environment, we can consider appropriately relaxing the flexibility of V2G, adjusting the access threshold of resources to participate in the spot market of electric energy and auxiliary service market, improving the competitiveness of electric vehicle V2G, and improving the enthusiasm of market players to use V2G. Worldwide, although V2G is still in its infancy, the large-scale development and application of electric vehicles has made the V2G applications widely available.

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