Research on Optimization Control Strategy of Vehicle-Road-Grid Charging and Exchanging Based on User Demand Guidance

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Abstract. Considering the time-space uncertainty of electric vehicle charging and changing demand, the uneven distribution and random diversity of charging stations, the big data cloud network is used to realize the real-time information interaction between charging and changing power station and electric vehicle. Based on the user demand orientation, an intelligent charging and changing optimization control strategy of “Vehicle-Road-Grid” integrating cloud vehicle operation data is proposed. Under the discrete electric vehicle charging demand, this strategy quickly organizes the supply information around the discrete point. On the basis of the minimum energy consumption between the electric vehicle charging request point and the supply point, considering the multi-dimensional factors such as the optimal interests of the electric vehicle users, the shortest waiting time for charging and changing, and the shortest driving distance for charging and changing, the multi-objective optimal configuration strategy is realized. The simulation results show that the strategy can stably select the charging and swapping scheme that best meets the actual needs of users, effectively improve the charging and swapping service experience of users, and enhance the adhesion and participation of users.

Keywords. Recharge; multi-objective optimization; control strategy.

1. Introduction
In order to further solve the energy problem of China’s high dependence on oil and gas, China’s 14th Five-Year plan puts the development of new energy industry in an important position. So, electric vehicles will usher in a period of rapid development. It has become the main goal of power industry development in the 14th Five-Year Plan period to accelerate the development of new energy, promote the intelligent upgrading of charging and swap technology for power plants and electric vehicles, and real-time charging and swapping regulation for users.

With the increasing popularity of electric vehicles and the development of charging infrastructure, charging station is becoming an important power supply point for electric vehicles. Taking Shanghai as an example, by the end of December 2020, 140 charging and swapping facilities operators have been connected to the municipal platforms in Shanghai, and 106908 public and special charging and swapping facilities have been connected to the city, including 62877 public charging piles and 44031 special charging piles. According to the statistics of Shanghai new energy vehicle promotion office, by the end of 2020, there will be more than 270000 private charging piles in Shanghai. In addition to public and special charging piles, there will be a total of 376908 charging and swapping facilities in
Shanghai. In 2020, nearly 121000 new energy vehicles will be promoted in Shanghai, and the number of new energy vehicles will exceed 420000.

At present, the research on orderly charging scheduling of electric vehicles at home and abroad focuses on the safe and stable operation of power grid [1-2], some on the maximization of users' interests [3-4], some on the optimal cost of charging station operators [5-8], and some on the optimization algorithm of game theory [9-13]. Considering the charging problem of electric vehicles from different perspectives, we can get different control strategies. If we consider the dynamic random variables and integrate the complex multi-objective optimization model of electric vehicle user demand, power grid safety, road traffic safety and so on, it is extremely complex. Therefore, it is more realistic and feasible to choose a focus for analysis. Based on the demand orientation of the electric vehicle customer, according to the time-space distribution of different electric vehicles and charging stations and the real-time status data of electric vehicles (such as the residual electricity, battery temperature, etc.), the purpose of this paper is to minimize the energy consumption of the power station, and consider the electric vehicle battery allowance. The main parameters are the waiting time and the distance to the charging station to solve the multi-objective optimization, and finally get the multi-objective optimal charging opinions.

2. Charging and Changing Model and Strategy

2.1. Suggestions on Charging Changing Decision
Considering that excessive discharge will have a negative impact on the life of the power battery, the charging and swapping behaviour decision of electric vehicle users is affected by many factors. Based on the current battery state, battery capacity, battery temperature and so on, the real-time analysis is carried out to make the decision whether to go to the charging station or the swapping station. The specific decision-making process is shown in figure 1.

![Decision flow chart of charging and swapping software.](image-url)
2.2. Charging and Swapping Model Based on User Demand Orientation

The system includes not only electric vehicle users, charging station operators and road traffic system, but also wireless communication system, information acquisition system and cloud data system. When formulating the response strategy to meet the charging and swapping demand of electric vehicle users, the above system and data are used to interact with the global traffic information, current vehicle speed information, acceleration information, location information, remaining power information, battery temperature information, etc. in real time and summarize them to the cloud data system. The cloud data system obtains the information in combination with the current data. The optimization algorithm is used to plan the optimal charging and swapping scheme suitable for the current electric vehicle, and the global traffic information of the current vehicle’s expected journey is generated comprehensively to help formulate a more energy-saving and convenient route navigation map. The user intelligent charging (figure 2) and power exchange process (figure 3) are as follows:

3. Optimization Algorithm of Charging and Swapping Strategy

3.1. Objective Function

This strategy takes the user demand side as the starting point, considers the demand of users to quickly reach the most suitable charging station, takes the minimum energy consumption and charging cost of charging station as the goal, and mainly considers the specific problems such as driving distance, user waiting time, whether the destination charging station can meet the charging demand to construct the objective function.

Firstly, according to the first objective, the power consumption from the user to the charging station is divided into two parts. The first part is the power consumption of the driving distance from
the current location to the charging station; and the second part is the waiting power consumption during driving and after arriving at the charging station. The distance between users and charging station can be expressed as follows:

\[ D(x) = mx \quad (1) \]

\( m \) is the power consumption per kilometer and \( x \) is the driving distance. Idle time power consumption can be expressed as:

\[ T(y) = ny \quad (2) \]

\( n \) is the power consumption of each minute for the vehicle to be charged, and \( y \) is the waiting time, then the total power consumption to the charging station can be obtained as follows:

\[ P(x, y) = D(x) + T(y) \quad (3) \]

The optimization objective is to minimize the power consumption during the period from the user going to the charging station to the beginning of charging. Namely:

\[ \min P(x, y) = \min [D(x) + T(y)] \quad (4) \]

At the same time, the constraint condition is the current remaining power of electric vehicle \( (u) \). There are the following constraints:

\[ x, y \geq 0 \quad (5) \]

\[ mx + ny \leq U \quad (6) \]

Among them, the current remaining power of electric vehicles is \( U \).

If the charging price is \( k \), the second goal of minimum cost is analyzed as follows. Suppose that when a charging vehicle makes a charging request, the required charging quantity is \( Q \) and the electricity price is \( k \), then the total cost is:

\[ Q(x, y) = kq + k[D(x) + T(y)] \quad (7) \]

The first part \( kq \) is the cost of charging immediately at the current moment, and the second part \( k[D(x) + T(y)] \) is the charge corresponding to the electric energy consumed when driving to the charging station. The cost of the expense part is expressed as:

\[ \min Q(x, y) = \min \{ kq + k[D(x) + T(y)] \} \quad (8) \]

By synthesizing equations (4) and (8), it is assumed that the two objectives are equally important, and the weight coefficients are 0.5 respectively. Then there is the final objective function:

\[ R(x, y) = \begin{cases} 
\min [D(x) + T(y)] \\
\min [kp + k[D(x) + T(y)]]
\end{cases} \quad (9) \]

At the same time, it should meet the following constraints:

\[ s.t. = \begin{cases} 
x, y \geq 0 \\
xm + ny \leq U
\end{cases} \quad (10) \]

3.2. Establishement of Simulation Model
First of all, the State-Grid-e-charging software is used to simulate the user’s charging application with a certain location as the coordinate origin, and the distance and number of surrounding charging stations are queried, as shown in table 1.
Table 1. Distribution of charging stations.

| Charging station | Distance (km) | Number of charging posts/number of unused | Electricity price (excluding service charge) (Yuan/kWh) |
|------------------|---------------|------------------------------------------|------------------------------------------------------|
| 1                | 0.3           | 10/10                                    | 1.4346                                               |
| 2                | 0.8           | 6/5                                      | 1.4346                                               |
| 3                | 1.5           | 6/3                                      | 1.4432                                               |
| 4                | 3.5           | 10/8                                     | 1.4346                                               |
| 5                | 6             | 5/5                                      | 1.5697                                               |
| 6                | 8             | 8/8                                      | 1.5697                                               |
| 7                | 10            | 50/42                                    | 1.4346                                               |

According to the above objective function, this paper simulates the whole process of charging demand of electric vehicle users. Matlab randomly generates multiple groups of charging requests with residual energy of u, and generates 10 groups of charging and replacement power stations around the world randomly, which are randomly generated as optional items, among which the waiting time of these charging and replacement power stations is 3-30 minutes of random integer data and random data with a distance of 1-10 km from the current electric vehicle. The simulation data can be displayed as follows:

Figure 3. User demand simulation diagram.

Figure 3 shows the specific charging station corresponding to two groups of random charging requirements. The yellow line in the figure corresponds to the right coordinate axis, and the charging waiting time is 0-25 minutes; and the blue column represents the distance from the charging station, expressed as 1-10 km from the left coordinate axis. The average electric vehicle consumption per kilometer is 0.12 degrees, and the power consumption per minute during waiting is 0.01 degrees. The electricity price is simulated according to 1.5 yuan/degree. The objective function (9) can be as follows:

$$R(x, y) = \begin{cases} 
\min(0.12x + 0.01y) \\
\min[1.5p + 1.5(0.12x + 0.01y)]
\end{cases}$$

(11)

In order to solve this problem, the dynamic random variables are not considered, and the location and waiting time of the power station can be obtained from the cloud data in reality. Assuming that the two objectives are equally important, the optimization tool function fgoalattain in MATLAB is used to record the optimization results of ten groups of demand information samples. The final results are as follows:
Figure 4. Comparison chart of multi objective optimization results.

The horizontal coordinate is the sample number in figure 4, and the ordinate represents the energy consumption. It can be seen from the figure that if the shortest distance or the shortest idle waiting time is considered, the total energy consumption of the user to the recommended power station is higher or equal to the optimization result considered by both the lowest cost and the least energy consumption. Therefore, the result of multi-objective optimization is better than that of single optimization. It must be pointed out that this strategy is based on the simplified model for simulation, without considering dynamic random variables and real-time optimization adjustment. It is only the optimization result of charging suggestion at the time when the user puts forward the demand. However, in reality, the distance and waiting time often have great changes in the process of users going to the charging and changing power station, so dynamic random variables and real-time prediction module should be added to the mathematical model.

4. Conclusion and Prospect
In this paper, based on the demand of electric vehicle charging and swapping users, considering the temporal and spatial uncertainty, the uneven distribution and random diversity of charging stations, the big data cloud network is used to obtain the real-time information of power station and electric vehicle. Then, a "Vehicle-Road-Grid" intelligent charging and swapping optimization control model integrating cloud vehicle operation data is proposed. Based on the minimum energy consumption between the EV charging request point and the supply point, the model considers the principle of minimum energy consumption of EV users, and focuses on two important factors: the shortest waiting time and the shortest driving distance. Then the objective function of multi-objective optimization is put forward and its constraints are defined. The simulation results show that the strategy can stably select the scheme with the least energy consumption recommended to the electric vehicle users.

This strategy is based on the simplified model, and does not consider the dynamic random variables, the real-time changes of charging waiting time and the number of charging piles. However, in reality, the distance and waiting time may vary greatly when users go to the charging and swapping power station. The dynamic random variables and real-time prediction module should be added to the mathematical model to improve.

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