Research on Distribution Strategy of Charging Piles for Electric Vehicles

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Abstract. The distribution and scale of charging piles needs to consider the power allocation and environmental adaptability of charging piles. Through the multi-objective optimization modeling, the heuristic algorithm is used to analyze the distribution strategy of charging piles in the region, and the distribution of charging piles is determined to meet the minimum consumption of charging path, and then the construction scale is determined according to the calculation of environmental fitness. The rationalization of charging pile distribution and construction scale can achieve the effective allocation of distribution and transmission.

Keywords: Electric vehicles; Charging pile; Multi objective optimization.

1. Introduction

With the development of the new economy, the whole world is required to reach a consensus on building a community of human destiny. The advantages of electric vehicles with low energy consumption and no pollution make them gain a firm foothold in new energy vehicles. Electric vehicles are driven by electric power, which is energized by rechargeable batteries mounted on the vehicle body, and then electric vehicles are charged by charging piles to complete energy transmission. Therefore, the distribution and construction scale of charging piles for electric vehicles will directly affect the charging efficiency of electric vehicles.

The distribution and construction scale of charging piles need to consider how to maximize the benefits of the charging piles. First of all, from the construction of charging piles, the maximum rechargeable coverage can be met with the minimum construction cost and scale [1] [2]. In addition, the distribution network power distribution of charging piles directly affects the user's efficiency and contributes to the economic benefits. Adjusting the charging power of charging piles can restrain the rated power of charging piles from decreasing during charging. At the same time, time-sharing charging scheduling is adopted to adjust the load and charging schedule of charging network for different charging times and different charging requirements, so as to improve charging efficiency and user satisfaction [3-6]. On the other hand, by adjusting the charging price at different times and places, users are encouraged to charge in non-centralized charging areas, thus reducing the waiting time for users to charge [7] [8]. In addition, to some extent, mobile charging devices can be considered, which can help solve the problem of temporary charging and reduce the cost of fixed charging piles to a certain extent [9].
The distribution of charging piles should also consider the characteristics of different batteries of rechargeable cars and the relationship between the path planning of electric cars and the distribution of charging piles. Literature [10] considers the charging characteristics of different batteries and the random distribution of charging time of residential users' electric vehicles, and puts forward the modeling method of charging pile daily charging load concentration to solve the charging problem of residential users [10]. In the literature [11], "Dijkstra algorithm+nearest neighbor method" is used to plan the path of the dynamic network system model of intelligent electric vehicles. The dynamic path planning problem is divided into the initialization stage to select the optimal path and the charging pile resource competition, and the time dispersion and SOC intelligent early warning are used to solve the multi-objective path optimization problem [11]. Literature [12] After analyzing the research status of self-service charging universal service system at home and abroad and the related materials of charging interface of existing charging piles, self-service charging service APP is designed, and functions such as power monitoring, charging reservation and payment are completed according to user experience requirements and system architecture specifications [12].

The distribution and construction scale of charging piles need to consider the cost, which is not only the construction cost of charging piles, but also the cost of users. The convenience of charging pile distribution is the primary requirement for users to choose electric vehicles. Based on the charging pile cost and user cost, this paper analyzes the functional relationship among charging pile investment, management cost, user charging consumption cost, road driving cost and waiting cost, establishes a multi-objective optimization model, and gives the scheme of charging pile distribution and construction scale in A city area.

2. Research and analysis of charging pile distribution strategy

Many characteristics of electric vehicles can not only promote the development of electric vehicles, but also limit the driving ability of electric vehicles. Therefore, the distribution of charging devices of electric vehicles is very important in supporting electric vehicles.

The distribution strategy of electric vehicles should fully consider the layout of cities and the convenience of charging local electric vehicles. Generally, before setting up the charging device, the overall planning of the city will be analyzed to study how to fully charge the electric vehicle in the most convenient environment, so that users can fully experience the convenience of the electric vehicle.

Generally speaking, the distribution strategies of charging devices at home and abroad are not consistent, but they are similar. The main difference is the distribution of population and city and the mentality of users. In foreign countries, the population is relatively small, and the distribution is scattered. The connection between cities mainly depends on highways, with farmland or mountains on both sides of highways, and the distance between the two cities is far away. Therefore, when considering the distribution of electric vehicles, it is necessary to consider the distribution strategy within and between cities. At the same time, foreigners' life style is relatively gentle, and they tend to be "semi-pastoral". They usually adopt fast charging mode or slow charging mode, but most of them adopt slow charging mode. In China, due to the large population base, dense population, fast pace of life and close connection between cities, the above three charging modes will exist in all cities in China, and people tend to use their only leisure time to complete this seemingly important but not bring substantial benefits to themselves.

Besides the urban planning and people's living conditions, we should also consider the nature of electric vehicles, which will affect the charging range and place of electric vehicles. Whether the vehicle charging station is fixed or not is divided into fixed station and random station. Fixed station means that the vehicle must return to its departure station after completing the service [13], and it often appears in public service vehicles such as buses; Random station means that vehicles don't have to return to their departure station, but the number of departure vehicles at any station should be equal to the total number of return vehicles [14].

Charging devices are generally set up to meet the charging needs of electric vehicle users. When setting up charging devices, users' idle time or available time will generally be considered. In this way,
on the one hand, the smooth running of the electric vehicle can be guaranteed, and on the other hand, the waste of unnecessary time is reduced for users. Based on this, after actually considering the distribution planning of the whole city, the charging devices of electric vehicles (ordinary household cars) will give priority to placing the charging devices in supermarkets, hotels, restaurants, communities and other places convenient for users to use. Besides, the charging devices will be placed at other points that need to be transferred or necessary on the basis of the optimization strategy. At the same time, in the same place, the charging device placement party will adopt the device placement methods such as full fast charging, fast charging and slow charging, battery replacement, etc. [15].

3. Multi-objective model construction

3.1. Analysis of charging pile cost and user cost
The location and scale determination of charging piles for electric vehicles should not only consider the costs caused by power grid reconstruction, purchase of corresponding construction land, environmental treatment around the charging piles, but also consider the social benefits and maintenance costs brought by the completion of charging piles [16]. The scale and distribution of charging piles will directly affect the on-the-road consumption cost and charging queuing cost of users, which directly reflects the relationship between the consumption cost between charging piles and users.

User cost includes the road cost consumed from the departure point to the charging pile location, the waiting time cost caused by queuing after arriving at the charging pile, and the electricity purchase cost paid by the user when charging. The charging pile cost includes the charging pile construction cost and the charging pile management cost. The scale and location distribution of charging piles should fully consider the interests of both parties and reduce the total social cost. This paper takes the minimum total social cost as the research objective to conduct multi-objective model analysis. Of course, other social factors should be considered in the distribution of charging piles, and only the above main factors should be considered in this study.

3.2. Build a multi-objective optimization model
The node set of transportation network after abstracting the location of charging piles is denoted as N, and each node represents an area where electric vehicles gather. \( r(r \in N) \) represents any node in the transportation network, \( S(S \subset N) \) represents node set with charging piles, \( s(s \in S) \) represents any node with charging piles, \( P_{r,r} \) represents all path sets from node \( r \) to node \( r \), and \( p(p \in P_{r,r}) \) represents any optional path between two points. It is assumed that there is a fixed time period \( [0, T] \), during which the charging requirements of all electric vehicles that need to be charged can be met. In this paper, the time cost of users is set in a fixed interval, and the time-consuming cost of electric vehicles is set in the \( [0, \tau] (\tau > 0) \) interval for discussion.

Because the user's behavior analysis data (such as the per capita possession of electric vehicles in the region, the purchasing power of consumers in the region, and the charging demand of users in the region) cannot be accurately obtained, it is assumed that the user's choice of charging path and charging pile is generally consistent with the choice when traveling, so different charging time, charging pile and charging path will produce different charging costs. So we give the cost expression.

\[
\begin{align*}
C_{p,rs}(t) = & \ Jv(t + \tau_{p,rs}(t)) + \beta_{s,r}\tau_{s}(t + \tau_{p,rs}(t)) + \beta_{p,r}\tau_{p,rs}(t) \\
\text{s.t.} \quad & \beta_{p} > 0 \\
& \beta_{s} > 0
\end{align*}
\]  

(1)

\( C_{p,rs}(t) \) in the cost expression represents the total cost for the user to charge from \( r \) point to \( s \) point at time \( t \); \( J \) is the charging price calculated by the charging company according to factors such as cost; \( \tau_{p,rs}(t) \) represents the time cost consumed by the electric vehicle from \( r \) point to \( s \) point at \( t \) time. We set the time consumption from the electric car in the \( s \) point to the charging road in this area to be 0;
Then $t + \tau_{p,rs}(t)$ is the moment when the user reaches the point s. $\nu(t + \tau_{p,rs}(t))$ represents the power consumption demand when the electric vehicle reaches the charging pile; $\tau_{s}(t + \tau_{p,rs}(t))$ represents the time consumption of electric vehicles in charging piles (including waiting time and charging time), and $\beta_{p,r}$ and $\beta_{s,r}$ represent the time-cost conversion coefficients of time consumption on the road and time consumption on charging piles, respectively.

It is assumed that the electric energy demand $\nu$ of all electric vehicles when they arrive at the charging pile is constant, and the charging efficiency $\eta$ of the charging pile is also constant, so the charging time of electric vehicles is $\frac{\nu}{\eta}$. From the above conditions, we know that the user's lowest road consumption cost condition is that the charging cost caused by the choice of s point and route p is the minimum charging cost at any time t in any r point, while other costs are greater than it [17]. The formula can be expressed as:

$$ C_{rs,\text{min}} = \inf\{C_{p,rs}(t) \mid p \in P_n, t \in [0, T], s \in S, r \in N \} $$

(2)

### 3.3. Scale and distribution cost of charging piles

#### 3.3.1. Scale of charging pile.

It takes $\tau_{s}(t)$ for the electric vehicle to reach the charging pile at time t, and the factors affecting the time consumption are the number of charging machines $g_s$ in the charging pile at point s and the number of charging vehicles $x_{s,s}(t)$ waiting to be charged. When $x_{s,s}(t) \leq g_s$, $\tau_{s}(t) = \frac{\nu}{\eta}$; When $x_{s,s}(t) > g_s$, the charging piles will line up. At this time, we should calculate the maximum charging pile of the electric vehicle:

$$ \tau_{s}(t) = \left\lfloor \frac{x_{s,s}(t)}{g_s} \right\rfloor \frac{\nu}{\eta} + \frac{\nu}{\eta} $$

(3)

In which, $\left\lfloor \frac{x_{s,s}(t)}{g_s} \right\rfloor \frac{\nu}{\eta}$ represents the queue time of charging cars, and $\frac{\nu}{\eta}$ represents the charging time.

At time t, the demand of charging pile for power load of power grid due to charging of electric vehicle can be expressed by the following formula:

$$ Q_s(t) = \begin{cases} x_{s,s}(t) \eta & \text{if } x_{s,s}(t) < g_s \\ \frac{\nu}{g_s} \eta & \text{if } x_{s,s}(t) \geq g_s \end{cases} $$

(4)

When the number of electric vehicles is less than the number of charging piles owned by charging piles, the power load demand of s-point charging piles for power grid can be regarded as the product of the number of charging piles and charging power; On the contrary, the power load demand of charging pile is equal to the power demand when all chargers work at the same time. From the above description, it can be known that the total electric energy demand $D$ of electric vehicles in $[0, T]$ period should be:

$$ D = \sum_s D_s = \sum_s \int_0^T Q_s(t) \, dt \quad s \in S $$

(5)

The design scale of electric vehicle charging pile directly affects its own variable management cost in $[0, T]$ period, which can be expressed as:

$$ K_{sv} = \int_0^T k_{sv} Q_s(t) \, dt \quad s \in S $$

(6)

Among them, $K_{sv}$ represents the variable cost of s-point charging pile in $[0, T]$ time period, and $k_{sv}$ represents the average cost caused by charging load, that is, the sum of electricity purchase price paid by charging company to power grid company, power grid governance cost caused by charging load and other management costs of charging pile.

#### 3.3.2. Charging pile distribution and electricity price setting.

When the electric power demand $D$ of electric vehicles is fixed, the layout of charging piles directly affects the input cost of charging
companies and the setting of charging price. Most of the cost of charging piles for electric vehicles mainly comes from the expansion cost of charging piles, the capacity increase cost of transformers, the cost of intelligent control equipment, etc.

\[ K_s = K_{sf} + K_{sv} = k_{sf}g_s + \int_0^T k_{sv} Q_s(t) \, dt \quad s \in S \]  

Among them, \( K_s \) represents the total cost paid by the charging company in \([0, T]\) time period after the charging pile is set at \(s\) point; \( K_{sf} \) represents the fixed cost investment in the construction of \(s\)-point charging piles; \( K_{sv} \) is the variable cost input of \(s\)-point charging pile; \( k_{sf} \) represents the average fixed cost of setting up a charging pile at \(s\) point (after conversion to \([0, T]\) period, the average fixed cost input of a single charger). Due to the influence of factors such as the strength of power grids and the transformation capacity of transformers in various regions, \( k_{sf} \) changes with the change of construction sites and the number of chargers [18].

After obtaining the cost function of the charging pile, the charging company formulates the charging price \( J \) as follows:

\[ J = (1 + R) \frac{K}{D} = (1 + R) \frac{\sum_{s \in S} K_s}{D} \quad 0 \leq R \leq 1 \]  

In the above formula, \( K = \sum_{s \in S} K_s \) can be regarded as the total cost input of the charging company, and \( R \) is the cost plus coefficient.

### 3.4. Total social cost

The scale and distribution of electric vehicle charging piles not only determine the input cost of charging piles, but also affect the user’s charging cost. In addition, the cost adjustment of charging piles also affects the user's cost through the change of electricity sales price. Total cost minimization is the distribution strategy studied in this paper. In a certain time period \([0, T]\), the distribution \(S\) and scale \(g_s\) of charging piles are regarded as the variables of the minimum cost function, which are expressed as follows:

\[ \min_{S, g} Z = K + C \]

\[ C = \sum_{r \in N} \int_0^T f_{p,rs}(t) C_{p,rs}(t) \, dt \quad p \in P_{rs} \]  

In the formula, \( C \) represents the total cost function of users, and \( f_{p,rs}(t) \) represents the number of electric vehicles that are sent from point \(r\) to point \(s\) at time \(t\) and choose to take path \(p\) to charge the charging pile.

### 3.5. Dynamic network constraint

#### 3.5.1. Time window constraint

The time window constraint can be expressed as:

\[ \tau_s + \tau_{p,rs} \leq \tau \]  

It means that the time cost of electric vehicle users from departure to charging cannot exceed \( \tau \).

#### 3.5.2. Conservation constraint of electric vehicle flow

The flow conservation constraints of electric vehicles are:

\[ e_s(t) = \sum_{r,s,p} f_{p,rs} \left( t - \tau_{p,rs}(t) \right) \]

\[ u_s(t) = \begin{cases} 
 e_s(t - \tau_s) & e_s(t - \tau_s) < g_s - x_{s,s}(t - \tau_s) \\
 x_{s,s}(t - \tau_s) & e_s(t - \tau_s) \geq g_s - x_{s,s}(t - \tau_s) > 0 \\
 g_s & e_s(t - \tau_s) > 0 > g_s - x_{s,s}(t - \tau_s) 
\end{cases} \]
In the formula, $f_{p,rs}(t - \tau_{p,rs}(t))$ represents the number of electric vehicles that are sent from point $r$ to point $s$ at time $t - \tau_{p,rs}(t)$ and choose to take path $p$ to charge the charging pile.

Equation (12) describes the relationship between the number of electric vehicles charging at $s$ point at different times and the number of electric vehicles starting from different electric vehicle gathering areas ($r$ point) before that. Formula (13) expresses the off-station situation of electric vehicles when the number of vehicles with different charging piles corresponds to the charging piles.

3.5.3. Traffic propagation constraint. Traffic propagation constraints can be expressed as:

$$\frac{dx_{s,s}(t)}{dt} = e_s(t) - u_s(t) \quad s \in S$$

(14)

The above formula describes the dynamic change of the charging queue.

4. Research methods and data establishment

4.1. Research technique

Reasonable layout of charging piles can minimize the total cost of charging piles and users. This paper provides ideas for the distribution and reasonable scale construction of charging piles by using heuristic algorithm. The above ideas are decomposed into two stages. Firstly, the construction site of charging pile is determined by the minimum cost of users on the road. Then, the total cost of users and charging pile is calculated by multi-objective model, and compared with the construction site determined in the first stage. The construction scale of charging pile is determined by adjusting the user's acceptance of the maximum charging time and balancing the total cost. The flow chart of charging pile distribution and scale construction is shown in Figure 2.

Determine the construction site of charging pile. First, find the parameters and coefficients in the relevant functional expressions, and calculate the unit investment cost and the number of vehicles with charging demand at each location. The required parameters include the time-cost conversion coefficient of time-consuming on the road and charging pile, and the input cost of charging company to build charging pile. Secondly, in the existing example, the shortest path method is used to calculate the on-
road driving cost of each path, and the minimum on-road driving cost is obtained. Thirdly, under the condition that the time window constraint is satisfied, it is checked whether \( \tau - \tau_p = \frac{\nu}{\eta} \) is satisfied when the user chooses the path with the minimum driving cost to reach \( S_1 \) point, and \( \tau_p \) is the minimum average driving time of all vehicles on the road. If the condition is met, find another point that can meet the average minimum on-road time cost of each point, repeatedly judge whether the condition is met in the minimum feasible set and determine the minimum input cost point. On the contrary, the time consumption cost reduced by building charging piles in other places is calculated.

Determine the scale of construction. Calculate the time consumption cost reduced by the construction of charging piles in other places, add the reduced time consumption cost and the increased input cost of the construction of charging piles in this place, and judge the total cost growth at this point according to the obtained results. If the result is greater than 0, the total cost increases, and this point is not the optimal choice point. If it is less than 0, it means that the absolute value of the reduced time consumption cost is greater than the increased input cost, and the total cost decreases, so the optimality of the construction site and scale can be determined.

In order to reduce the data error caused by time, traffic and other factors, this paper makes the following assumptions:
1. The charging behavior of users in the area is a known condition;
2. The lowest cost route for users is ideal, which is not affected by traffic congestion and weather.

4.2. Data procurement
Choose A city as the data analysis source, and use the existing map search method and Gaode map developer platform to obtain the relevant data of charging pile. First, browse the information content of the charging pile loaded in the map, then establish the charging pile search link on the developer platform, and obtain all the information of the charging pile through the protocol loaded by HttpURLConnection. The main acquisition code is shown in Figure 3. To increase the operability of data, JSON format data is parsed into UTF8 format. Then, the acquired data are preliminarily processed, and there are 40 items of preliminarily acquired data, including charging pile name, geographical coordinates, charging price, location, etc. However, some information needs to be deleted, changed in format, and calculated in multiple columns to obtain new data. After data preprocessing, keep the useful data after processing, visualize it on the developer platform, and analyze it according to the visualization results.
5. Stationary point analysis

According to the visualization results, it is found that the distribution of charging piles in A city is uneven, showing the situation of centralized, scattered around and disordered distribution in some areas. In order to increase the reliability of the research, some areas with dense distribution of charging piles are selected for analysis. At the same time, the community distribution in the analysis area is obtained, and the ability of analyzing users' charging demand is improved. The traffic and residents' living conditions in the intercepted area are plotted as shown in Figure 4, and the residential points are named by letters. At the same time, due to the different traffic conditions, population density, road length and traffic congestion among the residential points, the cost of the time spent on the way to reach each other is different. The shortest travel time between two points is calculated according to the shortest travel time between two points, as shown in Table 1.

![Figure 2. Get the main code of charging pile data](image)
Figure 3. Residential network structure diagram

Table 1. Minimum travel time between points

| Site | A   | B   | C   | D   | E   |
|------|-----|-----|-----|-----|-----|
| A    | 0   | 11  | 20  | 21  | 18  |
| B    | 11  | 0   | 11  | 14  | 20  |
| C    | 20  | 11  | 0   | 13  | 25  |
| D    | 21  | 14  | 13  | 0   | 26  |
| E    | 18  | 20  | 25  | 26  | 0   |

The charging piles within 2KM of residential point are regarded as the distribution area of charging piles in this residential point, and if there are two or more residential points in this area, it is regarded as the coverage area of residential points. According to the geographical coordinates of the processed data, the charging piles meeting the data range requirements are extracted and marked by Euclidean distance calculation method. Before this study, residents of residential areas and charging companies were investigated, and the input cost and construction demand of charging piles at the above-stagnation points were obtained through the analysis of the results, as shown in Table 2.

Table 2. Input cost of stationary charging pile and unit charging pile

| Site | Distribution quantity of original charging piles in the area | Unit input cost (10,000 yuan) | Number of vehicles required for charging |
|------|------------------------------------------------------------|--------------------------------|------------------------------------------|
| A    | 5                                                          | 250                            | 7                                        |
| B    | 4                                                          | 200                            | 6                                        |
| C    | 1                                                          | 300                            | 3                                        |
| D    | 3                                                          | 150                            | 4                                        |
| E    | 0                                                          | 400                            | 2                                        |

The charging modes of electric vehicles are slow charging, fast charging and battery replacement. In the fast-paced life, residents are generally willing to use the fast charging mode. In the fast charging mode, the charging speed is fast and the current is large, and the charging time is generally 20 minutes, which meets the travel requirements of most people. However, based on some needs of users, the charging time is dynamic. Therefore, the hard time window of charging time of rechargeable cars is [0, 20min], and the median charging time is 15 minutes in the residents’ charging survey data.

Based on the previous multi-objective model, according to Table 1, it can be concluded that the shortest travel time from points A and E to D and C to E is larger than the hard time window. Because the travel time of these three routes is longer than the maximum charging time borne by users, it is necessary to build new charging piles between points A and E and between points D and E to meet the constraints of the hard time window. Combined with the distribution of charging piles in residential
areas, the construction of new charging piles at point E accords with the optimal conditions of charging pile distribution optimization. According to the construction cost and user cost of charging piles, the total social cost is the lowest, and the construction of four charging piles at E point can meet the charging demand in the interception area.

6. Summary
In this paper, the distribution and scale of charging piles in the interception area are analyzed, and the multi-objective model is used to calculate the scheme of charging pile distribution and construction scale that meets the residents' living in this area. Through research and analysis, we can see the partial relationship between users and charging companies in the distribution and scale of charging piles. The layout of charging piles for electric vehicles is greatly affected by the constraints of charging demand of electric vehicles in different places to be selected, user time and the running cost of charging piles in the future. Therefore, in the distribution and scale construction of electric vehicle charging piles, it is necessary to fully consider the various needs of users and charging companies, and rationally construct charging piles. In the next step, we will study the route selection of electric vehicles under the condition of meeting the peak power of charging piles.

7. References
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