Charging station planning considering the total cost of construction of users and charging stations

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Abstract: Based on the improved particle swarm optimization algorithm, this paper considers the user time cost and the total cost of electric vehicle charging station construction, and establishes the site selection and volume model. The simulation analysis of MATLAB fully verified the feasibility of this algorithm in the location planning of a city. The experimental results show that the model can fully reduce the user's bypass distance, reduce the queuing time and the total cost of charging station construction, and has certain feasibility.

1. Introduction
With the deterioration of the environment and the depletion of traditional fossil energy, energy conservation and emission reduction are the development trend of all countries. Environmentally-friendly electric vehicles have not polluted the environment and have become a trend in the development of the automotive industry in various countries. In order to enable electric vehicle users to use charging facilities efficiently and conveniently, and to enhance the interoperability of piles, it is necessary to rationally plan and layout the charging facilities. Domestic and foreign scholars have conducted sufficient research on the location planning of charging stations. Gao Yajing and Guo Yandong proposed a two-step optimized location method, which fully considered the factors such as geography and distribution network, and quantified these influencing factors through fuzzy analytic hierarchy process. [1] Wang Dong, Liu Jichun, etc. proposed a charging station location and volume model considering the driver's travel chain. Through the travel volume of the travel chain, the vehicle characteristics of the residential area and the commercial area were analyzed, and the Monte Carlo method was applied to the user. The charging behavior is predicted. [2] Liu Zifa and Zhang Wei established a comprehensive optimization objective function considering geographic information, construction cost, and operating cost, based on land cost, investment cost of distribution transformer, and operating cost of power loss, and traffic flow is a constraint.[3]

In summary, the above literature selects the charging station from the economic, geographical, travel chain and other factors, ignoring the user's bypass distance, queuing time and station construction cost. This paper considers the location planning problem of electric vehicle charging station from the total cost of user and charging station construction, and solves it with improved particle swarm optimization algorithm.

2. User cost and total cost of charging station construction

2.1. User cost analysis
Under the conditions of national policy and the steady development of the electric vehicle industry, more and more users tend to choose electric vehicles. Electric vehicles inevitably need to consider the issue of timely charging. The rationality of charging station planning is conducive to more users’ travel. Generally, the running distance of electric vehicles is relatively close. Generally, the maximum mileage is about 300km. Considering the road conditions, safety factors, battery life and attenuation, the actual electric vehicle running mileage is 150~200km. When the user generates the charging demand, the detour distance from the demand point to the charging station and the queuing time of the charging station are considered. The generation of the charging demand is also related to the user's mileage anxiety. The current cruising range of electric vehicles in the market is generally short, so users generally have problems with mileage anxiety.

Therefore, when selecting the travel path, the user should consider whether the remaining power determines whether to charge. If the remaining power can support the distance between the user and the destination, there is no need to charge, otherwise charging is required. This paper assumes that the number of charging stations on the way of the user meets the charging demand generated by the user at any time, and the driving distance from the position where the charging demand is generated to the charging station is usually within the service radius of the charging station. Taking into account the different user habits, this paper has made a questionnaire of 100 people for users of different ages and different occupations. [4] The acceptance distance of different users to the charging station is as follows:

| distance       | Number of people | proportion % |
|---------------|------------------|--------------|
| Within 500 meters | 10               | 10           |
| Within 1000 meters | 18              | 18           |
| Within 2000 meters | 25              | 25           |
| Within 3000 meters | 20              | 20           |
| Within 4000 meters | 10              | 10           |
| Within 5000 meters | 10              | 10           |
| Within 6000 meters | 7                | 7            |

2.2. Charging station construction cost analysis

The cost of the charging station is one of the targets of the electric vehicle charging station for site selection planning. The cost of charging stations is roughly divided into construction costs and operating costs, of which construction costs include equipment investment and market development costs in the early stage. The costs involved in operation mainly include charging system platform construction and maintenance costs, equipment maintenance and repair costs, equipment standby power loss, and labor costs. The charging device of the charging station includes a charger, a battery maintenance device, a charging station monitoring system, and the like. In terms of power distribution facilities, it is necessary to follow transformers, power distribution cabinets, and cable laying.[5-6] The daily operating costs of the charging station include staff costs, equipment maintenance, and upgrading of technical equipment.

3. Mathematical model

The location planning model considering the cost of the user and the charging station is aimed at the user's arrival time at the charging station, the waiting time cost and the charging station construction cost, and the total cost is the objective function:

$$ \min F = M + T $$

Where: F is the total cost of the user and the charging station; M is the total time cost of the user; T is the total cost of the charging station construction.
3.1. Total cost of users
When a user generates a charging demand, he or she often selects a nearby charging station to charge, and it is desirable to have the shortest queuing time and charging time. Therefore, the total cost of the user considers the bypass distance and the queuing time. The expression is as follows:

\[ M = C(M_1, l_v + M_2) \]  

(2)

Where: \(M_1\) is the distance that the user generates the charging demand to reach the charging station; \(v\) is the driving speed of the electric vehicle; \(M_2\) is the queuing time; \(C\) is the cost coefficient.

3.1.1. Bypass distance. Assume that the planned area is a residential area, a commercial area, an industrial area, and the distance from the demand point to the nearest charging station is \(L_{ij}\). Assuming \(D > L_{ij}\), the user can complete the charging demand, otherwise it cannot. The shortest distance is obtained by the Dijkstra algorithm.

\[ M_1 = \sum_i \sum_j kP L_{ij} Z_{ij} \]  

(3)

\[ \sum Z_{ij} = n \]  

(4)

\[ L_{ij} \leq D \]  

(5)

Where: \(k\) represents the scale factor, taking into account the impact of the user's mileage anxiety; \(P\) is the total number of users; \(Z_{ij}\) indicates whether to establish a station at this point, the value is 0 or 1, \(Z_{ij}\) is 1 means that the station is built there, \(Z_{ij}\) is 0 Not building a station there; \(n\) is the total number of charging stations built in the area.

3.1.2 Queue time. According to the queuing theory, when the user arrives at the charging station for charging, if the number of chargers is greater than the number of electric vehicles to be charged, the electric vehicle can immediately accept the charging service, and if the number of electric vehicles is greater than the number of charging machines, it is necessary to wait in line. Assuming that the number of charging stations in the charging station is \(c_{hk}\) and the charging time is \(t\), according to the M/M/c model of the queuing theory, the time consumed by the electric vehicle users in the queuing process is [7]:

\[ M_2 = \sum_j \sum_{p=1}^{g} W_{pj} \]  

(6)

\[ W_{pj} = \frac{l! \rho}{l!(1 - \rho)^2 \lambda^2} p_0 + t \]  

(7)

\[ p_0 = \left[ \frac{c_{hk}}{h!} \frac{1}{\mu} \lambda^h + \frac{1}{c_{hk}} \frac{1}{1 - \rho} \frac{1}{\mu} \right]^{-1} \]  

(8)

Where: \(M_2\) is the total time spent in the charging process; \(p\) is one of the charging users; \(W_{pj}\) is the time when the electric vehicle user \(p\) is queuing at the charging station.

3.2. Total cost of charging station construction
The total construction cost of the charging station includes construction cost and maintenance cost. The specific expressions are as follows:

\[ T = \sum_{j=1}^{N} (T_{1,j} + T_{2,j}) \]  

(9)
Where: $T$ is the total cost of charging station construction; $T_{1,j}$ is the annual infrastructure construction cost of the charging station; $T_{2,j}$ is the annual facility maintenance cost; $N$ is the total number of charging station construction.

### 3.2.1 Charging station annual infrastructure construction cost
The expression is as follows:

$$T_{1,j} = (T_a + T_b + T_c) \frac{r_0(1 + r_0)z}{(1 + r_0)^2 - 1}$$  \hspace{1cm} (10)

Where: $T_a$ is the design, management and construction cost of the charging station in the early stage; $T_b$ is the investment and installation cost of some infrastructure, such as chargers, cables, etc.; $T_c$ is the transformation of the power grid, the construction cost of the network loss; $r_0$ is the investment recovery rate; $z$ is the age of operation.

### 3.2.2 Facility maintenance cost
The expression is as follows:

$$T_{2,j} = T_{1,j} \eta + T_0 \xi$$  \hspace{1cm} (11)

In the formula: for the conversion factor, the equipment maintenance, operation and maintenance personnel salary is converted to the initial construction cost; $T_0$ is the operating income of the charging station; for the proportional coefficient, the tax is proportional to the income.

### 3.3. Restrictions

#### 3.3.1 Power balance constraints
The expression is as follows:

$$P_b = P_L + \sum_{dj=1}^{dn} (P_{dj,j} + P_{dj,j})$$  \hspace{1cm} (12)

Where: $P_b$ is the injected power of the system balance node; $P_L$ is the system network loss; $P_{dj}$, $P_{dj,j}$, $j$ are the original active load of the distribution system node $dj$ respectively. Increase the active load of the new charging station $j$; $dn$ is the number of nodes in the distribution system [8].

#### 3.3.2 Node voltage amplitude constraint
The expression is as follows:

$$V_{dj}^{\min} < V_{dj} < V_{dj}^{\max}, dj = 1,2,\ldots,dn$$  \hspace{1cm} (13)

Where: are the lower and upper limits of the voltage amplitude of the distribution system node.

#### 3.3.3 Charging station service radius constraint
The expression is as follows:

$$L_{ij} \leq R_i$$  \hspace{1cm} (14)

Where: $L_{ij}$ is the distance from the demand point to the nearest charging station.

In addition to the above constraints, there are other factors that need to be considered when charging stations are selected, such as geographical environment, social conditions, traffic conditions, and user travel habits.

### 4. Model solving
Particle Swarm Optimization (PSO) was first proposed by Eberhart and Kennedy in 1995, starting with a random solution. Through iterative optimization, each particle is searched by tracking the historical optimal value and all particles. The optimal value is to update the spatial position and speed of the solution space, and finally find the global optimal. This paper uses PSO to realize the location planning of charging stations [9].

The overall planning process is as follows:
Step 1: The possible location and number of charging stations are determined according to the constraints of the charging station and other external factors.

Step 2: The total charging demand of the users is predicted in the planning area. The capacity and number of charging stations are determined.

Step 3: Initialize the particle swarm, the particle length is the number of charging stations, and 1 and 0 represent whether to establish a station at this position.

Step 4: Determine whether the candidate site satisfies the constraint condition, determine the location and capacity configuration of the charging station according to the constraint condition, and select the distribution network node matching the site as the site access point to perform security verification.

Step 5: Calculate the total cost of building and the total cost of the user for each particle that meets the constraints.

Step 6: The sum of the total cost of the charging station construction and the total cost of the user is used as the fitness function. The speed and position of the particles are updated. The step returns to the fourth cycle until the convergence or the maximum number of iterations is satisfied.

5. Case analysis

The planning of an electric vehicle charging station in a certain area is taken as an example for analysis. The area is 60 km². There are 1000 electric vehicles. The planning area is shown in Figure 1. In the particle swarm optimization algorithm, the particle swarm size is 50, the particle length is the number of candidate sites, and the number of iterations is set to 100. The learning factors c1 and c2 are both taken as two.

It can be known that the total social cost of building a charging station is the smallest when the number of stations built by the charging station is five. When the number of charging station constructions increases, the user's annual time spent on the charging station and the annual waiting time for charging are decreasing. Considering the service range of the charging station, the number of stations in the final charging station is 4, 5, 6, and 7, and the other conditions do not meet the constraints. When the number of stations is 5, the location of the station is shown in Figure 1. Charging stations are mostly distributed or close to residential areas and commercial areas, because users are more likely to travel in these areas, and traffic flow is relatively large [10].

| Table 2  | cost of different Electric vehicle charging Station |
|----------|---------------------------------------------------|
| Number of charging stations / seats | Time to reach the charging station / cost / 10,000 yuan | Charging time / cost / 10,000 yuan | Total cost of charging station / 10,000 yuan | Total social cost / 10,000 yuan |
| 4 | 69.27 | 897.56 | 78.32 | 537.04 | 1582.19 |
| 5 | 67.36 | 897.56 | 75.43 | 423.56 | 1463.91 |
| 6 | 65.78 | 897.56 | 69.56 | 451.26 | 1484.16 |
| 7 | 63.89 | 897.56 | 65.49 | 557.23 | 1584.17 |

6. Conclusion

In the process of site selection planning for electric vehicle charging stations, the total cost model of users and charging stations is established and solved by improved particle swarm optimization algorithm. The candidate sites are initially screened by external conditions such as environment and geography, and then optimized by minimizing the total cost consumed by users and charging stations. The location of the charging
station with the smallest total cost of the user and the charging station is close to the residential area or office area. This fully reflects the travel rules of the user who selects these locations as destinations. The results show that the time-consuming cost and charging waiting cost of the user are relatively low.

![Fig. 1 Charging station distribution](image)

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