Location planning of electric vehicle charging station based on HPSO-TS

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Abstract. Aiming at the optimization problem of electric vehicle (EV) charging station layout, an optimization model is constructed which takes the cost of all charging stations within the planning range as the objective function. Combining particle swarm optimization (PSO) and tabu search algorithm (TS), a hybrid algorithm of particle swarm optimization and tabu search (HPSO-TS) was proposed to solve the problem of EV charging station location. This algorithm increases the particle diversity by mutating the individual extremum, and uses TS in the later iteration to improve the late search ability of PSO and overcome premature convergence. Simulation results show that when solving the layout optimization problem of EV charging stations with service requirements and user demand constraints, HPSO-TS is superior to the computational results of PSO and mutation particle swarm optimization (MPSO). Compared with the basic algorithm, the improved algorithm has better efficiency and convergence, which proves the effectiveness and feasibility of the improved algorithm.

1. Introduction

Due to the deepening environmental pollution and energy shortage, the electric vehicle (EV) industry has been widely concerned [1]. Several countries, including China, have announced plans to ban the sale of gasoline and diesel cars in the coming years. However, the subsequent problem is that sufficient charging stations should be established with reasonable coverage of locations to ensure that consumers can drive EVs to various destinations conveniently [2, 3]. The biggest disadvantage of EVs is that their driving range is constrained by the battery power. Therefore, in order to ensure the timely charging of electric vehicles, it is first necessary to rationally plan and design the charging infrastructure of electric vehicles [4].

The rapid popularization of EVs has brought a large number of charging demands. Therefore, rapid and accurate prediction of charging demand distribution is helpful to accurately determine the location and capacity of charging facilities. In [5], according to the transportation route planning of gas stations, the capacitive flow refueling positioning model (CFRLM) is adopted to explicitly capture the EV charging demand of the traffic network. In [6], monte carlo simulation was conducted according to the...
probability distribution to predict the distribution of EV charging demand. After the prediction of EV charging demand, charging station planning can be carried out on this basis. There are usually two solutions to the layout problem of charging stations. Several indexes are put forward to evaluate the site selection of charging stations and the optimal scheme is selected according to the evaluation method. Another common approach is to build an optimal model that takes into account various constraints to determine the optimal location and capacity of EV charging stations.

Three variables need to be determined for EV charging station planning: site, capacity and the number of charging stations in this specific region [7]. Objective function constraint condition and method of solving programming model are three key elements of EV charging station planning. The location and size of charging stations not only affect the driving behavior of EV, but also have an important impact on the operation of power grid. Therefore, the planning of charging stations should take into account both user and electrical constraints. In addition, an appropriate planning method for charging stations should minimize the investment and operation and maintenance costs of charging stations. In [8], the problem of location and scale is studied, the location and quantity of chargers are determined while considering charging requirements. In [9], the optimization of charging station layout is considered in the planning of distribution network, and the comprehensive planning of distribution network and charging station is realized with the goal of minimum investment and operating cost. In [10], a method combining weighted Voronoi diagram and genetic algorithm is proposed in the planning of charging station.

Heuristic algorithm is a common method to seek the optimal solution of charging station layout planning, such as quantum genetic algorithm, simulated annealing algorithm and other intelligent algorithms. Particle swarm optimization (PSO) is the most common algorithm. PSO algorithm has the advantages of easy implementation, high precision and fast convergence. In recent years, in order to reduce the probability of PSO algorithm falling into local optimal, various improved PSO algorithms have been proposed. In [11, 12], the PSO algorithm with a linearly decreased inertia weight (PSO-LDIW) has been proposed. In [13], PSO algorithm with time-varying acceleration Coefficients is proposed. In this paper, tabu search (TS) is added to PSO algorithm, which combines the advantages of PSO in the early stage of search with the strong local search ability in the later stage of TS. The speed and accuracy of optimization are improved effectively. Finally, experimental results show the effectiveness and superiority of this algorithm.

2. Charging Station Planning Model

2.1. The Objective Function

The layout of EV charging stations should not only meet the charging needs of different users, but also consider the economy of planning and construction and the operating load of the corresponding distribution network. The objective of this paper is to minimize the cost of all charging stations within the planned scope, and the objective function is established as follows:

$$\min C_a + C_h$$  \hspace{1cm} (1)

The annual construction cost can be expressed as:

$$C_a = \sum_{k=1}^{N} (C_1 t_k + C_2 p_k + S_k) \frac{r_0^u}{(1 + r_0)^n - 1}$$  \hspace{1cm} (2)

Where $N$ is the total number of planned charging stations, $C_1$ is the unit price of transformer, $t_k$ is the number of transformers configured for the charging station $k$, $C_2$ is the unit price of charging pile,
$p_k$ is the number of charging piles configured for charging station $k$, $S_k$ is the infrastructure of charging station, $r_0$ is the discount rate, $n$ is the operating years.

The annual operation and maintenance cost can be calculated as a percentage of the initial construction cost. The annual operation and maintenance cost is shown as follows:

$$C_b = \eta \sum_{k=1}^{N} (C_1 t_k + C_2 p_k + S_k)$$

(3)

Where $\eta$ is the percentage of operation and maintenance cost in the investment cost.

2.2. Constraints of Integrated power Grid and Users

Since the power quality and user demand of the distribution network are affected by many other factors besides the layout of charging stations, the power quality and user demand of the distribution network are taken as constraint conditions.

2.2.1. Constraints required by the grid

When the charging load is large, it will affect the power quality and economy of the power grid. The voltage amplitude of each distribution network node shall meet the following constraints:

$$V_{i\min} \leq V_i \leq V_{i\max}, i = 1, 2, 3, ..., N_d$$

(4)

Where $V_i$ is the voltage amplitude of the node $i$, $V_{i\max}$ and $V_{i\min}$ respectively represent voltage upper limit and voltage lower limit. $N_d$ is the distribution network node.

The total charging power connected to the substation meets the following constraints:

$$\sum_{z=z_i}^{z_{M}} P_{ez} \leq P_{e\max}$$

(5)

Where $P_{ez}$ represents the charging power of the charging station, and $P_{e\max}$ represents the maximum allowable charging load of all substations in the planning area.

2.2.2. Constraints required by EV user

The user requires that the charging power is large enough and the charging station is close enough. The constraints are as follows:

$$\sum_{z=z_i}^{z_{M}} P_{ez} \geq P_{\max}$$

(6)

Where $P_{\max}$ represents the potential maximum charge demand.

In order to avoid the high road cost of EV users and improve the convenience of charging, the service radius of charging stations is limited

$$D_z \leq D_{\max}, z = z_1, z_2, ..., z_M$$

(7)

Where $D_z$ is the service area radius of the charging station, $D_{\max}$ is the maximum service radius of the charging station.
3. Implementation of The HPSO-TS Method

3.1. PSO Algorithm
PSO algorithm is an adaptive optimization algorithm based on population search [14]. This algorithm was first proposed by Kennedy and Eberhart in 1995. This algorithm modifies individual action strategies through information sharing among groups and individual experience, and finally obtains the solution of the optimization problem [15]. PSO algorithm first initializes a group of particles in the feasible solution space, and each particle represents a solution of the solution space [16]. Particles movement in solution space updates individual position by tracking individual extremum and group extremum.

The velocity and position update equations of particle $i$ are as follows:

$$V_{id}^{k+1} = \omega V_{id}^{k} + c_1 r_1 (P_{id}^{k} - X_{id}^{k}) + c_2 r_2 (P_{gd}^{k} - X_{id}^{k})$$

(8)

$$X_{id}^{k+1} = X_{id}^{k} + V_{id}^{k+1}$$

(9)

Where $k$ is iteration number, $r_1$ and $r_2$ are random numbers distributed in the interval of $[0, 1]$, $P_{id}^{k}$ is the optimal location searched by individual particles, $P_{gd}^{k}$ is the optimal position searched by all particles in the population, $C_1$ and $C_2$ are nonnegative constants, called acceleration factors.

3.2. Particle swarm mutation operation
When the particle swarm is too concentrated, it is easy to get into the local optimal value. In the search process, the particle speed will decrease with the proximity to $P_{gd}^{k}$, and when the distance between the particle and $P_{gd}^{k}$ approaches zero, the particle will stop the search. However, the convergence result may not be the global optimal solution but the local optimal solution. It can be seen from the formula (8) that changing the $P_{id}^{k}$ control of individual extremum can change the particle velocity and avoid falling into the local optimal value due to the rapid convergence of particles. Therefore, carry out mutation operation on individual extremum:

$$\hat{P}_{id}^{k} = P_{id}^{k} (1 + \mu)$$

(10)

Where $\mu$ is the random number satisfying the standard gaussian distribution.

3.3. Tabu Search algorithm
TS algorithm is a modern heuristic algorithm, which was proposed by Fred Glover, a professor at the university of Colorado. TS algorithm is a search method to jump local optimal solution. It avoids repeated searches by local neighborhood search mechanism and corresponding taboo criteria, and releases some good conditions of being taboo, so as to ensure effective exploration of diversification and finally realize global optimization.

The algorithm steps of simple tabu search can be described as follows:

1) Given the algorithm parameters, the initial solution $x$ is generated randomly, and the tabu table is set as null. Choose an individual as the current solution $X$.

2) Whether the termination conditions of the algorithm are satisfied? If so, end the algorithm and output the optimization result; Otherwise, continue the following steps.

3) Generate all (or several) neighborhood solutions by using the neighborhood functions currently solved, and determine several candidate solutions from them.

4) select the candidate solution $Y$ with relatively optimal fitness, and judge whether $Y$ meets the contempt criterion or not. If it is true, replace $X$ with $Y$ to become the new current solution, that is,
$X = Y$, and replace the tabu object that first enters tabu table with the tabu object corresponding to $Y$, and then go to step 6. Otherwise, continue the following steps.

5) Select the optimal state corresponding to non-tabu objects in the candidate solution set as the new current solution, and replace the tabu object elements that enter tabu table at the earliest with corresponding tabu objects.

6) Transfer step 2

Since TS algorithm can accept inferior solutions in the search process, it can jump out of the local optimal solution and enhance the probability of obtaining a better global optimal solution. Therefore, TS algorithm is a global iterative optimization algorithm with strong local search ability.

### 3.4. HPSO-TS Algorithm

A hybrid algorithm of particle swarm optimization and tabu search (HPSO-TS) combines the advantages of PSO algorithm in the early stage of search with the strong local search ability in the late stage of TS. Meanwhile, the mutation operation improves the diversity of PSO particles and effectively improves the speed and accuracy of optimization. The flow of HPSO-TS algorithm is shown in Fig. 1.

![Flow chart of HPSO-TS algorithm.](image)

**Figure 1.** Flow chart of HPSO-TS algorithm.

### 4. Case Studies

Based on the above model, Qingdao EV planning is taken as an example for simulation. It is assumed that the number of private cars in this urban area is 100,000 and the penetration rate of electric cars is 10%. Assuming that the fast charging time is 30 min and the slow charging time is 12 h, the average
battery capacity of each EV is 85kwh, the average maximum mileage is 440 km, and the charging power of the charger is 500 kW. The discount rate of regional charging stations is 4%, the operating life is 20 years, the charging efficiency is 0.9, and the operation and maintenance cost accounts for 10% of the investment cost. HPSO-TS algorithm was applied to solve the problem, the particle population $X_{pop} = 20$, the maximum number of iterations $It_{max} = 200$, the acceleration factor $C_1 = 1.9445$, the acceleration factor $C_2 = 1.49445$. The total cost is 3,636,873 yuan, and the optimal number of charging stations is 5 optimal charging stations, as shown in figure 2. The total cost is 3,636,873 yuan, and the optimal number of charging stations is 5. The optimal charging station planning diagram is shown in the Fig. 2.

![Figure 2. Optimal plan of charging station location.](image)

Three algorithms were used to solve the model respectively, and the convergence results were shown in Fig. 3. It can be seen that the total cost decreases gradually with the increase of iterations. The convergence rate of PSO algorithm is slower than that of HPSO-TS algorithm. The convergence of PSO algorithm is about 140 generations, and that of HPSO-TS algorithm is about 120 generations. The total cost obtained by HPSO-TS algorithm is less than that of PSO algorithm, indicating that the solution value of HPSO-TS algorithm is better than that of PSO algorithm. PSO algorithm is more prone to local optimization.

![Figure 3. Convergence of the three algorithms.](image)
The final optimization results obtained by the three algorithms are shown in TABLE. 1. The total cost of PSO is 5,473,584 yuan, and the optimal number of charging stations is 8. The mutation particle swarm optimization algorithm (MPSO) takes 75.93s to run. The total cost of MPSO algorithm is 4,503,367 yuan, and the optimal number of charging stations is 6. The MPSO algorithm takes 66.63 s to run. The total cost obtained by the HPSO-TS algorithm is 3,636,873 yuan, and the optimal number of charging stations is 5. The HPSO-TS algorithm takes 57.58 s to run. It can be seen that the MPSO algorithm and HPSO-TS algorithm are more efficient than PSO algorithm, and the solutions obtained are better than PSO algorithm, and the HPSO-TS algorithm is better than MPSO algorithm.

| algorithms       | POS       | MPSO      | HPSO-TS   |
|------------------|-----------|-----------|-----------|
| Total cost       | 5473584   | 4503367   | 3636873   |
| Number of charging stations | 8         | 6         | 5         |
| The algorithm takes time | 75.93     | 66.63     | 57.58     |

5. Conclusion
There is a close relationship between the large-scale promotion of EVs and the construction of charging stations. Combining PSO algorithm and TS, a HPSO-TS algorithm was proposed to solve the problem of EV charging station location. MPSO-TS algorithm introduces mutation operation, avoids particle falling into local optimal. TS was introduced to improve the performance of the algorithm. The simulation results show that the proposed method is faster and better than PSO algorithm in solving the optimization problem of charging stations.

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