Optimal Scale And Addressing Of Electric Vehicle Charging Stations

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Abstract

Taking into account the region's electric car number and distribution, charging station investment cost, operation cost, scrap income and user charging way power consuming cost case, an electric vehicle charging station optimization model is proposed. By using suitable for planning and the lack of global search optimization ability V diagram combined with global random searching ability of particle swarm optimization algorithm with, take advantage of these two methods and solve the model. The feasibility of the method is verified by a numerical example, and the results show that the method can effectively find the optimal configuration of the charging station, and solve the problem of the economic planning of the charging station.

Keywords: ***electric vehicle; Charging station planning; PSO; Voronoi diagram***

1. Introduction

China is one of the large oil consuming countries, the foreign dependency of high, oil import rate even exceeded 50%, and gas guzzling cars accounted for the national oil consumption amount of 25%[1]. In order to reduce dependence on oil and protect the environment, the automotive industry is moving towards the direction of energy conservation, environmental protection, green development. Electric vehicle with electric generation oil, can achieve "zero emissions", at the same time with the advantages of low noise, can effectively solve the energy and environmental problems. As a representative of a new generation of energy-saving and environment-friendly vehicles, electric vehicles is the future direction of the development of the automobile industry [2]. Planning and construction of electric vehicle charging station is the premise and basis of the application of electric vehicle[3], and domestic charging facilities construction plan is becoming a hot topic. Reference [4] compares the current situation of energy supply facilities of electric vehicles at home and abroad, and the different characteristics of different charging infrastructure and charging methods are described. Reference [5] analyzes the electric vehicle charging facilities planning characteristics of different stages, and puts forward the concept of charging mode selection optimization model and spacing ratio, the charge capacity redundancy, the charge level redundancy and so on. Reference [5] describes the characteristics of electric vehicle charging facilities monitoring, and proposes the design ideas and implementation methods of the electric vehicle charging facilities monitoring system. Reference [7] in research electric vehicle power supply on a regional basis, it is concluded that the planning of electric vehicle charging facilities should be combined with the distribution network planning. Reference [8-9] according to the principle of conservation of regional traffic flow, for electric vehicle charging station layout, charge capacity, establishes a comprehensive cost minimization model by considering the construction of charging station and the operating cost, and a numerical example is solved.

The object of this study is that social users such as taxis and private vehicles, taking into account the time value of a user's trips, is for users to quickly charge needs, so the main concern is planning rapid charging stations for electric vehicles slow users filling problems are not yet considered. In this paper, we mainly consider the investment cost, operation cost, maintenance cost, network loss and power line construction cost of the charging station. According to the charging demand of electric vehicles in the region, the optimal planning model of electric vehicle charging station is established. And solve the problem of layout economic planning for electric vehicle charging station by using Voronoi diagram and particle swarm optimization combined method.

2. Electric vehicle charging station Economic model

Planning charging station depends on the charging station investment and operation costs and user convenience. The investment operating costs including charging station investment costs, operating costs and the cost of new lines; The user in the charging station waiting time and the user's arrival time consuming, energy cost are indices of user convenience. Given the rapid charging station fast charging, charging station construction is to reduce as much as possible user waiting time ignored traffic congestion, road maintenance and other uncertain factors. Let the user charge on the way travel time and distance to the corresponding, for the sake of simplicity, can be converted to the power consumption cost and time cost as a measure of user convenience.

2.1 The number of charger in the Charging station

In charging station service area u, the total number of vehicles is M_u ,average daily energy consumption of electric vehicles is Q ,the average charging power of charger is P_c ,so the number of charger in the charging station[10]:

$$n_c = f_{\mathrm{ceil}}\left(\frac{M_u Q(1+\rho)}{K_X K_T T_C P_C}\right) \quad (1)$$

Among them, ρ is the charger charge capacity margin, K_X is the efficiency of the charger, K_T is more than one charger simultaneous rate, T_C is average effective working hours in a day.

2.2 Charging station construction cost

The construction cost includes acquisition cost, cost of land and cost of newly laid line. Acquisition cost includes charging machine, charging system, filtering systems and other related equipment. The construction cost of charging station[11]:

$$C_{c1} = \frac{r(1+r)^{L_c}}{(1+r)^{L_c}-1}\sum_{i=1}^{N_c}(W_c + q_c n_{ci} + e_c n_{ci}^2 + cl_i) \quad (2)$$

Among them, r is discount rate, L_c is charging station operating years, W_c is fixed investment, q_c is investment related to the unit charger unit price, e_c is the equivalent coefficient of investment related to the number of charger, including floor space, power distribution transformer capacity, etc. l_i is the length of the transmission lines need to lay a new charging station, c is laying unit price of transmission line.

2.3 Operating cost of charging station

Operating costs includes station equipment maintenance, site cleaning and personnel salary, etc. Set up operating costs at a charging station accounted for the proportion of the investment costs is ∂_c, so operating costs for the charging station:

$$C_{c2} = \partial_c C_{c1} \quad (3)$$

2.4 Charging way power costs

Charging way power costs is mainly determined by the user charging demand point to the charging station between the driving distance. To a year for 365 days of computing, Let demand point a select the nearest charging station c for charging, so the user to charge his way power costs:

$$C_{c3} = 365\sum_a s_{ac} q \quad (4)$$

Among them, S_{ac} is the distance between the charging demand point a and charging station c . q is electric vehicle unit power consumption cost.

Provided user charging demand point a coordinate is (x_a, y_a), charging station c coordinate is (x_c, y_c), λ_{ac} is the urban road nonlinear coefficient between charging demand point a and charging station c:

$$s_{ac} = \lambda_{ac}\sqrt{(x_a - x_c)^2 + (y_a - y_c)^2} \quad (5)$$

smaller value of λ_{ac} indicates transportation between two points more quickly. Different values in different formats road: the grid network is 1.00~1.41, the ring radial type is 1.10~1.20, the free style is 1.10~2.60, the mixing type is 1.00~1.40[12].

2.5 Time-consuming cost on the way

Given the fast charging speed, charging station construction is to minimize users waiting time, and queuing time can be ignored when the vehicle is on the way. To a year for 365 days, the user is charging time consuming:

$$C_{c4} = 365\beta \sum_{a} s_{ac} / v \qquad (6)$$

Among them, β is urban travel time cost factor, v is urban transportation average running speed.

2.6 Net loss cost

Loss cost refers to the cost of the new charging stations access to the grid after the original, the new network losses caused. This cost is related to the location of the charging station, which is one of the indicators to measure the impact of the location of the charging station on the economy of the power grid. Calculation formula of net loss cost:

$$\mathrm{C}_{c5} = r_s \sum_{i=1}^{N_c} \Delta \mathrm{P}_i \qquad (7)$$

Among them, r_s is annual conversion coefficient of net loss cost. P_i is net loss increased amount of new charging stations access to the grid after the original.

2.7 Scrap income of charging station

Charging station to reach the operating period, the station equipment scrap can get a certain income. Set up scrap income accounted for the charging station equipment investment to cost ratio is σ_c, so scrap income of charging station:

$$C_{c6} = \frac{r}{(1+r)^{L_c} - 1} \sum_{n_c}^{N_c} (q_c n_{ci} + e_c n_{ci}^2) \sigma_c \qquad (8)$$

2.8 Total cost of the charging station

The total cost of the charging station includes a charging station investment costs, operating costs, power consumption cost, time-consuming cost and retirement income. So the total cost:

$$C_c = C_{c1} + C_{c2} + C_{c3} + C_{c4} + C_{c5} - C_{c6} \qquad (9)$$

3. Constraint condition

1) The distance between the charging station is bound by the service radius, and the distance between two charging stations meet service radius R_c constraints:

$$\begin{cases} R_c < \lambda_{ac} s_{ac} < 2R_c \\ R_c \le D_{EV} \end{cases} \qquad (10)$$

Among them, D_{EV} is reasonable driving range of electric vehicles, namely the electric vehicle starting from the optimum power battery discharge depth discharge until mileage when the maximum discharge depth can[13-14].

2) The number of the charger in the charging station was bound by charging electricity demand and electricity network. Satisfy the inequality constraint[11]:

$$n_{c\min} \le n_c \le n_{c\max} \qquad (11)$$

Among them, $n_{c\min}$ is charger minimum number limit in the charging station. $n_{c\max}$ is charger maximum number of restrictions in the charging station.

3) Substation capacity constraint:

$$S_i \le S_{i\max} \qquad (12)$$

Among them, S_i is load of substation for corresponding area. $S_{i\max}$ is the maximum load of the substation.

4) Maximum charging power constraint for electric vehicles allowed to access in distribution network:

$$\sum_{i=1}^{N_c} P_{ci} \le P_c^{\max} \qquad (13)$$

Among them, P_{ci} is charging power of charging station i. $P_c^{\max}$ is maximum charging power of electric vehicles allowed to access in distribution network.

5) Charging station access point capacity constraint:

$$P_{cij} \le P_j^{\max} \qquad (14)$$

Among them, P_{cij} is maximum charging power of an access network node j to a charging station i. $P_j^{\max}$ is maximum access power allowed by network node j. This is mainly determined by the load at the node j and the transmission capacity of the line[15].

4. Solution of particle swarm optimization algorithm combined Voronoi graph

In view of the Voronoi graph is a local optimal location for a given growth point, but lack the ability of global optimization. Voronoi graph combined with particle swarm optimization algorithm can be used to better carry out charging station site planning.

Step 1: According to the total number of electric vehicles in the planning area n_C, applying the formula (1) to preliminarily estimate the total number of chargers

$N_{\Sigma c}$ in charging stations.

Step 2: In the region while randomly generated m sets of N_c charging stations coordinates, compiled into the initial particle population X, namely m is the population, X is the $m*2N_h$ order matrix, line i characterize the position coordinates of particle i of charging station:

$$X=\begin{bmatrix} x_1^1, & x_2^1, & ..., & x_{N_c}^1, & y_1^1, & y_2^1, & ..., & y_{N_c}^1 \\ x_1^2, & x_2^2, & ..., & x_{N_c}^2, & y_1^2, & y_2^2, & ..., & y_{N_c}^2 \\ & ...... & & , & & ...... & & \\ x_1^m, & x_2^m, & ..., & x_{N_c}^m, & y_1^m, & y_2^m, & ..., & y_{N_c}^m \end{bmatrix} \quad (15)$$

Step 3: Taking the coordinates of each charging station as the growth point for the Voronoi diagram, V diagram coverage area is the charging station service area. According to the total number of electric vehicles in the service area, to determine the number of the charging station n_c, the elements of the column t and the row i are symbolic of the number of the charger in the charging station t of the i particles:

$$n_c=\begin{bmatrix} n_1^1, n_2^1, ..., n_{N_c}^1 \\ n_1^2, n_2^2, ..., n_{N_c}^2 \\ ...... \\ n_1^m, n_2^m, ..., n_{N_c}^m \end{bmatrix} \quad (16)$$

Step 4: Calculate the particle fitness. Calculate the distance between charging station and charging demand point based on their location. According to the configuration of each charging station, calculate the total cost of each particle corresponding to the charging station, as the fit value of PSO algorithm and write down the current individual extremum pb and the global extremum gb. Constraint conditions are reflected by penalty function method.

Step 5: Update the particle swarm speed and position into the new charging station coordinate group, loop to step 3. When the iteration number or the convergence precision of the reservation is reached, the loop is exited, and the global optimal value is output, which is the optimal allocation of the charging station.

5. Example analysis

A city planning area is 81km^2, North and south, east and west towards all of 9 km. In the initial planning, it is divided into 26 functional areas, mainly used for industrial, residential, commercial and service, etc. There are three 35/10kV substations in this area, and the capacity is 2×16 MVA. Their distributions are shown in table 2. The total number of electric vehicles is 7535, distributed as shown in table 1. The probability that the car needs to be charged a day is 0.1. Suppose that the average capacity of electric vehicle is 50kWh, single charger power is 40kW, charging station minimum capacity allocation is 6 chargers, and maximum capacity allocation is 20 chargers[10]. The effective charging time of charging station is 16h, charging capacity margin is 20%, the charger charging efficiency is 0.9, and simultaneous rate is 0.8~1.0[15]. The electric vehicle urban travel time cost factor β is 20 yuan/ km, and consumption cost factor of electric vehicle at a speed of v is 0.5 yuan / km, which v takes 25km/h[15]. In this paper, the road is a grid network, and the nonlinear coefficient is 1.2. The values of other parameters are as follows:

$c=16500\,yuan/km$, $r=0.08$ $L_c=20\,year$, $W_c=1000000\,yuan$, $q_c=100000\,yuan/\text{stand}$, $e_c=30000\,yuan/stand^2$, $\sigma_c=10\%$ $\partial_c=10\%$ [11]

Table 1.The distribution of electric vehicles in 26 functional areas(coordinate unit: km)

Functional area	Coordinate X	Coordinate Y	vehicle retention	Functional areas	Coordinate X	Coordinate Y	vehicle retention
1	0.97	1.42	267	14	7.79	2.61	238
2	1.32	3.61	334	15	8.28	4.77	275
3	2.64	0.97	370	16	8.55	6.3	256
4	5.05	1.19	334	17	7.39	7.06	325
5	6.57	0.67	245	18	4.47	4.16	340
6	8.36	0.85	367	19	4.87	7.11	238
7	6.29	2.27	260	20	8.29	8.43	332
8	4.35	3.09	256	21	6.05	8.48	285
9	2.71	2.54	260	22	4.13	8.56	226
10	1.35	5.85	363	23	4.67	5.72	335
11	0.54	5.12	290	24	2.78	8.01	268
12	2.78	5.08	286	25	2.34	6.59	189
13	6.96	4.63	356	26	0.57	8.71	240

Table 2.The distribution of the 3 substations(coordinate unit: km)

substation	Coordinate X	Coordinate Y

1	3.5	6.1
2	3.9	2.8
3	6.8	5.1

Using the formula (1), preliminarily estimate area internal charger count of approximately 73. According to the capacity of the charging station configuration constraints, the number of charging stations can be 4~12 stands. Under the solution procedure, the optimal number of charging stations in the area can be 11, and the total cost of the 4~12 stands is shown in Figure 1:

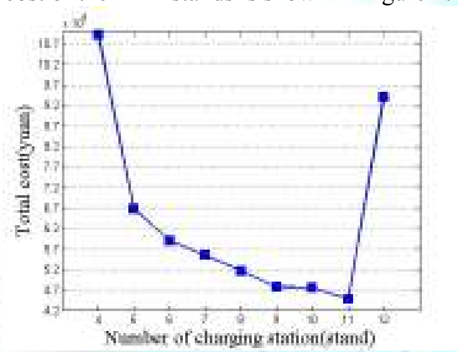

Figure 1.Different number of charging stations total cost

From the above results, the optimal allocation of the regional charging station is 11. By calculating the total cost of different number of charging stations in the area, it can be concluded that the total cost of individual cases to achieve a high. In view of the constraint conditions, the penalty function method is used, so when the total cost is very high, it can not meet the requirements of the charging station. That the investment of 11 or more charging stations cause waste of resources, investment 5 of the following charging stations can not meet the requirements of electric vehicle charging station.

In the optimal configuration, 11 charging stations location and capacity scale as shown in table 3:

Table 3. Optimal configuration of charging station(coordinate unit: km)

Charging station	Coordinate X	Coordinate Y	Charger/stand
1	7.8535	5.4235	7
2	5.0713	2.8581	6
3	3.1603	8.2687	8
4	7.8999	1.8814	9
5	2.0707	3.0788	9
6	4.7047	4.9235	7
7	4.0436	1.3870	7
8	6.2688	8.0503	9
9	2.7114	5.1513	6
10	7.9456	6.3875	6
11	2.0424	4.5732	7
Total cost (Yuan)		4472423	

In the planning mainly refer to the distribution of electric vehicles in the region, set charging station location as growth point to make Voronoi diagram. V diagram coverage area of each charging demand points prefer to use the corresponding charging station for charging. From the foregoing, the number of different charging station charger configuration is different, and it needs to be combined with the distribution of electric vehicles in the service area. Provide charging services for electric vehicles more quickly and economically without causing waste of resources. In this paper, by using particle swarm optimization algorithm combined with V diagram of the charging station planning, effective division of the service area, so that the charging station layout is reasonable and more close to the center of the charging demand point.

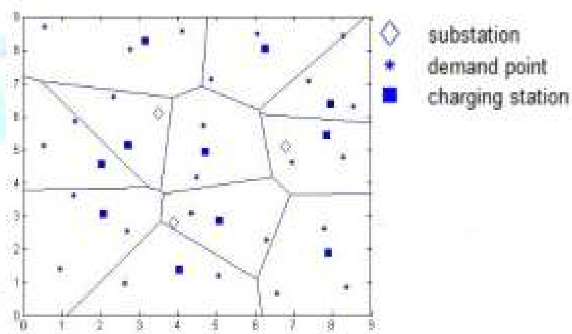

Figure 2. Layout of charging station

6. Conclusion

In this paper, on the site of the charging station, taking into account the benefits of both the charging station and the user, to minimize the total cost of the whole society as the target function, using suitable for planning and the lack of global search optimization ability V diagram combined with global random searching ability of particle swarm optimization algorithm with, take advantage of these two methods and solve the model. The practical example shows that, the solution method for the region's electric vehicle charging station planning has certain practicality and feasibility, and effectively solve electric vehicle charging station economic planning problems.

The charging station planning depends on the charging station investment and running cost and user convenience. In addition, charging station in planning by the regional nature of electricity, function and price, traffic jam and so on many external factors, the charging service network planning has put forward greater test, as a follow-up study of the subject.

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