The Planning of Electric Vehicle Charging Station Based on Grid Partition Method

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***Abstract*—The paper proposed a method of locating and sizing of charging station for electric vehicle based on grid partition. This method is aimed at minimizing the users' loss on the way to the charging station, zoning the planning area with grid partition method, and choosing the best location of each partition in GA (Genetic Algorithm) on the consideration of traffic density and charging station's capacity constraints. Through repeated calculations and adjusting the coverage of each partition and the sites of charging stations, this paper will finally get the reasonable planning of electric vehicle charging station in the whole area. The practical example proves that the methods and models in this paper are feasible.**

Keywords-grid partition method; electric vehicle; planning of charging station; genetic algorithm

I. INTRODUCTION

Currently, the world auto industry has entered a stage of energy transformation. The experts and scholars around the world have been actively exploring and striving to promote the transition of energy and power systems, as a result, the development of the electric vehicle began to accelerate. For the wide spread of electric vehicles, the charging stations are the premise and foundation, another requirement is to build an efficiency energy supply network as well as expanding the electricity market demand.

The planning of electric vehicle charging station has begun to catch eyes of many scholars at home and abroad. Reference [1] simulated the number of electric vehicles based on the distribution of residents. It conducted the site planning at the target of maximizing the charging station's profit from the time of putting into operation to the target year. The forecasting of charging demand did not consider the road information but just based on the distribution of residents. Therefore, there was a certain defect on the forecasting of charging demand. Reference [2] proposed three stages of the development of charging infrastructure, which were demonstration stage, public promotional stage and commercial stage. According to the characteristics of each stage, it proposed the optimization choosing model of charge mode and the principle, process and model of planning for charging infrastructure. However, the paper only gave the total construction capacity of charging infrastructure but did not do further research in the locating and sizing of charging station. Reference [3] put forward a two-steps model: first converged the road information into 'demand clusters' by hierarchical clustering analysis and then applied optimization techniques to conduct the site planning, while certain constraints and cost were considered. It focused on the capital constraints and running cost, but did not consider the users' loss on the way to the charging station. Reference [4] described Chinese current development of electric vehicle charging station and proposed the influencing factors and principle of planning of charging station. But it did not give a mathematical model for the layout of the charging station.

This paper is aimed at minimizing the users' loss on the way to the charging station, zoning the planning area with grid partition method, and choosing the best location of each partition in GA (Genetic Algorithm) considering traffic density and charging station's capacity constraints. Through repeated calculations and adjusting the coverage of each partition and the sites of charging stations, this paper will finally get the reasonable planning of charging station in the whole area.

II. THE MATHEMATICAL MODEL OF LOCATING AND SIZING

A. Locating Model

The main function of the city electric vehicle charging station is to provide the users with fast and high-qualified charging service which can not only facilitate the users but also minimizing the charging cost. So, this paper chooses the location on the consideration of the users' minimum loss on the way to the charging station. Suppose the cost of power loss is h_1 and the cost of indirect loss is h_2, the objective function can be expressed as the following formula:

$$H_{\min} = h_1 + h_2 \tag{1}$$

The cost of power loss:

$$h_1 = \frac{\sum L_j}{g} \times p \tag{2}$$

In the equation, $\sum L_j$ is the sum of weighted distance from the charging station j to the demand nodes in the service area. p is the charging price and g is the mileage per kilowatt-hour.

The cost of indirect loss:

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$$h_2 = \frac{\sum L_j}{v} \times k \quad (3)$$

In the equation, k is the cost of users' travel time and v is the average speed of electric vehicles.

The sum of weighted distance:

$$\sum L_j = \sum d_{ij} \times q_i \quad (4)$$

In the equation, d_{ij} is the distance between demand node i and charging station j. q_i is the charging demand of the node i.

B. Sizing Model

When calculating the charging demand of electric vehicles, the traffic flow of each intersection node is used to represent the road network traffic [5]. Suppose w is the number of the road sections connected with node i. $i+f$ is used to represent the node $i+f$ which connected with node i, $f = 1, 2, 3, ..., w$. $p_t^f(i, i+f)$ is used to represent the traffic flow of road section f which is between node i and node $i+f$ at the time of t. So the traffic flow of node i can be expressed as the following formula.

$$p_t^i = \sum_{f=1}^{w} p_t^f(i, i+f) \quad (5)$$

The traffic flow of any road section is two-way and non-symmetrical, that is $p_t^f(i, i+f) \neq p_t^f(i+f, i)$. So when calculating the traffic flow of any node, it should be from the same direction.

The charging demands of node i in period of T:

$$q_i = \int_0^T p_t^i \times \alpha \times \beta \times P_v dt \quad (6)$$

In the equation, α is the proportion of electric vehicles. β is the charge rate of electric vehicles. P_v is the average capacity of electric vehicles.

Suppose there are n_j nodes in the service area of charging station j, so the demand that charging station j should meet is expressed as the following formula:

$$Q_j = \sum_{i=1}^{n_j} q_i \quad (7)$$

The number of chargers in charging station j:

$$m_j = [\frac{Q_j \times \rho}{P \times k_x \times T_v \times k_t}] + 1 \quad (8)$$

In the equation, m_j is the number of chargers in charging station j. ρ is the capacity margin of the station. P is charging power of the chargers. k_x is the efficiency of chargers. T_v is the effective charging time of the station. k_t is the ratio of chargers for working at the same time.

III. GRID PARTITION METHOD

A. The Process and General Idea

The grid partition method estimates the number of initial partitions based on the charging demand of the electric vehicles in the planning area and the maximum and minimum capacity of the charging station. Also, it achieves the grid partition of the planning area by optimizing and adjusting the number and coverage of the partitions, and the relationship between charging nodes and partitions, in that way, each partition has only one charging station in it. The detailed process is shown in Fig. 1.

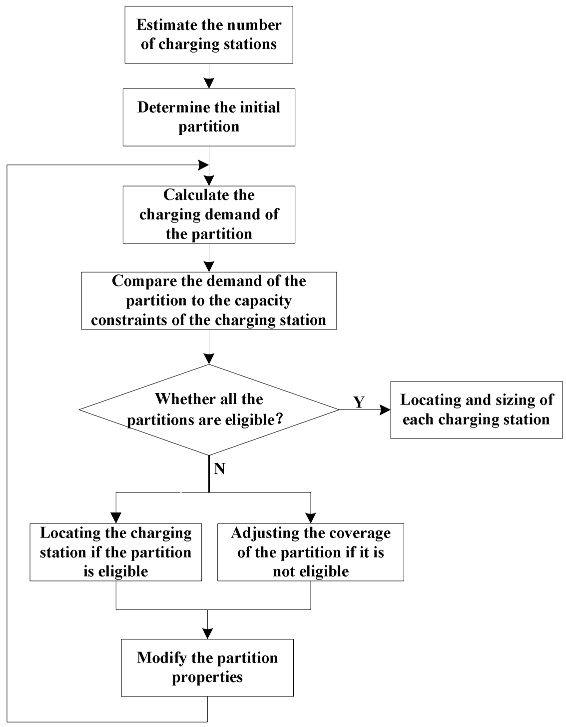

Figure 1. The overall process of grid partition method

B. The Initial Partition

1) Q: The total charging demand of the planning area

$S_{\min}$: The minimum capacity of the charging station

$S_{\max}$: The maximum capacity of the charging station

To use Q, $S_{\min}$ and $S_{\max}$ to estimate the number of charging stations (N): $N \in [N_{\min}, N_{\max}]$, and

$$N_{\min} = \frac{Q}{S_{\max}}$$
$$N_{\max} = \frac{Q}{S_{\min}} \quad (9)$$

2) Based on the estimated number of charging stations, the road network can be partitioned, and an initial partition data base comes into being. The data base includes partition label ($ZoneNo$), the number of partitions ($ZoneNum$), the charging demand of the partition ($ZoneDemand$), and the label, coordinates and charging demand of the nodes in the partition.

3) To select the initial location of the charging station targeting at the users' minimum loss on the way to charging station ($H_{\min}$) in the partition.

4) To determine the ownership of nodes on the boundary of partitions. Suppose node *i* is on the boundary of partition *j* and partition *k*. d_{ij} is used to represent the distance between node *i* and the charging station in partition *j*. d_{ik} is used to represent the distance between node *i* and the charging station in partition *k*. If $d_{ij} < d_{ik}$, node *i* will be assigned to partition *j*. Otherwise, it will be assigned to partition *k*. Meanwhile, the partition data base is modified.

C. Adjusting the Coverage of Partitions and Locating of Charging Stations

1) To calculate the charging demand ($ZoneDemand$) of each partition after the initial partitions are accomplished.

2) To compare the charging demand of the partition to the capacity constraints. If $ZoneDemand < S_{\min}$, it is defined as a small demand partition. If $ZoneDemand > S_{\max}$, it is defined as a large demand partition. If $S_{\min} \le ZoneDemand \le S_{\max}$, the locating of the charging station is conducted in this partition.

3) If partition *i* is a small demand partition, the nodes in the partition should be divided into the around partitions by measuring the distance from the nodes to the charging stations in around partitions. If the node is near to partition *j*, then put it into *j*, in that way, the nodes in partition *i* can be divided to the around partitions. Meanwhile, the partition data base is modified and the number of partitions minus 1.

4) If partition *i* is a large demand partition, it should be split into two partitions. At the same time, the partition data base is modified and the number of partitions plus 1.

5) Go to the step 1), repeated adjusting the coverage of the partitions, until all the partitions are eligible ($S_{\min} \le ZoneDemand \le S_{\max}$).

6) To conduct locating and sizing of the charging station in each partition by (1) and (8) after all the partitions are eligible.

IV. OPTIMIZED DESIGN BASED ON GA

The optimization locating of the charging station in each partition is achieved by GA [6]. The individual is coded by the real number and its chromosome length is 2: they are x-coordinate and y-coordinate. The fitness function is the reciprocal of the users' loss on the way to charging in the partition ($H_{\min}$). The initial individuals are got in random under the constraints ($x_{\min} \le x \le x_{\max}, y_{\min} \le y \le y_{\max}$), in the way of roulette to choose the individual from the group, and gradually find the best location by the iterative loop of variation, recombination and selection.

V. CASE STUDY

In order to illustrate the methods and models, a study case is constructed. There are 48 intersection points, 110 road sections in this area, and the planning area is 63km^2, the regional road net is shown in Fig. 2. The node coordinates and typical traffic data are shown in the Table below.

At the time of target year, the percentage of the electric vehicle is 15%, and the charging percentage is 10%. The paper supposes the capacity of each electric vehicle is 50 kWh. The power of every single charger is 96 kW; there are at least 6, at most 20 chargers in the station; the station's effective charging time are 16 hour; the margin of charging capacity is 1.2; the charger's efficiency is 0.9, coincidence factor is 0.8～1.0; the electric vehicle can run 7 km in each kWh; the energy charge is 0.8 Yuan/kWh; the average speed of electric vehicles is 20 km/h; and the cost of user travel time is 17 Yuan per hour when going out.

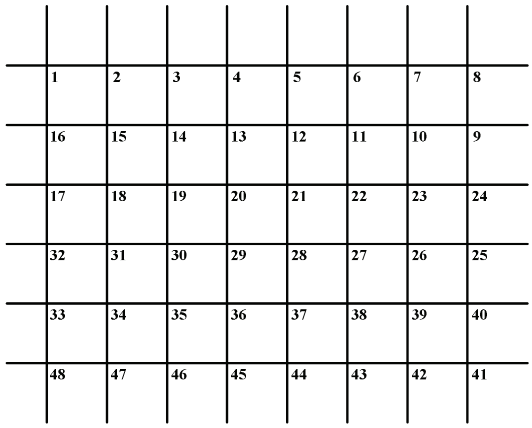

Figure 2. The road net of the planning area

TABLE I. THE COORDINATES AND TRAFFIC FLOW OF EACH NODE

Node Label	X	Y	Traffic Flow	Node Label	X	Y	Traffic Flow
1	1.0	6.0	4495	25	8.0	3.0	2012
2	2.0	6.0	2813	26	7.0	3.0	1435
3	3.0	6.0	3595	27	6.0	3.0	2156
4	4.0	6.0	3493	28	5.0	3.0	3211
5	5.0	6.0	5470	29	4.0	3.0	2543
6	6.0	6.0	4304	30	3.0	3.0	1242
7	7.0	6.0	2684	31	2.0	3.0	1059
8	8.0	6.0	4100	32	1.0	3.0	2132
9	8.0	5.0	4329	33	1.0	2.0	3055
10	7.0	5.0	2404	34	2.0	2.0	2185
11	6.0	5.0	4210	35	3.0	2.0	1327
12	5.0	5.0	3408	36	4.0	2.0	2566
13	4.0	5.0	2265	37	5.0	2.0	3526
14	3.0	5.0	1327	38	6.0	2.0	4210
15	2.0	5.0	2085	39	7.0	2.0	3401
16	1.0	5.0	3055	40	8.0	2.0	4329
17	1.0	4.0	2034	41	8.0	1.0	4200
18	2.0	4.0	959	42	7.0	1.0	2738
19	3.0	4.0	1242	43	6.0	1.0	4511
20	4.0	4.0	3040	44	5.0	1.0	3216
21	5.0	4.0	2660	45	4.0	1.0	1493
22	6.0	4.0	2099	46	3.0	1.0	3596
23	7.0	4.0	1314	47	2.0	1.0	2843
24	8.0	4.0	1712	48	1.0	1.0	5015

The process of calculation is shown as below:

1) To estimate the number of charging stations by (9), so $N_{\min} = 5, N_{\max} = 13$, the initial number of partitions (*N*) is to take the average of $N_{\min}$ and $N_{\max}$, $N = 9$. The initial partitions of the road net are shown in Fig. 3.

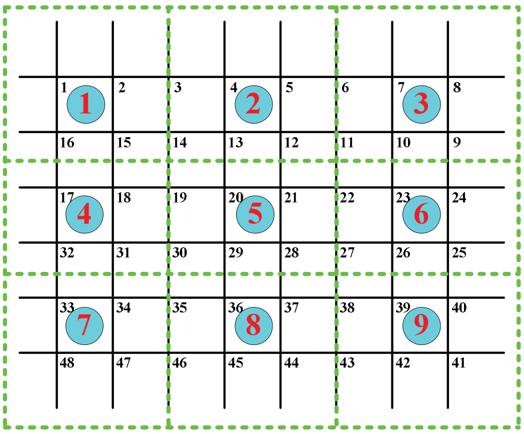

Figure 3. The initial partitions of the road net in planning area

2) The charging demand and the preliminary positions of charging stations in the initial partitions are shown in the Table below.

TABLE II. THE CHARGING DEMAND AND STATIONS' PRELIMINARY POSITIONS OF THE INITIAL PARTITIONS

Partition Label	X-coordinate of the Station	Y-coordinate of the Station	Charging Demand (kWh)
1	1.55	5.67	11182.13
2	4.84	5.76	16015.88
3	7.33	5.51	13330.50
4	1.43	3.47	5569.50
5	4.62	3.49	11117.63
6	7.23	3.44	6450.38
7	1.50	1.31	11669.63
8	4.86	1.56	13217.25
9	7.27	1.56	14271.38

3) Seven partitions are obtained after repeated adjusting the coverage of the partitions and the position of the charging stations follow the steps in Fig. 1. The labels of partitions are 1, 2, 3, 5, 7, 8 and 9. The charging demand and the final positions of the charging stations in these partitions are shown in the Table below.

TABLE III. THE CHARGING DEMAND AND FINAL POSITIONS OF THE CHARGING STATIONS

Partition Label	X-coordinate of the Station	Y-coordinate of the Station	Charging Demand (kWh)
1	1.72	5.46	15273.00
2	5.09	5.73	17362.50
3	7.77	5.18	12407.25
5	4.71	3.48	13644.75
7	1.69	1.54	15909.00
8	5.28	1.54	14641.50
9	7.69	1.83	13586.25

4) To calculate the size of each charging station by (7) and (8), the results are shown in the Table below.

TABLE IV. THE NUMBER OF CHARGERS IN EACH STATION AND USERS' LOSS

Partition Label	The Number of Chargers	The Users' Loss (Yuan)
1	15	15206.86
2	17	14431.12
3	11	9825.22
5	14	13417.06
7	16	15817.32
8	15	12349.70
9	14	10854.20
Total	102	91901.48

5) The coverage of partitions is shown in the Table below. and the layout of charging stations is shown in Fig. 4.

TABLE V. THE COVERAGE OF EACH PARTITION

Partition Label	The Labels of Nodes in the Service
1	1、2、3、14、15、16、17、18
2	4、5、6、11、12、13
3	7、8、9、10、23、24
5	19、20、21、22、27、28、29、30
7	31、32、33、34、35、46、47、48
8	36、37、38、43、44、45
9	25、26、39、40、41、42

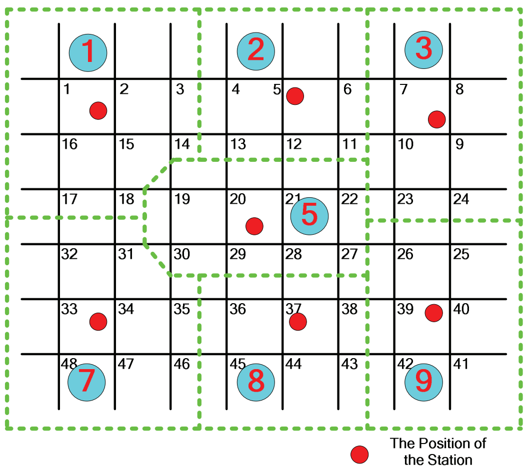

Figure 4. The coverage of partitions and the layout of charging stations

VI. SUMMARY AND OUTLOOK

This paper is aimed at minimizing the users' loss on the way to the charging station, zoning the planning area with grid partition method, and choosing the best location of each partition in GA (Genetic Algorithm) on the consideration of traffic density and charging station's capacity constraints. Through repeated calculations and adjusting the coverage of each partition and the site of charging stations, this paper will finally get the reasonable planning of electric vehicle charging station in the whole area. The practical example proves that the methods and models in this paper are feasible. However, the traffic density of road network is not considered in the formation of the initial partition. This makes the final result may not be the global optimal solution, but the local optimal solution. This issue will be resolved in further studies.

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