Optimal Planning of Charging Station for Electric Vehicle Based on Particle Swarm Optimization

LIU Zi-fa, ZHANG Wei, JI Xing, LI Ke

***Abstract*-- How to determine location and scale of electric vehicle charging station is a new problem for many researchers. A comprehensive objective function considering geographic information, construction cost and running cost is built in this paper. In objective function, construction cost consists of land cost, and investment in distribution transformer. Running cost includes power supply losses and with traffic flow as constraint conditions, which scientifically and comprehensively reflects the substance problem of locating and sizing of electric vehicle charging station. Electric vehicle charging station locating and sizing is a non-convex, non-linear, and combinatorial optimization problem. On the basis of the established objective function, an adaptive particle swarm optimization (APSO) algorithm is proposed to solve the problem in this paper. The proposed algorithm and optimization model are tested by a planning example of charging station for electric vehicle to verify the feasibility and effectiveness.**

***Index Terms*--electric vehicle; charging station; APSO; traffic flow**

I. Introduction

In recent years, as the rising of the price of oil and serious environmental problems brought by automobiles emissions, energy saving and emission reduction becomes a new task in the world. New energy vehicles usher in the best time of the development. According to industry experts' prediction, by 2020 China's 10%~20% of passenger vehicle sales will come from pure electric vehicle, charging type hybrid vehicles and other new energy vehicles. The number of urban traffic is electric ones primarily, and the electric vehicles will become the mainstream of the future development, a powerful mean and guarantee of energy saving and emission reduction soon. By the end of 2009, our country has 26.05 million private cars [1]. If power of every car is calculated as 5 kW, the total capacity is 130.25 million kW, which accounts for 14.9% of the national installed capacity; if energy consumption of every car is calculated as 2000 kW · h, the annual consumption adds up to 52.1 billion kW · h, which accounts for 1.41% of the national generated energy capacity. Obviously, after the electric vehicles go to scales, its overall power is enormous. Both hybrid vehicles and pure electric vehicles need to plug the power battery and public charging facilities. Now commonly used electric vehicle charging ways include conventional charging, rapid charging and battery quick-changed. Corresponding to different charging ways, the electric vehicles charging facilities can be divided into charging pile, charging station and exchanging power station.

How to optimize the electric vehicle charging station layout, becomes one of the problems that the city's planning department, transportation department and power supply department focus on. In allusion to this problem, XU Fan, etc. [2] discussed the construction situation of charging station, analyzed the various factors of the influence on the layout of electric vehicle charging station and put forward some suggestions of principle about the planning layout; XIN Jian-bo, etc. [3] introduced the electric vehicle charging mode and electric vehicle charging facilities construction mode, analyzed the factors which should be considered of the electric vehicle charging facilities construction and probed into the electric vehicle charging facilities construction demand forecasting methods; KANG Ji-guang, etc. [4] comparatively studied advantages and disadvantages of three types of charging modes. And from the external access, internal layout, capital investment and other aspects, expounded the construction of the charging station; LU Mang, etc. [5] elaborated the development situation of the electric vehicle charging facilities at home and abroad, compared and evaluated the advantages and disadvantages, the obstacles and development prospects of its construction and operation of the three kinds of business model; KOU Ling-feng, etc. [6] established an optimal cost model of regional locating and sizing of electric vehicle charging station, using the particle swarm algorithm, through solving the hypothesis examples proved the feasibility of the model.

The existing literatures mainly focus on the principle of site selection, the thought of site selection and the operational mode. From the angle of quantitative modeling, this article established a new model considering traffic flow and land cost of locating and sizing of electric vehicle charging station. The model simulated the number of electric vehicle by the traffic flow situation. With the construction cost and the traffic flow of electric vehicle charging station, the objective function added the operation cost of charging station, the cost of power supply operation consumption and the investment of distribution transformer.

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According to the model built, using particle swarm optimization (PSO) algorithm, variable inertia factors replacing constant inertia factors of basic PSO algorithm, we can achieve to speed up the convergence speed of the algorithm, reduce the possibility of spread, and improve the performance of the PSO algorithm. At last through a calculation example validates the feasibility and the availability of the locating model and the algorithm.

II. The Mathematical Model Of Electric Vehicle Charging Station Planning

A. *Principle of charging station planning*

"Demand" and "feasibility" are two most important factors that decide to regional electric vehicle battery charging station to be built or not. Demand is mainly influenced by the traffic flow produced by regional electric vehicle and the comprehensive distance from charging candidate station to every main road; while feasibility is decided by integrated factors such as geographical position, traffic, environmental protection, regional distribution capacity of candidate station, the regional overall planning, road network planning and so on. When working on the planning of the charging station, the following principles should be fully considered [2]:

1) Charging station distribution is in keeping with charging demand distribution as far as possible.

2) Charging station distribution is in keeping with traffic flow distribution as far as possible.

3) The layout of the charging station should take regional distribution grid actuality in consideration.

4) The planning of the charging station should satisfy city's overall planning and road network planning requirements.

5) The radius of charging station service should meet the requirements.

6) The planning of charging station should take the future development trend of electric vehicle in consideration.

B. *Influence factors of the charging station layout*

Summarizing the domestic and foreign electric vehicle charging station related literatures [7]-[12], it's found that following main factors influence electric vehicle charging station layout:

1) The number of regional electric vehicle. The general demand of electric vehicle battery changing is proportional to the number of regional electric vehicle. Only after regional electric vehicle reached a certain scale, the economic large-scale stationing of the electric vehicle charging station would come true possibly.

2) The types of electric vehicle users. Different types of users' demands about the endurance ability of electric vehicle and charging time are not identical, which affects charging ways and electric energy consumption, while charging station construction method and the power demand will also be direct influenced.

3) The ways of charging electric vehicle. Now commonly used electric vehicle charging ways include conventional charging, rapid charging and battery quick-changed. Corresponding to different charging ways, there are three electric vehicle charging facilities: charging pile, charging station and power station. The charging quantity, cost and maintenance operation cost that different charging facilities provide are not all same.

4) Power battery characteristics. Different kinds of power battery have different charging characteristics. The greater the charging current is, the higher the voltage is, the more the single car charging power demands, leading to the more the capacity of the charging station needs.

5) Charging time. The electric vehicle operating in different modes put forward different requirements for charging time, while the differences of charging time need different charging ways to meet. When the demand of charging is not high, which can be charged slowly, such as private cars; while the electric vehicle such as taxi need to charge quickly or change batteries quickly.

6) Charging environment. Power battery charging efficiency is influenced by the environment condition of charging station, especially environmental temperature. In normal temperature, the receptivity of battery charging is stronger; with environmental temperature decreasing, the receptivity of charging gradually reduces. Therefore, charging station construction should ensure the environmental temperature beneficial to the requirements of battery charging as far as possible.

C. *Mathematical model*

The main function of charging station is to provide all kinds of electric vehicle users fast, high quality electrical energy service. This paper takes the annual comprehensive cost of operation to target years minimize charging station as the target, takes the cost including the construction and operation of charging station into consideration, takes the traffic flow situation as constraint conditions, and establishes the integrated optimization mathematical model.

$$\min F_{\cos t} = C_i^c + C_i^r + C_i^d \tag{1}$$

$$C_i^{\mathrm{c}} = \frac{r_0(1+r_0)^m}{(1+r_0)^m - 1} \times \left(A_i^L C_i^L + N_i^T C_i^T + N_i^C C_i^C + C_i^F \right) \tag{2}$$

$$C_i^r = (\alpha + \beta) \cdot \varepsilon \cdot p \cdot N_i^{car} \tag{3}$$

$$C_i^d = \omega \cdot \sum_r \sum_j d_{rj} \tag{4}$$

$$N_i^{car} = \sum_r \frac{T_r \cdot \xi}{N_{ir}^T} \tag{5}$$

$$s.t. \quad \sum_r \frac{T_r \cdot \xi}{N_{ir}^T} \cdot \gamma_{\max} \le N_i^C \tag{6}$$

Here: Equation (1) stands for the minimization of the annual integrated cost of charging station, which includes the annual average construction cost of charging station, the annual operating cost of charging station and the cost of charging. Equation (2) means the annual average construction cost which convert to every year, where $i \in I$ indicates the regional number, r_0 indicates the rate of return on investment, m indicates fixed number of year of target operation, A_i^L and C_i^L means the proportion of land expropriation and their unit prices respectively, N_i^T and N_i^T means the amounts of distribution transformers and their unit prices respectively, N_i^C and C_i^C each means the amounts of chargers and their unit prices, C_i^F means constant cost. Equation (3) stands for annual average operating cost, where N_i^{car} shows the amounts of regional electric vehicle, p shows the average cost of every car charging every time, ε shows annual average times of charging per car, α expresses energy loss rate, β expresses the coefficient of charging station annual charging fees which personnel salary and maintenance costs convert to. Equation (4) stands for charging costs, it's the conversion that the integrated distance from regional road to transformer substation, where ω indicates conversion coefficient, $r \in R$ indicates the number of road in region i, $j \in J$ indicates the number of transformer substation which is to be built. Equation (5) stands for the relationship of the amounts of regional electric vehicle and regional traffic flow, where T_r shows the traffic flow of road r, ξ shows the occupancy factor of regional electric vehicle, N_{ir}^T shows the traffic flow which every car produces averagely. Equation (6) is constraint conditions, stands for the regional highest charging requirements charging station should be able to meet, where $\gamma_{\max}$ indicates the biggest synchronous charging rate, N_i^C indicates the amounts of regional chargers.

III. Particle Swarm Optimization Algorithm

A. Basic particle swarm optimization algorithm

Particle swarm optimization algorithm is a self-adapting evolution computation technology based on the population search put forward by Kennedy and Eberhart in 1995[13]. This algorithm through the individual cooperation between the populations realizes to search the optimal solution of the problems, as a kind of important optimization tools, particle swarm optimization algorithm has been successfully used in function optimization, system identification, neural network training and other application fields [14].

Suppose that m particles constitute a swarm in D dimensional space. The information of particle i can be expressed as a D-dimensional vector. The position of the i^{th} particle is $X_i = (x_{i1}, x_{i2}, ..., x_{iD})^T$, the speed $V_i = (v_{i1}, v_{i2}, ..., v_{iD})^T$, the optimal position of self-search $P_i = (p_{i1}, p_{i2}, ..., p_{iD})^T$, the whole particle swarm search the optimal position $P_g = (p_{g1}, p_{g2}, ..., p_{gD})^T$. The speed and position update equations of the particles respectively is:

$$v_{id}^{k+1} = wv_{id}^k + c_1 rand_1^k (p_{id}^k - x_{id}^k) + c_2 rand_2^k (p_{gd}^k - x_{id}^k) \quad (7)$$

$$x_{id}^{k+1} = x_{id}^k + v_{id}^{k+1} \quad (8)$$

Here: v_{ij}^k is the speed of the particle i in the j^{th} dimension, the k^{th} iteration; x_{ij}^k is the current position of the particle i in the j^{th} dimension, the k^{th} iteration; p_{ij}^k is the individual extreme point position of the particle i in the j^{th} dimension, the k^{th} iteration; p_{gj}^k is the global extreme point position of the whole population in the j^{th} dimension, the k^{th} iteration; w is the inertia factor; c_1, c_2 is the study factor; $rand_1$, $rand_2$ is the random number of [0,1]; $i = 1, 2, ..., m$, $j = 1, 2, ..., D$. When the flight speed of the particle is small enough or reaches the presupposed iterations, the iteration will stop, and then output the optimal solution.

B. Adaptive particle swarm optimization algorithm

The choice of inertia factor influences the convergence of the algorithm directly, which is the shoe pinches of PSO algorithm behaviors and properties. In order to avoid the example in the late of the algorithm appear "oscillation" near the global optimal solution easily, the inertial factor is made to change with adaptive value automatically, and its calculation expression is:

$$\omega = \begin{cases} \omega_{\max} - \dfrac{(\omega_{\max} - \omega_{\min})(f - f_{avg})}{f_{\max} - f_{avg}} & f > f_{avg} \\ \omega_{\max} & f < f_{avg} \end{cases} \quad (9)$$

$\omega_{\max}$, $\omega_{\min}$ is the maximum and the minimum of the inertial factor; f is the adaptive value of the particle; f_{avg} is the average adaptive value of every generation; $f_{\max}$ is the maximal adaptive value of the particle swarm.

IV. Calculation Steps

Use the PSO algorithm proposed by this paper to plan the city electric vehicle charging station, the process shows as follow:

Step 1: Particle swarm initialization. The position of the initial search spot x_i^0 and speed v_i^0 usually generated in allowable range randomly.

Step 2: Adaptive value calculation. Calculate the adaptive value of every particle according to (1).

Step 3: Optimal solution update. If the current position of the particle is better than the best position of own memory, use the current position to replace it; if the current global optimal position is better than the global optimal position which is searched so far, use the current global optimal position to replace it.

Step 4: Realize the update of the particle state according to (7), (8).

Step 5: Cycle operation. Return to step 2 to cycle calculate, until it meets convergence conditions or iterations achieves the maximum limit.

V. Case Study

This paper uses a district in Beijing as an example: Its total area is 103.08 square kilometers, the span of east and west is 11.92 km, the span of north and south is 11.22 km; there are 2 trunk roads, 8 secondary trunk roads, 15 branches, the permanent population is 173000, regional daily average total automobile flow is 72000. The geographical background of this area is shown in Fig.1.

Setting up several electric vehicle charging stations in the area to minimize the summation of the annual average construction cost (fixed number of year of target operation is 20 years) and the operation cost of charging station. In this example, according to the standard file "Technical specifications of electricity supply and assurance for electric vehicle: electric vehicle charging station" [15] which is published in Beijing, settled 4 kinds of levels of charging station, and assumed their respective service ability, corresponding construction cost, the amounts of chargers and floor space reasonably. As is shown in Table I, the construction cost includes the cost of the transformer, the cost of charger and other constant cost, land cost not included.

TABLE I
STATION LEVELS AND CORRESPONDING CONSTRUCTION COSTS

Charging Station Level	Service Capability [Car/Day]	Construction Cost [Ten-Thousand-Yuan]	Number of Charger	Floor Space [m^2]
1	360	690	45	1085
2	240	520	30	693
3	100	310	15	337
4	60	210	8	165

Considering the industrial land of the district accounts for larger proportions, according to the traffic flow date which get from the actual situation of investigation, and assume the market share of electric vehicle and maximal simultaneous charging probability reasonably, combined with the mathematical model of the traffic flow which is suggested forward, the number of the maximal simultaneous charging vehicle is 108. When the charging station is collocated as level 4, 14 charging stations at most are needed; when the charging station is collocated as level 1, 3 charging stations at least are needed. Use the number of the charging station n as the circulation variable (here the variable scope of n is 3 to 14), calculate the investment and the operating cost when the current number of charging station is n .In all the values of n , find out the calculated results of the minimal annual average investment and the annual operation cost that are correspond to n as the planning scheme.

Considering the land expropriation cost of different nature of the land are different, combining with the establishment of mathematical model and the data in Table I, we will get that when we build different numbers of charging station, due to the land nature, the land scale, the staff configuration and so on are different, the effects of construction cost, operation cost on the total cost are also different: As the amounts of charging station increase, the scale of charging station decreases gradually, the floor space and the operation cost of the single charger phases down, while the noumenon cost of the single charger rises gradually in the wake of the scale of charging station decreases, and because the noumenon cost of the charger is the main factor of effecting the total cost of the charger, when more charging stations are built, the total cost will rise gradually in the wake of the noumenon cost of the single charger increases.

The selection of the algorithm parameters is: the population scale is 50; the inertial factor ranges from 0.4 to 0.8; all the study factors are 2.0; limit the iteration times for 150. On the assumption that the example runs 50 times independently, work out that the construction cost of 3 to 14 charging stations respectively is: 404, 402, 405, 413, 426, 444, 467, 495, 528, 566, 609, 657 (ten-thousand-Yuan). Visibly, in the given condition, it's better to build 3 and 5 charging stations in the planning area, and building 4 charging stations in the planning area is optimal. We can see from the calculation results that: As the amounts of charging station increase, the total cost rises gradually, the calculation results accord with expectations, and it's shown that the coordinates and the levels of each charging station when 4 charging stations are built in Table II.

TABLE II
CHARGING STATION COORDINATES AND THE APPROPRIATE CONSTRUCTION LEVEL

Properties	Charging Sta.1	Charging Sta.2	Charging Sta.3	Charging Sta.4
Rank	1	2	2	4
Coordinate	1877, 1314	4305, 2864	777, 3492	2642, 4298

Table III is the comparison between the optimal calculation results of the basic PSO algorithm and the APSO algorithm; the average result is the average value of all the convergent iteration results in 50 iterations; the average step number is the average value of the iteration step number in 50 iterations; visibly, automatic regulate the size of w can speed up the convergence rate of the algorithm , reduce the times of the divergence, improve the performance of the PSO algorithm.

TABLE III
PERFORMANCE COMPARISON OF ALGORITHM FOR MINIMUM INVESTMENT

Algor i-thm	Optimal result [Ten-Thousand-Yuan]	Average Result [Ten-Thousand-Yuan]	Number of Convergence	Average Number of Step
APSO	402.1126	402.6237	49	86.68
PSO	405.2584	405.9382	43	138.65

We can obtain the final construction position as shown in Fig.1 due to the calculated coordinate:

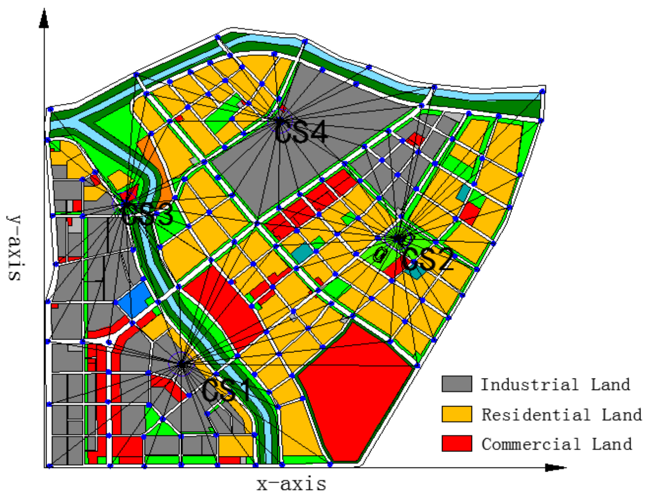

Fig. 1. Sketch map of charging station location.

According to the above analysis, we can see that choose different geographical position to build the charging station, because of the land cost, the traffic flow and so on of different areas are different, the cost and the levels of charging station are also different. This example indicates that , the electric vehicle charging station locating and sizing model which is established by this paper based on the traffic flow and the suggested optimization algorithm have good assistant decision-making effects on the planning work of electric vehicle charging station.

VI. CONCLUSIONS

This paper aims at to minimize the comprehensive cost of charging station, takes traffic flow as constraint conditions, establishes a new electric vehicle charging station locating and sizing model. Use the improved PSO algorithm, take a district in Beijing as a planning example to study, the conclusions are as follows:

1) The convergence rate of the basic PSO algorithm is fast, but there are also some shortcomings such as low precision, easy divergence and so on. This paper uses the inertia factor method, by changing the size of the inertial factor w in the process of calculation constantly, to overcome the shortcoming about the divergence of the basic PSO algorithm.

2) The proposed mathematical model, not only considered the influences of the construction investment of charging station, the operation cost of charging station and regional traffic flow on locating, but also the influences of geographic information on the investment cost of the construction; the result of planning is more scientific and reasonable.

3) Through the analysis of the example, it proves that the mathematical model and the optimization algorithm proposed by this paper are feasible and effective.

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