Location Planning of Charging Station for Electric Vehicle Based on Urban Traffic Flow

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***Abstract*—Large-scale use of electric vehicles significantly increase traffic pressure and load of distribution network, in complex urban traffic, rational planning electric vehicle charging station is particularly important for intelligent transportation and smart grid. This paper analyzes the urban traffic flow system, considered the traffic characteristics of electric vehicle and objective actual travel behavior process within the service radius, Using the Markov model to predict traffic flow demand of electric vehicles, it presents a real-time transport costs of charging stations to realize operating net income maximization, constraints are travel utility of traffic flow, traffic density and distribution network requirements, the use of immune optimization algorithm to compare. Simulation results show that the planning models and methods have important theoretical and practical value.**

***Index Terms*—electric vehicle, charging station, urban traffic flow, Markov model, immune algorithm**

I. INTRODUCTION

Nowadays, global warming and fossil energy depletion is the serious problem of the world[1]. Large-scale promotions of electric vehicles become an important measure to reduce greenhouse gas emissions and ease reliance on the use of fossil fuels. Electric vehicle charging infrastructure planning and construction is one of the main factors restricting the development of electric vehicles. Current electric vehicle charging facilities planning, particularly urban public charging station, charging pile plan is not perfect.

Electric vehicle charging station planning is closely related to the electricity grid transport network. Existing research mainly through the analysis of electric cars access to the distribution network[2-5] and the impact of transportation to explore the background of locating and sizing plan. In reference [6], from the planning level and operational level analyze the traffic characteristics of electric vehicles. In reference [7-8], the three aspects of electric vehicles, distribution network and road network as a whole to discuss the best electric vehicle charging path. In reference [9], considering the structure of the road network, traffic information and other factors, taking into account the interests of both the power grid and users to establish charging stations optimal planning models. In reference [10], utilizing closure location model, the candidate positions set in the charging station coincident nodes transportation network and distribution systems to establish multi-objective optimization decision model. In reference [11], it proposes a charging station site planning method, which takes into account the spatial characteristics of the electric vehicle travel, the maximum extent to meet the charging requirements. However, the above document does not involve to the traffic flow and electric vehicle charging facilities planning together. With the development of intelligent transportation network, traffic flow has become one of the important means to solve urban traffic problems, it is particularly important to study urban charging station planning based on the traffic flow.

This article is to study the planning of urban electric vehicle charging stations based on traffic flow theory, comprehensive analysis of the traffic characteristic distribution of electric vehicles and travel behavior process, through the establishment of Markov model for electric vehicles forecast traffic, in order to estimate the charging requirements of the charging station construction in the city. Considering the traffic flow theory and the economics of establish charging stations to establish charging stations optimal location model. Using a strong global search capability and faster, better convergence of immune optimization algorithm, through practical examples to illustrate the contrast constraints validity of the new programming model and methods.

II. CONSIDERING TRAFFIC FLOW OF ELECTRIC VEHICLES CHARGING DEMAND FORECAST

In complex traffic conditions of city, large-scale use of electric vehicles and building charging stations will undoubtedly increase partial traffic pressure and load. For the city's main traffic network, electric vehicle charging stations planning based on traffic flow will be more practical. Combined with the uncertain characteristics of electric vehicle distance and charging site, by the impact of traffic flow theory of electric vehicle to acquire the charging demand of station.

A. Traffic Flow Theory Analysis of Electric Vehicles

Traffic characteristic distribution and travel behavior process are the main contents of the traffic flow theory[12], when planning a new charging infrastructure, the need to predict traffic flow characteristics, by analyzing the relationship between the internal changes of urban traffic flow characteristics after building the new charging stations, to meet the travel needs of the user. At the same time traffic flow theory penetration of electric vehicles in the charging load demand forecast and the charging facility siting plans, the layout of electric vehicle charging stations play a key role.

Traffic characteristic of electric vehicles include a high degree of concentration and attracting heavy traffic. To effectively protect the electric vehicle continued driving ability, service radius of the charging station should be based on a single charge mileage 100km(or even less) computing[13], therefore, data collection and communication survey work needs to be done, to help understanding of traffic characteristics more comprehensive.

Accurate description of travel behavior process can be used as the basis for analyzing electric vehicle charging requirements[14], the different distributions of electric vehicles in the traffic flow will directly lead to differences in the needs of each charging station. Operating rules and Distribution patterns of urban traffic flow can be analyzed from five levels, which include understanding the problem, gather information, selection decisions, implementing travel, evaluation feedback after travel. However, research on electric vehicles travel behavior has a certain complexity, mainly in background complicated of travel decisions, many factors which is difficult to quantify, traveler different behavioral characteristics, etc. Electric vehicle charging demands need to assess by it, thereby helping to further improve the charging station planning. A typical electric vehicles travel behavior process shown in Figure 1.

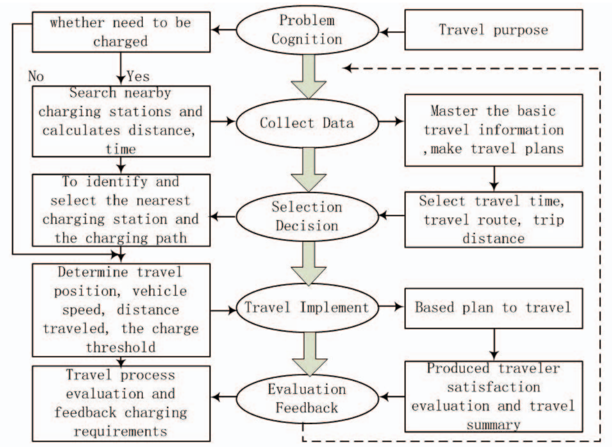


Fig.1 Electric vehicle travel behavior process

B. Demand for Electric Vehicles Traffic Flow Based on Markov Model

In urban traffic flow, the traffic flow as a time series, while Markov model is a powerful tool for the analysis of time series data[15]. This paper combined the transportation characteristics of electric vehicle with travel behavior information, using Markov model to simulate the electric car possible activities. The running state of electric vehicle in everyday life is divided into four types, E_1 (Travel state), E_2 (Living area state park), E_3 (Business district state park), E_4 (Workspace state park), and assuming that electric vehicle only occurs one of the above finite state.

Suppose analog electric vehicle travel behavior within a month (30 days) , take steps per unit time is 0.5h, then a total of 1441 steps, which is $t \in [0,1440]$,the initial state of the electric vehicle is $t = 0$. In the process of electric vehicle travel, each time segment forms a sequence of events until a Markov chain. Electric vehicle from the state E_m ($m = 1.2.3.4$) to state E_n can be described by probability condition:

$$p_{m\to n}^{t} = P\left(E_n^t \mid E_m^{t-1}\right) = P\left(E_n^t \mid E_m^{t-1} \cdot E_m^{t-2} \cdot \cdots \cdot E_m^{1} \cdot E_m^{0}\right) \tag{1}$$

In formula (1), E_n^t signifies state E_n generating at time t , the equation for any applicable.

Electric vehicle travel state space model of the four states $E = \{1,2,3,4\}$, which state transition probability matrix form as follows,

$$P_t = \begin{bmatrix} P_{1\to1}^t & P_{1\to2}^t & P_{1\to3}^t & P_{1\to4}^t \\ P_{2\to1}^t & P_{2\to2}^t & P_{2\to3}^t & P_{2\to4}^t \\ P_{3\to1}^t & P_{3\to2}^t & P_{3\to3}^t & P_{3\to4}^t \\ P_{4\to1}^t & P_{4\to2}^t & P_{4\to3}^t & P_{4\to4}^t \end{bmatrix} \tag{2}$$

In the above equation, subscript 1,2,3,4 signify "Travel state", "Living area state park", "Business district state park", "Workspace state park" respectively, meanwhile , $P_{2\to3}^t = 0$, $P_{3\to2}^t = 0$, $P_{2\to4}^t = 0$, $P_{4\to2}^t = 0$, $P_{3\to4}^t = 0$, $P_{4\to3}^t = 0$, $P_{1\to1}^t = 0$, $1 < t \le 1440$. So the state space transfer of electric vehicle can be described as shown in Figure 2.

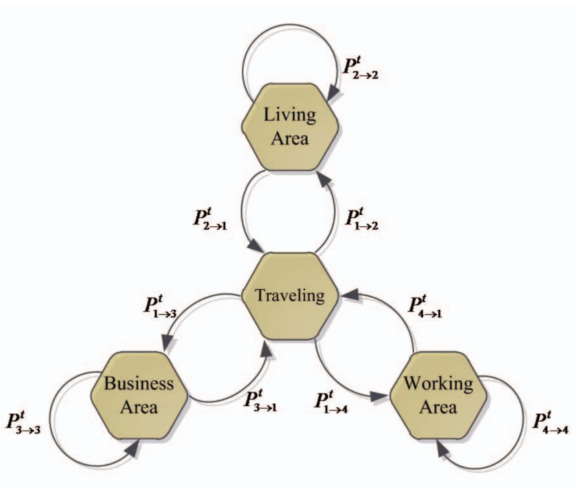


Fig.2 State space transfer chart of electric vehicle

In Figure 2, each time when the study of electric vehicle traveling state has certain limitations, driving an electric vehicle can hold or transferred to another state park, for electric cars parked, only to maintain the original state or transferred to a running state. Through analyzing the possibility probability of electric vehicles in various states to forecast load demand of the charging station, it may also planned charging station locating and sizing reasonably.

III. MATHEMATICAL MODEL OF EV CHARGING STATIONS PLANNING

A. The Objective Function of Charging Station Planning

This paper considered to establish charging station planning model on the basis of traffic flow characteristics. To maximize the economic benefits as the objective function planning, the mathematical models such as the formula (3).

$$\max G=\sum_{i=1}^{n}\left(I_{Ai}-C_i\right) \tag{3}$$

In the above equation, the total cost in revenue of charging station within proposal instead of G , n represents the number of charging stations, I_{Ai} represents the charging station i total annual revenue, and C_i represents the charging station to convert the total annual cost.

1. Charging Station Cost Model

Electric vehicle charging stations in the total cost is mainly composed of the construction investment costs, operation and maintenance costs, loss failure costs, human resources costs, improve recovery costs, charging requirements costs, real-time traffic costs. The charging station cost model C_i can be expressed as formula (4).

$$C_i=C_{i1}+C_{i2}+C_{i3}+C_{i4}+C_{i5}+C_{i6}+C_{i7} \tag{4}$$

Where C_{i1} represents construction investment costs of station i , C_{i2} represents operation and maintenance costs of station i , C_{i3} represents loss failure costs of station i , C_{i4} represents human resources costs of station i , C_{i5} represents improve recovery costs of station i , C_{i6} represents charging requirements costs of station i , C_{i7} represents real-time traffic costs of station i .

In which real-time traffic costs of station i have two parts, electric vehicle charging queue waiting costs and congestion costs. Congestion pricing will force some travelers to change the travel route, economy to adjust electric vehicle space on the network traffic distribution, and reduce road traffic. So, the formula is expressed as follow.

$$C_{i7}=\left[\alpha\cdot\beta\cdot T\cdot m+L\big/\left(V-\bar{V}\right)\cdot\beta\cdot m\right]\cdot 365 \tag{5}$$

In formula (5), α means travel time cost factor of electric vehicle, β means travel time value, T means the time of traffic congestion, L means the link length of traffic congestion, V means congestion traveling speed of electric vehicles, $\bar{V}$ means congestion threshold of electric vehicles (when $V\geq\bar{V}$,the traffic is ease ,this article will not be considered).

2. Charging Station Revenue Model

The operating income of charging station i mainly come from charging fees, government subsidies and related service fees. Where charging fees I_{i1} is related to users charge price p_1 , charging stations purchase price p_2 , annual maximum load utilization hours $T_{\max}$ and annual charging load demand M ,as follows,

$$I_{i1}=(p_1-p_2)\cdot M\cdot T_{\max} \tag{6}$$

You can also get charging station i total income expressed as,

$$I_{Ai}=I_{i1}+I_{i2}+I_{i3} \tag{7}$$

Where I_{i2} means government subsidies and I_{i3} means related service fees.

B. Constraints

1. Traffic Flow Constraints

$$\begin{cases} V<\bar{V} \\ \pi_r^k\geq U_r^k \\ 0\leq d_{t,i}\leq d_{jam} \\ 0\leq\omega_{t,i}\leq\omega_{i,\max} \\ r\leq R \end{cases} \tag{8}$$

In the above equation, π_r^k represents traveling utility of electric vehicle under traffic-balanced condition, U_r^k represents both electric vehicle users and origin-destination point of the charging station choosing the traveling utility of k -th charging path, $d_{t,i}$ represents traffic demand density of charging station i at time t , d_{iam} represents road congestion density in the area, $\omega_{t,i}$ represents the number of vehicles waiting charge of charging station i at time t , $\omega_{t.\max}$ represents the maximum number of queued, r means from the electric vehicle charging station to the user's distance and R means service radius of charging station.

2. Distribution Network Constraints

$$\begin{cases} \sum_{i=1}^{n}P_{Ci}\leq P_{C\max} \\ P_D\leq P_{D\max} \\ S_\varphi\leq S_{\varphi\max} \\ V_{j\min}\leq V_j\leq V_{j\max} \end{cases} \tag{9}$$

In the above equation, P_{ci} denotes charging power of charging station i , $P_{c\max}$ denotes the maximum charging power of electric vehicles connected to the grid, P_D denotes capacity needs of charging station node, $P_{D\max}$ denotes the maximum demand charge of charging station area, S_φ denotes the load of supply transformer and $S_{\varphi\max}$ denotes the maximum load of the transformer, $V_{i\min}$ and $V_{i\max}$ represent upper and lower voltage on node j respectively.

IV. THE PLANNING PROCESS OF EV CHARGING STATIONS

A. Affinity Analysis of Immune Optimization Algorithm

Assuming among the immune system, antibody group consists of N antibody and each antibody has M genes. Define the Information Entropy of gene j as $E_i(N)$, in this article on behalf of the planning of electric vehicle charging stations bring the traffic congestion level in a city.

The affinity $A_{v.ii}$ between antibody i and antibody j can be shown:

$$A_{v\ ii}=1\big/(1+E(2)) \tag{10}$$

Where $E(2)$ means the Information Entropy between antibody i and antibody j , affinity values between 0 and 1, and the affinity values is 1 that can show the best matching degree among antibodies and antigens[18], that is, the antibody is the optimal solution.

B. The planning steps of EV Charging Stations

Using immune optimization algorithm to analyze the planning and site selection of charging station, which objective function is to make the net income of charging station maximum, constraints incorporated into the objective function by the way of penalty function. Possible solutions will one by one test, in which satisfy the constraints and high affinity antibodies is promoted, further into the optimization process until terminated[19]. Detailed site planning simulation steps are as follows.

Step 1) Control variables are encoded; enter the charging station planning objective function and constraints as antigen in the immune algorithm, and possible site location as antibody.

Step 2) Produce the first generation antibody group, generating a charging station demand points with a random method. At this memory cell is empty.

Step 3) Calculate the objective function and affinity of optimization model. The affinity $A_{v,ij}$ and density of antibody need to be calculated respectively in order to ensure the diversity of immune algorithm. Further updates the memory unit, requires high affinity antibody was added to the memory unit, replace the original individual until retain the best individuals and groups.

Step 4) Calculate the expected value of the antibody in order to determine the promotion or inhibition of antibody production, having a higher probability of high expectations will be selected and optimization. After selection, surviving antibodies can proceed to the next step.

Step 5) through selection, crossover, mutation, meeting the requirements of the alternative sites will be produced.

Step 6) after the termination condition is satisfied, output location planning results, otherwise continue.

V. EXAMPLE SIMULATION AND ANALYSIS

This article takes planning electric vehicle charging station in an area as example. The acreage of land is 25 km^2, the ratio of electric vehicles accounted for vehicles is 15%, and the number of electric vehicles is expected to reach 3337. Assuming the average capacity of each electric car is 50 $kW \cdot h$ and the distribution capacity for charging station is 7200 kVA. Using the above knowledge, the charging requirements of charging station can apply possibility probability in various states of electric vehicle to forecast. Supposing the number of new charging stations is six, according to the objective function and constraints of the charging station location, randomly generated string of genetic code, and using immune optimization algorithm simulation. The main simulation parameters show in Table1 of Appendix.

For the charging station planning model proposed in this article, respectively on whether to consider traffic flow constraints in both cases and then simulate, respectively referred to as Case A and Case B. According to the affinity theory analysis shows, reduce information entropy lead to increased affinity values, and the greater the value of affinity, which may be closer to the optimal solution, from the formula (11) can also be seen in the perspective of mathematical analysis. In this article the degree of congestion which is brought by charging station planning and construction. In case A and case B, affinity with the increase in the number of iterations of the change process shown in Figure 3 of Appendix.

As can be seen from Figure 3, the average affinity values of case B is greater than the value of the case A, the iterations of case B reach optimal affinity values obviously less than case A, by Table 2of Appendix can be seen more objective comparison of the two cases.

By comparison shows, considering traffic flow model of electric vehicle charging station location can be faster and more accurately determine the location of charging stations, it has a good role in promoting and practical value of city planning electric vehicle charging station.

VI. CONCLUSION

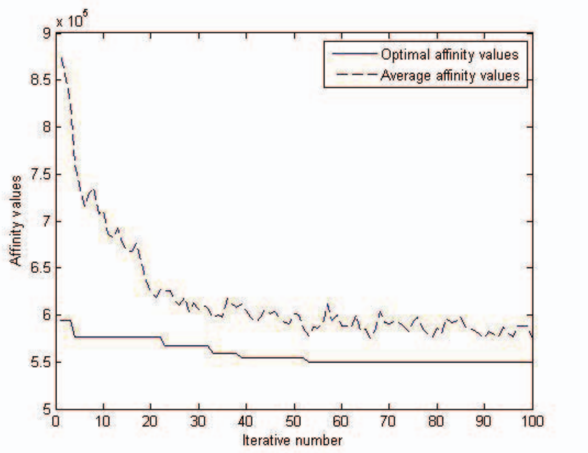
In this paper, in order to study electric vehicle charging station location planning better, it introduces urban traffic flow system, analyzing the traffic characteristics and travel behavior, and through the Markov model further predicted load demand of the charging station. This paper established a model for planning electric vehicle charging station, in full consideration of urban traffic flow constraints to seek maximum effectiveness of charging station.

Then using immune optimization algorithm to simulate objective optimization model, In the example analysis, by comparing whether to consider traffic flow constraints, this paper reflects the advantages of location planning model, the method is practical.

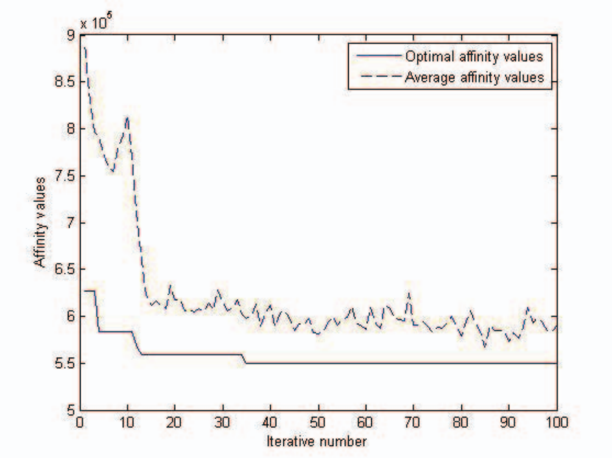
APPENDIX

TABLE 1
The Main Simulation Parameters

Parameter	Value
Load factor	0.75
Charging efficiency	0.9
Coincidence factor	0.9
Smooth traffic factor	1.0-1.2
Maximum iterations	100
Group size	50
Crossover probability	0.5-0.85
Mutation probability	0.4-0.6
Vaccination probability	0.2-0.3
Update probability	0.5-0.8



(A)



(B)

Fig.3 The change process of affinity with Iterations increases (A) Does not consider traffic flow (B) Consider traffic flow

TABLE 2

Two Constraints Situation Data Comparison

Parameter	Consider traffic flow	Does not consider traffic flow
Affinity values	6.16×10^5	5.95×10^5
Iterative number	34	51

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