Highway Charging Station Plan Based on Dynamic Traffic Flow Simulation

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Abstract. The reasonable arrangement of the charging station, the infrastructure used to charge the electric vehicle, is vital for the promotion of electric vehicles. As for highways, a highway charging station planning method based on the dynamic traffic flow simulation is proposed in this paper. First, the running and charging demands of electric vehicles on the highways are analyzed; second, considering the interests of investors and vehicle owners, a mathematical model is constructed to specify the objective function; thirdly, the dynamic traffic flow simulation method suitable for the highway condition is proposed; finally, a method is provided, the validity and practicability of this method are verified with examples, and its effects on the photovoltaic consumption are analyzed further in this paper as for the planning result.

1. Introduction

The electric vehicles, a green and pollution-free travel method, can relieve the energy crisis, environmental pollution and other problems effectively, and are widely promoted by every government in the world [1]. The reasonable arrangement of the charging station, the infrastructure serving the electric vehicles, can promote the popularization of electric vehicles effectively.

The highway is featured by such characteristics as full enclosure and strict access control, which are vital for ensuring the fast charging of electric vehicles during the intercity travel. Both domestic and foreign scholars have researched the highway charging station plan to some extent: in the literature [2] the construction of highway charging stations in Korea is investigated, and the investigation results show that now most of charging stations are constructed in the service area; in the literature [3] the probability that the electric vehicles are charged in the charging station are analyzed on the basis of electric distribution and running mileage, the location model is established for the purpose of maximizing the number of electric vehicles charged in the highway charging station, and the capacity model of charging station is established on the basis of queuing theory; in the literature [4] the charging demand distribution of electric vehicles in the highway network is analyzed, the 2-stage model optimizing the locations of electric vehicle charging station in the highway network is

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established, but the effect of dynamic traffic flow is not involved; in the literature [5], based on the actual conditions of Hainan Island, the travel rules are described via the OD matrix, the charging load distribution is confirmed by the clustering method, and finally the planning results are compared with the actual gas stations.

In general, although the preliminary research has been made on the highway charging station plan at home and abroad, the traffic flow simulation is considered simply and in most of cases the long-period statistical data of traffic flow or the statistical results of a profile of given time are used as the planning reference [6]. From the statistical data of entrance and exit of highway, the dynamic traffic simulation method proposed in this paper can simulate the traffic flow distribution on the highway effectively so as to optimize the charging station plan effectively in further.

2. Charging demand analysis

The highway charging station is mainly used to meet the charging demands of the electric vehicles that cannot meet the travel demands due to lack of electricity. Therefore, the fast charging mode applicable to the highway is researched in this paper. Under the highway conditions, at the moment t, the number of vehicles passing the given location on the highway is recorded as f_t, the permeability of electric vehicle is recorded as η, the electric vehicle whose state of charge Soc is below 0.3 is regarded in demand of charging, and the battery capacity of electric vehicle is recorded as E_{ev} so the charging demand of the electric vehicle i in demand of charging is:

$$Q_i = (1 - \text{Soc}_i) \cdot E_{\text{ev}} \tag{1}$$

3. Objective function

The maximizing of comprehensive annual costs considering the income of charging station and the cost of user is regarded as the objective function of charging station optimizing plan, which is detailed below:

$$\max\ B = -P_{sc} + P_{so} - P_{uw} \tag{2}$$

Wherein, P_{sc} indicates the annual expense of charging station construction cost; P_{so} indicates the annual expense of charging station operation income; P_{sr} indicates the annual expense of residual value of charging station out of service; P_{uw} indicates the waiting time cost of user.

3.1. Annual expense of charging station construction cost

$$P_{sc} = \sum_j (m_j a + b_j) \frac{r(1+r)^z}{(1+r)^z - 1} \tag{3}$$

Wherein, m_j indicates the number of chargers installed in the charging station j; a means the allocation expense of one charger; b_j means the fixed investment cost of the charging station j; r means the discount rate; z means operating years.

3.2. Annual expense of charging station operation income

$$P_{so} = (1-\omega) \frac{8760}{N_t} \sum_k \sum_j \sum_i A(Q_{\max} - Q_{i,j,k}) C_{i,j,k} (1 - S_{i,j,k}) \tag{4}$$

Wherein, N_t indicates the simulation period (hour); A indicates the charging price; Q_{max}, $Q_{i,j,k}$ indicate the full electric capacity of electric vehicle and the residual capacity of vehicle I passing through the charging station j at the moment k during the simulation period respectively; $C_{i,j,k}$ indicates the charging sign (1 indicates charging; 0 or else); $S_{i,j,k}$ indicates the waiting sign (1 indicates queuing for waiting; 0 or else); ω indicates the convert coefficient of annual value of electricity purchase, operation and maintenance expense of charging station to the annual operation income.

3.3. Waiting time cost of user

$$P_{uw} = \frac{8760}{N_t}\sum_k\sum_j\sum_i KS_{i,j,k} \tag{5}$$

Wherein, K indicates the unit time value of user's waiting for charging [7]. The number, position and quantity of charger of charging station are the optimizing variables of model, and other variables are determined through the running stimulation of electric vehicles.

4. Traffic flow simulation

Based on the aforementioned running and charging selection and other conditions, the traffic flow stimulation process is detailed below:

(1) Initially simulate the number, electricity distribution and destination distribution of vehicles passing through every crossing in the given period;

(2) Stimulate the vehicles entering a crossing one by one. The vehicle passes by every crossing and charging station in order after the crossing, and leaves the highway at the destination exit; when passing by a charging station, determine whether to charge; in case of charging, store the residual electric capacity and destination information (in the corresponding period based on the running time of vehicle), and then simulate the next vehicle.

(3) Based on the charging information in the above period, read the information of the vehicles entering every charging station and their destinations, and simulate the running of vehicles entering the charging station one by one. The vehicle passes by every crossing and charging station in order after this charging station, and leaves the highway at the destination exit; when passing by a charging station, determine whether to charge; in case of charging, store the residual electric capacity and destination information (in the corresponding period based on the running time of vehicle); now the charging sign C_i, j, k of vehicle can be determined.

(4) Renew the charging information of charging station, calculate the charging load and income, and then simulate the next vehicle.

5. Example analysis

5.1. Scene setting

The basic conditions of highway section to be planned are shown in Figure1. The crossing is at the coordinate [0, 135, 203, 274] (unit: km), the start and end crossings are located at 0km and 274km respectively, and two turnings are located at 135km and 203km respectively.

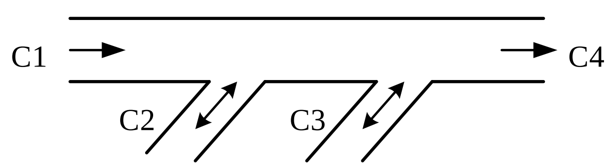

Figure 1. Schematic diagram of highway section to be planned

The number of vehicles entering and leaving every crossing on the typical date is shown in Table 4-8, and the time distribution of number of vehicles entering the crossing is shown in Figure 2. The time distribution of vehicles leaving the crossing is affected by the charging time.

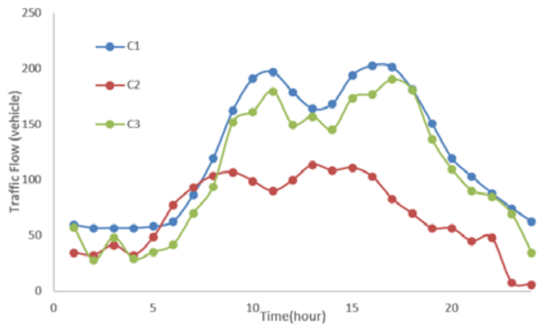

Figure 2. Traffic flow distribution on the typical date

The battery capacity, the electricity consumption per mileage, the charging time and other parameters are shown in Table 1. Assuming that the residual capacity of vehicle entering every crossing is evenly distributed in 50%-100% of available capacity of battery. The construction cost of charging station is in direct proportion to the construction scale. The construction cost of charging station equipped with 10 chargers is 3 million.

Table 1. Main Parameter List of Example

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
T_{char} (min)	30	Q_{max} (kWh)	40	T_{smpl} (min)	60	z	20
Q(kWh/km)	0.2	A(Yuan/kWh)	0.8	T_{wait} (min)	40	r	0.1
V(km/h)	100	w	0.85	Q_{min} (kWh)	20	K(Yuan/h)	17

5.2. Optimizing result

The electric vehicle charging station is optimized by the aforementioned model and method. In case of 3-6 charging stations, the overall optimizing result comparison results are shown in Table 2. The comparison results of every composition (*Psc* annual expense of charging station construction cost, *Pso* annual expense of charging station operation income, and *Puw* annual waiting-time cost of user) of corresponding objective function are shown in Table 3.

Table 2. Optimizing Result

Number of station	Target value/ 10,000 Yuan	Location coordinate of every station/ km	Number of chargers per station/ unit
3	135.8	[77.7,144.3,235.0]	[30,30,30]
4	155.8	[73.5,126.6,188.7,255.4]	[30,30,20,20]
5	129.4	[44.0,74.0,153.2,177.3,244.0]	[10,30,30,10,30]
6	103.9	[58.2,100.9,171.3,185.5,193.7,260.4]	[20,30,20,10,10,10]

Table 3. Economic Income of Every Charging Station

Number of station	Psc/10,000 Yuan	Pso/10,000 Yuan	Puw/10,000 Yuan
3	211.43	392.77	47.78
4	246.67	402.31	1.86
5	281.90	409.16	0
6	281.90	383.76	0

As shown in Table 2 and Table 3, the optimal comprehensive benefit can be achieved if this highway section is equipped with 4 chargers. If fewer than 4, the user's waiting cost will increase; if more than 4, the construction, operation and maintenance cost of charging station will increase. The time distribution of number of vehicles served by every charging station (S1-S4 in order as per the location coordinate) every day corresponding to the optimal allocation result is shown in Figure 3.

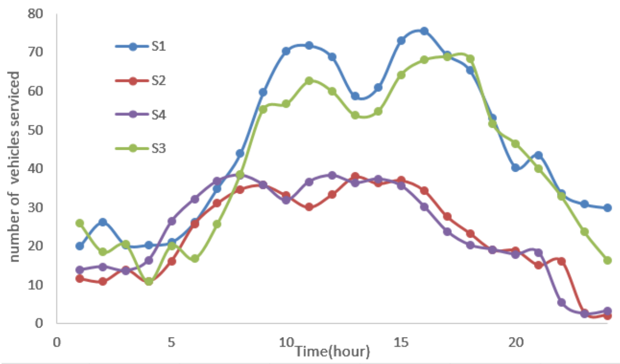

Figure 3. Number of vehicles served by every charging station

As shown in the following picture, considering that the regular load of highway charging station is the charging load, the charging load curve of charging station S1 is superposed with the typical 4MW photovoltaic output [8] of planned zone. As shown in Figure 4, the charging load curve is improved obviously, and the photovoltaic output and charging load curve has the sound mutual consumption effect, i.e. the planned charging station can consume the photovoltaic output effectively [9].

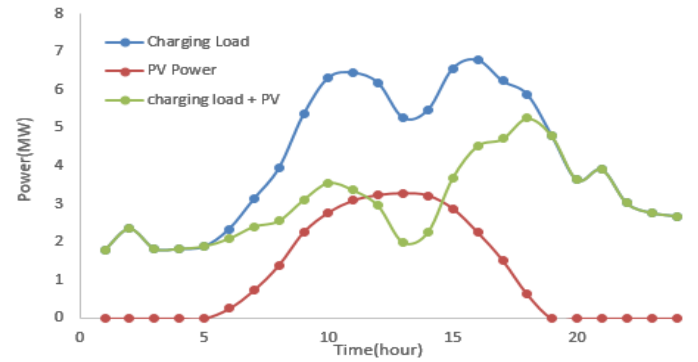

Figure 4. Photovoltaic consumption effect analysis of charging station

6. Conclusion

The application and promotion of electric vehicle is closely related to the construction of charging facility. In this paper, the charging station optimizing plan is researched as for the highway, a mathematical model taking the optimal comprehensive benefit of charging station investor and user as the objective function is constructed, the dynamic traffic flow simulation method applicable to highway is proposed, the validity and practicability of this method is verified with example, and the potential photovoltaic consumption effect of charging station is analyzed.

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