Research on layout planning of Charging Infrastructure for Private Electric Vehicle Charging Station

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Abstract. Green development is the theme of the world today. As a kind of pollution-free and convenient carrying tool, the electric vehicle (EV) has been developed rapidly. The layout of the charging station satisfies the customers’ charging demand. Establishing vehicle prediction and charging scale prediction models to meet customers with charging needs. In the research on the layout planning of the charging stations, the elasticity coefficient method is used to predict the number of private electric vehicle (EV), and the queuing theory model is used to predict the charging demand. Forecasting the scale of charging stations based on private electric vehicles ownership and charging demand. Finally, a city is selected as the planning area for example analysis. The feasibility and nationality of the charging station layout planning method were proved.

Keywords: Private electric vehicles, charging station, elasticity coefficient, layout planning.

1. Introduction
As a developing country, China has a large use of energy. In order to alleviate the pressure on environment and energy issues, new energy electric vehicles (EVs) are widely used. Private electric vehicles (EVs) have been widely used due to their low energy consumption, convenience, speed, and pollution-free. According to foreign evidence, when EVs were fully introduced in Los Angeles, atmospheric hydrocarbon levels were reduced by 98 percent and carbon monoxide by 99 percent (Chan C, 2007). The emergence of large number of electric vehicles (EVs) needs to solve the problem of electric vehicles charging stations. The article takes this as a starting point to study the theory and research methods of private electric vehicles (EVs) charging station layout planning.

Considering the randomness and disorder of the distribution of private electric vehicles (EVs), the layout planning of electric vehicles (EVs) charging stations has become a top priority. At present, the development of the EVs in China is still in its infancy, and the layout planning of stations is not perfect. It lacks a comprehensive and systematic theory. This article will focus on the prediction of the number of the EVs and the prediction of the scale of the charging station.

There are some researches on charging demand forecasting and charging station layout planning at home and abroad. In terms of charging demand scale prediction, many researches consider charging
demand from users' charging distance, driving condition of EV and capacity of charging battery, etc., and then establish charging demand prediction model based on this (Bibeau E etc., 2006). At the same time, a charging demand prediction model is also considered from the perspective of user travel time (Li G etc., 2012). In the aspect of charging station layout planning, the research mainly focuses on the impact of charging demand based on probability distribution on charging stations (Darabi Z etc., 2011). Some scholars also proposed to use the P-Center model and P-Median model (Hakimi, 1964), and the maximum coverage location model in the site selection theory to study the planning location of charging stations (Church R, 1974). The paper studies the site selection of charging infrastructure for private EV charging stations, which belongs to the site selection problem of energy supplement facilities and is a typical network facility site selection problem. The network site selection model is mainly divided into continuous site selection model and discrete site selection model. 

2. Model
This paper uses the elastic coefficient method to predict the number of electric vehicles. The elasticity coefficient is determined by the proportional relationship between the growth rate of the electric vehicles in a country or a certain city and the rate of GDP growth.

2.1. Electric Vehicle Ownership Model
The private electric vehicle ownership in the target year is:

\[ D = D_0 (1 + \alpha)^{t-t_0} \]  

Target year GDP:

\[ P = P_0 (1 + \beta)^{t-t_0} \]  

Elastic coefficient \( \varepsilon \):

\[ \varepsilon = \frac{\alpha}{\beta} \]  

Where, \( \alpha \) is the average annual growth rate of private electric vehicles; \( \beta \) is the growth rate of GDP. The determination of electric vehicle ownership can predict the charging scale of electric vehicles and the charging demand of users.

| Variable | Explanation |
|----------|-------------|
| D | Volume of private electric vehicles in the target year |
| \( D_0 \) | Volume of private electric vehicles in the base year |
| P | GDP of the target year |
| \( P_0 \) | GDP of the base year |
| \( \alpha \) | The average annual growth rate of private electric vehicles |
| \( \beta \) | Annual GDP growth rate |
| t | The target year |
| \( t_0 \) | The base year |

2.2. Queuing Theory Model
The charging behavior of electric vehicles satisfies the queuing theory model. As the customer source, the number of service counters is multiple. The service rule is first-come-first-served, and the service type is M/M/N. Electric vehicle charging service is regarded as a waiting system queuing with single channel and multiple service stations. Service time follows Poisson distribution. Charging demand is regarded as the service purpose, the electric cars are full of electricity leave as customers away. Though measuring electric cars queuing probability, forecast the electric vehicle charging demand of charging stations to measure time.
2.2.1. **Hypothesis.** Assume that electric vehicles arrive in charging stations always single, electric vehicles have arrived in time interval obey the parameter for $\lambda$ negative exponential distribution, the whole service system, a total of N reception counter service time and according to the independent, service time obey negative exponential distribution of parameters $\mu$ for when electric vehicles need to recharge, if it has free of charging pile accept charging service at once, or waiting in line, waiting time is infinite.

2.2.2. **Function.** The probability of customers waiting for charging in the charging system is:

$$P_0 = \left[ \sum_{n=0}^{\infty} \frac{\lambda^n}{\mu^{n+1}} + \frac{1}{\mu} \right]^{-1}$$

$$p_n = \begin{cases} \frac{\lambda^n}{\mu^{n+1}} P_0, & \text{when } 1 \leq n < C \\ \frac{\lambda^n}{\mu^n (1-C)} P_0, & \text{when } C \leq n < \infty \end{cases}$$

$$\rho = \frac{\lambda}{\mu}$$

The waiting charging probability of electric vehicle:

$$P\{N \geq c\} = \sum_{k=c}^{\infty} P_k = \frac{\rho_c}{1-(1-\rho_c) \rho} P_0$$

$$\rho_c = \frac{\lambda}{c\mu}$$

The scale of electric charging is predicted according to the number of electric vehicles and charging demand:

Take quick charging: quick charging power is generally 40 kilowatt-hours. The scale (number of charging piles) of a charging station within the maximum service radius of 1.2 kilometers is $N_1$:

$$N_1 = B \times T \times M$$

$$T = (1 - BCS) \times \frac{\epsilon_0}{\rho}$$

$$BCS = \frac{\epsilon_0}{\epsilon} \times 100\%$$

Slow charging: slowing charging is generally 6 kilowatts per hour, charging for 9-10 hours, and the number of charging piles in a charging station within the maximum service radius of 1.2km is $N_2$:

$$N_2 = B \times T \times M$$

Where, $B$ is the electric vehicles ownership; $T$ is the charging time of an electric vehicle; $M$ is the demand of charging electric vehicles; $BCS$ is the charge state of the remaining charging of a battery.

Electric charging station service radius is about 0.9km-1.2km, taking the largest service here radius of 1.2km. According to the survey slow filling time is about 9 to 10 hours, quick charge time is usually 2 hours in this paper. According to the nature of land used, the main consideration is to use the slow charging method in residential areas. The number of charging piles and the planning scale of charging stations are planned by using the carload and pile method in the parking lot of the community. In other areas, such as school districts and highway areas, quick charging is used and batteries are replaced when necessary.
2.3. Second Section
By 2017, 27168 new energy vehicles had been promoted in a certain city, including 1480 electric vehicles (including 761 electric buses), 3009 all-electric special vehicles and vans, 15153 private new energy vehicles, and 7616 rental and operating vehicles, among which 25000 charging piles had been built. According to the plan, the number of electric vehicles in the city will reach 100000 by the end of 2020. The total GDP of the city in 2017 was 721.3 billion. In 2018, the city’s GDP reached 782.29 billion. It is expected that the city’s GDP will reach 100 billion by 2020.

Table 2. This caption Statistics of electric vehicle charging stations (charging piles) at the end of 2017.

| Flight | Charging station | Charging pile | battery swap station |
|--------|------------------|---------------|---------------------|
| City   | Number of quick charging station | Slow charging | Quick charging | Number |
| A City | 11                | 1928          | 236                | 2      |

Forecast of charging demand of charging station:
The average annual growth rate of private electric vehicles $\alpha = 0.171$; The growth rate of GDP $\beta = 0.085$; Elastic coefficient $\varepsilon = 2.01$; Therefore, the growth rate of private electric vehicle ownership is 0.04. The private electric vehicle ownership is predicted to be 15759.

Electric vehicle ownership forecast:
a) Model parameter calibration
$\lambda = 6$ vehicles/hour; $\mu = 8$ vehicles/hour; $\rho = 0.75$; $c = 6$ vehicles
b) Demand for charging electric vehicles
$P_0 = 0.4722$, the probability of waiting for a charge is 0.001, charging demand for vehicles is 0.036 vehicles/hour., that is 2.16 vehicles/hour.
c) Electric vehicles charging scale
Quick charging:
Byd E5, for example, has a battery capacity of 60.48kwh, and quick charging power is 40kw/hour. Generally, the battery is first charged to 100% and then discharged to 30%-40%. It is assumed that the remaining battery is 40%, that is 24.19kwh. Therefore,
$$B = \frac{C_s}{C_0} = 0.4$$
$$T_1 = (1 - BCS) \times \frac{C_0}{P_0} = 0.9h$$
$$N_1 = 511$$

Slow charging:
Also taking Byd E5 as an example, the electric capacity is 60.8kwh, the slow charge power is 5kw/hour, and the remaining battery capacity is also assumed to be 40%. Therefore,
$$T_2 = (1 - BCS) \times \frac{C_0}{P_0} = 7.3h$$
$$N_2 = 4141$$

3. Conclusions
In this paper, the elastic coefficient method is used to predict electric vehicle ownership, and the queuing theory model is used to predict charging demand of electric vehicle charging stations. The specific research conclusions are as follows:
Based on the analysis of the operation mode and charging behavior characteristics of charging stations for private electric vehicles, the paper puts forward the queuing theory to predict the charging demand of private electric vehicles.
The elastic coefficient method is used to predict the ownership of private electric vehicles, and the elastic coefficient is correlated with GDP.
In order to facilitate the charging of users and improve the charging satisfaction of customers, and to minimize the total cost, the layout planning of charging stations for electric vehicles were carried out of your submission.

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