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Load Cluster Characteristic Analysis and Modeling of Electric Vehicles

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ABSTRACT

Electric vehicle, as a clean energy industry, is an important branch. Electric vehicles not only are the energy of the electric user, but also can be used as mobile and distributed energy storage unit to the grid. As a precondition of safety operation for power grid, studies of EVs' charging load characteristics is also the theoretical basis of intelligent scheduling EVs charging orderly. This paper assesses the future of the electric vehicles development prospects, and secondly establishes a charging model of a single EV. Then, considering stochastic distribution of the initial state-of-charge (SOC_0) and the arriving time of the vehicles, a cluster model of the charging station is proposed. Meanwhile, the paper from the types and charging mode of electric vehicles analyzes the behavior of EV. Finally, an example simulation is validated.

Keywords: Electric Vehicle; Potential of Development; Charging Mode; Cluster Characteristic; Poisson Distribution

1. Introduction

Electric vehicle, as a clean energy industry, is an important branch. Electric vehicles not only are the energy of the electric user, but also can be used as mobile and distributed energy storage unit to the grid. Compared with other loads, electric vehicles will not only be able to play a better role in load shifting, but also as a system of spinning reserve. However, a large number of electric vehicles charging will significantly increase the disorderly distribution system losses and damage power quality. Conversely, if the charging of electric vehicles coordinated control behavior, you can make disadvantages into advantages, reduce system peak load needs, and substantially reduce the negative impact.

At present, the load characteristic of electric cars is still very lacking. Most researches are focused on the battery charge and discharge characteristics and power harmonics problems. The generic battery model under considering dynamic response, the phenomenon of self-discharge, and temperature and other factors [1-5] has been studied a lot. The research of power harmonic focuses on the characteristics of a single charger and modeling [6-11].

However, in more sophisticated smart grid system, electric vehicles will be used as bidirectional energy trader, in the valley of charge when grid electricity purchased at low energy, to meet their own need to use; sold at high prices when the peak load electricity or act as a backup power supply to obtain profits. It not only can eliminate large grid electric vehicles negative impact, but also can be a large number of electric vehicles as a flexible load utilized to improve the system operation. This requires a study of charging agglomeration characteristics with random characteristics of large-scale electric vehicles and the electric vehicles charging load curve.

This paper assesses the future of the electric vehicles development prospects, and secondly establishes a charging model of a single EV. Then, considering stochastic distribution of the initial state-of-charge (SOC_0) and the arriving time of the vehicles, a cluster model of the charging station is proposed. Meanwhile, the paper, from the types and charging mode of electric vehicles, analyzes the behavior of EV. Finally, an example simulation is validated.

2. Charging Modes of Electric Vehicles

The report is expected that by 2015 the number electric vehicles will reach 500,000, by 2020, reaching 5,000,000. While in 2030, the electric car ownership is expected to reach 68 million or so.

2.1. Types of Electric Vehicles

Through the analysis of China's electric vehicle development, as well as some provinces and cities with the national release of the electric vehicle development plan, it sums up the future development trend of China's electric car substantially: 2010-2015, electric vehicles mainly in buses, official cars, taxis in demonstration; 2016-2020 in the public transport system, public service vehicles to achieve scale operation electric vehicles, private cars less; 2021-2030, to accelerate the development of electric cars, the proportion has increased. Chinese main types of electric are vehicles buses, taxis, public service vehicles, private cars.

2.2. Charging Mode

Charging modes of electric vehicles can be divided into slow charging (Charging mode L1), normal charge (Charging mode L2), fast charge (Charging mode L3), as shown in **Table 1**.

3. The Behavior Features of the Electric Vehicles

3.1. Behavior Characteristics of Pure Electric Bus

1) Driving distance

According to relevant data statistics in 2012, Tianjin buses, on average, each route mileage of 19.5 km. So, this article assumes that each single pure electric bus car mileage in obedience expected value is 19.5 km mean square error is within 5 km of normal distribution, the speed of 25 km/h.

2) Charging mode

Charging time of slow charging mode is longer, and not suitable for travel frequently pure electric bus; And quick charge although greatly shorten the charging time, it can bring greater impact to power grid, such as 10 minutes to finish 35 kWh battery requires 210 kW power charging. The battery life would also be affected. At present, Tianjin way of pure electric bus to replace the battery is given priority to, the change in power inadequate battery, fully charged battery, only a few minutes to complete this process.

Based on the above analysis, irrespective of the pure electric bus battery case, assume that their way of unified use to replace the battery. Ensure bus can replace the battery in time to complete, assuming that bus station and the terminal are equipped with in power plant, and have enough batteries can be replaced. According to Shanghai, Chengdu and other cities of pure electric bus operating experience, assuming that when electric cars arrive in plant power status is lower than 30% or not enough to complete the next single, it is necessary to replace the battery, replace the battery from charging in plant arrangement. In addition, bus operation time, place, relatively concentrated, charging can be concentrated in the existing parking lot construction of charging facilities.

3) Charging time scale

Assume that pure electric bus operating time is 8:00 am to 6 PM, buses may at any time during the battery discharged battery is low. It is assumed that in power station operating 24 hours a day, 24 hours a day to replace the battery to charge.

3.2. Behavior Characteristics of Private Electric Vehicles

Unlike buses, private cars are mainly used for commuting, average run twice a day, so the private car time connected to the electricity grid can be divided into the day and night in the home two hours in the company, respectively, to consider its behavioral characteristics.

1) Driving distance

A day’s travel journey of Private cars is between 40 km and 60 km, and supposed to work during the day and evening work schedule are equal, then the single range evenly distributed between 20 km and 30 km.

2) Charging mode

Whether parked or residence in the company parking lot, private car longer than the time grid, generally do not need fast charging, using slow charging or battery replacement approach is more reasonable choice, so here taking private cars with a slow fast charge and replace the battery in two ways. Slow charging for the use of private cars, assuming their ownership in the company parking lot and are building a sufficient number of charging facilities, the user can always access to the grid for charging; way to take a private car to replace the battery, and the front right Similar assumptions buses, if their berthing places remaining in the battery status is below 30%, or insufficient to complete the next stroke, the user must replace the battery, replace the battery down by the charging arrangements for power plants.

Table 1. Comparison of different charging modes of plug-in electric vehicles in China.

Charging modes	Rated voltage/V	Rated Current/A	Application areas
L1	Single-phase 220	16	Household
L2 2-1	Single-phase 220	32	Shopping malls, Parking lots
L2 2-2	Three-phase 380	32	Shopping malls, Parking lots
L2 2-3	Three-phase 380	63	Shopping malls, Parking lots
L3	600	300	Motorway service area, Charging stations, etc.

3) Charging time scale

Corresponding to the private car for power mode, for power plants can be at any time during the day down on the replacement battery trickle charge, the situation is similar to the pure electric bus.

4. Charging Agglomeration Characteristics

4.1. The Simple Charging Model of Electric Vehicle

Lithium battery is the mainstream development of electric vehicle [12,13]. This article takes lithium as the research object. Battery model always consists of a controlled voltage source and a constant value of resistance in series, the description of the model equation are as follows:

$$U_b = E_0 - \frac{KQ_i}{0.1Q + v(t)} - \frac{KQv(t)}{Q - v(t)} + Ae^{-Bv(t)} - Ri \quad (1)$$

$$v(t) = (1 - \frac{S_0}{100})Q + \int_0^t idt \quad (2)$$

where U_b is voltage of the battery; i is charging current; Q is the nominal capacity of the battery; R is the battery internal resistance; K is the battery polarization constant; E_0 is the battery constant potential; A, B are the constant index of charging battery; S_0 is initial charged battery state; SOC_0 is the battery remaining power.

1) If $U_b < U_{b\_max}$, $i = I_c$, generation into the formula (1), (2), U_b can be calculated.

2) If $U_b \geq U_{b\_max}$, then $i = 0$, $U_b = U_{b\_max}$.

The battery power in the process of charging is:

$$P = -U_b i \quad (3)$$

The two main battery parameters are given. U_n is nominal voltage of the battery (V). Q is battery capacity (A.h). For lithium battery, according to the literature, it can be derived that: $E_0 = 1.0834U_n$, $K = 0.005645U_n/Q$, $A = 0.08496U_n$, $B = 60.0619/Q$, $R = 0.01U_n/Q$. When the battery type is not at the same time, just the relationship in front of the coefficient is different.

For fixed nominal voltage and capacity of lithium-ion batteries, if SOC_0 is known, it can calculate the lithium battery charging power curve according to the formula (1) - (3).

Charging power of single electric vehicle can be considered a battery charging power, described by the formula (1) - (3).

4.2. Charging Load Agglomeration Characteristics of Electric Vehicle

(1) Random distribution characteristic of EV start charging time

Large-scale development of electric vehicles will be a greater impact on the distribution grid. To carry out electric vehicle charging load characteristics is a prerequisite to ensure the safe operation of the grid. It is to guide the electric vehicle charging orderly basis. Among them, the residential living and travel habits with regularity, which means that residential electric car charging station load is more conducive to the orderly charge control. Therefore, the load agglomeration characteristics study more practical value.

Due to the time of arrival every electric vehicle charging stations is random, so this article assumes that it is a random variable, and follow certain distribution, and the distribution of affected by time-sharing electricity price and residents' daily use habits. In real life, start charging time of the electric vehicle reaching charging stations is a random event, when it appears in fixed average density of the random and independent, so this incident number in unit time can approximately obey the poisson distribution.

Supposing that a random process technology $\{N_t, t \geq 0\}$, indicates a count of number of random time, process, and meeting the following three conditions:

1) $N_0 = 0$.

2) N_t is independent increment process.

3) If $t > 0$, $s \geq 0$, then $N_{t+s} - N_s$ obeys the poisson distribution. Making $k = N_{t+s} - N_s$, during the time of $(s+t, t)$, the probability of random event number *k* is :

$$P\{N_{t+s} - N_s = k\} = \frac{(\lambda t)^k e^{-\lambda t}}{k!}, \quad k = 0,1,2,\cdots \quad (4)$$

where λ is an important parameter of the poisson process. It determines the charging starting time of electric vehicle.

(2) Random distribution characteristics of initial state of battery

Charging starting state of electric vehicle SOC_0 depending on the owners charging habits is random. The initial state of electric vehicles SOC_0 is normally distributed $N(\mu, \sigma)$. μ is the mean value, and σ is the variance.

(3) Agglomeration model of EV

According to above analysis, the electric vehicle charging load agglomeration features can be described with the following model:

$$1) \quad N_{car} = [n_1, n_2, \cdots n_M] \sim P(\lambda), \quad M = \frac{T}{T_{step}} \quad (5)$$

where *T* is electric charging time, T_{step} is the length of the unit time slice, *M* is the total number of time slice.

2) That will generate normally distributed series S_0,

$$S_0 = [S_{01}, S_{02}, \cdots S_{0N}] \sim N(\mu, \sigma) \quad (6)$$

3) Charging load power of the *i*th EV can be calculated according to the initial state of charge, according to

the formula (1) - (3).

Hence, the characteristics of the cluster model of the charging station are affected by four important parameters λ, T, μ, σ. Getting the four parameters, we can simulate the corresponding load concentration characteristic of electric vehicles.

5. Simulation Analysis

(1) Simulation conditions

1) Considering the electric car's battery life, and user habits, etc., it can be considered private electric vehicle charging frequency is once per day.

2) Two cases are simulated as following

a) The first stage segments: 17:00 off work, the charging starting time is 20:00, expected to obey the variance of the Poisson distribution for the 10 minutes, and the leaving time is the next day 7:00 am or 7:00 after;

b) The second stage segments: 18:00 off work, the charging starting time is 21:00, expected to obey the variance of the Poisson distribution for the 10 minutes, and the leaving time is the next day 8:00 am or 8:00 after.

3) The other data

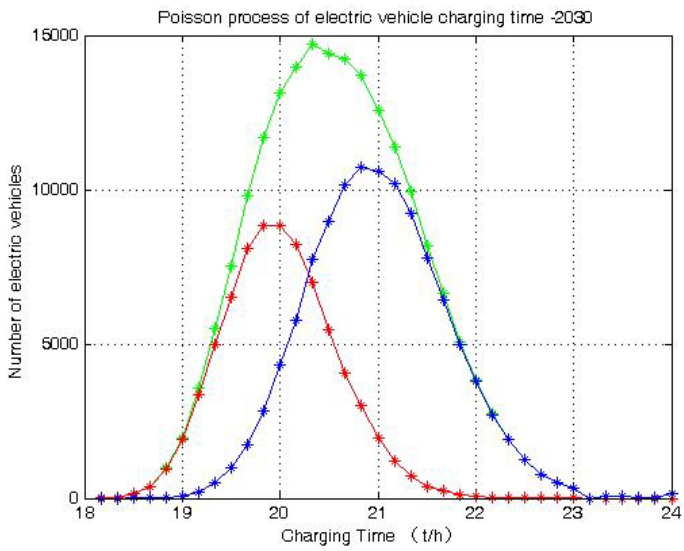
a) The type of battery is 120V/15A. SOC_0 obeys the normal distribution N(0.3,0.1).

b) About 20% - 30% of the private electric vehicle needing to be charged every day, then, in 2015, 2020 and 2030, the number of Tianjin private electric vehicle needing to be charged every day is 1400; 14000 and 191,250.

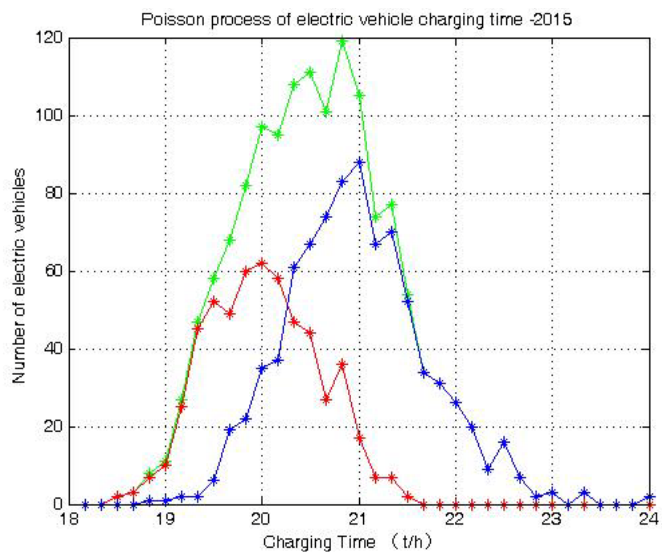
(2) The simulation results

The charging time of different time periods are as shown in **Figure 1**.

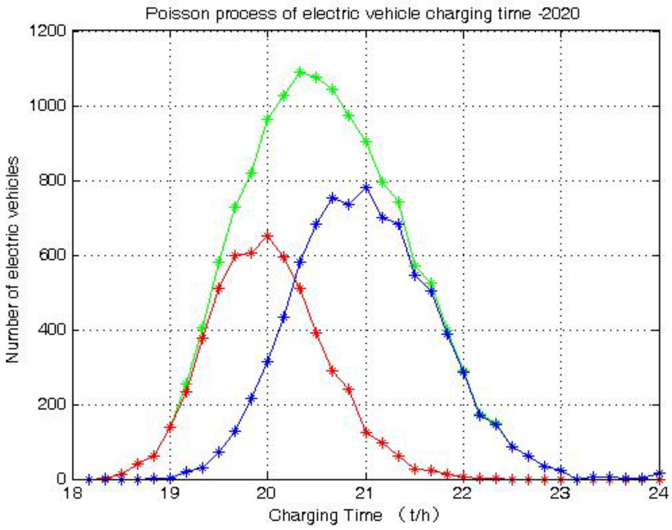
The power curves of overall load are as shown in **Figure 2**.



(a)

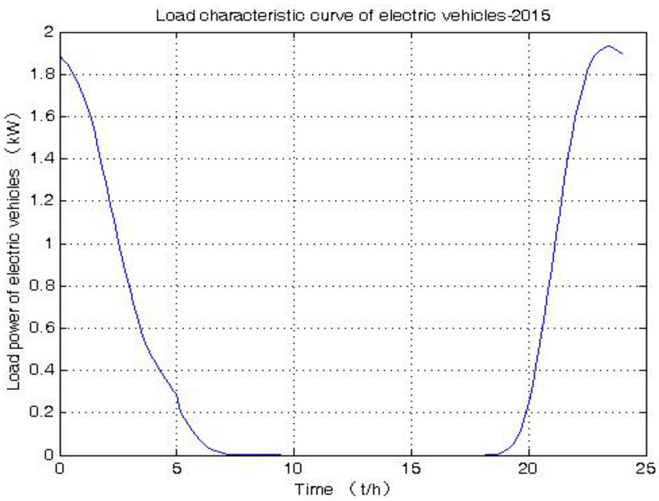


(b)

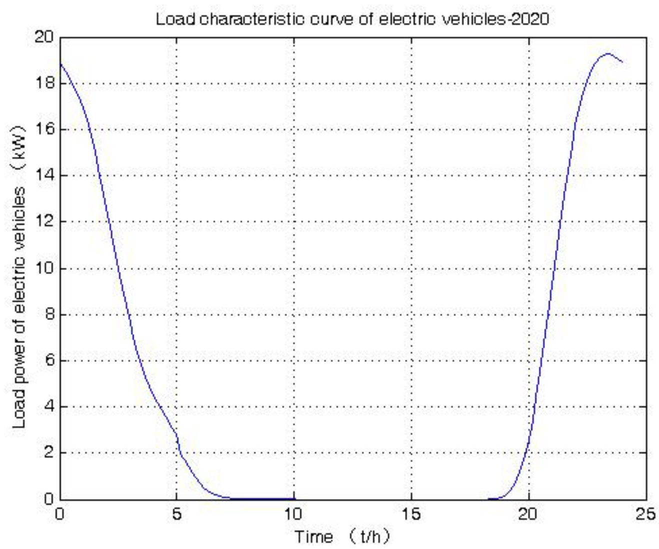


(c)

Figure 1. Poisson process of electric vehicle charging time



(a)



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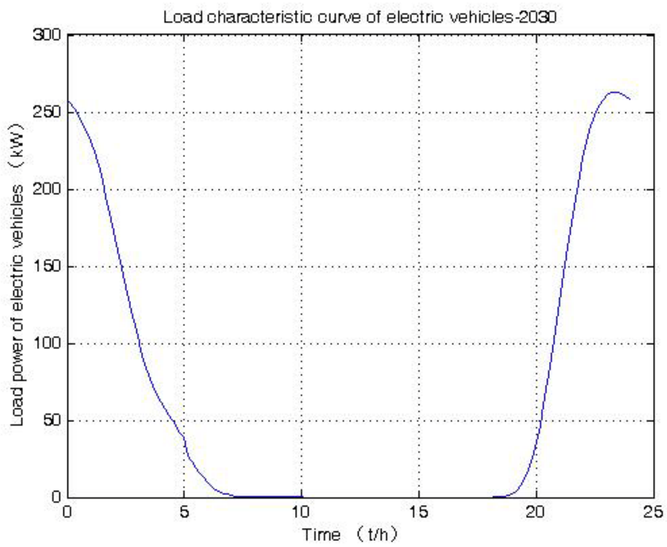

(c)

Figure 2. Load characteristic curve of electric vehicles

6. Conclusion

Charging load agglomeration features of electric vehicle are influenced by many factors. Based on simplified battery model, this paper puts forward the model of electric vehicle load cluster based on poisson distribution, and analyzes the four key agglomeration characteristic parameters. Simulation results show that the proposed agglomeration model of electric vehicles can reflect the charging starting time (SOC_0) and random distribution of electric vehicles at the same time. And, charging load of private electric cars in 2015, 2020, 2030 are forecasted. The prediction results to study the effect of future electric vehicle loading to the power grid have a certain reference value.

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