Charging Load Forecasting for Electric Vehicles Based on Fuzzy Inference*

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Abstract. Large scale of electric vehicles (EVS) integration will pose great impacts on the power system, due to their disorderly charging. Electric cars' charging load cannot be forecasted as the traditional power load, which is usually forecasted based on historical data. There need to be some other methods to predict electric vehicles charging load, in order to improve the reliability and security of the grid. This paper analyze the travel characteristics of electric vehicles, then use the fuzzy inference system to emulate the process of drivers' decision to charge their cars, the charging probability is attained in the given location. Finally, the daily profile of charging load can be predicted according to the numbers of electric vehicles forecasted in Beijing.

Keywords: electric vehicle, travel characteristics, charging load, fuzzy inference.

1 Introduction

Automobile driving consumes large amounts of oil resources and emits large amount of fumes, makes noise, brings about many negative impacts [1-3]. One of the most important ways to reduce carbon dioxide emissions to get rid of oil dependency for human is the development of new energy vehicles and promoting low carbon transport [2]. Electric cars can be charged using a socket connected to the grid, large-scale grid connection for charging electric vehicles will pose huge impacts on the grid, especially if users charge electric vehicles in the same period, which will improve the maximum power load, aggravate the load peak and off-peak difference, increase the difficulty of controlling the power grid optimization, impact power quality, and reduce the life of distribution transformer. Electric vehicle charging load prediction can reduce the impact on power grid caused by the electric cars connected to the grid, and provide reference for optimizing operation and planning of power grid. Traditional power load methods of prediction, such as time series prediction method, wavelet analysis, chaos theory, and the neural network, are passive predictions that depend on

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a large number of historical data and related influence factors . However, the electric cars industry is an emerging technology in China, there is few actual historical data of electric cars on the road. The prediction for EVS charging load mostly depends on the drive behavior and the statistics analysis of traditional fuel vehicle.

Electric vehicle charging demand of statistical model is established in [4], according to the statistical data of fuel vehicles, combined with the influencing factors of electric vehicle charging load. But EVS are supposed to charge only at home, and will begin to recharge immediately as soon as the cars get home. In [5] the charging load prediction is according to the number of electric cars of entering and leaving in a certain area for a period of time. It also assumes that electric vehicles recharge at home, and the charging power is constant, all travels outside can be supported with a single battery which is full charged. Paper [6] analyzed the important factors that affect the electric car charging such as parking location, travel distance, driving time, parking time , based on the driving mode of automobile, then attained the load profile in different areas and in different parking locations. Due to the electric car is still in development stage, there are a few charging facilities in public place, most of the electric cars will be charged at home [8]. Paper [7] traced and investigated a large number of the electric car drivers to study the driving behavior of electric cars, analyzed the probable charging location and charging time. The EVs recharged not only once a day or only at home in their actual use. Drivers decide to charge or not largely depends that if the remaining state of charge (SOC) can meet the power demand for next trip or whether the parking duration in given locations can meet the need of charging Fees of charging and parking, Income, oil prices, and the convenience of the charging infrastructure also will affect the users' decision to charge. But these factors are negligible compared to SOC and parking duration. The charging facilities will be improved much and increase gradually, because of the country's heavily promoted on electric cars. Therefore, the possibility of charging in residential, workplace and in the large-scale parking lot will be increased much, electric vehicles batteries can be charged at the main parking place successfully in the future.

This paper analyze the travel characteristics of electric vehicles, and then use the fuzzy inference system to emulate the process of drives deciding to charge their cars, the charging probability is attained in the given location. Finally, the daily profile of charging load can be predicted according to the numbers of electric vehicles forecasted in Beijing.

2 Travel Characteristics of EVS

The charging load of EVS has a strong randomness in temporal and space, which is determined by the driver behavior of the users when they use their cars. Travel features contain the information such as where they park their cars, parking duration, when they arrived at the destination and the state of charge when arrived. Therefore, understanding the electric car travel characteristics in time and space will be of great significance to forecast charging load distribution of the electric vehicles. Travel characteristics of vehicle are analyzed according to the Beijing municipal transportation development report in 2005 and the third trip survey [12, 13].

2.1 The Purpose of Travel

People usually drive their cars for commuting or not. The activities of commuter include the travel to school and work places to and from, the other non-commuting activities include shopping, entertainment and so on. Different travel purpose has different parking behavior, parking time will be last more than 3 hours in most of the commuter parking and residential parking, while the parking for business or other pleasure purpose the parking duration will be mostly concentrated in the 30 minutes between 3 hours. The time of parking in residential area are more concentrated, which usually last 10 hours, compared with the commuter parking [9]. The average travel daily times is 3.16 [13]. So the main travel purpose can be assumed to be at home, workplaces and large business places. Users generally go to work from residential areas in the morning, then go shopping or dining after the work, finally arrive home. In this paper, only the car users who have the fixed work will be discussed. The unemployed or retired, who's parking place and time is not fixed, and only a minority, are not discussed in this paper.

2.2 Residential Parking Time and Duration Analysis

The users generally set out from home in the morning in weekdays, and finally return home after a day of activity, and then the cars would stay at home for a long time till the next trip. Electric vehicles will have a great possibility to be recharged in the evening .Fig.1 shows the begin time of residential parking [14]. Only one peak of parking time in the residential area can be seen from the Fig.1, namely the evening peak at 17:00 - 19:00, the number of parking cars accounts for 51.09%, the cars generally stay at home till the next morning, parking duration in residential area generally last more than 10 hours, so the residential is often considered the most likely location to be charged for EVS.

2.3 Parking Time and Duration Analysis of Work Places

The drivers usually go to work at 7：00-8：00，which is during the rush hour, and most of the cars arrive at the work places at 8：00-9：00, accounted for 26%. The afternoon rush hour is between 17:00 and 18:00, and reaches the peak at 17:30, accounted for 35%. The peak time of arriving home is between 18:00 and 19:00 [12]. Because the work places are relatively fixed, the cars usually can stay for a long time, generally close to the working time 8 hours. The EVS can recharge when arrived at work places until their next trip after work. Due to the long parking duration at work places, the possibility of charging for EVS will be large.

2.4 Parking Time and Duration Analysis of Commercial Area

The main parking purpose in commercial area is commonly used to shopping, catering or entertainment. Parking time is short, most concentrated within 2 hours. The distribution of parking duration in commercial area is show in Fig.2. The average parking time is 79.8 minutes [10]. So if the charging infrastructure is available in shopping centers, the cars are most likely to be recharged in this place. Parking time in commercial places is usually at 12:00-13:00 and 17:30-19:00.

2.5 Travel Distance

The power demand of electric cars determines the charging behavior, whether the electric cars are charged or not is related the battery remaining power closely. The remaining state of charge in the electric vehicle battery is used to represent the charge demand in this paper. The charging time and the power energy drawn from the grid largely depend on the initial SOC before charging. SOC decreased linearly with the distance increasing. The average distance of private cars in Beijing is 19596 km, the average daily range of about 53.7 km, 14km per time [12]. BYD F3DM, for example, the power consumption per 100km is 16 kWh; the maximum range in electric mode is 60 km. The electric cars are likely to be charged after arriving at given destination. Travel mileage satisfy lognormal distribution according to the statistical analysis of the traditional car data, as shown in formula (1)

$$f_D(x)=\frac{1}{x\sigma_D\sqrt{2\pi}}\exp[-\frac{(\ln x-\mu_D)^2}{2\sigma_D^2}] \tag{1}$$

Where x is the daily distance, $\mu_D=3.2$, $\sigma_D=0.88$. As the cars traveling three times a day, the distance traveled to work can be assumed to be x / 3, the distance traveled to commercial area can be 2x / 3.

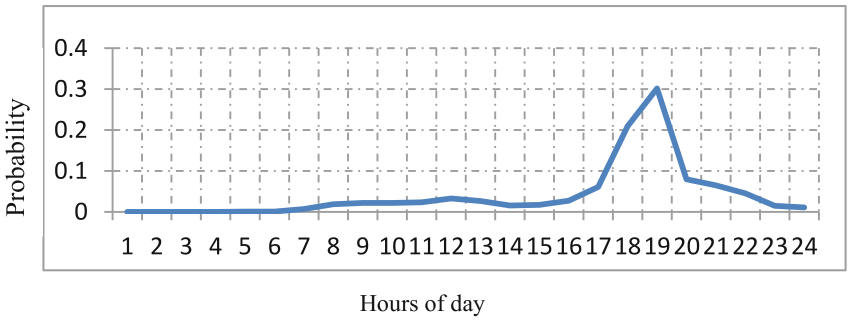

Fig. 1. The time distribution of starting to park in residential area

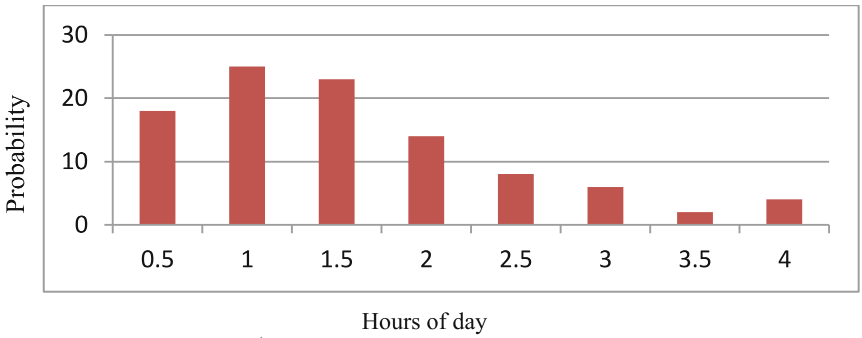

Fig. 2. The parking duration (hours) in commercial area

3 The Fuzzy Inference System of the Process to Decide to Charge

The fuzzy inference system (FIS) is an advanced algorithm framework, and widely applied in automatic control, artificial intelligence, pattern recognition, and many other fields. In this paper, the fuzzy inference is applied to emulate the process of decision-making for a driver when deciding to charge the vehicle’s battery. The input of fuzzy system is the distance before charging and the parking duration in a given location, then the inference rules are built according to users’ charging habits, finally the charging probability as an output of fuzzy system can be attained.

The charging behavior of electric vehicles largely determines distribution of space and time of the charging load. Drivers decide to charge or not largely depends that if the remaining SOC can meet the power demand for next trip or whether the parking duration in given locations can meet the need of charging. If the SOC is too low, the next trip can’t complete in electric mode for a plug-in hybrid. Drivers tend to charge the battery in the destination, if the parking duration is long, users also tend to charge the battery to full. Users are more willing to use power energy because of its saving and economic advantages and the price is low compared to oil price. Vague language will be used to describe the current SOC and the parking duration, just as charging a mobile phone, the actual accurate percentage of the remaining power will not be cared about. Users usually only estimate how much energy remained and how long the battery can be recharged fully. It is not easy to calculate SOC, but distance can be directly read from the odometer. It is easier to estimate the probably distance of next trip, and then decide whether to charge when knowing the maximum distance in electric mode for a plug-in hybrid. The language of fuzzy variables on distance traveled when arriving destination and the parking duration in the given place is used in this paper. Different electric cars have different battery capacity, so the maximum range in electric mode is different. Driving distance before charging is normalized based on its maximum all-electric range. The fuzzy set “low”, ”medium”, ”high” is used to cover the whole working area of the distance when arrived the destination. Fig.3 (a) shows membership functions created for the distance traveled before charging. Similarly, the length of time for parking also expressed by three linguistic terms (Short, Average, Long), as shown in Fig.3 (b). Parking events ranging from 30minutes to around 4 hours is labeled “M”, less than 30minutes is labeled “S”. Parking duration at home or work places is very long according to the above analysis. So the batteries of electric vehicles are likely to be recharged in these two regions. The reasoning rules of fuzzy inference rules are established according to the user's experience and the analysis of electric vehicle charging behavior, as shown in Table 1. Outputs produced by these rules acted on the two inputs of the fuzzy system, the membership functions created for charging probability is shown in Fig.3 (c). Then aggregated and defuzzified to gain the probability of charging in different location. Five linguistic terms is used to cover the whole area of the charging probability. The center-of-mass operation is used for defuzzification, more calculate details can be seen in [15-16].

4 Prediction and Analysis of Charging Load

4.1 Type of Battery

The type of battery determines the battery capacity, mileage, charging power characteristics. The rechargeable batteries commonly used include lead-acid battery, nickel cadmium battery, nickel metal hydride batteries and lithium ion batteries. Due to the extremely high performance advantages of lithium ion batteries, it will be the inevitable direction of power battery in the future. This article assumes that all electric vehicles use lithium ion batteries. Battery capacity designed can satisfy the demand of the day's mileage, but the volume is greater, the price will be higher accordingly. From the future perspective of the development, Cars can be likely to be recharged anywhere at any time .So while maintaining the same mileage, the battery capacity can be significantly reduced, thereby reducing the cost of production of electric vehicles, improving penetration of electric vehicles, especially for private cars travelling short. Lithium battery capacity in this article is assumed to be 16kWh.

4.2 Charging Mode

There are four ways of charging, according to China's automotive industry standards, as shown in Table 2.This article selects the charging way of 220 V (AC) / 16 A, namely the charging power is 3.52 kW. Charging mode determines the length of time for charging. The same stop time, but the charging mode is different, the intention of drivers' decision to charge will be different. Even the parking duration is short, if the charge mode is fast-charge, the possibility of charging for electric vehicles is still large, while the drivers would not recharge their cars if the charge mode is slow-charge with short parking duration. The membership function is based on the slow charge in this paper.

4.3 The Ownership of Electric Cars Prediction

The ownership of private cars in Beijing reached 4.075 million by 2012. The average annual growth rate of private vehicles is 14% several years ago, but it has slowed down significantly, because of the restriction measures on the cars in Beijing. The growth rate of private vehicles is only 3% in 2011.The policy for cars will not be changed much in Beijing for a long period of time. Therefore, the annual growth of private vehicles in Beijing is likely to remain 4%, so the total number of vehicles in 2015, 2020, 2030 can be predicted. The results shown as follows:

Year	2015	2020	2030
Number (ten thousand)	458.4	557.7	825.5

According to incomplete statistics of China Association of Automobile Manufacturers, the total new energy vehicles sold are 24000 in China from 2011 to the first half of 2013, while in Beijing are 3388, which are ranked the third in China, the number of private electric cars account for one percent of the total private vehicles in 2012. The number of electric vehicles in 2015, 2020, 2030 is assumed to account for 2%, 10%, and 30% of the total private cars in this paper.

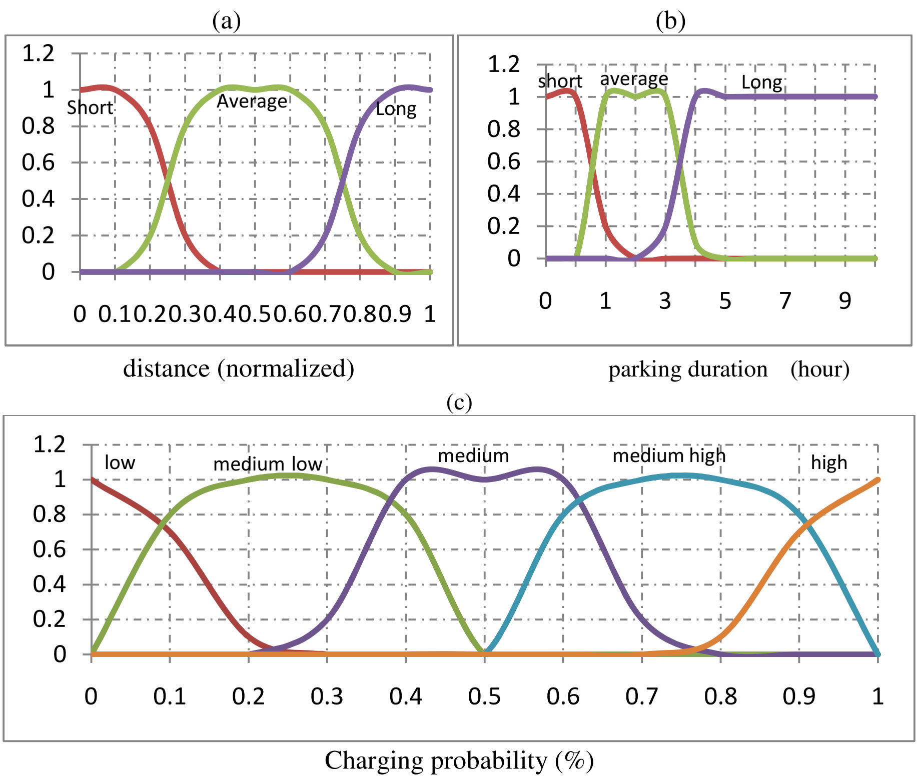

Fig. 3. Membership functions. (a) normalized driving distance; (b) parking duration;(c) charging probability

Table 1. Rules of the fuzzy system

If distance is	And parking duration is	Then probability of charging
Low	Short	Low
Low	Average	Medium Low
Low	Long	Medium
Average	Short	Medium Low
Average	Average	Medium
Average	Long	Medium High
Long	Short	Medium Low
Long	Average	Medium High
Long	Long	High

Table 2. Standard of charging ways

CHARGING MODE	RATE VOLTAGE	RATE CURRENT
1	220V(AC)	16A
2	220V(AC)	32A
3	380V(AC)	32A
4	400V/750V(DC)	125A
	400V/750V(DC)	250A

4.4 Prediction Steps

One day can be divided into three periods, namely the corresponding three charging period in the corresponding locations. When the forecast time is between 17:00-18:30, the electric cars are mostly concentrated in business areas to charge the battery using fast charging mode at this moment. Similarly, the time in residential area and working places can be assumed according to the time when the cars begin to be parked.

The probability of parking events in a day can be seen in Fig.4, according to 146950 parking records in Beijing [14]. The total number of cars parked in a fixed time can be attained according to the percentage in Fig.6 .The parking places can be known according to the forecasted time and the distance traveled before charging can be produced randomly by the daily probability density distribution. The length of time for parking and the distance traveled when arrived at the destination is used as the inputs of fuzzy system, and then the reasoning rules are activated. Finally, the hourly charging probability profile will be gained by defuzzification, as shown in Fig.5. Assuming that all vehicles will be recharged until the battery is full or till to the end of the time of parking. If the charging of electric vehicles will continue to the next moment, the charging probability at the next moment is 1. As shown in Fig.6, the parking events probability is 10.54% at 9 a.m., the number of electric vehicles is 11600 in 2015 according to the prediction above. Then, there will be 11600 * 10.54% = 1122 vehicles parking at this moment. The charging location can be supposed to be working places. The charging probability is 0.08 at 9 a.m. as shown in Fig.5. The charging power is 220*16=3.52kW, so the total charging load is 3.52 * 1222 * 0.08 = 344.1 kW. Because not all the electric cars will travel, assuming that 80% of the electric cars will travel and will be recharged in the parking locations. A random number r is produced, when r < = 0.8, the electric cars can be assumed to be recharged.

Assuming that the charging efficiency is 90%, the lithium battery charging power is 3.52 kW, and 12.26 kW. The time of day can be divided into 24 points. The expect of total charging power of all the electric vehicles parked in the specific time can be gained by Monte Carlo simulation, then the daily profile of charging load is attained.

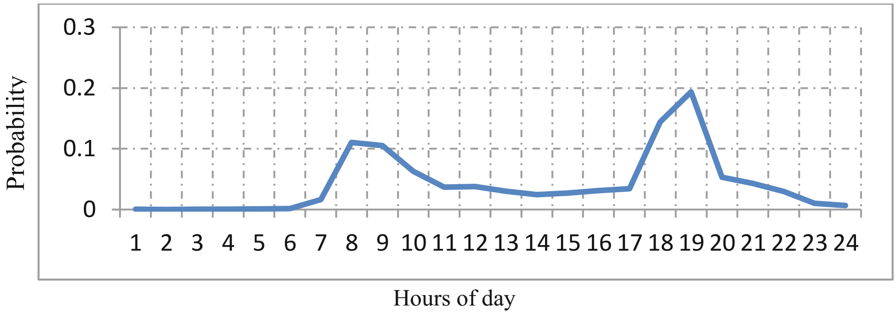

Fig. 4. The probability of parking in weekdays

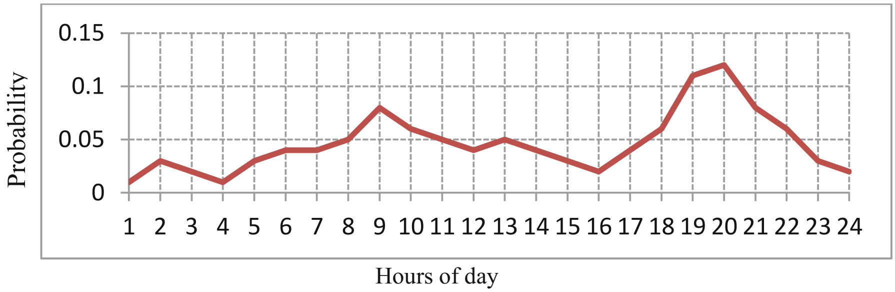

Fig. 5. The average probability of charging in weekdays

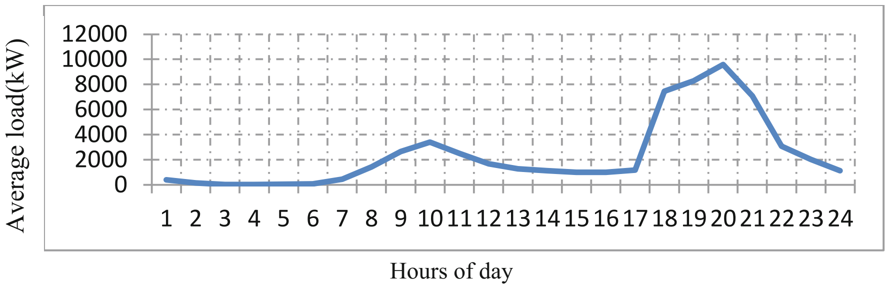

Fig. 6. Average load demand in weekdays in 2015

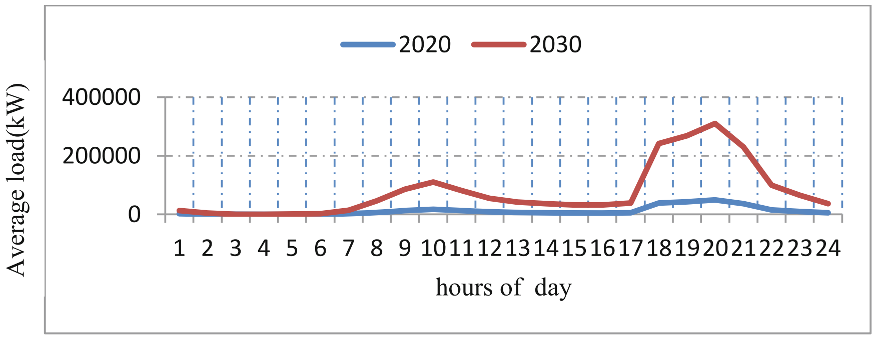

Fig. 7. Average load demand in weekdays in 2020 and 2030

5 Conclusion

The predicted profile as shown in Fig.6 and Fig.7 showed two peaks obviously, maximum load appears at night, because most of the private cars tend to charge their cars at night. The maximum load is respectively 9576.0kW, 49799kW, and 310745.9kW in 2015, 2020, 2030. The charging load is increasing dramatically due to the development of EVS. The results show that the time of peak is almost the same as the regular load peak, which will pose huge impacts on power grid. The profile of charging load is significant to study the power quality and load voltage loss. It also has reference meaning for studying the optimation of charging and vehicle to grid.

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