The Impact of Electric Vehicles on the Distribution Grid

Shao yun Ge, Long Wang[a], Hong Liu, Liang Feng

Key Laboratory of Smart Grid (Tianjin University), Tianjin, China

[a]wanglong@tju.edu.cn

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Abstract-Distribution grid will be greatly influenced when large scale electric vehicles are simultaneously charged or discharged. Firstly, the assumptions related to the charging and discharging power of EVs are discussed, and the probability of daily driving distance is examined. Secondly, the probability models of charging time, duration and power are studied, and the probability models of discharging time, duration and power are built according to the driving pattern of X city in China and the national household travel survey of America in 2001. Then, the probability equation of single electric vehicle's hourly charging and discharging power is derived. After that, the mathematical expectation of above probability equation is solved by Monte Carlo method. Finally, the impact of large scale charging and discharging electric vehicles on the daily load of X city is analyzed. The results provide the theoretical foundation for the application of large scale electric vehicles in X city.

Introduction

In the world where energy conservation, environment protection and low carbon emission are growing concerns, the development of new transportation tools has taken on an accelerated pace, and the electric vehicle (EV) appears as a preference.

The number of EVs will reach 60 million in year 2030 according to the Electric Vehicle Development Strategy Research Predicting Report published by Ministry of Industry and Information Technology [1]. Assumed that the EV number in X city will reach 0.2 million and each EV generates or consumes 5kW active power, so the total power that these EVs provide or consume is 1000 MW. As a result, the EV's charging and discharging power accounts for about 10 percent of the maximum daily load of X city. So the impact of charging and discharging EVs on the distribution grid has to be discussed before the large scale EVs are simultaneously being connected.

Most research works have focused on special scale profiles, loading profiles, and charging profiles for these electric vehicles. Special scale EVs are given at different hours, and their impact on the daily load of distribution grid is studied in Kou [2]. The charging and discharging characteristics of plug in electric vehicle (PHEV) based on transient state are discussed and their statistic formulas are derived in Yang Hong ming [3]. The EV using model is built after analyzing human travel pattern and car using statistical results in Bradley T [4]. The statistical model of EVs' power demand based on the national household travel survey (NHTS) of America in 2001 is built, and its impact on power grid is discussed in Tian Li ting [5]. The basic effects that PHEVs will have on the grid based upon their characteristics are covered by Hadley [6]. The general results about the impacts of PHEVs on distribution grid are determined by the number of vehicles and vehicle demand profile are given in [7]. A time coordinated optimal flow model for integrating PHEVs and vehicle-to-grid (V2G) in order to minimize power loss is suggested in Acha et al. [8]. A dynamic programming model for assessing the impacts of charging PHEVs on the distribution grid of Belgium is developed in Clement et al. [9]. The impacts of charging EV on the daily load curve are examined in [10] and [11]. All these above researches are carried out based on the charging or the discharging models built according to their own assumptions, and they are neglected to investigate the impact of large scale charging and discharging EVs on the daily load of distribution grid based on the probability models fitted with the driving pattern in X city in China.

This paper is organized in the following way: Section II introduces the probability of daily driving distance pattern based on national household travel survey of America in 2001 and the assumptions of daily driving statistical pattern in X city. Section III discusses the probability models of daily charging and discharging. Section IV studies the probability equation of single EV's hourly charging and discharging power, and calculates its mathematical expectation by Monte Carlo simulation method. Section V analyzes the impact of large scale charging and discharging EVs on the daily load of X city. Section VI concludes the whole work in this paper.

Assumptions of Daily Driving Pattern

Following are the probability of daily driving distance based on the national household travel survey of America in 2001 (NHTS) [12] and the assumptions.

(1) The Probability of Daily Driving Distance

According to the NHTS, it is easily to get the probability equation of daily driving distance as follows.

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

Where $\mu_D = 3.20$, $\sigma_D = 0.88$, $0 < x \le 200$.

Equation (1) defines that the maximum distance the EV could reach is 200 km.

(2)Assumptions of Daily Driving Statistical Pattern

(i) Battery capacity of each EV is $C_{battery}$ = 30 kWh, and the general energy consumption [13] is W = 0.15 kWh/km.

(ii) The driving speed is constant, V_{speed} = 25 km/h.

(iii) The charging and discharging power is constant, P_{chg}= P_{dischg} = 5 kW.

(iv) The distance the EV covers from home to workplace is equal with the distance back home from workplace.

(v) The EV is charged fully at home and discharged left enough power for back home from workplace.

(vi) The EV is parked at household between 18:00am and 6:00 am the next day.

Models of Daily Charging and Discharging

The models of charging and discharging are built based on the assumptions and the probability of daily driving distance listed in Section II.

(1)The Models of Daily Charging

(i) The Probability of Charging Time

According to the sixth assumption listed in Section II, we know that the EV's charging time is limited between 18:00pm and 6:00am the next day. The probability of charging time is built based on the NHTS [14], which is shown as follows.

$$f_{T_{chg}}(t) = \begin{cases} \frac{1}{\sigma_s\sqrt{2\pi}}\exp[-\frac{(t-\mu_s)^2}{2\sigma_s^{\ 2}}], & (\mu_s - 12) < t \le 24 \\ \frac{1}{\sigma_s\sqrt{2\pi}}\exp[-\frac{(t+24-\mu_s)^2}{2\sigma_s^{\ 2}}], & 0 < t \le (\mu_s - 12) \end{cases} \qquad (2)$$

Where $\mu_s = 17.6$, $\sigma_s = 3.4$, $t \in [0,6] \cup [18,24]$.

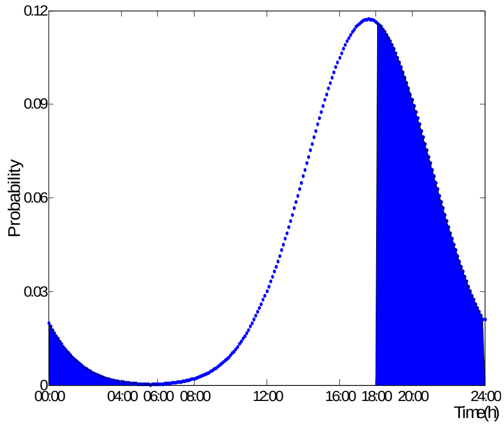

Fig. 1 the probability distribution of daily Charging Time

The probability distribution of charging period is shown as the blue area in Fig. 1. This blue area is accounted for about 45.32% of the total area, which could be calculated by the equation $\int_{18}^{24+6} f_{T_{chg}}(t)\,dt$.

(ii) The Probability of Charging Duration

According the first and third assumption in Section II, it is easy to know the charging duration is 6 hours for each EV.

(iii) The Probability Distribution of Charging

In order to examine the charging state at time t_0, here we introduce the random variable ξ_1. If the EV is charged at time t_0, we set ξ_1=1, else let ξ_1=0. Then we will get equation (3) and (4) as follows.

$$P(\xi_1 = 0) = F_{chg}(7 \le t_0 \le 17) \tag{3}$$

$$P(\xi_1 = 1) = 1 - P(\xi_1 = 0) \tag{4}$$

Here $F_{chg}(t_0) = \int_0^{t_0} f_{T_{chg}}(t)dt$.

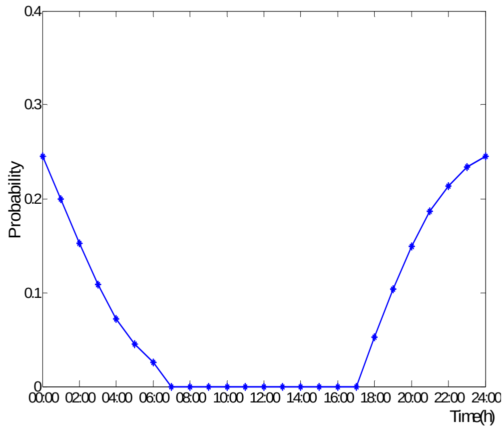

Fig. 2 the probability distribution of Charging

The probability distribution of daily charging is shown in Fig. 2. The probability is 0 at the time between 07:00am and 17:00pm. The maximum probability is appeared at 00:00am.

(2)The Models of Daily Discharging

(i) The Probability of Discharging Time

The probability of discharging time will be affected by the speed the EV drives and the distance between home and workplace. The time that the EV consumes from home to workplace or from workplace to home could be calculated by equation (5).

$$T_{run} = \frac{0.5L_D}{V_{speed}} \tag{5}$$

Where T_{run} is the time the EV consumes from home to workplace, L_D is the distance the EV covers daily.

Equation (5) shows the relation between the probability of the time the EV consumes from home to workplace and the probability of the daily driving distance.

With equation (1) and equation (5), it is easily to get the probability of discharging time which is shown as equation (6) as follows.

$$f_{T_{run}}(t) = \frac{1}{t\sigma_D\sqrt{2\pi}}\exp[-\frac{(\ln t - \ln 0.02 - \mu_D)^2}{2\sigma_D{}^2}] \tag{6}$$

Where $\mu_D = 3.20$, $\sigma_D = 0.88$, $0 < t \le 4$.

EVs will reach the workplace within 4 hours, so the probability of daily discharging time is between 6:00 am and 10:00 am.

(ii) The Probability of Discharging Duration

The probability of discharging duration will be affected by the following 4 factors, battery capacity of each EV, the general energy consumption per km, the discharging power, and the distance that the EV covers daily. The discharging duration could be calculated by Equation (7).

$$T_{dischg} = \frac{C_{battery} - WL_D}{P_{dischg}} \tag{7}$$

Where T_{dischg} represents the discharging duration and LD is the distance the EV covers daily.

Eq. (8) represents the probability of discharging duration, which would be derived by equation (1), equation (7), and other 3 variables.

$$f_{T_{dischg}}(t) = \frac{1}{(6-t)\sigma_D\sqrt{2\pi}}\exp[-\frac{(\ln(6-t) - \ln 0.03 - \mu_D)^2}{2\sigma_D{}^2}] \tag{8}$$

Where $\mu_D = 3.20$, $\sigma_D = 0.88$, $0 \le t < 6$.

It's easy to find out from Eq. (8) that the longer of the distance that the EVs cover, the shorter of the duration they are discharged. The reason behind is that the battery capacity of each electric vehicle is constant according to the assumption (i) listed in Section II.

(iii) The Probability Distribution of Discharging

In order to examine the discharging state at time t0, here we introduce another random variable ξ_2. If the EV is discharged at time t0, we set ξ_2=1, else let ξ_2=0. Then we will get Eq. (9) and (10) as follows.

$$P(\xi_2 = 1) = F_{dischg}(t < t_0, t + t_d \ge t_0) + F_{dischg}(t > t_0, t + t_d \ge t_0 + 24) \tag{9}$$

$$P(\xi_2 = 0) = 1 - P(\xi_2 = 1) \tag{10}$$

Where $F_{dichg}(t_0)$ is the joint probability density function composed of the probability of discharging time and the probability of discharging duration, t_d is the discharging duration, and *t* represents the current time.

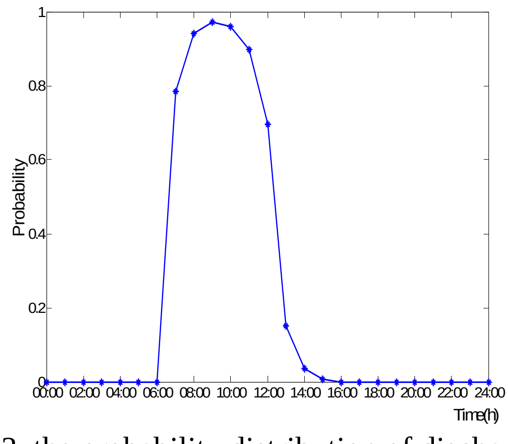

Fig. 3 the probability distribution of discharging

The probability distribution of daily discharging is shown in Fig. 3. The maximum probability is appeared at 9:00am, and the probability is *0* except the time between 7:00am and 16:00am.

Power Expectation of The Single EV

The EV owns three working states, discharging state $P(\xi_2 = 1)$, charging state $P(\xi_1 = 1)$ and stationary state $P(\xi_1 = 0, \xi_2 = 0)$.

The power that the single EV requires at time t_0 is calculated by equation (11).

$$P_{t_0} = P(\xi_1 = 1)P_{chg} - P(\xi_2 = 1)P_{dischg} \tag{11}$$

Where P_{t_0} .represents the power that the single EV requires at time t_0. The negative value of P_{t_0} represents that the EV supplies power to the distribution grid, and the positive values represents the EV consumes power from the distribution grid.

It is very difficult to get the analytical solution of Equation (11), so the Monte Carlo simulation method is introduced. The hourly power expectation of the single EV is calculated by Monte Carlo method based on equation (11), and the results are showed in Fig. 4.

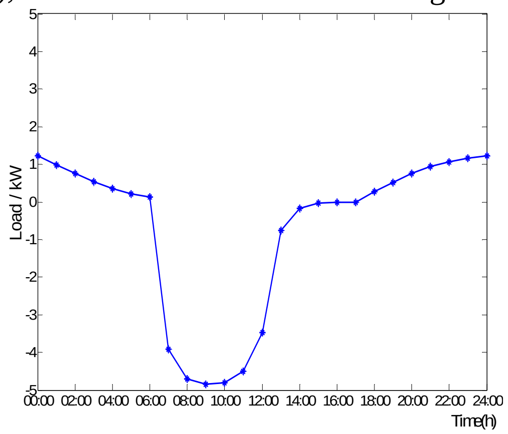

Fig. 4 the hourly power expectation of the single EV

The positive value in Fig. 4 represents that the EV is in charging state, the negative value shows it is in discharging state, and the zero value represents it is in stationary state. The maximum charging power is 1.227 kW at 00:00am and the maximum discharging power is 4.857kW which is appeared at 09:00 am.

The Impact of Large Scale EVs on the Daily Load of X City

According to the EV number assumption in Section I and the hourly power expectation of the single EV in Fig. 4, it is easily to get the impact of large scale EVs on the daily load of X city, which is shown in Fig. 5.

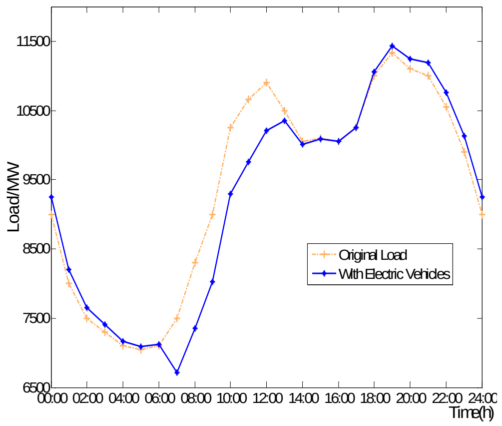

Fig. 5 the impact of large scale EVs on the daily load of X city

The orange line in Fig. 5 is the power demand curve without EVs, and the blue line is the load curve with large scale EVs connected. Fig. 5 indicates that the impact of large scale discharged EVs on the daily load of X city is mainly between 07:00am and 14:00pm. With large scale discharged EVs connected to the distribution grid, the total power demand in this period will be reduced hugely. The impact of charged EVs on the daily load is between 18:00pm and 06:00am the next day. With large scale charged EVs connected, the total power demand in this period will be increased to some extent.

The impact shown in Fig. 5 is harmful to the stability of the distribution grid, because it increases the peak power demand and decreases the valley power need. In other words, without control, the EVs will increase the peak-valley ratio of the load curve and make the load curve rougher.

The EVs will shave the load peak, fill the load valley, and make the load curve smoother only if a good charging and discharging strategy is provided. These results could be used as a fundamental reference for the application of large scale electric vehicles in X city.

Conclusions

This paper builds the probability model of discharging time and discharging duration, calculates and analyzes the hourly power expectation of the single EV by Monte Carlo method, and discusses the impact of large scale electric vehicles on the daily load of X city.

Without control, the EVs will increase the peak power need, decrease the valley power demand, and make the load curve rougher. The EVs will shave the load peak, fill the load valley, and reduce peak-valley ratio only if a good charging and discharging strategy is provided.

The next step of this research is to investigate the optimal control strategy of large scale electric vehicles to shave the load peak, reduce peak-valley ratio, and make the load curve smoother.

Acknowledgment

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