Modeling and Impact Analysis of large scale V2G Electric Vehicles on the Power Grid

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***Abstract*—With the rapid development of smart grid, the large scale vehicle-to-grid (V2G) electric vehicles (EVs) will been widely applied. However, the interaction between EVs and the power grid will bring many challenges. In order to lighten the adverse influence on the grid operation, the regional EV load should be estimated in advance. By thoroughly considering the impact factors of regional EV load on the gird, this paper presents a methodology to determine the regional EV load. Monte Carol simulation algorithm is adopted to draw the random numbers of impact factors and to achieve the simulation of EV load curve. Three kinds of EV load models are built and simulated including uncontrolled charging model, controlled charging model and controlled charging/discharging model. The impact of three different EV load models on the grid load curve and on the load rate and peak-valley difference of the grid is given in this paper. And the impact of different scale of EVs on the grid is also discussed. The EVs in Qingdao Economic and Technological Development Zone (QETDZ) in Qingdao city, Shandong Province, China are taken as an example to analyze the impact on the grid of different regional EV load models. The simulation results show that the three EV load models built in this paper are helpful to study the impact on the power grid and have a potential value in practical applications.**

Keywords-electric vehicle (EV); Monte Carol simulation; V2G; peak-valley difference

I. INTRODUCTION

VEHICLE-to-grid (V2G) mode is a kind of bidirectional energy exchange model in which plug-in electric vehicles (EVs) communicate with the power grid to sell demand response services by either delivering electricity into the grid or by throttling their charging rate[1][2]. The large scale application of V2G EV will bring a potential influence on the power grid [3-13]. It will increase the grid load, on the other hand it can also provide ancillary service by transferring electricity to the power grid as a smart energy storage unit.

Currently, several studies have been conducted on the modeling of EV load and its impact on the grid. Reference [4] develops mathematical model of Plug-in Hybrid Electric Vehicles (PHEVs) combined with distribution system components model, and the developed model is used to study the impact of uncoordinated and coordinated charging of PHEVs in distribution system. Oak Ridge National Laboratory (ORNL) is developing simulation models and energy management scenarios using the actual solar production and residential energy usage data, and a PHEV [5]. Reference [6] studies the impact of EVs on the grid in different scenarios with different seasons. Methodology for modeling and analyzing of the load demand in a distribution system due to EV battery charging are presented in reference [7][8]. Reference [9] proposes a coordinate charging strategy with the goal to minimize the power losses and maximize the main grid load factor.

The penetration of EVs may bring potential challenges to electric utility especially at the distribution level. The conclusion of reference [10] indicates that the load created by PHEVs in some cases may exceed the distribution transformer capacity. Reference [11] proposes a comprehensive approach for evaluating the impact of different levels of PHEV penetration on distribution network investment and incremental energy losses.

V2G mode EVs can exchange energy with the power grid. However, the previous references only focus on characteristics study of the charging load without considering the discharging process. While in reference [12] [13], the authors investigate different charging strategies for EVs with respect to their impact on the local power distribution network of a residential area. They assess the optimal car battery dis/charging scheduling to achieve peak shaving, reduction of the variability (over time) of the load, and cost reductions for electric mobility, respectively.

The aim of this paper is to model different kinds of EV loads by considering most of the impact factors on regional EV load. Then this paper will simulate the impact of different EV models and different EV scales on the grid based on the grid load curve of a real district in China.

The rest of this paper is organized as follows. Section II describes the impact factors on V2G EVs performance being as regional loads in this study. In section III, Three kinds of EV load models are built and simulated. Simulation results of the influence of EVs on the power grid are then presented and discussed in section IV. Finally, conclusions are given in section V.

II. IMPACT FACTORS ON V2G EVS PERFORMANCE BEING AS REGIONAL LOADS

There are many types of EVs. They can be divided into 3 categories in China: 1) Group vehicles. This includes buses for public transportation, street sweepers, garbage trucks,

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water trucks for sanitation departments, postal delivery vehicles for postal departments, electrical engineering vehicles for power utilities, etc. This type of EVs has the features of regular driving route and fixed parking lot. 2) Social vehicles. This includes official cars, business cars, and taxis and so on. The feature of this type is that driving route is strongly random and has a large radius. 3) Private vehicles. This type of vehicles has great randomness and short driving distance. As a V2G EV, it should have short driving distance and long parking time, plenty of time and capacity interact with the grid as well. In a word, V2G EVs are most suitable for private vehicles.

The most crucial impact factors on V2G EVs performance being as regional loads are the battery capacity, the single EV charging and discharging power, user behavior, and initial battery charge state, the scale of EVs [14][15]. Some of them, such as the battery capacity, the single EV charging and discharging power, the scale of EVs, may be acquired in advance. While the user behavior and initial charge-discharge state is random, those cannot be obtained beforehand. Therefore, the study on characteristics of EV charging and discharging load should take full account of these factors.

The user behavior is determined by two aspects, which are the start time of battery charging or discharging and the daily driving distance. Private vehicles are mainly used for work and leisure activities, and the location where to charge or discharge is probably at home or workplace. The time interval for discharging or charging is probably from reaching the workplace in the morning to punching out in the afternoon and from arriving at home in the afternoon to leaving home to go to work in the next morning. According to the working time in enterprises and government institutions in China, the probable charging and discharging time intervals are 9:00-17:30 and 19:00-7:00. According to the user behavior, most people would start to charge or discharge soon after arriving at home or workplace. The start charging or discharging time is closed to normal distribution and its probability density function is as follows:

$$f_{s1}(x)=\frac{1}{\sigma_{s1}\sqrt{2\pi}}\exp\left[-\frac{(x-\mu_{s1})^2}{2\sigma_{s1}^{2}}\right] \tag{1}$$

where, μ_{s1}=9； σ_{s1}=0.5

$$f_{s2}(x)=\frac{1}{\sigma_{s2}\sqrt{2\pi}}\exp\left[-\frac{(x-\mu_{s2})^2}{2\sigma_{s2}^{2}}\right] \tag{2}$$

where, μ_{s2}=19； σ_{s2}=0.5

According to the survey of national household vehicles by U.S. Department of transportation in 2001, the daily mileage can be approximately log-normal distribution using the maximum likelihood estimation [16]. Its probability density function is as follows:

$$f_D(x)=\frac{1}{x\sigma_D\sqrt{2\pi}}\exp\left[-\frac{(\ln x-\mu_D)^2}{2\sigma_D^{2}}\right] \tag{3}$$

Where, μ_D=3.5； σ_D=0.91

The daily mileage reflects the daily power consumption, and is related to the state of charge (SOC) of the EV battery. The initial SOC of an EV battery can be expressed as

$$soc_0=(1-\frac{\alpha d}{d_R})\times 100\% \tag{4}$$

Where, α is the number of traveling days, here is 1. d is the daily mileage. d_R is the maximum range of the EV, and the typical value for d_R is 80 miles [7].

Under given charging or discharging power, the active duration is related to initial battery SOC and final battery SOC. For analysis convenience, without considering the charging-discharging efficiency, the battery temperature, the change of voltage, the cycle times of battery charge/discharge, the charging or discharging duration is shown as follows:

1. The charging duration,

$$t_c=\frac{(soc_c-soc_0)}{r_{ci}} \tag{5}$$

Where soc_c is the final battery charging SOC. When the battery is fully charged, $soc_c=1$. r_{ci} is the charging current. For a battery with 1C rated capacity, assume charging at 0.1C and 0.2C charge current, the battery charge duration from empty to full is 10h and 5h, respectively.

2. The discharging duration,

$$t_d=\frac{(soc_0-soc_d)}{r_{di}} \tag{6}$$

Where soc_d is final battery discharging SOC. In order to improve the battery life, the minimum soc_d is 0.1. r_{di} is the discharge current. For instance, if a battery with 1C rated capacity is discharged respectively at 0.1C and 0.2C discharge current, the battery discharge duration from full to empty is 10h and 5h.

III. MODELING OF THE REGIONAL EV LOAD

The scale of electrical vehicle in a particular region is certain. The total daily EV load curve can be obtained by accumulating all EV loads in this region. The minimum time interval is in minute, and 1440 mins in a day is covered. The region EV load at each minute can be expressed as:

$$P_{Ti}=\sum_{n=1}^{N}P_{n,i} \tag{7}$$

Where, P_{Ti} is the total EV load power at the *ith* min, $i=1,2,...,1440$; N is the number of EVs in the area. $P_{n,i}$ is the *nth* EV load power at the *ith* min.