Construction Method of Electrical Vehicle Fast Charging Load Model

Tingting Wang1*, Zhuang Ma1 and Susheng Chen1

1 Shanghai Institute of Quality Inspection and Technical Research, Shanghai, 201114, China

*Corresponding author’s e-mail: wangtt@sqi.org.cn

Abstract. Electric vehicle (EV) has been increasing recent years, which brings more challenge to power grids, especially impacting on voltage stability. Building accurate EV model is important to evaluate voltage stability. Firstly, EV charging configuration is analyzed. Secondly, a static load model for EV is developed based on charging configuration. Finally, simulations analyze that Rs and Rl in the rectifier impact on voltage stability. The EV load model is developed and constant power, current and impedance (P, Z, I) load model impacting on voltage stability are compared, and results reveal that loading margin with EV load model is more lower than other load models such as P, Z, I.

1. Introduction

With the rapid development of economy, resource consumption and environmental pollution are more serious day by day. Electric cars (EV) have significant advantages over traditional cars in terms of energy consumption and environmental friendliness. It causes the rapid rise of the new type of clean energy for human’s health and living environment demanding.

As electric vehicles are affected by random factors such as the charging location, starting state of the battery and the charging time, there is greater impact uncertainty on the power grid compared with traditional cars. The research of large-scale electric vehicle access to the power grid involves many aspects, such as harmonic pollution, voltage drop, three-phase imbalance, influence on power quality of distribution network, influence on reliability of distribution network, etc. There is few research on the impact of EV charging on the voltage stability of the power grid. The load characteristics are the main factors affecting the voltage stability of the power grid, which means the importance of accurate load model for the study of voltage stability.

Dharmakeerthi et al. [1] studies the voltage stability of a large number of electric vehicles connected to the power grid by using CPF method, and the research results show that with the increase of electric vehicle permeability in the future, it will have a profound impact on the voltage stability of the power grid. Huang et al. [2] studies the influence of electric vehicle load on the voltage stability of power grid by modelling the load of electric vehicle as constant power (P) and constant impedance load (Z) using the method of small signal analysis. Zhang et al. [3] studied the influence of V2G on the short-term stability of power grid voltage by modelling the load of electric vehicles as constant impedance load (Z). Mingshen et al. [4] proposes a predictive control method to maintain voltage stability of EV charging stations. Makasa et al. [5] modelled the load of electric vehicles as a constant power load (P) and studied the influence of charging of electric vehicles on the voltage stability of the power grid.
From the above research, it can be seen that the load model plays an important role in the research on the voltage stability of the power grid. Therefore, this paper focuses on the construction of the EV charging load and then to analyze the influence of the EV load on voltage stability of the power grid.

2. Load modelling for electric vehicles (EV)

2.1 Charge configuration

At present, there are three charging methods for electric cars. The first is the household charging method with low charging current. The second is the AC charging method with higher charging current. The third is the DC power grid charging with high current. The first two charging methods are slow charging, and the third is fast charging. As fast charging mode provides electric vehicle users with short-term electricity and meets the urgent needs, it is favoured by more and more users. Therefore, the charging load model of EV in this paper is mainly focus on the fast charging mode. Fast charging is generally a high-power non-on-board DC charger that directly outputs DC to charge the battery of electric vehicles. The fast charger is generally composed of two parts, the front-end ac-dc rectifier and the back-end dc-dc BUCK converter. The structure of the fast charger is shown in figure 1.

![Figure 1. The structure of the fast charger.](image)

2.2 Construction of load model of electric vehicle

The equivalent circuit of the ac-dc rectifier model connecting the front end of the fast charger of electric vehicles with the power grid is shown in figure 2. The detailed derivation process from the d coordinate system to the q coordinate system is shown by Zhang [6]. The PV relation of the rectifier in the d-q coordinate system is shown in the formula 1- formula 3,

\[ V_d = L \frac{d i_d}{dt} + R_i i_d - L \omega i_q + d_i V_{dc} \]  
\[ V_q = L \frac{d i_q}{dt} + R_i i_q - L \omega i_d + d_q V_{dc} \]  
\[ C \frac{d V_{dc}}{dt} = \frac{3}{2} (d_i i_d + d_q i_q) - i_d \]  

Where R is the total resistance of the rectifier, which is the sum of the rectifier switching resistance R_s and the parasitic resistance R_L of the input filter. d_i and d_q are the DC load ratio of the d coordinate system and the AC load ratio of q coordinate system respectively. V_d, V_q, i_d and i_q are the voltage and current in d coordinate system and q coordinate system respectively.

![Figure 2. Equivalent circuit diagram of rectifier.](image)

In the stable state, rewrite formula (1)- formula (3) to formula (4)- formula (6),

\[ V_d = R_i i_d - L \omega i_q + d_i V_{dc} \]  
\[ V_q = R_i i_q + L \omega i_d + d_q V_{dc} \]
\[ i_d = \frac{3}{2} (d_i + d_q) \]  \hspace{1cm} (6)

In the d-q coordinate, the active power \( P \) and reactive power \( Q \) of the charger are,
\[ P = \frac{3}{2} (V_d i_d + V_q i_q) \]  \hspace{1cm} (7)
\[ Q = \frac{3}{2} (V_d i_q - V_q i_d) \]  \hspace{1cm} (8)

The controller of the rectifier of the charger is shown in figure 3. The voltage on the DC side can be adjusted by controlling \( I_Q \).

In this paper, it is assumed that the d-q coordinate system rotates at an angular speed \( \omega \) and is orthogonal to the grid voltage vector, so \( V_q = 0 \). In order to make the charger work under the unit power factor, the reference current \( i_{qref} = 0 \), so \( i_q = 0 \). Therefore, rewrite formula (4)-formula (7) as follows,
\[ V_d = R_i d + d_i V_{dc} \]  \hspace{1cm} (9)
\[ 0 = d_q V_{dc} + L \omega i_d \]  \hspace{1cm} (10)
\[ i_d = \frac{3}{2} d_i i_d \]  \hspace{1cm} (11)
\[ P = \frac{3}{2} V_d i_d \]  \hspace{1cm} (12)

By substituting equations (9) and (11) into equation (12), it can be concluded that,
\[ P = V_{dc} i_d + \frac{2}{3} (R_i \frac{d_i}{d_q}) \]  \hspace{1cm} (13)

The back end of the charger is equivalent circuit diagram of a Buck converter as shown in figure 4. PV relationship of Buck converter is shown in formula (14)- formula (15).
\[ V_s = V_b + L \frac{d i_L}{dt} + r i_L \]  \hspace{1cm} (14)
\[ i_L = i_b + C \frac{d V_b}{dt} \]  \hspace{1cm} (15)

In this paper, the battery of electric vehicle is modeled as a variable voltage source \( E_B \), and its equivalent circuit diagram is shown in figure 5.
Under steady state, capacitance C is open circuit. Rewrite formula (14)- formula (15),
\[ V_s = E_n + R_B I_n + r_i \]  
(16)
where, \( R_B = R_{B1} + R_{B2} \), and in a stable state,
\[ i_B = \frac{i_{in}}{k} \]  
(18)
\[ V_s = kV_{dc} = E_n + R_B I_n + r_i \]  
(19)
where \( k \) is the duty cycle of Buck circuit. Combined equations (13) and (18) as follows,
\[ P = kV_{dc} \frac{3Rk^2 i_B^2}{2d_2} + \frac{2d_2}{P_{vd}} \]  
(20)
Combined equations (9), (11) and (18) as follows,
\[ d_2 = \frac{v_d}{V_{dc}} \]  
(21)
\[ d_2 \approx \frac{v_d}{V_{dc}} \]  
(22)
Therefore, \( P_{vd} \) in equation (20) is
\[ P_{vd} = \frac{3Rk^2 i_B^2 V_{dc}^2}{2V_d^2} \]  
(23)
In equation (20), the charging power consumption of electric vehicles is composed of two parts, one is \( P_{CP} \) and the other is \( P_{vd} \), that is, \( P = P_{CP} + P_{vd} \). \( P_{CP} \) is obviously a constant part, that is, this part can be seen as a constant power load. \( P_{vd} \) is determined by equation (23) and called exponential load.

3. Simulation and verification of load model of electric vehicle and voltage stability of power grid
The purpose of this paper is to study the impact of electric vehicle load on the power grid voltage. Generally, the index to evaluate the power grid voltage stability is the load margin. Figure 6 shows the PV curve. Assuming that the operating point of the current system is \( P_{L0} \) and the critical point of system voltage collapse is \( P_{cr} \), load margin = \( P_{cr} - P_{L0} \) is the voltage stability load margin of the system [7].

Simulation experiments were carried out on the PSAT software platform, and the standard IEEE 14-node test system was adopted. It was assumed that one EV charging station was connected to the load node 14 of the standard IEEE 14-node, and the PV curve of the system was determined by the continuous power flow method (CPF).

The first simulation experiment is mainly aimed at analyzing the influence of rectifier converter Rs and Rs on the voltage stability of the power grid. The load model of electric vehicles is shown in table 1. Assume that the power factor of charging load is 0.95, and the simulation results are shown in
The lower the load margin is, the higher the impact is on the voltage stability of the power grid. It can be seen from figure 7 that the larger Rs and Rl are, the higher the impact is on the voltage stability of the power grid.

| resistance | α | b | The load model |
|------------|---|---|----------------|
| RL=0.1mΩ, RS=mΩ | 0.0036 | 2.764 | 0.9964 | LM1 |
| RL=0.1mΩ, RS=mΩ | 0.116 | 1.777 | 0.9884 | LM2 |
| RL=0.1mΩ, RS=mΩ | 0.144 | 1.306 | 0.9856 | LM3 |
| RL=0.1mΩ, RS=mΩ | 0.0246 | 1.842 | 0.9754 | LM4 |
| RL=0.1mΩ, RS=mΩ | 0.0174 | 1.172 | 0.9826 | LM5 |
| RL=0.1mΩ, RS=mΩ | 0.0244 | 2.179 | 0.9756 | LM6 |

The purpose of the second simulation experiment is to compare the influence of the load models Exp.1, Exp.2 and Exp.3 of electric vehicles established in this paper and the conventional P, I and Z load models on the voltage stability of the power grid. The configuration of EV load Exp.1, Exp.2 and Exp.3 parameters is shown in table 2. The simulation results are shown in figure 8. It can be seen from figure 8 that the load model of electric vehicles established in this paper has a higher impact on the static voltage stability of the system than the conventional load model of constant power, current and impedance.

| Lead resistance(R) | a | α | b | The name of the load |
|-------------------|---|---|---|---------------------|
| 0.01Ω             | 0.0463 | -2.324 | 0.9537 | Exp.1               |
| 0.02Ω             | 0.0721 | -3.101 | 0.9279 | Exp.2               |
| 0.03Ω             | 0.073 | -5.228 | 0.927 | Exp.3               |

The third simulation experiment aims to analyze the influence of power factor of electric vehicle load on voltage stability of power grid. In the experiment, the power factor was set at 0.95 and 0.98. It can be seen from figure 9 that compared with the load model of constant power, constant current and constant impedance, the power factor has a higher impact on the load model of electric vehicle established in this paper to the static voltage stability of the system.
4. Conclusion
In order to analyze the influence of electric vehicle load on the voltage stability of power grid, a static load model of electric vehicle load is established. An EV load consists of a battery and a charging unit. The EV charging load model can be replaced by a combination of constant power load and negative exponential load. The simulation results show that the accuracy of the load model is very important to the voltage stability analysis of the power grid. The load model of EV established in this paper has lower load margin and higher impact on the stability of static voltage than the conventional load model of constant power, current and impedance.

Acknowledgments
This paper is funded by the project of "16DZ2292700 Shanghai wind power equipment product certification and testing professional technical service platform" of Shanghai science and technology committee.

References
[1] Dharmakeerthi, C.H., Mithulananthan, N. Saha, T. K. (2014) Impact of electric vehicle fast charging on power system voltage stability. International Journal of Electrical Power & Energy Systems, 57: 241-249.
[2] Huang, H., Chung, C. Y., Chan, K. W., et al. (2013) Quasi-Monte Carlo based probabilistic small signal stability analysis for power systems with plug-in electric vehicle and wind power integration. IEEE Transactions on Power Systems, 28(3): 3335-3343.
[3] Zhang, C., Chen, C., Sun, J., et al. (2014) Impacts of electric vehicles on the transient voltage stability of distribution network and the study of improvement measures. In: IEEE PES Asia-Pacific Power and Energy Engineering Conference, Vienna. pp. 1–6.
[4] Mingshen, W., Yunfei, M. U., Hongjie, J. I. A., et al. (2015) A preventive control strategy for static voltage stability based on an efficient power plant model of electric vehicles. Journal of Modern Power Systems and Clean Energy, 3(1): 103-113.
[5] Makasa, K. J., Venayagamoorthy, G. K.. (2010) Estimation of voltage stability index in a power system with plug-in electric vehicles. In: Bulk power system dynamics and control Symposium. Brazil. pp. 1–7.
[6] Zhang, Z. G, Huang, Sh. D., Ren, G. F, Chen, J. H., (2006) Study on the control strategy of three-phase voltage SVPWM rectifier. Journal of changsha university, 18(4): 33-36.
[7] Wen, X. H., Yuan, Y., Ju, P., (2008) Comparison of static voltage stability load margin analysis methods. Electric power automation equipment, 28(05):59-62.