Analysis of Grid Loss of Charged Vehicles

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Abstract. Based on the improved equivalent circuit model of GNL, this paper first simulates the charging and discharging process of electric vehicle battery and analyzes the sources of losses. Afterwards, it illustrates the existing kinds of losses of the convertor and presents calculation formula by taking the Boost convertor as an example and putting forward the counting process and conclusion. In the end, it analyzes the power grid loss and proposes the methods to optimize load curve and reduce the losses .Besides, the objective function and constraint condition are listed according to the local charging strategy and the global charging strategy of power grid dispatching.

Introduction

The large scale of electricity vehicles merging into power grid would affect the energy supply, the apparatus capacity, power quality, power grid losses, depend ability, etc. Due to the use of DC charging mode, the harmonic pollution and power losses would be produced in the process of rectification and inversion which is not obvious in small-scale grid power but it's serious in large-scale. In addition, for the peculiarity of electricity vehicles that it can be used as load and can also be used as power supply, when a family uses the electric vehicle battery power to supply the household electricity, the household electricity consumptions would be reduced in peak time and this constitutes a family-vehicle-power grid system. The main problem of that involve the losses of convertor, so it is meaningful to discuss the losses.

The Electric Vehicle Grid-connected Model

The Equivalent Circuit Model of Thevenin Battery. Battery system modeling is currently dominated by three models: the electrochemical model, mathematical model and electrical model. The electrical model which uses voltage source, resistor and capacitor composed circuit to simulate the dynamic character of the battery, and it can also be combined with other system to design and simulate, that's why the electrical model is used here. There are three main types of electrical models: equivalent circuit model, AC impedance model and run time model. Here the equivalent circuit model is selected.

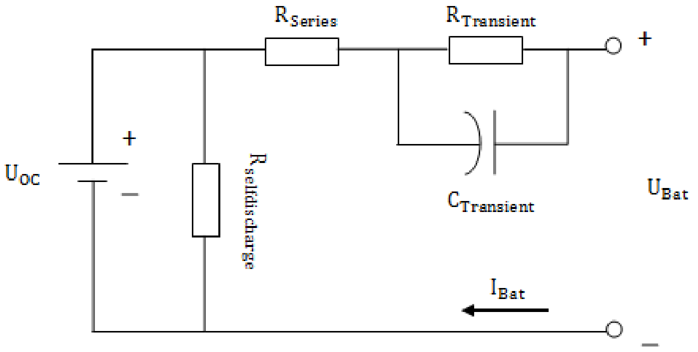

Figure 1. Equivalent Circuit Model

The picture shows that the most representative Thevenin equivalent circuit model which uses ideal voltage source U_{oc} to describe the battery open circuit voltage and predict the response of the battery to the instantaneous load in a certain SOC by a series resistor R_{series} and a RC parallel network consists of $R_{Transient}$ and $C_{Transient}$.

The Improved Equivalent Circuit Model based on GNL. PNVG and GNL can compensate for the defects of the Thevenin model and it can reflect the transient response to battery and steady-state current voltage characteristics which has a good simulation performance. However, the simulation accuracy of the battery capacity and operation time and the nonlinear relationship between open circuit voltage and SOC are limited. In consideration of the battery charging and discharging of electric vehicles, the self-discharge rate of 5% per month can be neglected, so we can use the simplified model and parameters to accurately simulate the performance of the battery. Improved circuit model as the picture shows below.

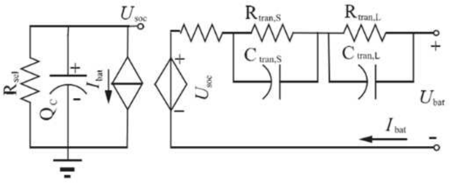

Figure 2. The improved circuit model based on GNL

It can be concluded that the energy loss mainly comes from inductance, capacitance and controlled source.

The Calculation and Analysis of the Losses of Converter

Introduction. A converter's efficiency is determined by many factors, including usage of the components, switching frequency and so on. The losses of converter contains conduction loss, blocking loss, and switching loss. Under these circumstances, the converter is a Bidirectional DC to DC Converter, an Unidirectional DC to DC Converter, or an Inverter. Conduction loss and switching loss should be calculated separately in all losses and then be collected together with others as the total losses. Efficiency is measured as the following equation.

$$\eta = \frac{\mathrm{Input}_{\mathrm{Power}} - \Sigma\left(\mathrm{Losses}\right)}{\mathrm{Input}_{\mathrm{Power}}} \tag{1}$$

(1) IGBT loss. IGBT losses are divided into two categories: conduction loss and switching losses.

The conduction loss is determined by the IGBT equivalent diagram: a voltage source connected in series with a resistor. The formula for calculating the conduction loss $P_{conduction}$ is given by:

$$P_{conduction} = F_{SW} \bullet \int_0^{\frac{1}{F_{SW}}} \left(V_s + R_{on} \cdot I_c\right) \cdot I_c \cdot dt \tag{2}$$

Where V_s is the forward voltage drop (V), R_{on} is the on-state resistance (Ω), I_c is the collector current (A), and F_{SW} is the switching frequency (Hz).

(2) Inductance Losses. The copper loss in the inductance is included:

$$P_{induc} = R_L \left(I^2 + \frac{\Delta I^2}{12} \right) \tag{3}$$

R_L is equivalent cascade inductive resistance; I is the current that go through the inductor; and ΔI is ripple current.3)

(3) Diode Losses. Diode conduction losses can be calculated by the following equation:

$$P_D = R_D \cdot I_{on}^2 + V_D \cdot I_{on} \tag{4}$$

In this equation, P_D is the conduction losses of the diode (W); I_{on} is diode current (A); $R_D$is diode resistance (Ω); V_D is diode voltage (V).

Losses in Boost PFC Converting Circuit. Boost converting circuit is a single non-isolated dc converter whose output voltage is equal to or higher than input voltage. The main circuit mainly composed by the switch, rectifier diodes, filter inductor and output filter capacitor. It differs from the Boost chopper circuit simply in the different control method. However, the working process is basically the same. Typically, switching losses in Boost PFC circuits include fast rectifier diode losses, switching losses and inductor losses. But other spurious losses are also included. Among these factors, rectifier diodes and switch losses influence most on the machine's performance and reliability.

The Loss of the Rectifier Diode is Mainly Composed by Three Parts. One is the opening lossP_{Don}, one is the on-state lossP_{Dcon}, and another is the turn-off lossP_{Doff}.

(1)Open loss. If t_{fr} is the forward voltage recovery time of the diode, V_{FR} is the maximum voltage of the forward reverse of the diode, V_F is the typical value of the diode drop, I_F is the forward current of the diode, I_{RM} is the maximum value of the diode reverse recovery current, t_{rr} is the recovery time of reverse, then during this period, the opening loss P_{Don} can be expressed as:

$$P_{Don} = \frac{1}{2} f_c I_F \left(V_{FR} - V_F \right) t_{fr} \tag{5}$$

Where f_c is the switching frequency.

(2)On-state Loss. The general on-state loss can be calculated from the product of the forward conduction voltage drop V_F and the forward current I_F of the ballast diode. When the resistance of the diode isR_D, the on-state loss P_{Dcon} is:

$$P_{Dcon} = V_F I_{Dav} + R_D I_{Drm}^2 \tag{6}$$

Where I_{Dav} is the average diode current value and I_{Drm} is the effective value of the diode current.

(3)Turn off Loss. In fact, the turn-off loss P_{Doff} is mainly caused by the reverse recovery current of the diode. It can be approximated as:

$$P_{Doff} = \frac{1}{4} f_c I_{Drm} K_F V_F t_{rr} \tag{7}$$

Where K_F is the temperature coefficient of the diode reverse recovery current.

In summary, the total switching loss of the rectifier diode is

$$P_D = P_{Don} + P_{Dcon} + P_{Doff} \tag{8}$$

Loss of Switch Tube. Similar to the rectifier diode, the loss of the switch is also caused by the opening loss P_{Qon}, on-state loss P_{Qcon}, and turn-off loss P_{Qoff}.

(1)Open Loss:

$$P_{Qon} = \frac{2}{3} f_c C_{OSS} U_O^2 + P_{VDoff} = \frac{2}{3} f_c C_{OSS} U_O^2 + \frac{1}{4} f_c I_{VDrms} K_f V_R t_{fr} \tag{9}$$

(2)On-State Loss:

$$P_{Qcon} = I_{VQrms}^2 R_{VQ} \tag{10}$$

(3)Turn off Loss:

$$P_{Qoff} = \frac{1}{2} f_c U_O I_L t_{fr} \tag{11}$$

Therefore, the total loss of the switch is $P_0 = P_{Qon} + P_{Qcon} + P_{Qoff}$

Where f_c is the switching frequency, C_{OSS} is the output capacitance of the switch, I_{Drms} is the SR current rms, K_f is the temperature coefficient of the SR reverse recovery current, V_R is the output voltage, t_{fr} is the rise time of SR, I_{Qrms} is Q Of the effective value of the current, R_Q is the on-resistance at a given temperature by Q,and I_L is the inductor current whose value is I_{in}.

The Energy Loss of Inductance. The energy loss mainly consists of copper loss、magnetic hysteresis loss and eddy-current loss. The expressions are showed below:

Copper loss : $$P_{Cu} = I_{2L} R_{Cu} \quad (12)$$

Magnetic hysteresis loss : $$P_n = K_h f_c B_m^{1.6} \quad (13)$$

Eddy-current loss : $$P_V = \frac{1}{6\rho} \pi^2 d^2 B_W^2 f^2 \quad (14)$$

K_h is a proportionality coefficient, B_m is peakflux density, ρ stands for specific resistance stands for density of the object, B_w is working magnetic flux density.

2.2.4 The analysis of decreasing the loss of BOOST PFC convertor.

(1)the main loss of BOOST PFC convertor is switching loss and inductor loss. Therefore, in the process of designing a convertor, we are supposed to choose a power switch tube, which has an advantage of fast turn-off speed.

(2) turn-off loss of rectifier diode occupies a large part of the total losses.

(3)In order to enhance efficiency, firstly, we ought to decrease the reverse recovery current. Moreover, ZVT-PVC, which owns subsidiary loop, or saturable inductor need to be used.

3.The analysis of transmission losses

Because of the electric cars large-scale merge into the power grid, the losses brought to power grid are assignable. Thus, we are able to reduce transmission losses via generating strategy of charging cars.

3.1 The significance of Smooth load curve to lower transmission losses

As is illustrated in works cited, we can draw a conclusion that: the smaller variation is, the more smooth the load curve is. And the total losses get closer to the minimum losses of constant load.

3.2charging strategy of electric cars

3.2.1 Local Charge Strategy

Local charge strategy is a way, which has the independent control on the electric vehicle charge of every family. Considering that it doesn't take other family into account, the result is only local optimum, not global optimum.

Firstly, according to Home base load value, we found constant base load value $L_{O,1,b}^i$, which has the equal electric quantity with the former in time frame [a, b], then we solved Constant charging load$L_{O,c}^i$, which is corresponding to the electric car charging load. Adding these we can get to Family constant load gross$L_{O,l}^i$.In order to make actual load curve closer to constant total load curve, we listed objective function and constraint condition below, and determine charging power $f_c^i(t)$ finally.

Objective function:

$$\min g = \int_a^b \left(f_l^i(t) - L_{o,l}^i\right)^2 dt = \int_a^b \left(f_{l,b}^i(t) + f_c^i(t) - L_{o,l}^i\right)^2 dt \quad (15)$$

Constraint condition:

$$\begin{cases} f_l^i(t) \le L_{max}^i \\ C_a^i + \int_a^b f_c^i(t)\,dt = C_b^i \end{cases} \quad (16)$$

3.2.2 Global Charge Strategy

Global is a charge strategy that is used to control and coordinate electric cars charging process of all family users in a residential area. Differing from Local Charge Strategy, Global Charge Strategy aims at exchanging information for all family users in an area and thus gain the global load. For this load will vary with electric cars join up and drop out, this load can get to the optimal result.

Simulating to Local Charge Strategy, Firstly we solved out constant base load value $L^{i}_{O,g,b}$, which has the same electric quantity with the base load value in time frame [a,b].Then we solved constant base load value$L^{i}_{O,c}$,which is corresponding to The electric car charging load. Adding these we can get to Family constant load gross $L^{i}_{O,l}$.In order to make actual load curve closer to constant total load curve, we listed objective function and constraint condition below, and determine charging power $f^{i}_{g}(t)$ finally.

Objective function:

$$\min g=\int_{a}^{b}\left(f_{g}^{i}(t)-L_{o,g}^{i}\right)^{2}dt=\int_{a}^{b}\left(f_{g,b}^{i}(t)+f_{c}^{i}(t)-L_{o,g}^{i}\right)^{2}dt \tag{17}$$

Constraint condition:

$$\begin{cases} f_{l,b}^{i}(t)+f_{c}^{i}(t)\le L_{max}^{i} \\ C_{a}+\int_{a}^{b}f_{c}^{i}(t)\,dt=C_{b} \end{cases} \tag{18}$$

Conclusion

This paper aims at decreasing charging loss, based on charging and recharging model, dividing total loss into two parts: converter loss and power grid loss. About converter loss, firstly introduce possible source of loss, and then take one typical conversion circuit as an example, offering a proposal to decrease loss; about power grid loss, we firstly introduce measures to decrease power grid loss and prove its rationality. After that, we propose two schemes, which is used for comprehensive use of charging strategies. Those two strategies are used for decreasing power grid loss.

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