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Research On Intermittent Charging Effect In Electric Vehicle Energy Metering

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Abstract

With the rapid development of electric vehicles, the DC charging energy metering problems received much attention. New charging methods have been developed and the traditional metering method is not suitable. This paper analyzes the pulse intermittent charging method and variable voltage intermittent charging method for fast charging. The effective value method and time domain integral method are compared. The error formula and its influencing factors are analyzed. It indicates that the effective value method is inappropriate for intermittent charging.

Keywords: **electric energy metering; pulse charging; voltage intermittent charging; effective value method; time-domain integral method.**

1. Introduction

Nowadays, we are facing more and more serious air pollution problems. The motor vehicle exhaust is the main source, as well as an important reason for causing haze. In order to reduce carbon emissions and solve the environment pollution, electric vehicles have been developed rapidly and accompanied by with lots of charging stations. A variety of direct current charging methods have been developed and the related electric energy measurement problems are put forward.

In general, there are two types charging modes as slow and quick charging. The former utilizes traditional electricity network and charging time is about 5~8 hours. While the latter use high power DC charger, and the charging power is from 50kW to 150kW (for electric bus, the charging power even up to 400kW), the charging time is less than 40 minutes. A very promising method as intermittent charging can achieve depolarization, a higher charge acceptance rate, extend battery life and reduce the charging time. However, such a new method brings new energy measurement problems due to its intermittent characteristics.

For conventional time domain DC power measurement, the electric energy can be calculated by voltage and current effective value or instantaneous power integral. In effective value mode, the effective value of voltage and current are calculated firstly, and then charging power and energy can be obtained. While for integral mode, the voltage and current are sampled synchronously, the instantaneous power can be obtained and then accumulating for energy. When the voltage and current changes slowly, the metering results of these two methods are similar. But in intermittent charging mode, the obvious difference is revealed.

Hence, this paper compared the differences between above two metering methods in intermittent charging. We'll deduce the error formula and analyze the influencing factors, and followed by the metering simulation for intermittent charging.

2. Intermittent charging principles

J.A.MAS proposed the acceptable charging current which based on the lowest gassing rate in 1967. The battery charging current curve is an exponential function (shown in figure.1) with attenuation coefficient α. Its corresponding equation is

$$i = I_0 e^{-\alpha t}$$
(1)

where i is the battery acceptable charging current at any time, and I_0 is the initial maximum acceptable charging current, α is decay rate constants.

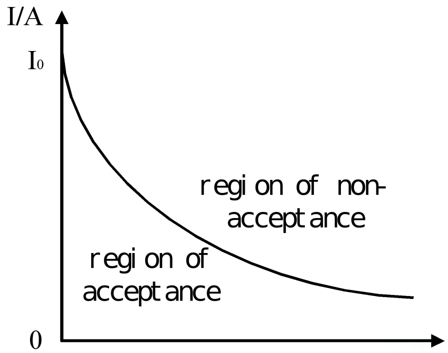

Figure.1 Acceptable charging current curve

In traditional quick charging, the current is raised very high (for example 700A) and the battery water loss inevitably. The pulse charging can depolarize and maintain a higher acceptance rate [1,2]. The main idea is the charging current with pulse form, and the charge energy and time can be controlled by adjusting the pulse amplitude or duty cycle. The charging current is shown in Figure.2. However, this method has the following drawbacks as lower conversion efficiency, the electrode active substance easily falls off which has negative impact on battery life.

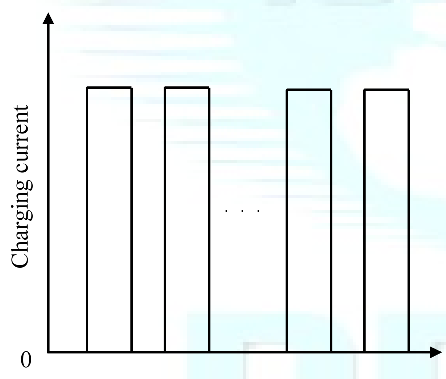

Figure2 Pulse charging method

To solve the above problems, Chen [3,4] proposed a variable current intermittent charging method. Through intermittent stop process, the produced oxygen can be absorbed by battery again. And the concentration polarization and ohmic polarization are eliminated. It doesn't produce a lot of gas and heat, the battery damage is small and can be charged in a shorter time. In addition, Wang [5] then put forward a variable voltage intermittent charging method as shown in Figure.3. It adopts the intermittent charging in the early and then the constant voltage in the later. Therefore, it approximates the battery's best charging curve much better.

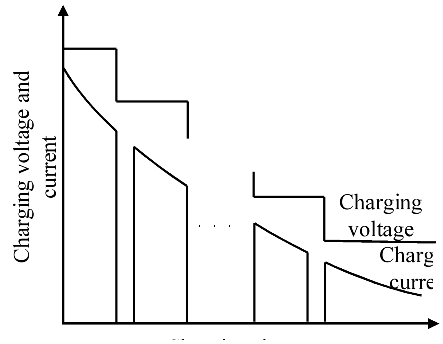

Figure.3 Variable voltage intermittent charging method

3 Metering analysis of pulse and variable voltage intermittent charging

Here, we set up the metering model of pulse charging and variable voltage intermittent charging firstly. And then, the effective value method and time domain integral method are used to calculate electric energy. Finally, the error of effective value method is analyzed with reference value as time domain integral method.

3.1 Metering analysis of pulse charging

In this model, the voltage amplitude is constant as U, the current I, the duty cycle μ, with period T. The electric energy in time interval $t_1=nT$ is calculated by effective value method and integral method correspondingly.

For effective value method, the voltage and current effective value calculation formula

$$U_{\text{rms}} = \sqrt{\frac{1}{T}\int_0^T u^2(t)\,\mathrm{d}t} \quad I_{\text{rms}} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,\mathrm{d}t}$$

(2)

We obtain the effective value as

$$U_{\text{rms}} = U \,,\, I_{\text{rms}} = \sqrt{\mu} I$$

(3)

Thus, the energy is

$$W_{\text{rms}} = \sqrt{\mu} IU * t_1$$

(4)

While for time domain integral method, the electric energy is

$$W_{\text{time}} = \int_0^{t_1} u(t) * i(t)\,\mathrm{d}t = \int_0^{\mu t_1} UI\mathrm{d}t = \mu UI t_1$$

(5)

Finally, the error of effective value method is

$$\varepsilon=\frac{W_{\text{rms}}-W_{\text{time}}}{W_{\text{time}}}=\frac{\sqrt{\mu}-\mu}{\mu}$$

(6)

It can be seen that the electric energy metering error exist in effective value method. The error is only related to the pulse duty cycle and irrelevant to any other factors.

3.2 Metering analysis of variable voltage intermittent charging

Variable voltage intermittent charging is shown in Figure 3, according to the current acceptable charging current curve is decreased exponentially as the attenuation index α, intermittent pulse duty cycle is μ, period is T, the charging current starting time is I, the voltages in every charging cycle are U_1 , U_2 , U_3 , $\cdots U_n$ respectively, calculated power in the period of time $t_1=nT$ by effective value method and time domain integral method.

For the effective value method, assumed the beginning currents of every cycle are I_1 , I_2 , $I_3,\cdots,I_n$, respectively. We've $I_1=I$, $I_2=I*e^{-\alpha T}$, $I_3=I*e^{-2\alpha T}$ and $I_n=I*e^{-(n-1)\alpha T}$. The effective current value in the first charging period is:

$$I_{\text{rms 1}}=\sqrt{\frac{1}{T}\int_0^{\mu T}\left(Ie^{-\alpha t}\right)^2\mathrm{d}t}=I*\sqrt{\frac{1-e^{-2\mu\alpha T}}{2\alpha T}}$$

(7)

Therefore, the power in the period 0 to t_1 is

$$\begin{aligned}W_{\text{rms}}&=\sum_{n=1}^{N}U_n*I_{\text{rms},n}*T\\&=T*\left(U_1I_{\text{rms},1}+U_2I_{\text{rms},2}+\cdots U_nI_{\text{rms},n}\right)\\&=TI*\sqrt{\frac{1-e^{-2\mu\alpha T}}{2\alpha T}}*\left(U_1+U_2e^{-\alpha T}+\cdots U_ne^{-(N-1)\alpha T}\right)\end{aligned}$$

(8)

While for time-domain integral method, the calculate power:

$$\begin{aligned}W_{\text{time}}&=\int_0^{NT}U_n*Ie^{-\alpha t}\mathrm{d}t=W_1+W_2+W_3+\cdots W_n\\&=\int_0^{\mu T}U_1*Ie^{-\alpha t}\mathrm{d}t+\int_T^{(\mu+1)T}U_2*Ie^{-\alpha t}\mathrm{d}t+\\&\quad\int_{2T}^{(\mu+2)T}U_3*Ie^{-\alpha t}\mathrm{d}t+\cdots\int_{(N-1)T}^{(\mu+N-1)T}U_n*Ie^{-\alpha t}\mathrm{d}t\\&=\frac{U_1I}{\alpha}\left(1-e^{-\alpha\mu T}\right)+\frac{U_2I}{\alpha}\left(e^{-\alpha T}-e^{-\alpha(\mu+1)T}\right)+\\&\quad\frac{U_3I}{\alpha}\left(e^{-2\alpha T}-e^{-\alpha(\mu+2)T}\right)+\cdots\frac{U_nI}{\alpha}\left(e^{-\alpha(N-1)T}-e^{-\alpha(\mu+N-1)T}\right)\\&=\frac{I(1-e^{-\alpha\mu T})}{\alpha}*\left(U_1+U_2e^{-\alpha T}+\cdots U_ne^{-(N-1)\alpha T}\right)\end{aligned}\qquad(9)$$

The measurement error for the effective value method is

$$\varepsilon=\frac{W_{\text{rms}}-W_{\text{time}}}{W_{\text{time}}}=\sqrt{\frac{\alpha T\left(1+e^{-\alpha\mu T}\right)}{2\left(1-e^{-\alpha\mu T}\right)}}-1\qquad(10)$$

We can find that for the effective value method, the error is related to the attenuation index α, duty cycle μ and period T.

4 Simulation of electric energy error based on effective value method

4.1 Metering analysis of pulse charging

For pulse charging, the voltage is constant and the amplitude is set 30V. The amplitude of the pulse current signal is 100A, and the duty cycle is 10% to 100%, and the period is 0.02 s, as shown in figure 4. According to the time domain integral method and the effective value method, the error curve is shown in figure 5.

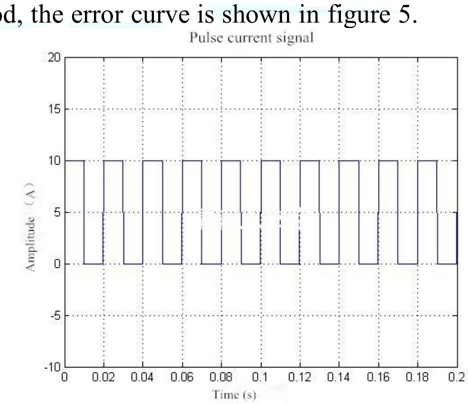

Figure 4 Pulse charging current signal

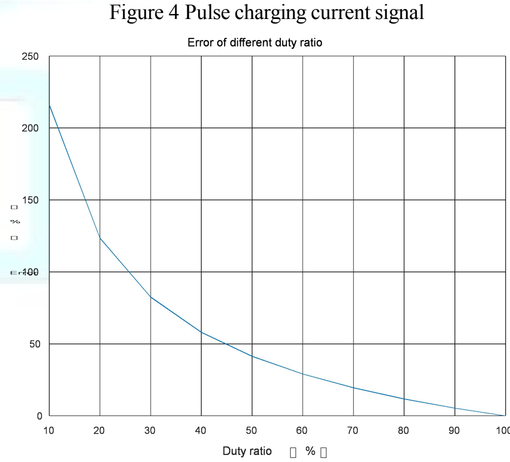

Figure5 Electric energy error of effective value method

As shown in Figure 5, with the increase of duty cycle of the current signal, the error of effective value method is gradually reduced. When the duty cycle is 45%, the calculation error is 50%; when the duty cycle is 25%, the error is even 100%. Therefore, the effective value method isn't suitable for pulse charging.

4.2 Metering analysis of variable voltage intermittent charging

For variable voltage intermittent charging, the voltage is constant and set the amplitude 30V. The initial amplitude of intermittent pulse current signal is 100A. The current has an exponentially decay. The duty cycle and period are set from 10% ~ 100%, and 1 ~ 10s, correspondingly. The attenuation index is 0.1 ~ 1 as shown in figure 6. The effective value method error is shown in Figure 7.

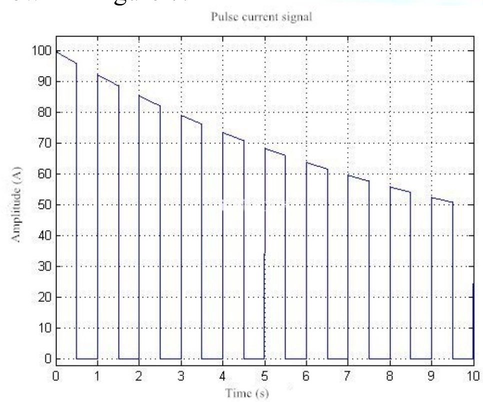

Figure 6 Variable voltage intermittent charging current signal

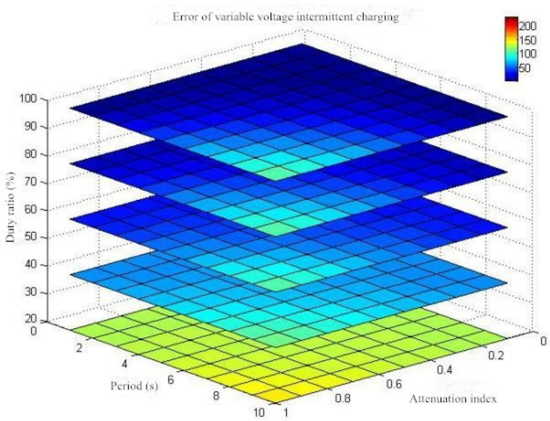

Figure 7 Electric energy error of effective value method

We can find from Figure 7 that, when the other two factors are fixed, the smaller duty cycle means the greater error, the bigger attenuation means the greater error and the longer period means the greater error. The maximum error even exceeds 200% in above settings. Therefore, the effective value method is also inappropriate for variable voltage intermittent charging.

5 Conclusions

For new type of charge methods as pulse charging and variable voltage intermittent charging, this paper adopted the effective value method and time domain integral method respectively for electric energy metering. The error formula has been deduced and its influencing factors are considered. The duty cycle, attenuation coefficient and periodic can affect the metering error. The effective value method isn't suitable for pulse charging and variable voltage intermittent charging. The maximum error even exceeds 200%. Therefore, the traditional effective value method is not applicable to the electric car intermittent charge measurement.

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