Analysis of Electric Vehicle DC High Current Conversion Technology

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Abstract. Based on the background of electric vehicles, it is elaborated the necessity about electric energy accurate metering of electric vehicle power batteries, and it is analyzed about the charging and discharging characteristics of power batteries. It is needed a DC large current converter to realize accurate calibration of power batteries electric energy metering. Several kinds of measuring methods are analyzed based on shunts and magnetic induction principle in detail. It is put forward power batteries charge and discharge calibration system principle, and it is simulated and analyzed ripple waves containing rate and harmonic waves containing rate of power batteries AC side and DC side. It is put forward suitable DC large current measurement methods of power batteries by comparing different measurement principles and it is looked forward the DC large current measurement techniques.

1. Introduction
China's oil, coal and other energy consumption are increasing year by year with the development of economy. Furthermore, air pollution of fog and haze is becoming more and more serious and it is mainly caused by vehicles’ exhausted gas. So China's 12th Five-Year plan is to develop new energy vehicles, and the number of new energy vehicles will reach 5 million by 2020. New energy vehicles are dominated by electric vehicles, and electric vehicle power source is power batteries mounted on the vehicle. The power batteries can provide electric vehicles’ driving motor with electric energy. On the one hand, the charging electric energy accurate metering of electric vehicle power batteries is relate to the electric vehicle owners interests, on the other hand the batteries’ remaining power accurately indication can provide a mileage for the driver and residual electric quantity information. So it is necessary for electric vehicle power batteries accurate metering.

During the process of the power batteries charging, the charging voltage and current are constantly changing, and there has a wide range of voltage and current variation. In addition, power batteries charging belong to nonlinear load and the charging current is bidirectional pulse signal. In the charging process of the charger, the charger’s DC side contains ripple waves and harmonic waves. There are fast and slow charge ways of power batteries charging. Slow charge generally uses small current constant voltage or constant current in charging. Slow charge current is about 15A, and the charging time is 5 hours to 8 hours. Fast charge uses high current charging. Fast charge current can reach 150A~600A, and the charging time is 20 minutes to 2 hours. The national standard also specifies that reference current of the electric energy metering device is from 10A~500A between charger DC output terminal and the batteries interface[1]. There are constant current charging, constant voltage charging and stage charging. The constant voltage charging current gradually reduces with gradually increasing of the batteries terminal voltage, and when current is less than a certain
value, the charging process is end. The constant voltage charging process is closer to the best charging curve. Stage charging is methods combined with constant current and constant voltage.

The discharge voltage and discharge current of power batteries mounted on the vehicle also change. Seen from the car's electricity indicator, start, acceleration, deceleration, braking and the change number of passengers of vehicles will directly cause discharge current change of batteries. It has been reported that the instantaneous discharge current peak value of the electric bus can reach 400A during the period of the Olympic Games[2]. The discharge current of power batteries become smaller when the vehicle is downhill. Therefore, the range of discharge current is relatively wide, and the current ripple and shock load are also accompanied by the discharge process of power batteries.

The charge and discharge of electric vehicle power batteries have some characteristics of high voltage, high current, wide dynamic range and containing ripple waves and harmonic waves. The following points need to be considered about power batteries electric energy metering accurate calibration. Firstly, measurement ranges of voltage and current are widely. Secondly, the conversion distortion degree of DC high current converter is small. As the power batteries charging DC side contains ripple waves, the sampling signal is required to linear proportion to the original high current signal containing interference signals. It can ensure that small amplitude ripple current is measured without distortion. Thirdly, the conversion time of the DC high current converter is short in order to ensure calibration synchronization of the voltage and current. Fourthly, the charging DC side of power batteries contains high order harmonic waves and the sampling frequency should reach about 10 times measuring frequency of ripple or harmonic waves. So selecting a suitable measuring equipment of DC high current can ensure the electric power accurate calibration of the power batteries.

2. DC high current measurement methods

The direct measurement of DC high current is very dangerous, and it is better to measure indirectly by various methods. The principles of the DC high current conversion are divided into two categories. One category is shunts measurement methods and DC high current value is obtained by measuring added a resistance’s voltage. The other category is the magnetic induction measurement methods. According to the magnetic field established by the measured current, the DC high current value is obtained by measuring magnetic potential, magnetic flux or magnetic induction strength.

3. DC high current measurement principle

3.1. Shunts measurement methods

Shunts measurement methods for DC high current measurement are divided into built-in shunts resistance and external shunts resistance. The built-in shunts resistance method is to expand the ammeter measuring range by parallel with a resistor $R$ in the ammeter. The disadvantage of this method is that internal resistance is smaller for the large range ammeter. When the DC high current flows through the ammeter, ammeter will heat, and the DC high current measurement needs thick wires to connect to the ammeter. The external shunts resistance method is that a resistance $R$ is connected in series with the current loop. When the current flows through the resistor, two ends of the resistance will generate a voltage drop. The voltage value $V$ is measured by voltmeter and the current value $I$ is obtained in current loop by the ohm's law $I=V/R[3]$.

3.2. Magnetic induction measurement methods

The measurement principles of magnetic potential, magnetic flux or magnetic induction strength are to use the electromagnetic induction principle of a secondary winding to a primary winding and convert the large current to the small current.

3.2.1. Magnetic potential modulation principle. The DC current transformer is composed of a primary winding, a secondary winding and an iron core. This principle is to change the iron core choke coil inductance by the measured DC, and the change of choke coil inductance can make AC current
changes of winding. The magnitude of the primary DC current determines the magnitude of the secondary AC and the saturation degree of the iron core. There are two core coils around the iron core. The coil $N_1$ is connected with a DC constant current source $I_1$, and the coil $N_2$ is connected with an AC voltage source $u~$ by a resistance $R$ [4]. Working principle is shown in figure 1. The relationship between the magnetic field intensity $H$ and the magnetic induction intensity $B$ is shown in the magnetization curve figure 2.

**Figure 1. Electromagnetic DC current transformer principle**

Iron core closed magnetization curves are simplified as ideal rectangular magnetization curves. The horizontal axis is exciting current, and the vertical axis is magnetic flux inside an iron core. $\phi \propto B$, and $H=\omega i$. Ideal magnetization curves of $\phi$ and $i$ are shown in figure 3. According to the AC power cycle change of the secondary coil, the change of flux and load current in the coil is analyzed, as shown in figure 4, and the analysis steps are as follows.

**Figure 2. Closed magnetization curve of ferromagnetic material**

**Figure 3. Ideal magnetization curve of iron core**

1. When $t<0$, the DC power supply is closed in the core primary winding, and the coil flux $\phi_m$ is constant inside the iron core.

2. When $t=0$, the AC power $u~$ begins to work. The current $i~$ of Load $R$ equals to 0. The work point of iron core is in the saturation point 1. The magnetic flux is $\phi_m$. The secondary magnetic permeability $u$ tends to zero. $u=\Delta B/\Delta H$. The inductance $L$ and the magnetic permeability $u$ have a relationship, and $L \propto u$. The inductance is basically zero.

3. During $0<t<t_1$, the load current $i~$ increases with the increasing of the AC potential, and $i~=U_0 \sin \omega t/R$. In the core magnetic flux generated by the constant DC source and AC source gradually reduces, and the working point moves from point 1 to point 2.

4. During $t_1<t<t_2$, the load current continues to increase with AC $i~$, and the core flux gradually decreases. The working point suddenly changes from point 2 to point 3. As the magnetic flux not changing suddenly, $i~$ is not greater than $I~$ immediately, but to maintain the constant current value $I~$.

5. During $t_2<t<t_3$, the load current is changed from positive to negative with the AC voltage source. The coil flux gradually is greater than zero, and the working point is from 3 to 2. As the flux cannot sudden change and the load current maintains value $I~$. The working point is back to 2. In the process of the working point moving from point 2 to point 3 $\Delta \phi=0$, and at this time current jumps from $I~$ to $i~$. The working point jumps from point 2 to point 4 of the iron saturation section.

6. During $t_3<t<T$, core saturates and the current $i~$ is resistance current of AC potential. When $t=T$, the AC current goes back to the initial state of $t=0$, and the core flux equals to $\phi_m$. 

![Diagram](image-url)
It can be seen that the load current is DC from $t_1<t_2$ section, and the value is $I_1$. Using two such transformers, you can get the whole cycle DC. According to the electromagnetic current transformer principle, two identical closed iron cores are respectively wound with a primary winding and a secondary winding. The primary winding is connected in series with the measured circuit and the secondary winding is connected to the auxiliary AC circuit. The DC current can be obtained in the whole period. This connection mode may be secondary winding series DC mutual inductor.

3.2.2. Magnetic flux balance principle. Zero flux current transformers are based on flux balance, and use detecting winding dynamic to detect magnetic flux in the core. The signal is through the electronic circuit to the compensation winding, and the compensation winding’s compensation makes primary winding ampere turns ratio equal to secondary winding ampere turns ratio of the excitation current in the core. Zero flux current transformers have a primary winding $N_1$, a secondary winding $N_2$, a detecting winding $N_0$, a compensation winding $N_3$ and an electronic circuit, as shown in figure 5.

![Figure 5. Zero flux current transformer principle](image)

$I_3=0$ and $I_1N_1+I_2N_2=I_0N_0$ without compensation current. When adding electronic circuit compensation, magnetic potential balance equation is: $I_1N_1+I_2N_2+I_3N_3=I_0N_0$ in the core. $I_0$ is magnetizing current in the iron core, and $I_0'$ is magnetizing current after adding compensation. $I_2'$ is the secondary current after adding compensation. $I_3$ is current that is regulated by induced potential through electronic circuit of detecting winding, and $I_3$ have linear relationship with the magnetizing current in the core. By adjusting the electronic circuitry, $I_1N_1=I_0N_1$, and at this time, $I_1N_1+I_2N_2=0$.

Zero flux current sensors are composed of $N_1$ and $N_2$, and the magnetic flux is near zero flux state[5]. DC current comparators include magnetic modulator DC comparators, magnetic amplifier DC comparators and Holzer DC comparators etc. The magnetic modulator DC comparators are based on an electromagnetic balance principle. According to the nonlinear relationship of $B-H$ in the soft magnetic core, the alternating magnetic flux of the iron core can generate high order harmonic waves when the AC modulation excitation is added in the core. When there is no DC or low frequency bias magnetic field in the iron core, the $B-H$ curves are symmetrical. Only the odd harmonics are in the alternating magnetic flux. When the DC or the low frequency offset magnetic field is added to the iron core, the symmetry of the $B-H$ curves are damaged. Even harmonic waves are generated in alternating magnetic flux, and the even harmonic amplitudes and phases reflect the magnitude and direction of the bias magnetic field. The DC bias signal is measured by using the principle, and the magnetic modulator DC current comparator principle is shown in figure 6.
By adjusting the excitation source signal level or power amplifier intensity, excitation pulse signal passes through power amplifier to transformer \(T_1\). When the DC \(I_0=0\), \(W_e\) outputs symmetrical odd harmonics. Detector output is zero. When the DC \(I_0\neq 0\), detector \(W_e\) outputs even harmonics. The signal passes through detector and power amplifier \(A\), then injects current \(I_s\) in opposite direction in the secondary winding \(W_s\). DC Ampere turns of magnetic core \(T_2\) turn balance. Detecting winding \(W_e\) complete the detection of zero magnetic field through the negative feedback controlling the magnetic core \(T_2\) balance. At this time \(I_0W_0=I_sW_s\), so as to get the output current \(I_s\) [6].

4. DC high current measurement technology of vehicle mounted power batteries calibration system

4.1. Vehicle mounted power batteries calibration system

The power batteries charging and discharge of electric vehicles have a wide measurement range, and the charge and discharge contain ripple waves and harmonic waves. The electric energy calibration of electric vehicle power batteries is simulated in lab, and the calibration system principle is shown in figure 7. Charge process and discharge process of batteries are simulated by a voltage source and a current source. The national standard specifies output the maximum and the minimum current ranges of a DC charger and specifies the output current period and the random deviation not greater than a value of actual current peak to peak 10%. So the batteries charging waveforms are relatively stable[7]. The discharge of power batteries is simulated by a voltage source and a current source, and the discharge waves include fluctuating signals.

The voltage source and the DC small current signal after converted by DC high current converter are both connected to an acquisition card. The voltage source and the current source are input to a device of vehicle mounted power batteries electric energy metering, and the power signal of the device is connected to the acquisition card. Data of the acquisition card is transmitted to the computer (PC), and electric energy value is calculated out by considering the impact of ripple, harmonic and other factors. The electric energy value calculated by computer is compared with another electric energy value output from the power batteries electric energy metering device.

4.2. AC side and DC side signal’s analysis of charging rectifier for electric vehicle power battery
Power batteries charging use three-phase 6-pulsating rectifier to complete AC to DC conversion, as shown in figure 8. Thyristors of 6 bridge arms are triggered to turn on in sequence by trigger signal of equal interval 60° during normal running, such as 1 to 6, 1 and 2 turn on→1, 2 and 3 turn on→2 and 3 turn on→2, 3 and 4 turn on……→1 and 2 turn on, and Loop turn on. When the two bridge arms are turned on at the same time, rectifier voltage $u_i$ equals to the AC side line voltage. When three bridge arms are turned, two-phase short faulty of the AC system and commutation is realized. At this time, the rectified voltage $u_i$ change into the half of the two line voltages sum.

![Figure 8. Three-phase 6-pulsating bridge rectifier principle](image)

Hypothesis: ① The commutation voltage provided by rectifier AC side is the three-phase symmetrical positive sequence fundamental voltage and it does not contain any harmonic component. ② The rectifier has a three-phase symmetrical structure, and each phase parameter is the same; ③ The DC side inductance is infinite, and the AC side reactance is zero; ④ The commutation process and the current fluctuation are neglected. The model is under the above assumptions, and the time-domain and the frequency-domain signals of AC side current and DC side voltage of the rectifier are simulated as shown in figure 9~ figure 14.

![Figure 9. Rectifier AC side current time domain waveform](image)

![Figure 10. Rectifier AC side current harmonic waveform containing rate](image)

![Figure 11. Rectifier DC side voltage time domain waveform](image)

![Figure 12. Rectifier DC side voltage ripple wave containing rate](image)
The simulation results show that the current of the rectifier AC side in the time domain is a section of trapezoidal wave, as shown in figure 9. Rectifier AC side current harmonic wave containing rate is analyzed in the frequency domain and harmonic waves frequencies in 250Hz are the most, as shown in figure 10. When the rectifier AC side contains harmonic waves and DC side time domain wave transformed by the rectifier is nearly sine wave, as shown in figure 11 and figure 13. The rectifier DC side voltage is analyzed in the frequency domain, and the ripple waves of the 300Hz are the most as shown in figure 12. The current harmonic is the most at 300Hz, as shown in figure 14.

It can be seen that the rectifier can produce high order harmonics at AC side and DC side. Rectifier is a harmonic current source for AC side, and rectifier is a harmonic voltage source for DC side. The DC current harmonic containing rate is rather low at DC side. Under the ideal work condition, 6-pulsating rectifier ripple waves frequencies are in 300Hz, 600Hz, 900Hz, 1.2 kHz, 1.5 kHz, 1.8 kHz, 2.1 kHz and 2.4 kHz, and the ripple frequency containing rate is rather low above 2.4 kHz. The harmonic wave times of 6-pulsating rectifier at DC side is 6 times (300Hz), 12 times (600Hz), 18 times (900Hz), 24 times (1.2 kHz) and so on, and more than 24 times harmonic content depressing obviously. In order to ensure the DC power metering accuracy in the charging process, sampling rate should consider the DC side harmonic below 24 times. The sampling rate of the metering standard device is about 10 times ripple or harmonic waves measurement frequency.

4.3. Measurement principle selection of DC high current converter for power batteries calibration
Charging and discharge of power batteries have characteristics of high voltages, large currents, and wide measurement ranges, especially containing ripple waves and harmonic waves at power batteries charging DC side. Thus electric power calibration system of power batteries needs a DC high current converter of high stability, small temperature coefficient and good frequency response.

Shunts measurement generally needs not the auxiliary power supply and it has anti electromagnetic interference characteristics. Shunts can measure DC current and AC current, and the DC current measurement range is from several tens of mA to several tens of kA above. Of course, there are also disadvantages. When we measure DC high current by shunts, section, volume and power consumption of shunts are larger. Therefore, it is necessary to consider self heating influence on the measurement accuracy. The metal material shunts may be selected and this shunts resistance values have little change with the temperature increase.

DC transformers based on magnetic potential, magnetic flux or magnetic induction strength are called electromagnetic transformers. Electromagnetic transformers have simple structure, low failure rate, small size, small power consumption, low cost, good temperature characteristic, good stability of time, good ability to resist the stray magnetic field, electrical isolation effect and greater load ability compared with shunts. In particular, zero flux current transformers can maintain the measurement accuracy in the measurement range of mA to kA level with high stability, signal-to-noise ratio, fast response time and good dynamic performance. But zero flux current transformers have complex insulation structure, high insulation cost and poor anti electromagnetic interference ability. Zero flux current transformers are suitable to measure DC current on HVDC transmission system converter station neutral line. The electromagnetic transformer generally has a relatively larger secondary
current ripple and poor linear degree. It is need to pay special attention to amperure turn balance and imbalance for measurement accuracy influence, and it is suitable for industrial measurement.

In addition, there is a Faraday magneto optic effect measurement, and the principle is polarization plane deflection of lights when the lights penetrate an optical device. The optical current sensors of this principle have good the insulating performance, good anti-interference ability, low power consumption, light weight, small size, wide measurement frequency band and wide dynamic range. It is widely used in strong electromagnetic field environment of the electric power system intelligent substation and the DC transmission project. It realizes complete isolation of high pressure and low pressure by the optical signal for measuring DC high current. But high precision optical devices are very sensitive to the temperature, vibration and other environmental factors, and the measurement accuracy is affected by environment changes. According to standard of GB/T 29318-2012 electric energy metering for electric vehicle off-board charger, the minimum current of electric vehicle power batteries is 0.01I₀≈0.1A. Therefore it is necessary for measurement to overcome sensitive to environmental changes and ensure the measurement accuracy of small current.

In the Holzer effect measurements, closed loop Holzer current sensors have the high accuracy, good linearity and small temperature drift, and DC, AC or pulse current can be measured at the same time. Current measurement ranges are very wide and measure current ranges are from 1mA to 50kA. But cost and the power consumption are high and the volume is large. It is necessary to select the Holzer current sensor of different principles according to the Holzer device different performance indexes, and Holzer device requirements are more strictly, too. Therefore, the measurement accuracy of the Holzer current sensor is greatly restricted by the Holzer components itself.

Various DC high current measurement methods have some limitations. No matter which methods you choose, it needs to overcome the defects of the methods itself. In addition to the self heating problem, it is obvious advantages to measure by shunts for DC high current measurement of electric vehicles power batteries. In addition, DC current transformer measurement may be considered.

5. Conclusion

Power batteries charging interference comes from power grid fluctuation and harmonic interference. During the process of batteries discharge, batteries interference comes from the interior electric motor and drive system of vehicle. Vehicle vibration brings element loose and interface signal interference issues, and these will affect electric power accuracy calibration. At present giant magneto resistance effect sensor has the small size, high sensitivity, strong anti-interference ability, wide linear range, good temperature stability, good static and dynamic performance, broad application prospects but not mature technology. Sensors of Faraday magneto optic effect principle have better anti-interference ability, and will have better development. With the continuous development of new technology and materials, the small volume, large dynamic range, strong anti-interference ability, higher accuracy and more stable DC high current converters will be developed, and they will directly improve the electric vehicle DC electric energy metering calibration level.

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