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Research and Construction of DC Energy Measurement Traceability Technology

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Abstract. With the implementation of energy saving and emission reduction policies, DC energy metering has been widely used in many fields. In view of the lack of a DC energy measurementtraceability system, in combination with the process of downward measurement transfer in relation to the DC charger-based field calibration technology and DC energy meter and shunt calibration technologies, the paper proposed DC fast charging,high DC, small DC voltage output and measuring technologies,and built a time-based plan by converting high DC voltage into low voltage and high current into low current and then into low voltage, leaving DC energy traceable to national standards in terms of voltage, current and time and thus filling in the gap in DC energy measurement traceability.

1. Introduction

With the launch and implementation of national energy saving and emission reduction policies in relation to distributed power supply and electric vehicles, the DC energy metering technology will become an inevitable trend, breaking the landscape dominated by AC in the field of electric energy metering. According to the plan of constructing electric vehicle charging facilities, in Hunan province, when the total annual charging demand is about 1.5 billion KW until 2020, given that electric energy metering results in 1% deviation as a whole, users or power companies will suffer from an economic loss of around RMB 15 million, thus seriously affecting the fairness of trade settlement. For the purpose of fair trade settlement in the field of DC energy metering, it is imperative to build a DC measurement traceability system.

2. Application field of DC energy metering technology

DC energy metering technology has been widely used in the field of DC charging facility for electric vehicles, i.e. DC charger for electric vehicles fixed on the ground and quickly charges, which quickly charge batteries by converting AC into DC with a special charging device for power batteries of electric vehicles in a conductive manner and was installed on a freeway. In this field,research is mainly about the methods of measurement traceability with DC chargers and the gauges installed therein including DC energy meters and shunts.

Thanks to the popularization of distributed energy, DC energy metering technology develops among traditional users, especially the combination of DC variable frequency air conditioners and solar power generation, making the DC energy metering mode go into homes. In terms of DC energy application among traditional users, research is mainly about the measurement traceability with DC energy meters.

3. Contents of research on DC energy measurement transfer technologies

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3.1 DC charger-based field calibration technology

Electric vehicle charging facilities include AC charging pile and DC charger.A DC charger is designed for fast charging of batteries, with large charging capacity and current. From technical point of view, future DC energy meters will be high-current and high-precision, and there are currently popular DC chargers of the maximum current up to 300A (subject to the charging plugs thereof), but those for rail transit may be of over 1kA. With the technical progress in batteries and conductive cables, in accordance with users' requirement of shortening charging hours, the required current will become increasingly large in the future, making high current be a difficulty in the DC charger-based calibration technology.

DC charger-based field calibration consists of real load calibration and virtual load calibration.Real load calibration is the calibration made in the event of electric vehicle charging, with which only chargers can be calibrated in the existing condition, rather than the metering performance thereof. Virtual load calibration is to calibrate the range of chargers by providing different load points through virtual power load.Whether in relation to virtual load or real load, a standard meter (i.e. field charger calibrator) is required to make a comparison in connection with the data of measurement with an impact machine.

According to the ElectricEnergy Metering for Electric Vehicle Off-board Charger (GBT 29318-2012), in relation to a charger, the rated voltage is 100V~750V, and the reference current is 10A~500A, and the degree of accuracy is level 1 or 2. For the purpose of DC charger calibration, firstly, the status and parameters of the charger to be calibrated must be confirmed with a standard device, that is, the standard device should exchange information with the charger, so as to determine whether the charger can be calibrated and the calibrated parameters, in connection with which the process is called interaction.

Secondly, to make formal calibration, the DC charger is connected with an end of the charger calibrator (with a special charging socket) through special electrical connecting wires, of which the other end connects with power load. When the charger provides DC, the calibrator may accurately measure its electric energy, as shown in Fig.1. After connection of the DC charger to the input end of the calibrator and connection of the output end to the load, through adjustment to the load parameters and comparison between the electric energy values measured with the calibrator and the charger at different load points, the operation error in relation thereto may be calculated.

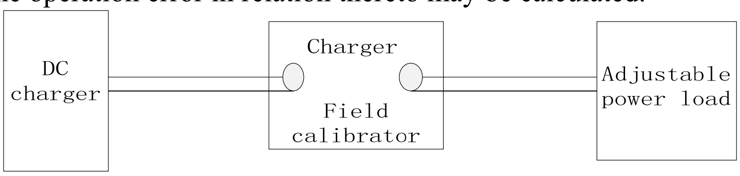

Fig.1 Schematic Diagram of Charger-based Field Calibration

In addition to the metering error,calibration should be made in relation to the error in the amount of payment for charging. To determine the error therein, comparison may be made between the amount obtained by multiplying the quantity of electricity within a period displayed on the charger by the corresponding unit rate and the amount of payment displayed thereon.

A charger calibrator is mainly designed to solve the problems in connection with measurement of high DC. Currently, resistance method, Hall process and DC comparator are mainly used, with which the accuracy is 0.2%/a, 0.5%/a and 5ppm/a respectively. A traditional DC compactor can only be used for comparison concerning DC measurement instead of capturing the rapid change in current,making it impossible to adapt to the broad dynamic range of current in the event of DC charging of electric vehicles; In addition, DC often contains AC component, the impossibility of measuring AC will exert a large effect on the overall metering error. Therefore,a broadband current compactor should be used to fast and accurately measure AC and DC, thus facilitating charger-based field calibration.

Charger calibration is in a lab with worse environment, especially in terms of the large temperature and relative humidity ranges of -40℃~55℃ and 20%~90% respectively; the charger supplies power through three-phase AC of grid, leaving a wide dynamic range and large surge current, particularly when DC is used for fast charging, in which case hundreds of ampere large current may be generated; moreover, the testing equipment for field calibration should be portable and resistant to earthquake to a certain extent.

With regard to the problems above, the equipment for charger calibration should be well environmentally adaptable, for which the solution is as follows: 1)mechanical or electrical contacts are cancelled for the current measuring loop concerning the main etalon for the calibration, so as to prevent instantaneous short circuit(arising from protection and one shift)in current loop and enable the instrument to well resist the impact of high current. 2) The components of all instruments are of wide temperature, and excellent circuit design and manufacturing process is used, so as to reduce the effect of large temperature and humidity range on metering. 3)on the basis of good structure design, the main etalon is installed within an anti-seismic portable instrument container equipped with rollers to facilitate dragging; and filled with many cushioning materials, it is well resistant to earthquakes.

3.2 DC energy meter and shunt calibration technology

Currently, DC energy meters on the market include the types of direct access and indirect access. A direct access type DC energy meter is to measure electric energy by inputting high voltage U and high current I into the meter.An indirect access type(shunt access generally)DC energy meter is to measure electric energy by converting high current(0~300)Ainto small-signal DC voltage(0~75mV) through a DC shunt, with which calibration should be made on the performance of shunt, in addition to the DC energy meter; however, same as a normal DC energy meter, the voltage input end directly connects to the DC voltage measured. Therefore, to calibrate DC energy meters, consideration must be given to the direct access type and indirect access type meters and their DC shunts,all of which may be calibrated through DC energy meter (shunt) calibration devices.

3.2.1 Precise high DC output and measuring technology

To calibrate direct access type meters and shunts, the calibration devices should provide high voltage and high current output. According to the scope of measurement with a DC energy meter of the maximum voltage up to 1000V and the current up to 600A, the 1000V DC voltage output technology has been mature at present. However, the high-precision and steady 600A DC output source is a difficulty in the DC energy meter calibration technology.

There are two solutions for output of high current. In terms of solution 1, output voltage using an adjustable voltage source,and convert it into current through a shunt, following which adjust the output of adjustable voltage source through negative feedback circuit in relation to the voltage at both ends of the shunt,thus ensuring steady and accurate current output, as shown in Fig.2.

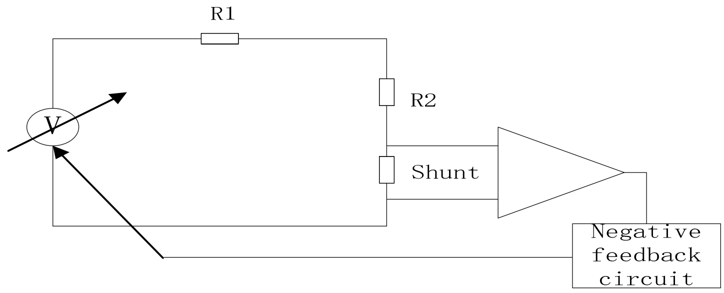

Fig.2 Schematic Diagram of Adjustable Voltage Source Outputting High Current

In terms of solution 2, switching power supply is used to generate high current, as shown in Fig.3.Same as solution 1, this solution is to adjust the output of power supply through negative feedback. Differently,in a negative feedback loop, current is monitored through a Hall sensor for feedback regulation. With a Hall sensor,when current I_P passes through a coil, magnetic fields generated on the wire are aggregated by magnetic rings, and a signal will be output from the Hall component installed on the wire, in which case a multi-turn winding is added on the coil on which there isoffset current I_S that generates magnetic fields through the multi-turn winding opposite to those generated by I_P, thus compensating previous magnetic fields. When the magnetic field generated by multiplying I_P by the number of turns is equal to that generated by multiplying I_S by the number of turns,the output of Hall component is zero. Based on the above principle, through monitoring of the output of Hall component and I_S, the

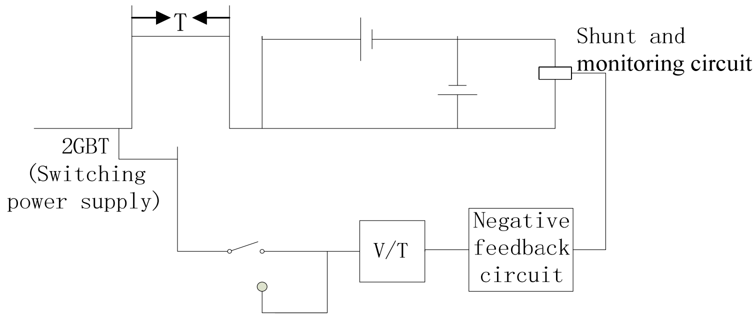

Fig.3 Schematic Diagram of Switching Power Supply Generating High Current

value of current I_P may be obtained. With the method, high current generated by switching power supply may be monitored, thus realizing negative feedback and value output.

3.2.2 Micro and precise DC voltage output and measuring technology

National standard Stationary DC energyMeter(GB/T 33708-2017)gives explicit specification and technical requirements for indirect access type DC energy meters. To ensure the compliance with the technical requirements, in relation to the micro and precise DC voltage output of DC energy meter calibration device, the following requirements must be met: the minimum output voltage is ±20μV, and the basic error in voltage output in ±1μV, and the output stability is 300 nV/min. However, when the calibration device is used to calibrate the DC energy meter,there will be a great error due to the effect of thermoelectric and contact potential of wires and terminals. For instance, in view of the copper temperature effect of about 0.5μV/°C, thermoelectric and contact potential will result in an error of 50μV in the
process of calibration, which is far beyond the technical requirements.To solve this, on the one hand, the effect of interference signals including thermocouple and contact potential must be eliminated, and micro DC voltage should be measured with the four-wire measurement method, and in combination with the small signal testing process, a precise DC small-signal voltage standard source should be designed; on the other hand, the input resistance of DC energy meter and shunt should be increased to reduce the effect of the materials including wires on measurement accuracy.

4. Construction of DC energy measurement traceability system

DC energy measurement traceability is a set of bottom-up system from a measuring instrument to national standard. After calibration of the instruments including DC charger, DC energy meter and shunt, consideration should be given to the feasibility of DC energy measurement traceability against national standard.

4.1 Basic working principle of DC energy meter

When DC power P=U*I, the integral of power to time is electric energy, that is, $E=\int U*Idt$. According to the formula, to measure electric energy, it is necessary to take samples for the values of voltage, current and time. Fig.4 is the schematic diagram of the typical DC meter structure:

According to the basic working principle,high voltage U and high current I measured are transported to the multiplier after conversion, through multiplying of the instantaneous value of voltage by current,direct voltage U is output, which is in direct proportion to the mean power within a period, afterwards, a voltage to frequency converter is used to convert into pulse frequency f for division, and a counter is used to count within a period to display the corresponding electric energy value.

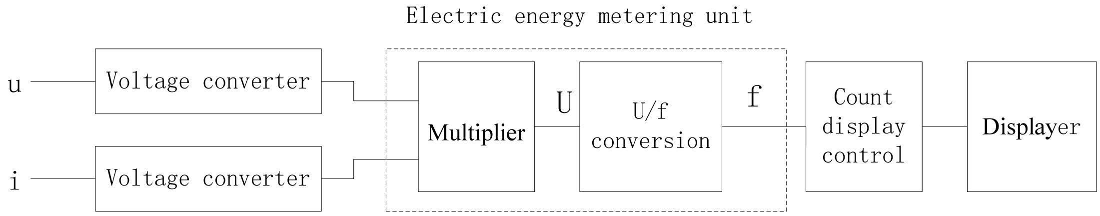

Fig.4 Schematic Diagram of DC energy Structure

According to the basic formula of E=∫U*Idt, the basic working principle of DC energy meter and the principle of DC energy meter calibration, to achieve DC energy-based metrological traceability, the values of voltage,current and time must be traced. To achieve the accuracy of 0.005% as required, the accuracy of measurement of DC voltage and current should be controlled within 0.0025% at least, but the time measurement accuracy is generally high, being over magnitude 10^{-6}, regardless of the effect on electric energy. The diagram of DC energy measurement traceability system is shown in Fig.5.

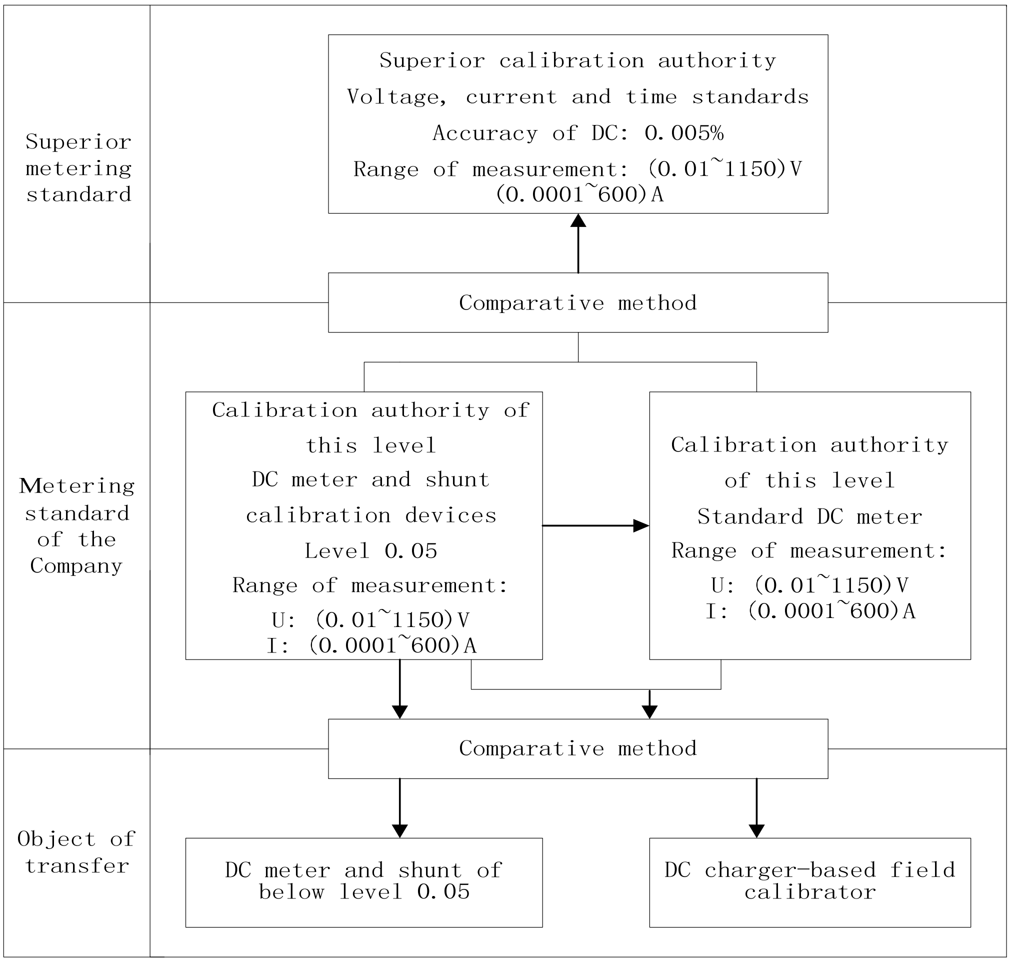

Fig.5 DC energy measurement Traceability System

4.2 DC voltage traceability method

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Through precise V/V conversion, high voltage of DC is converted into the low voltage of 1V, following which samples are taken through high-precision digital multimeter to output sampling signals of voltage U.

To measure the high voltage of DC of 10mV~1150V and ensure the accuracy is controlled within 0.0025%, it is infeasible to achieve direct measurement using a DC voltmeter. On the one hand, the commercial 8 and half-bit digital multimeter is subject to measurement of the maximum DC voltage of 1050V; on the other hand, the input impedance of digital multimeter reduces with the increase of voltage range. When the voltage range is 1000V in the event of 3458A, the input impedance is 10 MΩ, but calorific value is in direct proportion to U^2/R, and long-term use of high-voltage range will lead to high temperature of instrument, thus affecting the measurement accuracy.

Therefore, it is necessary to measure DC voltage in an indirect manner,and conduct V/V conversion through a precise AC and DC voltage shunt of level 0.001 to convert high voltage of DC of 10mV~1150V into 1V DC voltage, following which measurement is made through a 3458A digital multimeter, and the overall measurement accuracy is equal to the sum of proportional accuracy of shunt (10 ppm) and the measurement accuracy in the event of 1V, 3458A (about 4.5 ppm), which is superior to 0.0025% (25ppm).

4.3 DC traceability

It is necessary to measure the high DC of 0.1mA~600A and ensure the accuracy is controlled within 0.0025%, and the commercial 8 and half-bit digital multimeter is subject to measurement of the maximum DC of 20A. Therefore, the measurement must also be made in an indirect manner, and discussion is made as follows in the event of the current range of 0.1mA~100A and 100A~600A.

4.3.1 0.1mA~100A DC

Precise AC and DC coaxial shunts are used for I/V conversion and conversion of high DC into 1V voltage, following which measurement is made through a 3458A digital multimeter, and the overall measurement accuracy is equal to the sum of proportional accuracy of coaxial shunt (20 ppm) and the measurement accuracy in the event of 1V, 3458A (about 4.5 ppm), which is superior to 0.0025% (25ppm).

4.3.2 100A~600A DC

I/I conversion is conducted according to the DC ratio standard to convert high DC into 1A DC which is then converted into 1V DC voltage through a 1Ω precise resistance, following which measurement is made through a 3458A digital multimeter, and the overall measurement accuracy is equal to the sum of proportional accuracy of DC ratio standard (1ppm~2ppm) and the measurement accuracy in the event of 1V, 3458A (about 4.5 ppm), which is superior to 0.0025% (25ppm).

The schematic diagram of DC measurement traceability is shown in Fig.6.

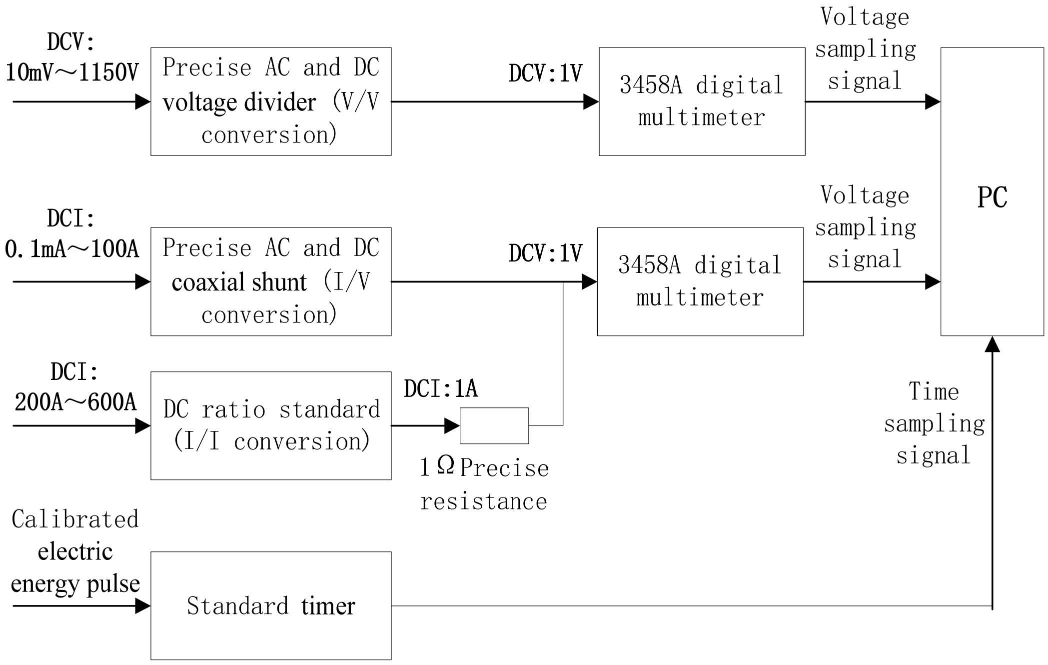

Fig.6 Schematic Diagram of DC energy measurement Traceability

5. Conclusion

To build a DC energy measurement traceability system, the difficulty lies in high current output measurement and low voltage measurement accuracy. To measure DC energy, full consideration should be given to the effect of ripple. Any DC power supply is to output DC power through supply with AC power supply and rectification, and both the fluctuation of AC network and electromagnetic noise and interference will affect DC output. Absolutely, the waveform is not a straight line theoretically, but superposes AC signals of a certain frequency on a straight line, which will lead to a great effect on the DC energy measurement accuracy. This is also a difficulty and a key in connection with the DC energy measurement traceability technology.

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