Energy measurement scheme of off-board charger suitable for virtual load verification

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Abstract—Aiming at the shortcomings of the existing off-board charger energy measurement scheme, this paper proposes an off-board charger energy measurement scheme suitable for virtual load verification. By adopting the gun head measurement scheme, the voltage sampling is replaced from the pile to the gun head, avoiding the influence of the gun line voltage, and more in line with the measurement point setting requirements. Using an integrated DC power meter instead of the combined measurement scheme with the DC power meter and shunt avoids the accuracy effect caused by the heat of the shunt, which is convenient for the management of the built-in measurement instruments and meets the requirements of the seal of the verification regulations. The scheme supports the virtual load verification method, avoids the problems of large power consumption and heavy equipment in the real load verification, and improves the verification efficiency. By comparing the electricity errors of real load verification and virtual load verification, the feasibility and accuracy of the electric energy measurement scheme are verified, which has good engineering application value.

1. INTRODUCTION
In March 2020, the charging piles for new energy vehicle were included in one of the seven major areas of "new infrastructure", which means the scale of charging piles will increase significantly. At the end of 2019, The State Administration of Quality Supervision issued a document to manage charging piles as compulsory verification measuring instruments. It is also required to complete the verification of charging piles for trade settlement before January 2023.

However, most of the energy metering schemes of off-board chargers that have been put into operation are rough and not standardized enough, and its design cannot meet the requirements of mandatory verification [1]. Moreover, due to the structural design of charging piles, existing off-board chargers only support real load verification methods. However, real load verification has disadvantages such as high energy consumption, large equipment, and low efficiency, which increase the difficulty of periodic verification. Most of the existing research focuses on the safety performance of charging piles and site selection planning. In terms of the safety performance of charging piles, The authors in [2] conducted a comprehensive assessment of the information security risks of charging piles from the perspective of asset value and security threats, and effectively identified the vulnerabilities and safety risks of the charging pile system. In [3], the research article has developed a set of verification system for DC charging piles for electric vehicles, which provides a test environment and method for related tests of charging piles. The factors affecting charging safety and gave corresponding solutions were analyzed in [4, 5]. In [6], the authors summarized the common faults of charging piles and analyzed the impact of the operation of charging stations on the distribution network. In terms of site selection planning, a
collaborative planning model for the distribution network and charging piles according to the power demand of each load point were established in [7]. In [8], the research paper proposed an optimal planning model for charging stations based on traffic flow and comprehensive consideration of network loss and voltage offset. At present, the research on charging piles mostly focuses on safety performance evaluation and site selection, and the related issues of charging pile electric energy measurement need to be further explored and improved.

Therefore, Under the dual background of mandatory verification requirements and vigorous construction for charging piles, it is necessary to reasonably regulate and optimize the electric energy metering scheme of off-board chargers, and design a metering scheme that meets the requirements of low power consumption and high efficiency verification at the same time.

2. EXISTING ELECTRIC ENERGY MEASUREMENT PLAN AND VERIFICATION REQUIREMENTS

2.1. Existing electric energy metering scheme

At present, the metering and charging of off-board chargers are based on the combined metering data of the indirect DC power meter and the shunt inside the charging pile. As shown in Figure 1, The DC electric power meter converts the DC current into the corresponding small voltage signal through the shunt for electric energy measurement calculation. The voltage sampling is set on both sides of the live line and the neutral line in the charging pile, but the specific location of the voltage sampling is not clearly defined and required.

The basis for the mandatory verification of off-board chargers is the verification regulation JJG1149-2018 Electric Vehicle Off-board Chargers. The verification items are 6 items including appearance inspection, insulation resistance test, working error, indication error, payment amount error and clock indication error.

2.2. Principles of real load verification

Affected by the structural design of the charging pile, The existing charging pile compulsory verification only supports the real-load verification method. The principle is to insert an on-site calibrator (that is, a standard electric power meter) between the charging pile and the electric vehicle (or the load of the simulated electric vehicle), Comparing the electrical energy of the standard watt-hour meter and the DC power meter in the pile. Based on the electric energy value measured by the standard electric power meter, determine whether the charging equipment measurement is accurate. The real load verification method is as follows:

Figure 1. The energy measurement of the existing off-board charge
In the case of continuous operation of the standard electric power meter and the checked charging pile, using the indication value of the electrical energy output from the tested charging pile and the measured electrical energy value of the standard power meter to determine the working error of the tested charging pile.

The working error $\gamma$ (%) of the tested charging pile is calculated according to formula (1).

$$\gamma = \frac{E' - E}{E} \times 100 + \gamma_0$$

(1)

Where $E'$ defended as the difference between the electric energy indication value when the charging pile under inspection stops charging and when it starts charging. $E$ defined as the electric energy value measured by standard electric power meter. $\gamma_0$ defined as the determined system error of the verification device, and the value of $\gamma_0$ is 0 when it does not need to be corrected.

The standard power meter runs synchronously with the tested charging pile. The ratio (%) between the electric energy value represented by the last word (or minimum index) of the tested charging pile and the accumulated $E'$ should not be greater than 1/10 of the tested charging pile grade index.

Under each load power, record the error measurement data at least twice and take the average value. If the average value is within the working error limit of 0.8~1.2 times of the tested charging pile, it is measured twice again, and the working error of the tested charging machine is calculated by taking the average value of each measurement data.

2.3. Existing difficulties in compulsory verification

The following problems exist in the implementation of compulsory verification under the existing electric energy metering scheme of charging pile:

Firstly, the measuring point of charging pile and the position of inspection point are not unified. During compulsory verification, the on-site calibrator is measured at the head of the charging gun, but the actual measuring point of the charging pile is near the internal power meter. There are physical phenomena such as voltage drop of charging gun cable and contact resistance at wiring point between the actual measuring point and the charging gun head, which will lead to rational error in the measurement results at the two measuring points. Even if the error of charging pile at the actual measuring point meets the requirements, the verification cannot be guaranteed.

Secondly, it is difficult to implement the requirements for the seal of the charging pile prescribed by the verification regulations. The verification regulations require that the location of the electric power meter or measurement module used inside the charging pile be sealed. The replacement or repair of metering accessories of charging equipment such as shunts and other main components will affect the metering accuracy of the entire pile. Sealing the electric power meter alone cannot ensure that the measurement results will not be artificially altered during the verification period. However, if the charging equipment is sealed as a whole, it will lead to the need to authorize the opening of the seal and reconfirm the seal each time during the on-site operation upgrade and maintenance of the charging equipment. As a result, there is a large demand for implementation personnel and a heavy workload for the metering confirmation of the seal again, which seriously affects the work efficiency.

Third, the existing structure design of charging pile only supports a single verification method of real load verification. The real load verification is performed by simulating the charging of the electric vehicle through the load box. The verification process consumes a lot of energy, the load boxes are large in volume and mass, inconvenient to transport, high in manpower and material costs, and the verification efficiency is low, which cannot support and meet the growing construction demands of charging piles and periodic verification requirements in the future.

3. ENERGY METERING DESIGN SCHEME SUITABLE FOR VIRTUAL LOAD VERIFICATION

Aiming at the shortcomings of the existing metering scheme and structural design of non-on-board charging electromechanical energy, this paper proposes a metering design scheme for off-board charger suitable for virtual load verification.
3.1. The overall design of the program

The off-board charger virtual load verification device is mainly composed of a DC constant voltage source, a constant current source, an electric energy error calculation module, an electric energy pulse sampling module, an error display module, and computer automatic calibration software. The working principle block diagram of the system is as shown in Fig.2.

The user sets the calibration point through the computer interface and transmits it to the microprocessor. The microprocessor calculates the selected voltage and current, and controls the constant voltage source and constant current source to switch to the best range. The off-board charger generates standard pulses and outputs them to the pulse acquisition module. The electric energy error calculation module compares the pulse number of tester and the pulse number of calibration system to calculate the electric energy error, and transmits the data value to the display module for display.

\[
\gamma_i = \frac{m_0 - m_i}{m_i} \times 100\% \\
\]

\[
m_0 = \frac{N \times C_0}{C_1} \\
\]

\[
C_0 = \frac{f \times 3600 \times 1000}{U \times I} 
\]

Where: \(N_1\) is the number of low-frequency or high-frequency pulses of the tester. \(C_0\) is high-frequency pulse constant of the verification device, imp/kWh. \(C_1\) is low-frequency pulse constant of
charging pile, imp/kWh, \( f \) is the pulse frequency of the calibration system. \( U, I \) are calibration system output voltage and current full-scale value.

3.2. Unified The head of charging gun as the measuring point
As shown in Figure 3, The voltage sampling line is overlapped on both sides of the fire line and the zero line in the pile, but there is no clear provision on the sampling position in the relevant regulations and specifications. The scheme removes the voltage sampling line randomly set in the original pile. Connect a set of voltage lines in the gun head cable in parallel for the voltage sampling of the DC power meter in the off-board charger, so that the actual metering point of the off-board charger and the metering point of the on-site calibrator are located on the charging gun tip, so as to ensure the consistency of the measurement point and the verification point.

3.3. Using integrated DC electric energy meter
The integrated DC power meter uses a built-in current sensor to replace the original external separate shunt for current sampling, and realizes the direct measurement of DC power under high DC current. At the same time, the performance of the current sampling circuit is optimized by increasing the heat dissipation area and reducing the impedance of the current line, so as to reduce the heating of the sampling element, ensure the good thermal stability of the integrated DC power meter, improve the measurement accuracy, and facilitate the sealing management of it. As shown in Fig. 4, an integrated DC watt-hour meter is adopted for measurement.

3.4. Design of applicability for virtual load verification
The virtual load verification method refers to the use of an external power source to input the specified load value into the voltage loop and current loop of the off-board charger to simulate the actual workload of the electric vehicle. At the same time, the voltage of the detection standard meter is connected in parallel, and the current is connected in series to the voltage and current loops. The electric energy of the standard electric power meter and the DC electric power meter in the pile is compared, and the
electric energy value measured by the standard electric power meter is used to determine whether the charging equipment is accurate. The error calculation principle of the virtual load verification method is the same as that of the real load verification.

Due to the independent voltage and current loops in the virtual load verification, the actual verification energy consumption is extremely small. However, the off-board charger lacks a current short-circuit point inside, and cannot form a current loop necessary for virtual load verification.

![Figure 5. DC virtual load verification gun holder panel](image)

The solution is to pre-install a sealable virtual load verification gun holder on the outside of the off-board charger pile as shown in Figure 5. The test power source passes the virtual load verification gun holder and auxiliary power terminal to the DC power meter in the off-board charger. Electric current and auxiliary power loop supply power. The pin definition of the DC virtual load verification gun base is shown in Table 1. Refer to Table 1 to define the pre-connection of the internal voltage and current lines of the verification gun base and the DC energy meter. Specifically, as shown in Figure 5, connect the A+ and A- pins to the positive and negative voltage terminals of the DC energy meter respectively. The DC+ and DC- pins are respectively connected to the positive and negative current terminals of the DC electric power meter. The positive terminal and negative terminal pins of the auxiliary power supply on the panel are respectively connected to the positive terminal and the negative terminal of the auxiliary power supply of the DC power meter. The S+ and S- pins are connected to the RS485A and RS485B terminals of the DC power meter. And the CC1 and CC2 pins are connected to the positive and negative pulse output terminals of the DC power meter. The PE pin is connected to the ground wire of the off-board charger.
Table 1 DC virtual load verification gun base definition

| Identification symbol | Features         |
|-----------------------|------------------|
| DC+                   | DC current+      |
| DC-                   | DC current-      |
| S+                    | 485A             |
| S-                    | 485B             |
| A+                    | DC voltage+      |
| A-                    | DC voltage-      |
| CC1                   | Pulse+           |
| CC2                   | pulse-           |
| PE                    | Protective grounding |

When virtual load checking, turn off the charging station and insert the test power source into the verification gun base from the outside of the pile. Insert the auxiliary power supply into the auxiliary power terminal of the panel, and the voltage, current and auxiliary power circuit of the DC power meter in the off-board charger can be powered by the virtual load verification gun base and auxiliary power terminal, which constitutes the virtual load verification condition and realizes the virtual load verification without opening piles.
4. EXPERIMENTAL VERIFICATION

According to the aforementioned plan, one off-board charger and one single-phase AC charging pile were transformed. This test is based on *JIG 1148-2018 Electric Vehicle AC Charging Pile* and *JIG 1149-2018 Electric Vehicle Off-board Charger*. In accordance with the requirements of the charging pile verification, the virtual load verification method and the real load verification method are used for off-board vehicles. The electric energy error of the charger was tested for comparison and verification. In the experiment, the virtual load test point is ensured to be consistent with the real load test point, and the two sets of experimental standards are ensured to be consistent by connecting the field calibrator in series as the standard.

The real load verification wiring diagram of the off-board charger is shown in Figure 7. Connect the off-board charger's internal power output positive terminal DC+ and output negative terminal DC- to the field tester and then connect to the load box. The on-site tester detects the standard electric energy $E$ for a period of time, and at the same time samples and measures the electric energy meter inside the charger to obtain the electric energy $E'$ consumed during this period of time. Put $E'$ and $E$ into equation (1) to calculate the working error of the off-board charger with real load verification. Then measure the working points of different powers, and get 6 groups of data of different working points.

The wiring diagram of virtual load verification for off-board chargers is shown in Figure 8. The virtual load verification connects the test power source to the virtual load verification gun base through the verification gun head to supply power to the internal voltage and current loops of the off-board charger. At this time, the positive terminal and negative terminal of the current output of the test power source are connected in series with the field tester and the internal electric energy meter of the charger to form a current loop. The voltage output positive and negative terminals of the test power source are connected to the positive and negative voltage terminals of the field tester, and the A+ and A- of the gun holder are connected to the positive and negative voltage terminals of the internal electric power meter after virtual load verification. The internal electric power meter of the machine is connected in parallel with the field tester to form a voltage loop. After a period of measurement, the consumed electric energy $E'$ measured by the internal electric power meter and the standard electric energy $E$ measured by the on-site tester are obtained. Similarly, put into equation (1) to calculate the working error of the virtual load test of the off-board charger. Then the working points of different powers are measured, and data of 6 groups of different working points are obtained respectively.

The test results of off-board chargers obtained through two sets of data are shown in Table 2 and Figure 9.

![Figure 7. The off-board charger real load experiment wiring diagram](image)
Figure 8. The off-board charger virtual load experiment wiring diagram

**Table 2** The experiment comparison result of virtual and real load verification of off-board chargers

| Voltage/V | Current/A | Average error of real load/% | Average error of virtual load/% | Revised error of real load/% | Revised error of virtual load/% | Difference between real & virtual load before revised/% | Difference between real & virtual load after revised/% |
|-----------|-----------|-------------------------------|---------------------------------|-----------------------------|---------------------------------|------------------------------------------------------|------------------------------------------------------|
| 500       | 100       | -0.11                         | -0.17                           | -0.2                         | -0.2                             | 0.06                                                 | 0.1                                                  |
| 500       | 60        | -0.15                         | -0.16                           | -0.2                         | -0.2                             | 0.04                                                 | 0.0                                                  |
| 500       | 40        | -0.14                         | -0.16                           | -0.2                         | -0.2                             | 0.02                                                 | 0.0                                                  |
| 500       | 20        | -0.11                         | -0.11                           | -0.1                         | -0.1                             | 0.00                                                 | 0.0                                                  |
| 350       | 60        | -0.15                         | -0.15                           | -0.2                         | -0.2                             | 0.06                                                 | 0.1                                                  |
| 200       | 10        | -0.16                         | -0.15                           | -0.2                         | -0.2                             | -0.01                                                | 0.0                                                  |

| Voltage/V | Current/A | Average error of real load/% | Average error of virtual load/% | Revised error of real load/% | Revised error of virtual load/% | Difference between real & virtual load before revised/% | Difference between real & virtual load after revised/% |
|-----------|-----------|-------------------------------|---------------------------------|-----------------------------|---------------------------------|------------------------------------------------------|------------------------------------------------------|
| 500       | 100       | -0.11                         | -0.17                           | -0.2                         | -0.2                             | 0.06                                                 | 0.1                                                  |
| 500       | 60        | -0.15                         | -0.16                           | -0.2                         | -0.2                             | 0.04                                                 | 0.0                                                  |
| 500       | 40        | -0.14                         | -0.16                           | -0.2                         | -0.2                             | 0.02                                                 | 0.0                                                  |
| 500       | 20        | -0.11                         | -0.11                           | -0.1                         | -0.1                             | 0.00                                                 | 0.0                                                  |
| 350       | 60        | -0.15                         | -0.15                           | -0.2                         | -0.2                             | 0.06                                                 | 0.1                                                  |
| 200       | 10        | -0.16                         | -0.15                           | -0.2                         | -0.2                             | -0.01                                                | 0.0                                                  |

**Table 3** The experiment comparison result of virtual and real load verification of off-board chargers

| Detecting method           | Equipment schedule | Size/mm | Total size/mm | Weight/kg | Total weight/kg | Test Time/s |
|---------------------------|--------------------|---------|---------------|-----------|-----------------|-------------|
| Virtual load verification | DC power source    | 625*590*260 | 1000*800*550 | 53        | 64              | 10          |
|                           | Calibration adapter| 375*265*270 | 1000*800*550 | 10        | 26              | 20          |
|                           | Cable              | /       |               | 1         |                 |             |
| Real load verification    | Scene calibrator   | 560*460*260 | 2800*2000*250 | 26        | 210             | 20          |
|                           | Test load          | 3*(690*535*745) | 0        | 180        |                 |             |
|                           | Cable              | /       |               | 4         |                 |             |

It can be seen from Table 2 and Figure 9: The maximum point of the difference between the virtual and actual load comparison test of the off-board charger appears at the (500V, 100A) and (350V, 60A) measurement points. The average error difference between real and virtual loads before rounding is 0.06%, the difference after rounding is 0.1%, and the errors of the remaining measurement points are 0 after rounding. For the first-level pile, an error of 0.1% will not be used in the evaluation of the pile verification results.
The difference between real and virtual loads verification (%)

Before revised
After revised

Figure 9. The experiment comparison result of virtual and real load verification of off-board chargers

In addition, the size, weight and test time of the field test equipment for the virtual load detection and real load detection of off-board chargers and AC charging piles are compared, as shown in Table 3. It can be seen from Table 3 that the dummy load verification method is significantly reduced compared to the real load verification method in terms of equipment size, weight and test time, and has a greater improvement in the portability and detection efficiency of the device than the real load verification method.

5. Conclusion

An off-board charger energy measurement scheme suitable for virtual load verification is proposed in this paper aiming at the shortcomings of the existing off-board charger energy measurement scheme. The three key technologies of the proposed measurement scheme including charging gun head metering, integrated DC energy meter and virtual load verification, has made a breakthrough in solving the three pain points in the existing off-board charger energy measurement scheme, such as the disunity of metering points, the inability of metering instruments to seal and the inability to support virtual load verification. The feasibility and accuracy of the proposed metering scheme has been verified by comparing the errors of real load verification and virtual load verification.

The metering scheme proposed in this paper can provide a reference for the design of the electric energy metering scheme for the newly built charging pile, and can also be applied to the improvement and optimization of the electric energy metering scheme for the running charging pile. The implementation of virtual load verification technology can significantly reduce the investment and transportation costs of real load verification equipment, as well as greatly reduce the workload of testers and effectively improve the verification efficiency.

Acknowledgment

This paper is sponsored by Science and Technology Project of State Grid Zhejiang Electric Power Co., Ltd.(5211YF200053).

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