Test Method of Communication Protocol of Standard Group Components of Electric Vehicle Charging Equipment

Yao Bai¹*, Panpan Tang², Jing Zhang², Jialin Zhang¹
¹Shijiazhuang Tone Electronics Technologies Com.Ltd, China, 16 Nanzhong Road, Nanshao, Changping, China
²China Electric Power Research Institute Co., Ltd, China

*Corresponding author e-mail: 16521001631@sjzte.org

Abstract. In recent years, the rapid development of the electric vehicle industry has made research on the communication protocol detection of the standard components of its charging equipment more and more important. The consistency of the charging communication determines whether the charging process can be carried out normally. During the charging process, the inconsistent communication messages of the standard components will directly lead to the failure of the charging process of the electric vehicle charging equipment. The purpose of this article is to study the communication protocol test method of the standard set of electric vehicle charging equipment. This article first analyzes the whole process of DC charging of electric vehicle charging equipment, and determines the detection method combining positive detection and negative detection according to the various stages of communication, and explains it. Then analyze and study the consistency of the communication protocol of the electric vehicle charging equipment standard group components, and determine the test indicators used to test and evaluate the DC charging communication consistency of the electric vehicle charging equipment. Finally, according to the analysis and research on the consistency of DC charging communication of electric vehicle charging equipment, a test plan for testing the consistency of communication is determined. The experimental data shows that the leakage current limit set in the experiment is 30mA, and the maximum error in the actual measurement is 1.1mA. The test results show that the controller on the cable can provide protection in case of leakage, and the measurement error is less than ±5mA.

Keywords: Electric Vehicles, Charging Equipment, Communication Conformance, Communication Testing

1. Introduction

Since the rise of the electric vehicle industry, research on its core technology has developed by leaps and bounds. However, there is no complete set of technical requirements and test indicators for the communication protocol of the standard components of charging equipment [1-2]. The development of electric vehicles and the research work of electric vehicle charging equipment testing technology are
imperative. Although the current communication protocol has a unified national standard, electric vehicles and charging equipment produced by different manufacturers still have the problem of inconsistent charging communication [3-4]. It often happens that a specific model is loaded into the charging pile and passes through the charging handshake phase, but cannot enter the charging phase [5-6]. Therefore, in order to solve the problem of difficult charging of electric vehicles, there is an urgent need to study the communication protocol test methods of standard components of electric vehicle charging equipment [7-8].

Many scholars at home and abroad have conducted research on the communication protocol test method of the standard components of electric vehicle charging equipment, and have achieved very impressive results. For example, Latifi M conducted a functional test on the AC charging pile of electric vehicles [9]; Umoren IA designed a portable test equipment that can be used to test portable charging piles on site [10]. Hariri A designed the testing equipment for fast charging piles [11].

This article first introduces the communication protocol of the standard components of the electric vehicle charging equipment, and explains the charging handshake phase, the charging parameter configuration phase, the charging phase, and the final charging phase and the preloading communication consistency detection sequence. At the same time, through the analysis of the consistency of the messages, the test indicators for the consistency of the DC charging communication are determined, and the theoretical work of the test method research is completed. This article also briefly introduces the classification of communication message parameters, as well as the method steps for positive and negative tests at each stage of communication costs. And through two methods of positive test and negative test to complete the test of the message logic and message content. Finally, according to the results of the test data analysis, a reasonable assessment of whether the tested charger meets the charging communication consistency requirements.

2. Test method of communication protocol of standard group components of electric vehicle charging equipment

2.1. Communication consistency detection method

Taking the charging device as an example, the detection system simulates the charging communication between the battery management system and the charger. According to the requirements of the communication protocol, that is, in an ideal communication state, it sends information such as battery status and charging requirements to the external charger and performs a test. The response message and the charger communication process have completed a positive test [11]. Then, the detection software will modify the standard messages at each stage of the communication cost to make them non-protocols, and then execute the communication process to detect changes in the external charger response message and communication process, and complete the negative test.

(1) Consistency detection method in the handshake charging phase.

First complete the communication rate and test system of the car charger, which can be set to 250kbps according to the communication requirements, then complete the physical connection and activation, and finally match the low auxiliary power supply voltage. The expected result is that the external charger sends a CHM handshake message to the test system (the test system simulates BMS) in a 250ms cycle.

After receiving the CHM message, the test system will respond to the BHM message on the charger with a 250ms cycle. The expected result is that after the vehicle charger receives the BHM message, it will stop sending the CHM message, complete the insulation detection, and then send a CRM message with SPN2560 = 0x00 in a 250ms cycle.

Since the data length of the BRM message is 41 bytes, after receiving the CRM message, the test system will use the data transfer protocol function to send the BRM message in 6 data packets with a 250 millisecond cycle. The expected result is that once the external charger uses the data transfer protocol function to successfully receive the BRM message, it will stop sending the CRM message
with the confirmation code 0x00, and then send the CRM message with SPN2560 = 0xAA to loop 250ms.

If the test system receives a CRM message with a confirmation code of 0x00, it does not use the transport protocol function to send the BRM message required by the protocol content. The system performs a negative test, and the expected result is that the battery management system continues to receive the charger identification failure message with the confirmation code 0x00, and the system operation stops during the handshake phase.

(2) Consistency detection method in parameter configuration stage.

After successfully receiving the CML and CTS messages, the test system will determine whether it can be charged normally according to the time synchronization and maximum output capacity information contained in the message, and then send the 0xAA confirmation code in the 250ms cycle BRO message. The expected result is that after successfully receiving the BRO message, the electric vehicle charging device stops sending two messages, CML and CTS, and judges the charging preparation status of the charger. If the next charging step is possible, the charger will send a CRO message with a confirmation code of 0xAA within a period of 250 milliseconds. If it is not ready to charge, the charger will send a CRO message with a confirmation code of 0x00.

(3) Consistency detection method in charging stage.

The first is that the test system sends BCL messages in a period of 50 milliseconds, and uses the transmission protocol function to send BCS messages in two data packets in a period of 250 milliseconds. The expected result is that the on-board charger stops sending CRO messages with the confirmation code 0xAA, and uses the data transmission protocol function to receive the BCS messages, and then sends the CCS messages containing the overall status of the charger in a 50ms cycle.

After the normal charging starts, the test system will send BMV messages, BMT messages and BSP messages in a period of 10 seconds. Because the data length of the above three messages is uncertain, the on-board charger will use the transmission protocol function in its reception.

During the charging process, if the BMS power battery is abnormal, the test system will send a BSM message according to the reason for the abnormality to understand the power battery status information.

(4) Consistency detection method at the end of charging.

At the end of charging, the test system sends BSD messages in a 250ms cycle. The expected result is that the external charger will send a 250ms CSD message and complete the charging after receiving the message.

Negative testing means that the test system did not send BSD messages. The expected result is that the on-board charger is still in the charging phase and continues to send CST charging termination messages to the battery management system. Until the BSD message timeout expires, the charging phase ends.

2.2. Learning algorithm of brushless dc motor control RBF for electric vehicles

In the RBF neural network learning algorithm, there are three main parameters: the center value of the basis function, the variance and the connection weight from the hidden layer to the output layer. The learning methods of the RBF neural network are diverse, and there are also many corresponding radial basis function centers. The radial basis function in RBF neural network often adopts Gaussian function, so the activation function of RBF neural network can be expressed as formula (1):

$$R(x_p, c_i) = \exp\left(-\frac{1}{2} \|x_p - c_i\|^2\right)$$  \hspace{1cm} (1)

The basis function of the RBF neural network is a Gaussian function, and the variance $\sigma_i$ can be

$$\sigma_i = \frac{\epsilon_{max}}{\sqrt{2h} \cdot i = 1, 2, ... h}$$  \hspace{1cm} (2)
obtained:
The weight of the neuron between the hidden layer and the output layer can be directly calculated by the least square method. The calculation formula is as follows:

$$\omega = \exp(-\frac{h}{c_{\text{max}}\|x_p-c_i\|} \cdot p=1,2...P, i=1,2...h)$$  \hspace{1cm} (3)

3. Experimental research on the communication protocol test method of the standard group components of electric vehicle charging equipment

Experimental procedures and steps.

Step 1: Check the consistency of the communication protocol.

The detection system simulates the communication between the battery management system and the car charger, then analyzes the charging response information data of the car charger, and scans the logic and content of the message at each stage. When the entire charging process can be completed in accordance with the content of the national standard protocol and the on-board charger can respond to messages that comply with the protocol, this indicates that the on-board charger is positive and can meet the requirements.

Step 2: Configure experiment parameters.

The BMS uses the transport protocol function to send BCP messages in a 250ms cycle. After successfully receiving the external charger, it will send CML messages in a 250ms cycle and CTS messages in a 500ms cycle. According to the data information contained in the CML and CTS messages, the BMS determines whether the charger can be used to charge it, and then sends a BRO message with SPN2829 = 0xAA in a 250ms cycle. The charger determines the readiness based on this message. If it can be charged, it will send a CRO message with the confirmation code 0xAA within a 250 millisecond period. If it cannot be charged, it will send a CRO message with a confirmation code of 0x00 within a period of 250 milliseconds.

Step 3: Test during the charging phase.

BMS uses the transmission protocol function to send BCS messages in a 250ms cycle and BCL messages in a 50ms cycle. After the charger receives the message, it will send a CCS message in a 50ms cycle to start normal charging. If the BMS battery is abnormal, send a BSM message based on the reason for the abnormality. After receiving abnormal power battery information, the charger will send a CST message to stop charging.

Step 4: Positive test during the charging phase.

After entering the charging phase, the BMS completes the relevant charging preparations, and then sends the corresponding charging status information to the charger outside the ship, and then the charger responds to the corresponding status message data according to the charging preparation. In addition, the BMS sends the battery status information to the charger according to the test requirements.

After receiving the correct message, the BMS verifies whether the received message conforms to the communication standard according to the communication message logic between the charger outside the car and the BMS, and then sends the next message box.

Step 5: Test at the end of charging.

The BMS sends BSD messages in a 50ms cycle. After the charger receives the BMS statistics message, it will send a CSD message in a 250ms cycle to stop charging.

4. Experimental analysis of the test method of the communication protocol of the standard group components of electric vehicle charging equipment

4.1. Measured data of the voltage monitoring function of the charging protection device in the cable

This study conducted an external charging test for electric vehicles. In the actual test, overvoltage protection, overvoltage protection and virtual load are used to verify overvoltage protection, fault current protection, ground fault automatic control protection and current protection by regulating the
AC output of the voltage to leak into the actual car system. Table 1 lists the experimental data of over-voltage and over-voltage protection in the external test.

**Table 1.** Measured data of the voltage monitoring function of the charging protection device on the cable

| Experiment number | Overvoltage threshold/V | Overvoltage self-recovery threshold/V | Undervoltage threshold/V | Undervoltage self-recovery threshold/V |
|-------------------|-------------------------|--------------------------------------|--------------------------|---------------------------------------|
| 1                 | 256.2                   | 255.5                                | 175.3                    | 184.9                                 |
| 2                 | 267.2                   | 255.1                                | 175.2                    | 185.3                                 |
| 3                 | 265.9                   | 255.1                                | 175.6                    | 185.7                                 |
| 4                 | 266.7                   | 256.1                                | 175.9                    | 185.2                                 |
| 5                 | 267.3                   | 254.2                                | 174.9                    | 185.4                                 |

![Figure 1](image.png)  
**Figure 1.** Measured data of the voltage monitoring function of the charging protection device on the cable

As shown in Figure 1, the test method of this study has good adaptability to fluctuations on the power supply side, and can achieve the required design indicators: too high or too low voltage will interrupt charging, thereby protecting the charger and battery, and after the voltage returns to normal, the charging starts again, thereby reducing the manpower wasted in manual operation.

4.2. Leakage current test data of the charging protection device on the cable

In addition, the leakage current protection function test is simulated: a power resistor with adjustable resistance is connected in series between the active cable of the AC input port of the charger and the grounding cable. In order to simulate a possible leakage experiment and monitor the data uploaded from the leakage current sensor via the wireless network. Record the value of the current flowing through the resistor during the operation of the relay to verify the reliability of the leakage protection function. Then, connect a small resistor power supply and IGBT series circuit between the live wire and the ground wire. At 40mA, the real-time performance of the leakage protection system is verified by measuring the time difference from the IGBT to the complete disconnection of the relay. The specific data of the experiment is shown in Table 2.
Table 2. Measured data of the leakage current monitoring function of the charging protection device on the cable

| Experiment number | Leakage current value/mA | Leakage protection action time/ms |
|-------------------|--------------------------|----------------------------------|
| 1                 | 29.6                     | 11                               |
| 2                 | 29.8                     | 12                               |
| 3                 | 30.0                     | 10                               |
| 4                 | 30.1                     | 11                               |
| 5                 | 30.0                     | 10                               |

Figure 2. Measured data of the leakage current monitoring function of the charging protection device on the cable

As shown in Figure 2, the leakage protection function of the system is very stable, the error from the preset value of 30mA is within 5%, and the action time is less than 15ms, which can effectively protect the operator in the event of a leakage accident.
As shown in Figure 3, the leakage current limit set during the experiment is 30mA. The maximum error in the actual measurement is 1.1mA. The test results show that the controller on the cable can provide protection in case of leakage, and the measurement error is less than ±5mA. Therefore, it meets the design requirements and can perform the leakage protection function.

5. Conclusion
With the continuous development of electric vehicle technology, the consistency of communication between battery management systems and standard charging equipment components has become more and more obvious. The consistency of communication is a prerequisite for normal charging. If the communication messages are inconsistent during the charging process, the charging process will be abnormal immediately, and the charging equipment will be damaged in severe cases. This paper takes the non-vehicle charger as an example to analyze and study the consistency of the test and communication protocol of the standard components of the electric vehicle charging equipment. The main results and conclusions drawn are as follows:

According to the content of the national standard agreement, the logic and content detection of the message are used as indicators for communication consistency detection. The detection methods performed in each stage are explained and the detection steps are set. The test results show that the communication protocol of the standard set of electric vehicle charging equipment components in this study has passed the consistency check.

Based on the analysis results of the detection scheme proposed in this paper and the actual detection data, a reasonable evaluation of the consistency index of the DC charging communication message of the external charging equipment tested for the electric vehicle. Through positive and negative detection methods, it is determined that the standard components of the charging equipment can pass the consistency detection of the communication protocol.

The detection data obtained in the communication consistency detection process clearly shows the information of each communication process, and based on the information, the charging status of the external charger and power battery of the electric vehicle can be observed intuitively, so as to determine whether the charging Work properly.

Acknowledgments
Supported by Open Fund of Beijing Engineering Technology Research Center of Electric Vehicle Charging/Battery Swap(China Electric Power Research Institute) (YDB51202001463).

References
[1] Aftab M A, Hussain S, Ali I, et al. IEC 61850-Based Communication Layer Modeling for Electric Vehicles: Electric Vehicle Charging and Discharging Processes Based on the International Electrotechnical Commission 61850 Standard and Its Extensions[J]. IEEE Industrial Electronics Magazine, 2020, 14(2):4-14.
[2] Li Y, Wang Y, Wu M, et al. Replay Attack and Defense of Electric Vehicle Charging on GB/T 27930-2015 Communication Protocol[J]. Journal of Computer and Communications, 2019, 07(12):20-30.
[3] Knapp D, Z Jakó, Sayed N E. Wireless Authentication Solution and TTCN-3 based Test Framework for ISO-15118 Wireless V2G Communication[J]. Infocommunications Journal, 2019, 11(2):39-47.
[4] Wang L, Chen B. Distributed control for large-scale plug-in electric vehicle charging with a consensus algorithm[J]. International Journal of Electrical Power & Energy Systems, 2019, 109(JUL.):369-383.
[5] Mack A, Usiak T. Interactive test stand for electric vehicle components[J]. AUTOBUSY – Technika Eksplotacj Systemy Transportowe, 2019, 20(1-2):93-98.
[6] Baik S, Jin Y, Yoon Y. Determining Equipment Capacity of Electric Vehicle Charging Station Operator for Profit Maximization[J]. Energies, 2018, 11(9).
[7] Carcangiu S, Fanni A, Montisci A. Optimization of a Power Line Communication System to Manage Electric Vehicle Charging Stations in a Smart Grid[J]. Energies, 2019, 12(9):1767.

[8] Aveklouris A, Vlasiou M, Zwart B. A Stochastic Resource-Sharing Network for Electric Vehicle Charging[J]. Control of Network Systems, IEEE Transactions on, 2019, 6(3):1050-1061.

[9] Latifi M, Rastegarnia A, Khalili A, et al. Agent-Based Decentralized Optimal Charging Strategy for Plug-in Electric Vehicles[J]. IEEE Transactions on Industrial Electronics, 2019, 66(5):3668-3680.

[10] Umoren I A, Shakir M Z, Tabassum H. Resource Efficient Vehicle-to-Grid (V2G) Communication Systems for Electric Vehicle Enabled Microgrids[J]. IEEE Transactions on Intelligent Transportation Systems, 2020, PP(99):1-10.

[11] Hariri A, Hariri M E, Youssef T, et al. A Bilateral Decision Support Platform for Public Charging of Connected Electric Vehicles[J]. IEEE Transactions on Vehicular Technology, 2018, PP(99):1-1.

[12] Sun Y G, Yu M H, Sim I, et al. Deep Learning Based Error Control in Electric Vehicle Charging Systems Using Power Line Communication[J]. The Journal of The Korea Institute of Intelligent Transport Systems, 2018, 17(4):150-158.