Research on DC Charger Interoperability Test for Electric Vehicles

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Abstract: DC charger is an important facility for electric vehicles to quickly replenish electric energy. Its operation safety, reliability and interoperability are of great significance for improving the popularity of charging facilities and the development of electric vehicles. Starting from the charging process of DC charger, this paper develops a set of DC charger interoperability testing device in combination with relevant testing specifications of DC charger, and carries out relevant tests on DC charger to verify the effectiveness of this set of equipment.

1. Introduction

With the development of economy, the contradiction between demand of people for energy and green ecology becomes more and more serious. At present, local disputes among countries also lead to the fluctuating price of fossil energy represented by oil, which further increases the challenge of energy demand. At present, 90% of petroleum resources are used for transportation, so reducing automobile exhaust emission is an important channel for carbon emission and creating green ecology. By the end of 2019, China had a total of 4.2 million new energy vehicles and 1.219 million charging facilities, making great progress in the field of electric vehicles. Although China has made remarkable achievements in electric vehicles and charging facilities, users have a wait-and-see attitude towards purchasing electric vehicles due to the limited battery life and inconvenient charging of electric vehicles. In order to promote the standardized development of electric vehicles, China successively issued relevant national standards in 2015 and 2017, which are used to refine the specification of charging piles and the compatibility of electric vehicles [1-4]. However, in the actual operation process, due to the factors such as slow equipment update cycle, the incompatibility between car and pile will inevitably occur frequently.

In order to improve the interoperability of charging piles, some scholars have carried out related researches in this field. Literature [5] studies the interoperability test methods of AC charging facilities and develops a set of AC interoperability test platform for the interoperability of AC charging facilities. Literature [6] designed an interoperability test system, which can carry out charging process control and abnormal charging tests on DC chargers. In literature [7], a mobile test platform for EV charging facilities is introduced, which can be used for field testing and improve the efficiency of testing. As the structures of AC and DC charging piles are different, they are often tested separately in terms of interoperability, which requires different testing platforms. In order to improve the test efficiency of AC and DC charging piles, a device for consistency test of AC and DC charging facilities is proposed in literature [8]. This device can facilitate the unification of AC and DC charging interfaces of EV and realize the comprehensive test of EV charging interfaces. DC charger is the main way to achieve rapid
charging, and its output power is often up to dozens of kilowatts, which has a huge promoting effect on improving charging efficiency and increasing battery life of electric vehicles. Therefore, DC chargers often need to complete the charging process in a short time, and the charging compatibility of various car models needs to be met. In this paper, the control guiding process of DC charging is firstly analyzed, and a set of DC charger interoperability test device is designed aiming at the charging process of DC charger, and a practical test is carried out with this device on DC charger to verify the effectiveness of this device. This paper is composed of the following parts: the main components of the interoperable test device are introduced in the second chapter, the relevant test results are introduced in the third section, and the relevant conclusions are obtained in the last chapter.

2. The structure of device
The DC charger and EV are connected with plug. The interface is composed by DC+, DC-, PE, S+, S-, CC1, CC2, A+ and A- including two DC transmission line, protective ground wire, communication lines, connection circuits and low voltage auxiliary power circuits. The low voltage auxiliary power is 12 V. When a EV is connected to the DC charger, the connection status is confirmed firstly, and then the DC charger start insulation self-test, after the self-test is completed, the corresponding switches is closed to make the primary DC circuit conductive. In the charging stage, the DC charger could adjust the output voltage and current in real time. When the charging stop condition is reached, the switches is disconnected and a charging stop message is also sent. Normal charging process test and abnormal charging test need to be carried to test the interoperability of DC charger according to relevant test standards and DC charging process.

The principle of the DC charger interoperability test device is shown in Figure 1. The platform is mainly composed of programmable AC power, programmable DC load, battery simulation device, data acquisition device, high-precision power meter, oscilloscope, control box, vehicle interface simulation device, CAN interface, the serial port server and industrial computer. The highest operating voltage of the platform is 1000 V, and the programmable DC load is a pure resistive load. The control box and vehicle simulation device complete the simulation of various charging characteristics of EV with the help of battery simulation device. The high-precision power meter is used to measure the input and output power, voltage, and current of the tested charger. The industrial computer is used to run the test software which complete automatic control and data waveform acquisition.

3. Simulation
In order to verify the effectiveness of the device, a DC charger with a good working condition is used to test the device in this chapter. The input voltage of the DC charger is 380 V, the output range of DC voltage is 200 V ~ 750 V, and the maximum output power is 60 kW.

3.1 The test of normal charge
Under normal charging conditions, five tests are required including connection confirmation test, self-check stage test, charge readiness test, charge stage test and normal charge end test. In this chapter, three of the test items are selected as verification experiments to test the effectiveness of this device.
3.1.1 Under normal charging conditions

Connection confirmation test is the first basic test, which is used to ensure the correctness of the physical connection. It is used to determine the connection state by detecting the voltage of relevant test points. Table 1 shows the test results of connection confirmation. It can be seen from the Table 1 that the test device can meet the test requirements of the charger in the first test step.

| State  | Charging state | Voltage in point 1 (V) Qualified | Voltage in point 1 (V) Measured | Voltage in point 2 (V) Qualified | Voltage in point 2 (V) Measured |
|--------|----------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| State 0| No             | 6±0.8                            | 6.022                            | 12±0.8                           | 12.065                           |
| State 1| No             | 12±0.8                           | 11.920                           | 12±0.8                           | 12.075                           |
| State 2| No             | 6±0.8                            | 6.029                            | 6±0.8                            | 6.101                            |
| State 3| Yes            | 4±0.8                            | 4.062                            | 6±0.8                            | 6.097                            |

3.1.2 Self-check stage test

Self-test is a necessary test to ensure the safe and reliable in charging stage [2]. In the test stage, the resistors $R_t$ with different resistances are connected between DC+ and PE and between DC- and PE. Symmetrical and asymmetrical insulation tests are performed between DC+ and PE or between DC- and PE, and the test voltage is the rated output voltage of the charger. According to relevant national standards, if $R > 500 \, \Omega/V$, the charging process is safe; if $100 \, \Omega/V < R \leq 500 \, \Omega/V$, an insulation abnormality alarm will be issued, but it can still be charged normally; however, if $R \leq 100 \, \Omega/V$, it is regarded as insulation failure, and charging will be stopped. It can be seen from Table 2 that under the condition of symmetric and asymmetric insulation faults, the device can carry out relevant detection on the DC charger.

| The failure          | Requirements          | Instructions          | Charging is allowed |
|----------------------|-----------------------|-----------------------|---------------------|
| Asymmetric           | DC+ Insulation abnormality | 100Ω/V < R ≤ 500 Ω/V | Abnormality on Fault on | Yes         |
| DC+ Insulation       |                        |                       |                     |              |
| DC+ insulation fault |                        |                       |                     | No           |
3.1.3 Charging stage test
In the charging stage, the vehicle sends charging demand parameters to the DC charger, according to which the charging voltage and current are adjusted by charger in real time, and the respective state information is communication to each other. The detection sensitivity of the detection device is judged by detecting the error of voltage and current output. Table 3 and Table 4 show the results of the charging stage test. It can be seen that the device can complete this test.

| AC input voltage (V) | DC output current (A) | Demand value (V) | Measured value (V) | Error (%) |
|---------------------|----------------------|------------------|-------------------|-----------|
| 380                 | 40.000               | 475.000          | 475.746           | 0.157     |
|                     |                      | 750.000          | 749.949           | 0.006     |

Table 3. The results of voltage control error

| AC input voltage (V) | DC output voltage (V) | Demand value (A) | Measured value(V) | Error (%) |
|---------------------|----------------------|------------------|-------------------|-----------|
| 380                 | 16.000               | 40.000           | 39.906            | 0.23%     |
|                     |                      | 80.000           | 78.365            | 2.04%     |

Table 4. The results of current control error

3.2 Abnormal charge test
As an electric vehicle energy interaction device, charging equipment should ensure good safety and universality in normal charging state. In addition, in case of abnormal charging state, charging facilities must have sufficient interoperability to ensure reasonable and effective countermeasures in case of various faults. In this paper, common faults of DC charger are tested to verify the effectiveness of the developed equipment, including communication interruption test, vehicle interface disconnect test and test of output voltage exceeding vehicle allowable value.

3.2.1 Communication interruption test
Communication interruption is a common fault in the charging process of electric vehicles. When the communication between vehicle piles fails, the DC charger needs to interrupt the charging operation quickly. According to relevant national standards, the DC charger disconnects the relevant contactor within 10s after the communication timeout failure of the charger occurs; After three communication timeouts, it is judged as communication interruption fault and the charging machine stops charging. Table 5 shows the test results of communication interruption of a DC charging pile. It can be seen from the test results that the device can carry out the relevant communication interruption test correctly on the charger.

3.2.2 Vehicle interface disconnect test
In the vehicle interface disconnection test, the normal charging process is simulated at first, and then the vehicle simulator simulates the disconnection of the vehicle interface (usually in the way of vehicle
communication line CC1 disconnection). After disconnection, the connection state, communication state and charging state of the vehicle at this stage are detected.

Table 5. The results of communication interrupt test

| Test item            | Output voltage (V) | Output current (A) | Reconnect three times | Re-entering the charging stage | Time of disconnecting K1 and K2 (s) | Time of disconnecting K3 and K4 (s) |
|----------------------|--------------------|--------------------|-----------------------|--------------------------------|-------------------------------------|-------------------------------------|
| Communication fault  | -0.0291            | 0.0026             | Yes                   | --                             | --                                  | 6.8784                              |
| Communication resume | 475.8004           | 0.0024             | --                    | Yes                            | 1.1760                              | --                                  |

If the vehicle interface is judged to be disconnected from the complete connection, the DC charger will immediately stop charging, disconnect the relevant contactors within 100ms, and issue the corresponding alarm prompt. Table VI shows the test results, it can be seen that the device could satisfy this test.

Table 6. Results of the vehicle interface disconnect

| Test Item  | Output Voltage (V) | Output Current (A) | Time of Disconnecting K1 and K2 (s) | Warning |
|------------|--------------------|--------------------|-------------------------------------|---------|
| Interface Break | -0.0426           | 0.0042             | 0.0415                              | Yes     |

3.2.3 The DC charger output voltage bigger than the max charge voltage of vehicles

During the normal charging process, the output voltage of the DC charger must be within the permissible range of the vehicle battery. When the output voltage of the charger exceeds the allowable range of the EV battery, the charger will quickly terminate the charging operation.

In the charging process, if the output voltage of the DC charger is greater than the maximum allowable charging voltage of the vehicle, the charger will stop charging within 1s, disconnect correlation contactor and issue warning prompts [2]. Table 7 show the test results of the DC charger.

Table 7. The results of the DC charger output voltage bigger than the max charge voltage of vehicle

| Test Item | Maximum Charging Voltage (V) | Output Voltage (V) | Time of Disconnecting K1 and K2 (s) | Warning |
|-----------|-------------------------------|-------------------|-------------------------------------|---------|
| Output Voltage | 750.              | 15.2659           | 0.8125                              | Yes     |

4. Conclusion

In this paper, the charging process of DC charger is firstly analyzed, and then a set of interoperability testing device of a DC charger is developed in combination with relevant testing standards. A DC charger with a good working condition was tested under normal and abnormal charging conditions in this device. The experimental results show that the developed DC charger interoperability device can effectively carry out related interoperability tests on the DC charger.

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