Research and Analysis on Low-temperature Charging Control Strategy of Electric Vehicle

Chan Li, Lixue Chen* and Jin Li
China Automotive Technology and Research Center Co., Ltd, Tianjin

*Corresponding author e-mail: chenlixue@catarc.ac.cn, lichuan@catarc.ac.cn, lijin@catarc.ac.cn

Abstract. In this paper, the pure electric vehicle is taken as the research object. Under the same conditions (such as the same limit temperature) under different conditions, the charging control strategy test of the collective prototype and the same vehicle is carried out under different conditions. The test data is used to analysis vehicle charging control strategy and key technical indicators that affect charging performance. The test results show that from the analysis of the collective prototype test, AC charging can be started normally in the low temperature environment. The charging power of most test vehicles has a certain attenuation compared with the normal temperature, and the charging time has a certain increase. From the same temperature comparison test of the same car, the difference of charging current trend, battery input current, battery temperature and maximum charging current between low temperature and normal temperature is analyzed.

1. Introduction
In recent years, new energy vehicles have developed rapidly. As of June 2019, the number of new energy vehicles in China has reached 3.44 million, accounting for 1.37% of the total number of vehicles. Compared with the same period last year, it increased by 1.45 million vehicles, an increase of 72.85%. However, with such achievements, more and more problems have been exposed, among which the charging problem has become an important factor restricting the development of new energy vehicles.

China has a vast territory, electric vehicles (EVs) all over the country, including northwest and northeast China for a long winter and cold. However, the new energy vehicles in the low-temperature environment have many problems, such as shortened driving mileage, longer charging time, and reduced power, which bring inconvenience to users and serious user complaints, resulting in less promotion and application in cold areas. The decrease of charging performance in low temperature environment will affect the popularization and development of EVs in cold area.

At home and abroad, the research on extreme environment charging of battery pack (component level) has been carried out. For example, literature [2] studies the aging rule of low-temperature charging of lithium-ion batteries for electric vehicles. Literature [3] studies the charging and discharging characteristics of lead-acid batteries with limit current, proposes the improvement method of low-temperature charging of lead-acid batteries, and literature [4] studies the design and verification of charging control in low-temperature environment of batteries. However, due to the complex
structure of the whole vehicle, the study of single battery or battery pack can not fully simulate the performance of the charging performance of the whole vehicle level. Literature [5] studies the low-temperature performance of lithium-ion power battery, and proves that the amorphous carbon coated negative electrode composite can realize the low-temperature charging and discharging of lithium-ion power battery. Literature [6] studies the working model of lithium-iron phosphate battery for high-low temperature electric vehicle.

In this paper, the EV is taken as the research object, and the low-temperature charging test method of EV test electric vehicle evaluation management rules (2019 version) is adopted to carry out the low-temperature environment charging test for different brands and models of vehicles, record the voltage, current, power and charging report data in the charging process, and analyze the charging performance of electric vehicles in the low-temperature environment. This paper will study and analyze the low-temperature charging control strategy from the aspects of charging time, charging energy, charging current rising trend, maximum charging current, communication protocol message battery charging demand(BCL), the battery total charging state (BCS), and the battery state message(BSM) voltage current and the relationship between battery temperature and state of charge (SOC).

2. Test

2.1. Test platform

By simulating high temperature, high cold and other environments in the environment bin and using the real working conditions of the "three high" test field, the charging signal acquisition (voltage, current, power rate, energy, message, etc.) under various limit environments is realized by using energy metering device, waveform recorder, can communication acquisition device, fault simulation device, etc.

Among them, the AC charging equipment is 7KW electric vehicle power supply equipment (EVSE), the DC charging equipment is 120kw, and the rated current is 250A DC EVSE. The environmental chamber is a 66m³ temperature shock test chamber.

![Figure 1. Simple diagram of test platform.](image)

2.2. Test method

The test method in this paper comes from ‘EV-Test electric vehicle evaluation management rules (2019 version)’.

2.2.1. Test conditions. Specifications of AC charging equipment: 7kW AC charging equipment. Specifications of DC charging equipment: DC charging equipment no less than 120kW. All charging equipment shall meet the requirements of GB/T 34657.1-2017, GB/T 34658-2017, GB/T 20234.1-2015, GB/T 20234.2-2015 and GB/T 20234.3-2015.
2.2.2. Vehicle pretreatment. The power battery is discharged before the test. First, the test vehicle is driven at a steady speed of 70% ± 5% of the maximum speed of 30 minutes to discharge the vehicle's power battery. The discharge ends when the vehicle speed cannot reach 65% of the maximum 30 minute vehicle speed.

2.2.3. Test flow. (1) Low temperature - 10 °C charging: soak the vehicle in - 10 °C environment for 14-16 hours before charging, and test in this environment. For the AC charging test, insert the plug at the power supply equipment firstly, and insert the plug at the vehicle, then operate the electric vehicle power supply equipment(EVSE) to start charging and check the charging state of the vehicle, the vehicle shall start charging. During charging, if the charging interface is equipped with an electronic lock, the electronic lock device shall remain locked. For the DC charging test, between the EVSE and the EV, the electric quantity in the charging process shall be continuously recorded in real time at a collection frequency of not less than 1Hz, and the charging time t1 (unit: h, value accurate to two decimal places) and the charging electric quantity E1 corresponding to 80% SOC (according to the DC charging communication message) shall be recorded.

(2) The vehicle shall be immersed in the environment of (25 ± 5) °C for more than 12 hours before charging and tested in this environment. Between the EVSE and the EV, the electric quantity in the charging process shall be continuously recorded in real time at the acquisition frequency of no less than 1Hz, and the charging time t2 corresponding to 80% SOC (expressed in h, with the value accurate to two decimal places) and the corresponding charging electric quantity E2 shall be recorded.

3. Test results and analysis

In this paper, the charging performance of 7 models (1#-7#) is analyzed and tested according to the test method in Chapter 1. The output of charging equipment, input voltage, current and power of EV charging are collected by energy metering device, and the charging time and quantity are calculated. The waveform recorder is used to record the start-up waveform of AC charging in low temperature environment. The whole charging process GB / T 27930-2015 communication message is recorded by CAN communication acquisition device, the communication message is analyzed and processed, and the relationship between the message BCL, BCS, CCS voltage and current and the maximum, minimum temperature and SOC value of BCS is analyzed.

![Figure 2. Photos of test site.](image-url)
3.1.2. DC charging result at low and normal temperature. The charging time and energy data of 7 sample vehicles at low and normal temperature are shown in Table 1. According to the data, the charging time of most vehicles (6/7) in low temperature environment is increased compared with that at room temperature, and the attenuation ratio of 1# sample vehicle is the largest, reaching 2.55. The smaller the time attenuation ratio is, the smaller the charging power in the low-temperature environment has a certain attenuation compared with the room temperature condition, and the 6# sample vehicle has the highest attenuation degree, with the attenuation rate of 0.815. However, the low-temperature charging capacity of 4# and 5# sample cars is higher than that of normal temperature charging, which is due to different low-temperature charging strategies. The preheating of the batteries of the two sample cars consumes more energy, resulting in the low-temperature charging capacity higher than that of normal temperature charging. See Figure 4 for the time attenuation ratio and power attenuation ratio of low-temperature charging.

Among them, low temperature charging time attenuation ratio coefficient

\[ k_1 = \frac{t_1}{t_2} \]  

(1)

Energy attenuation ratio

\[ k_2 = \frac{E_1}{E_2} \]  

(2)

| NO. | Charging at normal temperature t2 (h) | Charging at low temperature t1 (h) | Time decay scale \( k_i \) | Charging at normal temperature E2 (kWh) | Charging at low temperature E1 (kWh) | Energy decay scale \( k_2 \) |
|-----|-----------------------------------|-----------------------------------|-----------------|-----------------------------------|-----------------------------------|-----------------|
| 1#  | 1.55                              | 3.95                              | 2.5483871       | 28.91                             | 26.71                             | 0.923902        |
| 2#  | 1.35                              | 1.79                              | 1.32592593      | 41.64                             | 41.309                            | 0.992051        |
| 3#  | 0.85                              | 0.96                              | 1.12941176      | 35.16                             | 33.08                             | 0.940842        |
| 4#  | 1.24                              | 2.61                              | 2.10483871      | 40.96                             | 52.53                             | 1.282471        |
| 5#  | 1.07                              | 1.7                               | 1.58878505      | 33.73                             | 36.47                             | 1.081233        |
| 6#  | 0.98                              | 0.93                              | 0.94897959      | 53.69                             | 43.76                             | 0.815049        |
| 7#  | 1.07                              | 2.09                              | 1.95327103      | 41.45                             | 38.92                             | 0.938963        |

Figure 3. AC start charging waveform of a sample vehicle.
Calculate the average charging rate $v$ through the test data

$$v = \frac{E}{t} \quad (3)$$

Where, $v$ is charging rate. See Table 2 for charging rate results of sample vehicle.

![Figure 4. Attenuation ratio statistics.](image1)

**Table 2. Charging rate of test sample.**

| NO. | Charging ratio at normal temperature (kW) | Charging ratio at low temperature (kW) |
|-----|------------------------------------------|----------------------------------------|
| 1#  | 18.65                                    | 6.76                                   |
| 2#  | 30.81                                    | 23.08                                  |
| 3#  | 41.36                                    | 34.46                                  |
| 4#  | 33.03                                    | 21.13                                  |
| 5#  | 31.52                                    | 21.45                                  |
| 6#  | 54.79                                    | 47.05                                  |
| 7#  | 38.74                                    | 18.62                                  |

It can be seen from Table 2 that in low temperature environment, the charging rate is reduced. This is due to avoiding the influence of high current charging on battery life in low temperature environment. By reducing the charging current, and using the vehicle thermal management system to heat the battery. This will inevitably increase the charging time and reduce the charging rate. However, the charging rate of the 1# sample vehicle at low temperature is quite different from that at normal temperature. The charging rate at normal temperature is about three times of that at low temperature, which proves that the low-temperature charging performance of the sample vehicle under the low-temperature charging strategy is poor and needs to be optimized. However, the low-temperature charging performance of the 6# sample vehicle is high. Through the internal low-temperature charging strategy, the low-temperature charging rate has not significantly reduced, and the impact on user experience satisfaction is small.

### 3.2. Comparison test results of different temperatures of the sample vehicle

Through CAN signal acquisition device, it can collect the communication message of EV and EVSE. According to GB/T 27930-2015, we can analyze BCL, BCS, the charger charging state (CCS) and BSM, analyze the relationship between battery demand current and SOC of battery in low-temperature environment, and compare the difference of charging performance in low-temperature environment and normal temperature environment. See Table 3 for the statistical table of physical quantities required by the test included in the corresponding communication message.

Taking the 5# sample vehicle as an example, the charging communication protocol message is analyzed. The voltage and current curves of BCL, BCS, CCS and energy meter in low temperature environment are shown in Figure 5. It can be seen from Figure 5 that the voltages of BCS, CCS and
energy meter are almost identical. There will be a slight difference between BCS current and energy meter current. That is, the current of the power battery is less than the output current of the charging post. See Table 4 for the comparison of BCS current and energy meter collection current in a period of charging. In this period, the current of energy meter is about 6A higher than that of BCS. This part of Table 3.

| Message | Physical quantity collected |
|---------|-----------------------------|
| BCL     | Voltage demand              |
|         | Current demand              |
|         | Charging voltage measurement|
| BCS     | Charging current measurement|
|         | SOC                         |
| CCS     | Voltage output value        |
|         | Current output value        |
| BSM     | Maximum power battery temperature |
|         | Minimum power battery temperature |

Table 4. Difference between BCS current and energy meter current.

| Time identification | 496.67 | 596.67 | 696.67 | 796.67 | 896.67 |
|---------------------|--------|--------|--------|--------|--------|
| Current of BCS(A)   | 27.8   | 28     | 27.4   | 27.5   | 27.3   |
| Current of energy meter(A) | 33.2 | 33.2   | 33.2   | 33.2   | 33.2   |

| Time identification | 996.67 | 1096.7 | 1196.7 | 1296.7 | 1396.7 |
|---------------------|--------|--------|--------|--------|--------|
| Current of BCS(A)   | 27.6   | 27.6   | 27.6   | 27.5   | 27.3   |
| Current of energy meter(A) | 33.2 | 33.2   | 47.6   | 47.6   | 47.6   |

Figure 5. Voltage and current curves of BCL, BCS, CCS and energy.

The current is allocated by the vehicle charging strategy and can be used to heat the temperature of the power battery, which also reflects the charging efficiency of the power battery.

It can also be seen from Figure 5 that the closer the temperature of the power battery is to the nominal temperature, the greater the charging current, the shorter the charging time and the lower the life loss of the power battery.

Figure 6 and Figure 7 show the relationship between the voltage and current of BCL and the highest and lowest battery temperature of BSM at low temperature and normal temperature respectively. The temperature of the power battery in the process of charging in two environments is analyzed. Under normal temperature, the temperature of the highest and the lowest power battery is basically the same, while under low temperature, the temperature of the highest and the lowest power...
battery is obviously different. This shows that the temperature of the power battery pack is unbalanced in the process of charging in low temperature environment. From the perspective of demand current trend, the demand current decreases with time under normal temperature, and increases continuously under low temperature. The difference of growth trend is determined by the temperature of power battery and the SOC value of current battery.

![Figure 6](image.png)

**Figure 6:** The relationship between the key parameters of BCL and BSM at room temperature.

![Figure 7](image.png)

**Figure 7:** The relationship between the key parameters of BCL and BSM at low temperature.

The figure below shows the relationship between the voltage and current of BCS and the SOC of battery at low temperature and normal temperature. It can be seen from Figure 8 that when the vehicle reaches the end of charging condition (80% SOC) at low temperature and normal temperature, the voltage value of BCS is the same, 378V. The charging current at room temperature decreases with charging time, which is contrary to that at low temperature. The maximum charging current can reach 242A under normal temperature, but only 216.2A under low temperature.
Figure 8: Relationship between voltage and current of BCS and SOC of battery at low and normal temperature.

4. Conclusion

In this paper, the electric vehicle is taken as the research object, and 7 sample vehicles are charged in low temperature environment. The data of voltage, current, power and charging message are recorded in the charging process, and the charging performance of electric vehicle in low temperature environment is analyzed. According to the test results:

(1) According to the analysis of the test results of the collective sample vehicle, the AC charging can be started normally in the low temperature environment. The charging capacity of most test vehicles has a certain attenuation compared with the normal temperature, and the charging time has a certain increase.

(2) According to the comparative test results of different temperatures of the same sample vehicle, under the environment of low temperature and normal temperature, the rising trend of charging current is opposite. The input current of battery is less than the output power of the charging pile collected by the energy meter. Under the environment of low temperature, the temperature of battery is uneven, and the maximum charging current is

References

[1] Data of China Business Industry Research Institute. 2019-07-04.
[2] You, H., Dai, H., and Li, L., “The Aging Law of Low Temperature Charging of Lithium-Ion Battery,” SAE Technical Paper 2019-01-1204, 2019, doi:10.4271/2019-01-1204.
[3] Lu Kewei, Wang Lin, Zhao Xiaowei. Low temperature charging improvement of lead-acid battery [J]. Battery, 2018, v.48; no.249 (01): 38-41.
[4] Yang Yumei, Han Youguo, Yao Chaohua, Wu Hongtao. Design and verification of charging control in low temperature environment of battery pack [J]. Power technology, 2019,43 (03): 405-407 + 419.
[5] Wang Hongxia, Wang Yongwu, Zou Yufeng. Study on low temperature performance of lithium-ion power battery [J]. Power world, 2018 (03): 38-39 + 43.
[6] A. L. Karunin, S. V. Bakhmutov, V. V. Selifonov, A. V. Krutashov, E. E. Baulina, E. V. Avrutsky, A. I. Filonov, K. E. Karpukhin, "Hybrid cars - a high road to economical and environmentally friendly transport", Automotive Engineers, no. 3, pp. 38, 2007.