CHARGING STATIONS FOR ELECTRIC VEHICLES IN EUROPE, JAPAN, CHINA AND USA

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ABSTRACT:

In the face of energy crisis and environmental pollution problems in the world, all the countries in the world vigorously promote the development of electric vehicles. Electric vehicle charging infrastructure is the necessary infrastructure to the development of electric vehicles, the construction type, scale and operation mode directly restricts the development of electric vehicle industry. Because of the environment in various countries, the level of development of electric vehicles as well as the different concerns, the electric car commercial operation will also take a different mode of operation. So analysis the different charging system in detail, find out the differences between the countries of the charging system.

The main contents of this thesis include the following aspects:

Firstly, the charge and discharge characteristics of battery for electric vehicles and battery management technology are analyzed, then talk about the three charging modes of conventional charging, fast charging and battery replacement. Also compare the three different modes.

Secondly, charging interface compared by countries, detailed account of the GB/T(China), CHAdeMO(Japan), SAE(America) and IEC(Europe) four standard charging interfaces. Also made a explanation with the variety of standard interfaces in a detailed definition.

Thirdly, analyzed two kinds of electric charge in the process of information transmission: CAN bus communication and PLC communication, introduced two communication modes of information transmission and information layer, and a variety of advantages and disadvantages. At the same time also made examples with which kind of communication were used in each standard.

Finally, summarized the full text, although the charging standards in different countries are different, if the big global automobile manufacturers want to open the market in some different regions, they must conform to the local national standards and regulations. So this paper may as a reference to the major automobile manufacturers.
Chapter 01: INTRODUCTION

1.1 Academic background and practical significance

The development of modern social civilization is largely dependent on oil energy. Since the oil is not renewable resources, with the increasing of oil energy consumption, the energy crisis has become a serious problem faced by human being. While burning fossil fuels will produce a large number of harmful gases, in the global warming but also affect human health, so looking for alternative energy sources has become a concern of all countries.

Electric vehicle charging facilities is an important infrastructure for electric vehicles to provide energy supply operation required, it is a key factor to restrict the development of the electric vehicle industry in addition to the price of the electric vehicle and the manufacturing technology, to do a good job of large-scale promotion of electric vehicles, it is necessary to build a perfect charging facilities service network. The construction of charging facilities in countries all over the world only at the initial stage, most of charging facilities have been built belongs to the exemplary nature, impossible to conduct application in accordance with the corresponding model. Therefore, it is necessary to combined with different electric vehicle charging demand characteristics of good charging facilities construction and regulatory plan, improve the convenience of electric vehicle charging, so as to attract more people to buy electric cars, so as to realize the electric car and charging the implementation of construction of positive feedback, and promote the healthy development of the electric car industry, promote the realization of the strategic objectives of the overall energy of the country.

1.2 World electric vehicle charging facilities

As the United States, Germany and Canada in the early 1980s have developed the electric car, built charging station for electric vehicles to provide emergency services, and to develop a clear charging facilities construction plan, in order to adapt to the continuous development of electric vehicle charging demand.

(1) USA

The development of electric vehicle charging facilities in the United States is very fast. On January 2011, the number of charging stations in the United States is only 1972, by January
2012, has been increased to 6311, to March of 2013, the United States has constructed 5678 public charging stations, 16256 public charging piles, which 3990 is located in California, 1417 is located in Texas, 1141 in Washington State[1].

As the world's largest electric vehicle company Tesla in the California United States, the charging facilities construction of Tesla is swift and violent. In October 2012, Tesla in California established global first super charging station, and free for the owners to provide charging services. June 2013, Tesla has announced that they will along Interstate 5 to build a battery exchange station in California, which can be completed in about 90 seconds for the electric car exchanging work. Tesla also said, to the end of 2013 will set up with battery replacement technology corridor type charging station, by 2015, cover 98% of the United States and Canada. As of the end of 2013, Tesla has already built 71 super charging stations in the United States, across east coast to west coast, Tesla electric car can run from Los Angeles after New Mexico, South Dakota, Wisconsin all the way to New York.

(2) Japan

Japan has been on the electric vehicle charging stations are at the forefront of the world, in March of 2010, Japan established the CHAdeMO Association, to accelerate the standardization of charging facilities related parameters and interfaces.

Nissan, Sumitomo commercial and other Japanese vehicle producers will jointly accelerate the production of electric vehicle charging equipment, plan to 2020 to build 4000 electric vehicle charging stations in Japan, for the purchase of electric vehicles to provide consumers with more convenient services. Nissan, Sumitomo commercial, NEC and other Japan Inc. jointly funded the establishment of Japan Charge network company and cooperation with Familymart convenience chain stores, East Japan high-speed roads, Narita Airport, etc., more than 20 places in the capital region of car sales outlets, convenience stores, the highway service area set fast charging equipment. At the same time, the Japanese JX mine nisseki Sanyo Electric Company also start charging facilities construction and operations, expanding the popularity of electric vehicles charging facilities in the country.

As of July 2013, Japan built a total of more than 4700 electric car charging stations, of which 1700 fast charging stations, more than 3000 regular charging stations. Due to charging facilities can not meet the electric vehicle development needs, Toyota, Nissan, Honda and
Mitsubishi four car companies signed an agreement will be built a 4000 fast charging stations and 8000 conventional charging station, to satisfy the electric car charging demand\textsuperscript{[2]}.

(3) EU

France is one of the most successful countries in the world to promote the application of pure electric vehicles, there are 40 years of experience in the promotion of electric vehicles\textsuperscript{[3]}, at the same time, Paris is the first city to use clean energy vehicles into the bus system of the city, the city has a large number of pure electric buses to participate in public transportation. In addition, EDF is also actively involved in the operation of electric vehicles, the company has 1500 electric vehicles, technical center has specialized in electric vehicle research, promotion and application of the department. Full tracking and service in all areas of convenient transportation, public transportation, urban logistics, municipal vehicles and electric vehicle energy supply infrastructure, etc\textsuperscript{[4]}.

2010 Germany announced the establishment of ‘National platform for electric vehicles’, is divided into 7 working groups, driven by technical working group, battery technology group, infrastructure construction group, etc. Electric vehicle charging facilities has been put into the national development platform. Germany since May 2011 launch electric vehicle exhibition project, in addition to the government, the Ministry of economic affairs, the Ministry of environmental protection and other investment, participating enterprises also actively carry out capital matching, in order to jointly promote the standardization of charging for electric facilities construction.

Based on part of the commitment to environmental sustainability, in 2013, the government of Holland launched a plan, plan to 2015 in the country for the 16 million residents of Holland to build 200 charging stations, reach an average of 50 km per seat.

In September 2013, Austria's largest energy company, Verbund and SIEMENS jointly established the Smatrics company, for the construction of electric vehicle charging station in Austria. By the end of 2013 the number of charging stations in Austria will be increased from 29 to 60, by 2014 will be increased to 80.

(4) China

With the support of China's efforts to promote new energy related policies, China's electric vehicle charging facilities are also at the forefront of the world. On June 2006, BYD research
and development in Shanghai also built the first electric vehicle charging station. In 2008, in order to meet during the Olympics electric buses charging demand, Beijing built the first centralized electric vehicle charging station Beitucheng charging station. 2009, China State Grid Corp built in Shanghai Jiuxi electric vehicle charging station, become the first to have a commercial operation of the function of electric vehicle charging station. Since then, the country began a large-scale charging station construction.

At present, China mainly electric vehicle charging facilities by the State Grid, China Southern Power Grid, Sinopec, PetroChina, CNOOC Putian, BYD, and other enterprises to participate in the construction and operation. The main building is the national grid and southern power grid two major Power Grid Corp, The two Power Grid Corp will as a strategic focus on electric vehicle charging station, hope that in the new energy automotive era use charge stations to replace the status of the gas station. PetroChina, Sinopec, CNOOC three major chemical companies, also saw the charging station construction contains enormous business opportunities, plan to gradually enter the charging station industry, to seize the market.
Chapter 02: Electric vehicle and battery

2.1 Electric vehicle

Electric vehicle, as the name suggests, is powered by electricity, which is at least one kind of power source from car batteries. Electric vehicles can be divided into Battery Electric Vehicle (BEV), Hybrid Electric Vehicle (HEV) and Fuel Cell Electric Vehicle (FCEV) according to the driving mode.

(1) Battery Electric Vehicle (BEV)

BEVs are powered by a rechargeable battery (Mainly for lead-acid batteries, Ni-MH / Ni-Cd battery, lithium battery etc.) or super capacitor to provide power for the car, through the vehicle motor to drive the vehicles. Compared with fuel vehicles, the biggest advantage of BEVs is that it can realize the "zero discharge" of the tail gas, at the same time noise and vibration is small, so BEVs are the first choice models to replace fuel vehicles.

(2) Hybrid Electric Vehicle (HEV)

Hybrid electric vehicle is a car with two or more than two kinds of power source, fuel generators and electric power are usually used as mixed, the use of energy storage elements (rechargeable batteries or super capacitors) to provide power to the car. Collocation ratio according to two different kinds of energy, the hybrid electric vehicle can be divided into four types: micro mixing, light mixing, full mixing and plug-in hybrid, can achieve the effect of two kinds of complementary power.

(3) Fuel Cell Electric Vehicle (FCEV)

Fuel cell electric vehicles are using fuel cells (through the electrochemical reaction from chemical energy conversion to electric energy), as the power source of the car, usually using hydrogen fuel cell as power source. Hydrogen fuel cells do not produce harmful substances in the process of the reaction, at the same time, the energy conversion efficiency is 2-3 times that of ordinary internal combustion engine, so the fuel cell electric vehicle is the future development direction of the car.

2.2 Electric vehicle battery
Electric vehicle power battery is one of the most core parts of electric vehicle, is the main energy source of electric vehicles. In order to meet the needs of electric vehicles, battery in addition to electric vehicles to provide driving force, but also need to provide energy to the relevant vehicle low voltage system, power steering system and air conditioning system, battery characteristics directly affect the driving performance of electric vehicles.

2.2.1 Battery performance parameters

(1) Capacity

The battery capacity is the amount of energy released by the battery from the charging state to a certain condition when the battery is discharged to the cut-off voltage, for the battery can store quantity, the unit is usually A.h. Because the active material in the battery can not be fully utilized by 100%, therefore, the actual capacity of the battery is generally less than its rated capacity.

In the constant current discharge, the actual capacity is:

\[ C = I t \]

In the constant resistance discharge, the actual capacity is:

\[ C = \int_0^t I dt = \frac{1}{R} \int_0^t U dt \approx \frac{1}{R} U_{av} t \]

Form in: \( I \) represents discharge current; \( T \) represents the discharge duration; \( R \) represents the discharge load; \( U \) represents the battery voltage during the discharge; \( U_{av} \) represents the average value of the battery voltage during the discharge.

(2) Energy and power

Battery energy is the power output of the battery under certain discharge conditions, can be expressed as the product of rated voltage and capacity of the battery, the unit is usually W.h. The power of the battery is the energy output by the unit time, the unit is usually W.

Due to the different quality and volume of the battery, in order to facilitate comparison and analysis, can mass energy density (Wh/kg) and volumetric energy density (Wh/L) to represent
the battery energy characteristics and mass energy density (W/kg) and volumetric energy density (W/L) to represent the characteristics of battery power.

(3) State of Charge (SOC) and Depth of Discharge (DOD)

The state of charge of the battery is the percentage of the remaining battery power \( Q_r \), which is the percentage of the battery's rated capacity \( Q \).

\[
SOC = \frac{Q_r}{Q}
\]

During the charging and discharging of the battery, the SOC state of the \( t \) time cell can be expressed as a dynamic state:

\[
SOC_t = SOC_0 + \frac{\int_0^t dt}{Q}
\]

When the battery is full of electricity, the SOC = 1, when the battery is completely discharged, its SOC = 0.

SOC and electric car's remaining life course has the most direct relationship, also on the间接影响 of the owner of the charging demand situation.

Depth of discharge refers to the percentage of battery has the release of electricity for battery rated capacity. According to the definition of state of charge and discharge depth:

\[
DOD = 1 - SOC
\]

In order to avoid the battery overcharge or over discharge, in the course of the operation of electric vehicles, must pay attention to the state of charge and the depth of discharge

(4) Cycle life

Cycle life is that the battery capacity is reduced to a certain standard before, battery can experience the number of cycles of charging and discharging. With the increase of battery charge and discharge times, the chemical properties of the battery will be decreased gradually.

(5) Voltage and Resistance
Batteries can be rated as a voltage source under ideal conditions, its voltage is open circuit voltage, the resistance is the resistance of the voltage source. The working voltage of the battery and the battery load, discharge current, environment temperature and so on have the very big relations. The internal resistance of the battery and the battery of the active material, the state of charge, charge and discharge rate are related.

(6) Working temperature

In order to meet the relative performance of the battery, the battery must work within a certain temperature range, this temperature range is called the working temperature of the battery. When the temperature is high, the battery life will be shortened; when the temperature is low, the discharge capacity of the battery will be reduced.

2.2.2 Battery charging and discharging characteristics

During the charging process, the charging characteristics change with the change of the charging voltage, charging current, ambient temperature and the time of charging.

According to different charging voltage and current, battery charging method can be divided into five types: constant current charging, constant voltage charging, stage charging, pulse charging and intelligent charging.

2.2.2.1 Charging characteristics

(1) Constant current charging

In the process of constant current charging, the charging current is kept constant by adjusting the charging voltage and resistance. Voltage rise at the beginning of the charge is very fast, in the middle stage, the charging voltage is relatively stable, charging voltage has a clear rise in the late charge. The charging process is shown in Figure 2-1.
Figure 2-1 The diagram of constant current charging process

(2) Constant voltage charging

In the constant voltage charging process, by adjusting the charging current and resistance to maintain the battery charging terminal voltage remains unchanged, the charging current decreases with the charging process. The charging process is shown in Figure 2-2.

Figure 2-2 The diagram of constant voltage charging process

(3) Stage charging

Charging process is a combination of constant current charging and constant voltage charging. During the first charging period, the constant current charging is adopted, and constant
voltage charging is adopted at the later stage of the charging. The charging process is shown in Figure 2-3.

![Figure 2-3 The diagram of stage charging process](image)

(4) Pulse charging

Due to the battery in the charging process may produce polarization phenomenon, in order to eliminate this kind of situation, when the charging voltage reaches a certain stage, the battery is charged with constant current by intermittent pulse. The charging process is shown in Figure 2-4[5].

![Figure 2-4 The diagram of pulse charging process](image)
(5) Intelligent charging

Intelligent charging is in the whole process of charging, through the detection of battery voltage change, analysis of the battery can accept the charge current, to the maximum extent to meet the best charging curve and charging. The charging process is shown in Figure 2-5[5].

Figure 2-5 The diagram of intelligent charging process
2.2.2.1 Discharging characteristic

There is a certain relationship between the discharging characteristics and the ambient temperature voltage, the capacity of the battery, the voltage.

(1) Terminal voltage characteristics

The terminal voltage of the battery decreases with the increase of the discharge time of the battery, discharge the battery according to different discharge rate, the end voltage of the battery is also different. The relationship between the working voltage of the electric vehicles and SOC typically shown in Figure 2-6[6].

![Figure 2-6 The diagram of relationship between the battery discharge voltage and SOC](image)

(2) Capacity characteristics

The capacity of the battery is directly related to the discharge rate and temperature. With the increase of discharge rate, the capacity of the battery will decrease. The relationship between the typical electric vehicle battery available capacity and the discharging current is shown in Figure 2-7, the relationship between the available capacity and temperature are shown in Figure 2-8.
Figure 2-7 The diagram of relationship between the available capacity and the discharge current of battery

Figure 2-8 The diagram of relationship between the available capacity and the temperature
(3) Resistance characteristics

In the case of battery discharging, the DC resistance and discharge current and temperature are related, using lithium battery as an example, the discharge of DC resistance and temperature as shown in Figure 2-9.

![Figure 2-9 The diagram of relationship between the lithium iron phosphate battery internal resistance and temperature](image)

2.2.3 Battery Pack Technology

Due to the voltage, capacity, power and other performance of the monomer battery can not meet the needs of electric vehicles, the battery is connected in series to improve the voltage, and the battery is connected in parallel to increase the capacity. This series parallel to the battery to form a battery module to form the final battery technology is called the battery pack Technology.

When the battery is in group application, from the battery to the battery module to the battery pack, the performance of this reduction step by step, service life is significantly reduced, life of the battery pack is only one tenth of the life of the battery. Single cell in the process of grouping, due to the same type of monomer battery performance is not exactly the same, the
internal resistance, voltage and capacity are different, this difference in the use of the process will continue to grow, this inconsistency will reduce the battery capacity, part of the battery gets high voltage and high current during the charging process, the overall performance of the battery pack can be severely affected by the occurrence of over heat and so on.

In order to reduce the inconsistency of different cell in the battery pack, each single battery capacity, internal resistance, voltage, self discharge rate and other performance parameters as consistent as possible the application of cell sorting technique in the assembled battery, in the process of using the battery pack equalization technology makes the battery SOC and other states as far as possible to keep in its parameter range.

2.2.4 Battery management

From the foregoing description and summary, battery technology remains a key constraint for the development of electric vehicles. To deal with problems that can easily arise such as fair use, temperature control, timely problems detection, we need battery management system (BMS) to improve battery efficiency and reliability through effectively monitoring and battery management.

As mentioned above, power battery is achieved by assembling a number of batteries. In fact, not all cells are in the same state. If for the reason of individual batteries damaging or not working properly that cause the entire battery group cannot work, it is an inefficient behavior. Battery management system carries on the unified management for the entire battery module. According to the battery voltage, current, temperature and other parameters to determine the working status of the battery, BMS ensures the smooth operation of the motor car, which includes charging mode selection and execution, battery detection, protection and other major functions. Take TESLA electric cars for example.

Seen from the above TESLA 18650 lithium cobalt oxide used in electric vehicles could meet higher mileage life, but its stability at high temperature as compared to nickel-cobalt manganese lithium (NCM) and lithium iron phosphate is not satisfactory. Therefore, in terms of security there is a need to have BMS to detect and protect.

Each 18650 lithium cobalt oxide battery pack contains the security system, and is distributed to each segment. There are fuses at both ends of lithium cobalt oxide 18650. When the battery is overheating or excessive current, the fuse will cut off the battery in order to avoid an abnormal situation (overheating or excessive current) which may affect the entire battery pack.
Security device is the last barrier. It cut off a cell when there is a problem. If it comes to replacing, the entire battery pack can be replaced in the unit of slice. Each battery is connected in parallel, and different slices and bricks are connected in series. That is, in the process of driving, when a battery has some problems, the vehicle will not stop and the problem will affect only the vehicle mileage.

The reason of monitoring the working status of the entire battery pack and control system of each cell is due to the battery monitoring device which can monitor the status of each battery cells brick. Apart from the current and voltage, it can also identify the cell operating temperature, the relative position of each tile, and whether there is smoke.

Battery temperature is a key factor affecting performance. The conditions will fluctuate when it is too high or too low. Thereby the system needs to constantly balance each battery temperature. The above-mentioned these guarantees on security and battery performance have benefited from this design battery management system.
Chapter 03: Energy supply modes of electric vehicles

Electric vehicle batteries in accordance with the different types of energy supply, can be divided into two modes of vehicle charging and battery replacement. The vehicle charging mode according to the type of charging current and charging time can be divided into two types of AC charging and DC charging.

3.1 Vehicle charging mode

Vehicle charging mode refers to the on-board and off-board charger, charging pile, directly to the electric vehicle battery charge.

3.1.1 AC charging mode

AC charging refers to the external AC charging pile to provide AC power for electric vehicles with on-board charger, through the car charger to realize AC / DC conversion for vehicle battery charging, this charging mode requires the electric vehicle equipped with its on-board charger AC /DC conversion device, Because of its smaller charging current (usually 0.3C - 1C), the charging time is longer, so the AC charging is also known as the AC slow charging.

AC slow charging process begins with a constant current charging, battery voltage grows at a high rate, charge to close to the end of charge voltage, constant current charging stage ends. Then, the voltage is almost constant (or slightly increased), and the charging current drops continuously with the charging voltage of the terminal voltage. When the charge current drops to 0.1C, indicates that the battery is full, the termination of the charge. The basic characteristics of the AC slow charge are as follows:

（1）AC charging current is relatively low, and the charging time is longer, general charging time for 5-8 hours, charging time for large capacity battery, sometimes up to 10 hours or more.

（2）AC charging required power supply and charging current is relatively low, charging equipment and installation costs are relatively low.

（3）The use of AC charging can be selected in the grid load trough charging, the use of peak valley electricity price in the lower valley price, you can reduce the cost of charging
（4）AC charging equipment has the characteristics of simple, convenient and fast from the user point of view.

（5）AC charging mode for the vehicle charging mode, charging equipment is mainly AC charging pile.

3.1.2 DC charging mode

DC charging refers to the AC / DC conversion through the non vehicle DC charger, to change AC to DC, charging for electric vehicle batteries, DC charging are a vehicle charging mode, the main charging equipment is DC charger. DC charger is independent outside the body, the DC cable and standard interface is directly connected with the electric vehicle battery to supply energy for vehicle, electric vehicle itself does not need to be equipped with AC / DC conversion charger, DC charger is usually installed in the charging station.

AC slow charging time is longer, can not meet the demand for electric vehicles, When the electric car running in the process of low battery power, it is necessary to carry out DC fast charging. General charging current of 1C-5C, the fast electric energy supply on the vehicle using large DC current, the charging time of 12 minutes to 1 hours, because the DC charging time is short and the charging speed is fast, the direct current charging is also called DC fast charging. DC fast charging is usually not required to fully complete the battery, only need to meet the needs of the following driving. It is in 10 to 30 minutes to charge the battery from 50% to 80% DC fast charging characteristics are as follows:

(1) DC fast charging current is larger, generally in 1-5C, charging time is relatively short, generally in 12 minutes to 1 hours or so, good convenience.

(2) DC fast charging for battery life damage is serious, only as a supplement to conventional charging, so more for emergency charging.

(3) Due to the adoption of fast charging, the charging current is large, which puts forward higher requirements for the charging technology and method.

(4) The cost of DC fast charging equipment is relatively high.

(5) The charging efficiency of DC fast charge is relatively low.
(6) DC fast charging process will affect the power grid load and power quality, and the protection of the charging process is relatively complex, and increase the risk of the operation of the power grid.

3.2 Battery replacement mode

Battery replacement mode is the use of the battery pack has been charged to direct replacement of electric vehicles will be near the power consumption of the battery pack, to realize the electric car to supplement the power, The entire battery replacement process generally takes only a few minutes. In this mode, the electric vehicle owners can use battery leasing method for battery replacement, so as to save more time and money, and provide the company to replace the battery can provide professional maintenance of the battery, to extend battery life. The characteristics of battery replacement mode are as follows:

(1) Short supply of energy, improve the convenience and efficiency of the use of vehicles.
(2) The replacement battery can be charged at the electricity trough period, reduces the charge cost and improves the economic performance.
(3) Can solve the contradiction between the charging time and the driving distance, realize the fast power supply.
(4) Due to the larger battery weight, the professional requirements of the replacement of the battery is stronger, the need for professionals with professional equipment to quickly complete the replacement of the battery, charging and maintenance.
(5) To charge the replaced battery using split type charging, charging equipment is mainly used to split type DC charger.
(6) Maintenance intensive exchange of battery, the battery is conducive to timely detection of problems, can improve the service life of the battery.
3.3 Comparison of two models

Compares advantages and disadvantages of different modes as shown in Table 3-1:

<table>
<thead>
<tr>
<th>Vehicle charging model</th>
<th>Battery replacement model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy supply time is longer</td>
<td>Energy supply time is short</td>
</tr>
<tr>
<td>Charging voltage is high, and the security is poor</td>
<td>Charging voltage is low, and the security is good</td>
</tr>
<tr>
<td>The power of single charging equipment is big, the technology is difficult</td>
<td>The power of single charging equipment is small, and the technology is mature.</td>
</tr>
<tr>
<td>Charging facilities cost is relatively low</td>
<td>Charging facilities cost is relatively high</td>
</tr>
<tr>
<td>Battery consistency difference increased fast</td>
<td>Can slow the consistency of the battery difference</td>
</tr>
<tr>
<td>Power Harmonic pollution is relatively large</td>
<td>Power Harmonic pollution is relatively small</td>
</tr>
<tr>
<td>Battery life is short</td>
<td>Can effectively improve the battery life</td>
</tr>
<tr>
<td>Charging interface standard is high</td>
<td>Different models of battery standards are not uniform</td>
</tr>
</tbody>
</table>

Table 3-1 Compares advantages and disadvantages of different modes
3.4 Non-contact charging

Whether the vehicle charging mode or the battery replacement mode, the battery charging is generally through the wire and cable to connect the charging facilities and batteries, which belongs to the conductive charging or wired charging. In this way, due to the limitation of geographical position, there is a certain inconvenience, non-contact type charging mode came into being.

Non-contact charging the principle is the use of electromagnetic induction or radio wave mode, the electric energy is converted into a special laser or microwave beam, and a receiver is arranged on the electric vehicle, and the energy is converted into electric energy and is charged by the receiving device. According to the different induction methods, non-contact charging can be divided into three kinds of electromagnetic induction, microwave and magnetic resonance. The non-contact charging technology is still in the research stage, did not put to use on a large scale, charging principle as shown in Fig. 3-1:

![Diagram of non-contact charging principle](image)

Figure 3-1 The diagram of non-contact charging principle
Chapter 04: General situation of conductive charging standardization of electric vehicles

4.1 International main standards for conductive charging interface of electric vehicle

At present, the electric vehicle conductive charging is mainly used in two ways: DC charging and AC charging. Because the power of DC car charger can produce higher, so the charging time is short, more for fast charging. Japanese auto companies Nissan, MITSUBISHI and Tesla mainly uses a fast charge of CHAdeMO, to quickly attract consumers. Such as Nissan "Leaf" when used 30 minutes will be able to fill 80% of the electricity. At the same time, Japan has tried to promote its DC fast charging standard to the international electrical commission. And plans to vigorously promote the CHAdeMO approach to Asian countries in the large-scale application of electric vehicles. AC charging voltage commonly used civil power is supplemented by vehicle battery charger, car charger due to the restrictions and the volume of cooling conditions, the lower power, so longer charging time. Therefore, often use the night peak valley electricity for electric vehicles to slow charge.

The electric vehicle charging interface standard is divided into four systems: the International Electrotechnical Commission (IEC), American Society of Automotive Engineers (SAE), Japanese Electric Vehicle Association (JEVS) and Japanese electric vehicle charging Association (CHAdeMO), and Chinese national standards (GB/T).

IEC has released two series of standards, one of which is the IEC 61851-1:2010 "electric vehicle conductive charging system first parts: General requirements", IEC 61851-21:2001 "electric vehicle conductive charging system twenty-first parts: conductive connection to DC / AC power on the electric vehicle requirements", IEC 61851-22:2001 "electric vehicle conductive charging system twenty-second parts: AC electric vehicle charging station", Another series of standards is IEC 62196-1:2011 "electric vehicle conduction charging first parts: General requirements", IEC 62196-2:2011 "conductive charging of electric vehicles: compatibility and interoperability requirements for dimensions of AC plug and conductive pipe fittings". EU standards EN 62196-1:2012 and EN 62196-2:2012 are equivalent to the adoption of IEC 62196-1:2011 and IEC 62196-2:2011 to become the European countries
adopt AC charging standards. Because, IEC 62196-3: DC charging interface standard is being developed, so the European countries to use the DC charging interface is not the same.

SAE drafting and promulgation of the relevant standards for the SAE J1772-2010 "electric vehicle conductive charging connector". The purpose of the standard is to determine the electric vehicle in the residential, workplace and public charging stations for the exchange of charging interface definition. But for DC fast charging standard is not released. The UL 2251 "electric vehicles' sockets, plugs and connectors were released in 2007 by the Underwriters Laboratories in the United States, various test methods for connectors are provided.

JEVS draft standard has JEVS C601-2001 "electric vehicle charging plug, socket", JEVS G105-1993 "electric car is suitable for the economic charging station fast charging system connectors". Currently, the Japanese AC charging interface requirements in line with the SAE J1772, DC charging interface requirements in line with the provisions of JEVS G105-1993.

China issued three national standards in the electric vehicle charging interface, respectively GB/T 20234.1-2011 "electric vehicle conductive charging system - Part 1 connection: General requirements", GB/T 20234.2-2011 "electric vehicle conductive charging connector - Part 2: AC charging interface", GB/T 20234.3-2011 "electric vehicle conductive charging system - Part 3 connector: DC charging interface". The three main reference standard IEC 62196, so the Chinese charging interface standard and technically closer to EU standards. Although the standards are voluntary standards, but to solve the different domestic Chinese automakers, companies charging different grid interface is not uniform issue.

4.2 Analysis and comparison of key technical indexes of electric vehicle conductive charging connector

Below for Europe, America, Japan and China four widely used electric vehicle conductive charging connector standards, Focus on its charging mode, rated value, plug power, protection level 4 key technical indicators for comparative analysis, find out the difference of each standard, and analyze the future development of the conductive charging connector standard.

4.2.1 Charging mode standards

(1) EU standards
European standard EN 61851-1: 2011 is equivalent to international standards IEC 61851-1: 2010 defines the following four kinds of charging mode.

Charging Mode 1: The electric car is connected to the current does not exceed 16A, the voltage does not exceed 250V of the single-phase AC power grid or voltage does not exceed 480V of the three-phase AC power grid, the use of socket has been standardized in the power supply conductor and use phase line, neutral line and ground protection.

Charging Mode 2: The electric car is connected to a current does not exceed 32A, 250V single-phase AC voltage does not exceed the power grid or the grid voltage does not exceed the three-phase AC 480V, the power supply side the use phase, neutral and protective earth conductor, and electric installed or on the control box on the cable between the car and the power supply plug guide means having a control and leakage current protection device (RCD). The control box on the cable should be installed in an electric vehicle or a plug from the power supply device within 0.3 meters, or installed in the power supply plug.

Charging Mode 3: When the electric vehicle is connected to the AC power grid, a special power supply device is used, the electric vehicle is directly connected with the AC power grid, and a control guiding device is arranged on the special power supply equipment.

Charging Mode 4: When the electric vehicle is connected to the AC grid, using off-board charger, the electric car will be indirectly connected with the AC power grid, and on-board charger control guide device installed[7].

(2) American standards

American Standard SAE J1772: 2010 defines three kinds of charging modes, namely:

AC Level 1 Charging: A method that allows an EV/PHEV to be connected to the most common grounded electrical receptacles (NEMA 5-15R and NEMA 5-20R). The vehicle shall be fitted with an on-board charger capable of accepting energy from the existing single phase alternating current (AC) supply network. The maximum power supplied for AC Level 1 charging shall conform to the values in Table 1. A cord and plug EVSE with a NEMA 5-15P plug may be used with a NEMA 5-20R receptacle. A cord and plug EVSE with a NEMA 5-20P plug is not compatible with a NEMA 5-15R receptacle.

AC Level 2 Charging: A method that uses dedicated AC EV/PHEV supply equipment in either private or public locations. The vehicle shall be fitted with an on-board charger capable
of accepting energy from single phase alternating current (AC) electric vehicle supply equipment.

DC charging: A method that uses dedicated direct current (DC) EV/PHEV supply equipment to provide energy from an appropriate offboard charger to the EV/PHEV in either private or public locations.[8]

(3) Japanese standards

Japan Electric Vehicle Association has developed a JEVS G101~G105 "electric vehicle fast charging system" series of standards, regulations and performance test requirements DC charging modes, including charger, lead-acid battery, charging station, communication protocols, connector. Although Japan is not defined in the standard charging mode all kinds, according to Japan's current development situation, Japan to promote and develop DC charging mode[9].

(4) Chinese standards

China Standard GB/T 18487.1-2001 "electric vehicle conductive charging system - General requirements" and GB/T 20234.1-2011 are four kinds of electric vehicle charging mode is defined, its definition and description of functional requirements is basically the same with IEC 61851-1.

Charging Mode 1: Connected to the AC power grid in the electric car, in the power supply side used in line with the rated current of the requirements of GB 2099.1, not less than 16A plug and socket, in the power supply side using the phase line, neutral and protective grounding conductor, and use the earth leakage protective device in the power supply side.

Charging Mode 2: When the electric vehicle is connected to the AC power grid, the power supply side uses a plug socket which meets the requirement of GB 2099.1, on the supply side used phase line, neutral and protective grounding conductor, and the charging connecting cable installation guidance and control device.

Charging Mode 3: When the electric vehicle is connected to the AC power grid, a special power supply device is used, the electric vehicle and the AC power grid are directly connected, and a control guiding device is arranged on the special equipment.
Charging Mode 4: Electric vehicle is connected to AC power grid, using off board charger, electric vehicles and the AC grid connected indirectly[10].

Different modes of power supply equipment rated as follows:

<table>
<thead>
<tr>
<th>Charging mode</th>
<th>Nominal voltage</th>
<th>Nominal current</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>220V(AC)</td>
<td>16A</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>32A</td>
</tr>
<tr>
<td>3</td>
<td>440V/750V(DC)</td>
<td>125A</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>250A</td>
</tr>
</tbody>
</table>

The AC power supply equipment provided in public places shall meet the requirements of the charging mode 3

Table 4-1 Different modes of power supply equipment rated

4.2.2 Ratings

The nominal value of the charging voltage and current is influenced by the power structure of each country and region, and the regulation of the maximum voltage and current is different. IEC 62196-2:2011 specifies the rating of the AC charging interface, the DC rating is under consideration, no release. At present, the European Union and the United States are not on the DC charging interface, the AC charging interface to the United States and Japan only provides a single phase voltage and current rating. China standard GB/T 20234.2 and GB/T 20234.3, respectively, provided the AC charging and DC charging voltage and current rating.

The standard of charging voltage and current of each country is shown in the following table 4-2:
<table>
<thead>
<tr>
<th>Different regions</th>
<th>Interface types</th>
<th>Maximum voltages/V</th>
<th>Maximum currents/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>AC Single phase</td>
<td>250</td>
<td>70</td>
</tr>
<tr>
<td>EN 62196-2</td>
<td>Three phase</td>
<td>480</td>
<td>63</td>
</tr>
<tr>
<td>DC</td>
<td>Not defined</td>
<td></td>
<td></td>
</tr>
<tr>
<td>American</td>
<td>AC Single phase</td>
<td>240</td>
<td>80</td>
</tr>
<tr>
<td>SAE J1772</td>
<td>Three phase</td>
<td>Not defined</td>
<td></td>
</tr>
<tr>
<td>DC</td>
<td>Not defined</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>AC Single phase</td>
<td>250</td>
<td>50</td>
</tr>
<tr>
<td>JEVS TG G101-2000</td>
<td>Three phase</td>
<td>Not defined</td>
<td></td>
</tr>
<tr>
<td>JEVS G105-1993</td>
<td>DC 500V</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>AC Single phase</td>
<td>250</td>
<td>32</td>
</tr>
<tr>
<td>GB/T 20234.2</td>
<td>Three phase</td>
<td>440</td>
<td>32</td>
</tr>
<tr>
<td>GB/T 20234.3</td>
<td>DC 750V</td>
<td>250</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-2 Provisions of national standards for charging voltage and current values

### 4.2.3 Insertion and withdraw force

Under normal circumstances, the connector in order to ensure the reliability and stability of the adapted, provisions required insertion force connector can not be greater than the rated value, To ensure that users will not be difficult into the socket, the pull-out force not less than the rated value, to prevent loose or fall, resulting in damage to equipment and disconnected.

IEC 62196-1:2011 provides power supply plug insertion and pull out of the charging socket, the whole process of the vehicle plug insertion and pulling out of the vehicle outlet shall be less than 100N. National standards based on the actual situation of various countries on the connector plug force requirements are different.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AC charging interface</td>
<td>&lt;100N</td>
<td>&lt;60N</td>
<td>Insertion force ≤ 90N Withdraw force ≤ 30N</td>
<td>&lt;140N</td>
</tr>
<tr>
<td>DC charging interface</td>
<td>&lt;100N</td>
<td>&lt;60N</td>
<td>≤ 90N</td>
<td>&lt;140N</td>
</tr>
</tbody>
</table>

Table 4-3 National standards for insertion force requirements
4.2.4 Protection levels

Shell protection grade of the product, to prevent the intrusion of foreign objects, the characteristics of dust waterproof, moisture resistant, to ensure safe use of electricity. IEC 61851-1: 2010 provides that when used indoors, the power supply plug and the power supply socket, the vehicle plug and the vehicle socket are inserted together, the protection should be the lowest level of IP21. When used outdoors, the power supply plug and the power supply socket, the vehicle plug and the vehicle socket are inserted together, the protection should be the lowest level of IP44, the power supply plug and power supply socket, plug and socket vehicle not inserted timely, the level of protection should be respectively reached the lowest IP24.

EU, China on the protection of the connector level requirements are using IP code, but the specific requirements vary. United States has adopted protection class and test methods specified in UL50. However, the definition can be equivalent to IEC 60529 protection class, Japan waterproof rating and test methods specified in JIS D 0203, there is no requirement for dust.

<table>
<thead>
<tr>
<th>Protection level</th>
<th>Europe</th>
<th>America</th>
<th>Japan</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connected</td>
<td>IP24</td>
<td>3R(IP54)</td>
<td>S1</td>
<td>IP54</td>
</tr>
<tr>
<td></td>
<td>IP44(outdoors)</td>
<td>3R(IP54)</td>
<td></td>
<td>IP55</td>
</tr>
<tr>
<td></td>
<td>IP21(indoors)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4-4 National standards for protection class distinction

According to comparative analysis above, it can be concluded that China standards close to EU standards, especially in charge mode, plug and protection level terms with the EU requirements are basically the same, but the degree of protection more stringent than the EU standards. Since the voltage and current rating depending on the power grid structure of each country or region, if only to compare the numerical size can not objectively reflect the technical requirements of the charger.

4.3 Charging couplers in different standards
4.3.1 AC charging couplers

(1) AC charging coupler in GB/T 20236 (China)

The layout of the AC charging coupler is shown in Figure 4-1, 4-2 and 4-3, where totally 7 pins are defined as below:

- AC power (L, N, 250/400 V, 16/32 A),
- Protective earth (PE),
- Control pilot (CP, 30 V, 2 A)
- Connection confirmation (CC, 30 V, 2 A)
- Backup (NC1, NC2)

![Diagram of AC vehicle plug in GB/T 20236](image)
Figure 4-2 The diagram of AC vehicle socket in GB/T 20236

Figure 4-3 The diagram of AC charging interface connection in GB/T 20236
(2) AC charging coupler in SAE J1772 (America and Japan)

The layout of the AC charging coupler is shown in Figure 4-4, 4-5 and 4-6, where totally 5 pins are defined as below:

- AC power (L1, 120 V AC, 1-phase, 12A/16A),

- AC power (L2, N, 208 to 240 V AC, 1-phase, \( \leq 80 \) A),

- Equipment ground/Chassis ground (PE),

- Control pilot (CP, 30 V, 2 A)

- Proximity Detection (PD, 30 V, 2 A)

![Diagram of AC vehicle plug in SAE J1772](image)

Figure 4-4 The diagram of AC vehicle plug in SAE J1772
Figure 4-5 The diagram of AC vehicle socket in SAE J1772

Figure 4-6 The diagram of AC charging interface connection in SAE J1772
(3) AC charging coupler in IEC 62196 (Europe)

The layout of the AC charging coupler is shown in Figure 4-7 and 4-8, where totally 7 pins are defined as below:

- AC power (L1, L2, L3, N, 250/500 V, 32 A),
- Protective earth (PE),
- Control pilot (CP, 30 V, 2 A)
- Proximity (PP, 30 V, 2 A)

![Figure 4-7 The diagram of AC vehicle plug in IEC 62196](image)
The charging interface connection characteristic diagram is almost the same as the GB/T, but the NC1 and NC2 in GB/T should use the L2 and L3 instead separately.

From the point of view of the shape of the communication interface, three standards are different, the IEC Type2 and GB standards is most close to, using the layout of the seven core, seemingly can each other general, but the actual plug in the vehicle end due to respectively by the head of a mother and the male head in core design, so they can not be used interchangeably. SAE standard as a result of the use of only 5 core interface, so it's charging connection interface with GB and IEC type2 completely incompatible. However, SAE and GB are using a mechanical lock structure, and IEC only by the internal electronic lock mechanism for the vehicle plug and socket lock.

4.3.2 DC charging couplers

(1) DC charging coupler in GB/T 20236 (China)

The layout of DC charging coupler is shown in Figure 4-9, 4-10 and 4-11, where totally 9 pins are defined as below. Since the cable should be attached to the EVSE (Electric Vehicle Supply Equipment) permanently, only plug and socket at vehicle side are defined.

- DC power (DC+, DC-, 750 V, 125/250 A)
- Protective earth (PE),
- CAN bus (S+, S-, 30 V, 2 A)
- Connection confirmation (CC1, CC2, 30 V, 2 A)

- Low voltage auxiliary power supply (A+, A-, 30 V, 20 A)

Figure 4-9 The diagram of DC vehicle plug in GB/T 20236

Figure 4-10 The diagram of DC vehicle socket in GB/T 20236
(2) DC charging couplers in CHAdeMO (Japan)

The layout of DC charging coupler is shown in Figure 4-13, 4-14 and 4-15. Due to the use of CAN communication protocol, so in addition to the common connection confirmation, guidance and DC charging pin, there are also two extra pins for CAN communication, so the entire CHAdeMO interface connecting pin up to 10 cores. Where totally 10 pins are defined as below:

- DC power (6, 5, 750 V, 125/250 A)
- Ground wine (1),
- Charging sequence (2, 10, 12V, 2A)
- CAN bus (8, 9, 30 V, 2 A)
- Connect proximity detection (7, 12V, 2A)
- Vehicle charge permission (4, 12V, 2A)
Figure 4-12 The diagram of DC vehicle plug in CHAdeMO

Figure 4-13 The diagram of DC vehicle socket in CHAdeMO
(3) DC charging couplers in IEC 62196-3 (Europe)

The layout of DC charging coupler is shown in Figure 4-15 and 4-16, where totally 9 pins are defined as below. The configuration of IEC 62186-3 is very similar to the GB/T 20236, but it is only charge with current of 250 Amperes.

- **DC power** (DC+, DC-, 750 V, 250 A)
- **Protective earth** (PE),
- **CAN bus** (S+, S-, 30 V, 2 A)
- **Connection confirmation** (CC1, CC2, 30 V, 2 A)
- **Low voltage auxiliary power supply** (A+, A-, 30 V, 20 A)
Figure 4-15 The diagram of DC vehicle plug in IEC 62196-3

Figure 4-16 The diagram of DC vehicle socket in IEC 62196-3
(4) DC charging couplers in SAE J1772 (America)

The layout of DC charging coupler is shown in Figure 4-17, 4-18 and 4-19, where totally 7 pins are defined as below. But for DC charging, there are only 5 pins are defined, the pins of L1 and N/L2 are unused when in DC charging, actually this is a combo coupler.

- DC power (DC+, DC-, 600 V, 200/80 A)
- Equipment/chassis ground (PE),
- Control pilot (CP, 30 V, 2 A)
- Proximity (CS/PP, 30 V, 2 A)
- Low voltage auxiliary power supply (A+, A-, 30 V, 20 A)

![Figure 4-17 The diagram of DC vehicle plug in SAE J1772](image)
Figure 4-18 The diagram of DC vehicle socket in SAE J1772

Figure 4-19 The diagram of DC charging interface connection in SAE J1772
As with the AC charging communication interface, the standards of IEC and GB/T are most close to, but the SAE and ChadeMO are totally different, the SAE use a combo charge interface as a DC charge interface, but the pins on the combo coupler also can use as AC charge when the L1 and L2/N are defined.
Chapter 05: Communication protocols between off-board conductive charge and battery management system for electric vehicle

One of the most critical issues that restrict the development and popularization of electric vehicles is the performance and application level of the power battery. The goal of optimizing the intelligent charging method of battery is to realize the battery charging, monitoring the discharge status of the battery, avoiding over discharge phenomenon, so as to achieve the purpose of prolonging the service life of the battery and saving energy. Charging intelligent should be through a battery of battery management system and charger and charging pile of seamless connection to achieve.

5.1 Research on communication requirement of electric vehicle charging

At present, whether it is the Chinese national electric vehicle interface standard or other worldwide electric vehicle interface standards, the definition of the rated current provided by the charging interface is not unique, there are a variety of rated current to choose from, so that different regions, and even the same region of different charging points to provide a different charging current. This requires an electric vehicle charging before charging equipment can be obtained to provide the rated current, in order to determine whether to meet the charging requirements. Electric vehicle access grid will affect the planning and operation of the power system, charging without reasonable control of power grid will produce more serious influence. An orderly charging policy charging control grid load is reduced operating risk, improve operational efficiency and reliability of the effective means. When electric cars can be charged with the charging device to interact, get the charging system information, calculate the optimal charging method. Electric vehicle charging can be according to the rates in different periods, the travel demand, battery status, power grid can provide the load information, calculate the most suitable way charging and will need to inform the charging equipment, to achieve the purpose of optimization of charging.

For electric vehicle charging pile and electric vehicle communication, the primary problem to solve is the interface between the two. Currently there are optional Interface: Serial Interface (such as RS232，RS-485，CAN bus etc. ), Ethernet, Wireless communication mode (such as GPRS，Wi-Fi and so on), PLC communication mode.
5.1.1 Special communication cable (Serial Interface and Ethernet)

The most representative and most use of the special communication cable is CAN bus system, CAN bus can be widely used, CAN bus communication with a high degree of reliability, timeliness and flexibility characteristics are inseparable, its main features are as follows:

(1) CAN bus communication method is extremely flexible, it abolished the traditional station address code form, using multi-master work, each node on the network can take the initiative to send a message to one or more other nodes on the bus when the bus is idle.

(2) CAN bus node to transmit to the bus information according to the important degree is divided into different priority, each packet has its own priorities, the priority of the packet is determined by the identifier, ID is smaller, the higher priority. Each message has a unique identifier in the CAN network, which can meet the real-time requirements of different, improve the real-time of CAN communication.

(3) CAN bus with Collision Detection Carrier Sense Multiple Access method, the bus access conflict resolution through non-destructive bus arbitration technology. At the same time, if there are multiple nodes simultaneously send messages to the CAN bus, the bus access violation occurs, then the bus arbitration will be based on priority, low priority nodes send the initiative to withdraw, but can continue to send high priority. As long as the bus is idle, it will not send the packet retransmission. Thereby reducing the bus access conflict arbitration time, avoiding network paralysis under heavy network load caused by the situation.

(4) CAN bus each node after receiving the message sent by other nodes, the first packet identifier is analyzed to determine whether the packet's relevant, if the relevant processing; if not relevant, it is ignored, greatly improving the the reaction speed of the bus.

(5) CAN bus can be realized through packet filtering point-to-multipoint, and global broadcast and other forms of transmission and reception of data, without special "scheduling."

(6) CAN bus transmission rate associated with the communication distance, the maximum transfer rate of up to 1Mbps (which the communication distance up to 40m), the maximum communication distance up to 10km (In this case the transmission rate of less than 5kbps).

(7) The number of nodes on the CAN bus depends on the bus driver circuit, without changing the application layer and the other nodes hardware and software conditions may increase or decrease any node on the bus can be connected to the current up to 110.
CAN bus standard frame (CAN2.0A) message identifier consists of 11-bit binary coding composition, up to 2032; extension of the standard frame (CAN2.0B) message identifier consists of 29-bit binary coding composition, the number hardly Restricted\(^\text{[11]}\).

CAN bus communication using a short frame format, each frame of data is 0 to 8 bytes, the control command to meet the general requirements of work status and test data. Frame communication not only with short transmission time is shorter, but also improve the anti-jamming capability, reduce the error rate and improve the reliability of communication.

CAN bus cyclic redundancy check (CRC), each frame has CRC information, node after receiving information, the CRC is determined by the received information is correct. CAN bus via a cyclic redundancy check error detection as well as through other ways to monitor, filling inspection and packet format, to ensure the reliability of communication data.

CAN bus can use a variety of communication media, twisted pair, coaxial cable or optical fiber, the current widespread use of shielded twisted pair, fiber optic directed popularity trend.

CAN bus interface focused on the physical layer CAN protocol and data link layer functions, you can complete the communication data frame processing, including bit stuffing, block coding, cyclic redundancy check, determine priority and many other features.

CAN bus through fault diagnosis mechanism, at the discretion of the bus node serious error condition has shut down automatically output, cut off contact with the bus, the bus to avoid the impact on other nodes\(^\text{[12]}\).

The disadvantage of using a dedicated communication cable comprising: an existing national standard does not define a dedicated communication cable AC charging. One method is to use two spare terminals and implement communication functions, but involves the modification of the existing national standards and the transformation of the charging cable problem. Taking into account the rising costs, line weight gain and other issues, the existing charging cable are not doing this in which two cores.

### 5.1.2 PLC communication mode

The advantage of the PLC communication mode is that: no need to increase the special communication cable; no need to transform the existing charging equipment; and have good compatibility with the existing charging equipment. Using PLC for communication only
requires the integration of a communication module in the control module of the charging device. The programmable logic controller has the following distinctive features.

(1) Easy to use, simple programming. With the brief ladder logic diagram, or statements programming language, without the knowledge of computer, so the system development cycle is short, easy to debug. In addition, can modify the program online, change the control scheme without dismantling the hardware.

(2) Function is strong, the performance price ratio is high. There are hundreds of thousands of programming elements that can be used by users in a small PLC. It has a strong function and can achieve very complex control functions. It has a high performance to price ratio compared with the same function of the relay system. PLC can communicate through the communication, to achieve decentralized control, centralized management.

(3) The hardware is complete, the user is convenient to use, and the adaptability is strong. PLC products have been standardized, serialized, modular, equipped with a variety of a variety of hardware device for selected users, users can convenient and flexible system configuration, system composed of different functions and different scales. PLC installation and wiring is also very convenient, generally connected to the external connection terminal. PLC has a strong load capacity, can be directly driven by the general electromagnetic valve and small AC contactor.

The hardware configuration can be determined by modifying the user program, which is convenient and fast to adapt to changes in the process conditions.

(4) High reliability and strong anti-interference ability. The traditional relay control system uses a large number of intermediate relay, time relay, due to poor contact contact, prone to failure. PLC software instead of a lot of intermediate relay and a time relay, only with the input and output of a small amount of hardware components, wiring can be reduced to 1/10-1/100 relay control system, because contact contact fault caused by bad is greatly reduced.

PLC adopt the a series of hardware and software anti-interference measures, has a strong anti-interference ability and average fault time to reach more than tens of thousands of hours, can be directly used in industry field, strong interference, PLC has been the majority of users recognized as one of the most reliable industrial control equipment.
(5) The design, installation and debugging of the system are less. PLC software functions to replace the relay control system in a large number of intermediate relays, time relays, counters and other devices, so that the control cabinet design, installation, wiring workload greatly reduced.

The ladder diagram program of PLC is designed by sequential control design method. This programming method is very regular, it is easy to master. For complex control systems, the design of the ladder diagram is much less time than the same function of the relay system circuit diagram.

The PLC user program can simulate the debugging in the laboratory, with a small input signal switch is simulated by the light emitting diode on the PLC can observe the output signal of the state. To complete the installation and wiring system, found in the adjustment process field problems in general can be solved by modifying the program, system debugging time is much less than the relay system.

(6) Maintenance workload is small, maintenance is convenient. The failure rate of PLC is very low, and there is a perfect self diagnosis and display function. PLC or external input device and actuator failure, can according to the PLC on the light emitting diode or a programmer to provide information and quickly identify the fault reason, by replacing module can be quickly ruled out so.

5.1.3 wireless communication mode

At present the wireless communication technology has been quite mature, the application range is also more and more widely, but the wireless communication application in the exchange of charge and it can not overcome the shortcomings.

(1) Poor communication security, the signal is easy to be monitored.

(2) How to successfully identify the charging equipment connected to the electric vehicle.

(3) Improvement of existing charging equipment for electric vehicle.

The third reason is that the existing electric vehicle charging equipment based on safety considerations are using the metal shell, plus decorative non metal shell. In order to reduce the shielding effect of the metal inner casing to the wireless signal, the wireless communication antenna is required to be placed outside the inner shell. How to transform the existing
charging equipment, to ensure the communication while ensuring the protection performance is difficult. So in this topic we only discuss CAN bus communication mode and PLC communication mode.

5.2 CAN bus system between the electrical vehicles and charging stations

CAN (Area Network Control) is a high speed serial data communication network proposed by German Bosch company in the 80 generation in twentieth Century. The earliest application in automotive internal communication is used to solve the wiring harness problem caused by the application of a large number of sensors, actuators and other electronic devices, as well as the data exchange between the various electronic devices. Currently, CAN bus has been developed as an international standard ISO international standards, has been Motorola, Intel, Philips and other companies supported. Can bus has high communication speed, higher reliability, strong anti-interference ability, price advantages, at present not only the application in automotive electronics, but also widely used in the fields of aviation, ships, industrial control, medical equipment and building, automation equipment[13].

5.2.1 CAN bus related concepts

CAN bus related concepts are as follows:

(1) Messages
The data on the bus is sent in different message format, but the length is limited. When the bus is idle, any node on the network can send messages.

(2) Bit rate
In different system, can bus bit rate is different, but in a given system, can bus bit rate is the only, and is fixed. The bit rate of CAN bus is set up by the CAN controller after power on reset.

(3) Priorities
CAN bus through the message identifier to determine the priority of the message, high priority messages can be sent in the bus access conflict priority.

(4) Remote Date Request
In CAN bus, data nodes can send remote frames to other nodes, which require other nodes to send data frames with the same message identifier to obtain the required data.

(5) Multimaster

In CAN bus idle, any node can send message to the bus, called "multi master" mode.

(6) Arbitration

In order to solve the bus access conflict, the arbitration mechanism is introduced in CAN bus. CAN bus through a bit by bit comparison message identifier to achieve arbitration. During arbitration, every transmitter will monitor the level of the bus and send yourself the bit level, and if it continues to send consistent. If the monitoring to the bus level is "dominant" and the level to be sent to "hidden", then the lost arbitration, quit sending state.

(7) Safety

To ensure safe transmission data, CAN bus using a variety of measures, error detection, error calibration and self-test error. CAN bus error detection methods are mainly surveillance, cyclic redundancy check, bit stuffing, and packet format checks. Can check out all the dispatcher error, distribution of up to five arbitrary transmitter all local error message, error, message length less than 15 burst errors, message in either an odd number of errors. All nodes that detect the error will calibrate the error message, the message will be invalid, and will be sent automatically.

(8) Fault Confinement

When the CAN bus in the interference, will be judged as a permanent fault or a short interference. If a permanent fault, the bus will automatically cut off the connection between the fault node and the bus, if the bus is not affected by transient interference.

(9) Single Channel

CAN bus adopts half duplex communication mode, two-way transmission of information through a single channel. Channel can be achieved through shielded or non shielded twisted pair, coaxial cable or optical fiber.

(10) Acknowledgment
All the receiver after receiving the message, the CRC verification, if the message is consistent with the message to send a response flag, if not consistent, then send a response error flag, the error message will be re-sent\(^{[14]}\).

### 5.2.2 CAN bus hierarchy structure

CAN bus protocol specification CAN2.0B, based on the OSI seven layer reference model defines the CAN bus of the three layer, respectively, the physical layer, data link layer and application layer\(^{[15]}\). The hierarchical structure of CAN bus network is shown in Fig 5-1.

![Figure 5-1 The diagram of CAN bus network hierarchical structure](image-url)
The physical layer is the circuit to connect the nodes to the bus. It is mainly divided into three parts: physical signaling layer (PLS), physical medium additional properties (PMA) and media related interface (MDI). The main function of the physical signaling layer (PLS) is to implement the functions related to bit encoding/decoding, bit timing and bit synchronization. Physical medium attachment properties (PMA) the main function is to define the driver and receiver characteristics, realize the bus to send/receive function, and provide a method of fault detection for bus. The medium dependent interface (MDI) defines the mechanical and electrical interfaces between the physical medium and the medium access unit (MAU) [16].

The main function of the data link layer is to realize the encapsulation and disassembly of the data. In addition to the need to send the data to add additional information to the bus, after receiving the information, the removal of additional information to get data information. Flow control and error control of data transmission in the communication process, to ensure the accuracy of data transmission. Data link layer can be divided into logical link control (LLC) and media access control (MAC). The main function of the logical link control sub layer (LLC) is to realize the selective reception of the message and to provide the overload information by the receiving filter. Media access control (MAC) is the core of the CAN protocol specification, and the main functions of the protocol specification can be divided into two parts [17]. One is the sending function, including:

1. Package of data: add additional information to the sent data frame.
2. Frame coding: CRC calculation, add SOF, RTR, CRC, ACK, etc.
3. Media access management: when the bus occurs more than 7 consecutive "hidden" bits will be able to determine the bus is idle, began to send messages.
4. Execution of Arbitration: bus access conflict, the implementation of arbitration.
5. Error detection: execution monitoring, message format checking.

The other is the receive function, including:

1. Data frame: to receive the data frame to remove additional information, access to data information.
2. Error detection: perform CRC validation, format validation, bit stuffing, etc.
(3) Transmit response: After receiving the message, if the message is received, the message is received.

(4) Error calibration and fault definition.

5.2.3 CAN bus frame type

When CAN bus transfers data, the packet transmission according to certain requirements into different blocks of code, in the transmission of these blocks of code, in the head and tail of a block of code with fixed message format, the code block is clamped in the middle, which constitute the "frame".

There are four types of message transmission in CAN bus, which are data frame (Frame Date), remote frame (Frame Remote), error frame (Frame Error) and overload frame (Frame Overload).

(1) Date Frame

Data frames transmit data from the transmitter to the receiver. It consists of seven fields (field is the basic component of the frame, it is a section of the definition of good logical data, can be data, pointers or links): Start of Frame, Arbitration Field, Control Field, Data Field, CRC Field, ACK Field, and End of Frame. The structure of data frame is shown in fig 5-2.

![Figure 5-2 The diagram of data frame format](image)

(a) Start of Frame

The frame start marks the beginning of the data frame, which is composed of a dominant bit (logic 0), when the bus is idle (more than 7 hidden bits), the node begins to send the message. Hard synchronization of all nodes in the first start of the start of the frame.

(b) Arbitration Field

CAN bus protocol specification defines two frame formats: standard frame and extended frame. The difference between the standard frame and extended frame that arbitration field
from 11 standard frame identifier (Identifier) RTR bit (Remote Transmission Request bit) and composition, the extended frame 29 by the arbitration field identifier (Identifier) and bit SRR (Substitute Remote Request bit), IDE bit (Identifier Extension Bit), RTR bit (Remote Transmission Request bit) components. Standard frame and extended frame format arbitration field are shown in Fig 5-3 and 5-4.

(c) Control Field

Control Field consists of six bits, it indicates the byte length of the data field. Standard and extended frame control field of the frame is not the same. Standard frame of the control field by the IDE bit (identifier extension), the reservation bit R0 and 4 bit data length code (DLC). Extended frame control field is composed of R0, R1 and 4 bit data length code (DLC). The control field of the standard frame and the extended frame is shown in fig 5-5.

IDE bit (identifier extension) in standard frame (identifier extension) is dominant (logical 0). Reserved bit R1 and R0 must be dominant (logical 0). Data length code (DLC) indicates the
number of bytes in the data field. Data field can have 0~8 bytes, using DLC binary coded representation. For example, the number of bytes in the data field is 2, the DLC3-DLC0 is 0010B.

(d) Data Field

The data field is composed of the data in the data frame, and the data length can be 0~8 bytes.

(e) CRC Field

The CRC field is composed of CRC sequence and CRC Delimiter. The format of the CRC field is shown in fig 5-6.

![Figure 5-6 The diagram of CRC field format](image)

The CRC sequence is obtained by the cyclic redundancy calculation of the frame check sequence, which is used for the CRC test. In the computation of cyclic redundancy, the polynomial is divided into 15 non-filled bit streams, including the start of the frame, the arbitration field, the control field, the data field, and the 0-position. This polynomial is the following polynomial:

\[ X^{15} + X^{14} + X^{10} + X^{8} + X^{7} + X^{4} + X^{3} + 1 \]  

the remainder is CRC sequence. This calculation process can be calculated by using the 15 bit shift register\(^{[19]}\).

After the CRC sequence is the CRC definition, it is a separate hidden bit (logical 1).

(f) ACK Field

The response field includes ACK Slot and ACK Delimiter. The response field format is shown in fig 5-7.
Both the response gap and the response interval are implicit (logical 1). When a receiving node receives the correct and effective message, during the send ACK slot, the response signal to the bus send a dominant position (logic 0), the sending node will be based on the response signal, to determine whether the packet is received correctly.

(g) End of Frame

The end of the frame consists of 7 hidden bits (logical 1), which indicates the end of a frame.

(2) Remote Frame

A node on the bus can request another node to send a data frame with the same identifier by sending a remote frame. The remote frame is composed of the frame start, the arbitration field, the control field, the CRC field, the response field and the frame end. The remote frame format is shown in fig 5-8. Compared to the remote frame and data frame, no data field, and remote frame RTR for recessive (logical 1), contrary to the data frame. Since the remote frame does not have a data field, the data length code (DLC) does not have any meaning, it can be any number between 0~8. The remote frame is also divided into standard format and extended format, the standard format of the remote frame of the arbitration field has 11 identifiers, and the extension of the format of the arbitration field has 29 bit identifier.

![Diagram of ACK field format](image)

**Figure 5-7** The diagram of ACK field format

![Diagram of remote frame format](image)

**Figure 5-8** The diagram of remote frame format
(3) Error Frame

When an error is detected on the bus, the node sends the error frame to the bus. Error frames are composed of Error Flag Superposition and Error Delimiter of different nodes. Error frame format as shown in fig 5-9. Error flags are divided into Error Flag Active and Error Flag Passivity. The active error flag consists of 6 successive dominant bits (logical 0). An active error flag is sent to the bus to indicate the error, as detected by the error "active" node; The active error flag does not conform to the CAN bus message bit filling rules, other nodes after discovering the error, CAN bus to send an active error flag, which cause the error flag overlap. Error flag for 6~12 bit.

![Error Frame Diagram](image)

Figure 5-9 The diagram of error frame format

Passive error flag consists of 6 successive hidden bits (logical 1). An error "passive" node is detected, sending a passive error flag on the bus to indicate the error.

The error definition is made up of 8 recessive (logical 1).

(4) Overload Frame

An overload frame provides an additional delay between adjacent data frames or remote frames. The overload frame is composed of Overload Flag Superposition and OverloadDelimiter. The overload frame format is shown in Fig 5-10.

![Overload Frame Diagram](image)

Figure 5-10 The diagram of overload frame format
The overload flag is composed of 6 consecutive dominant bits (logical 0). Due to the overload flag in violation of the rules of the interval of the intermittent field, the other nodes in the detection of overload signs will send overload flag, resulting in the overlap of the overload flag. Overload flag can be sent when the node is in the following three cases:

(a) The delay of the next data frame or remote frame caused by the internal cause of the receiver.

(b) A dominant position (logical 0) is detected in the first or second bit of the interval.

(c) A dominant bit (logical 0) is detected in the last bit of the error frame or the overload frame, and also sends an overload flag, but the error counter does not increase.

The overload definition is made up of 8 hidden bits (logical 1).

(5) Interframe Space

The inter frame space is mainly used to separate the data frame or the remote frame from the front frame. Error frames do not need to be separated from the frame before the overload frame.

The inter frame space consists of a batch field and a bus. The inter frame space format is shown in fig. If a node has just sent a passive error flag, the inter frame space consists of the intermittent field, the suspended transmission, and the bus idle. At this time the inter frame space format as shown in fig 5-11 and 5-12.

Figure 5-11 The diagram of interframe space format (1)
The interval consists of 3 hidden bits (logical 1). During the interval, all nodes are not allowed to send data frames or remote frames. Bus free time is arbitrary. When the bus is free, any node can send message to the bus. Suspend transmission is a node in the transmission of a passive error flag before sending the next message, between the intermittent field and the bus, the 8 hidden bits are transmitted between the idle and the bus. If the other node needs to send a message at this time, the node is converted to a receiving node.

5.2.4 CAN bus communication principle and communication flow

CAN bus communication process can be divided into the following: sending request, bus arbitration, message transmission, error detection and receiving response.

(1) Sending request

The microcontroller will need to send the data to the CAN controller, the data in the CAN controller will be filled in accordance with the bit stuffing into the message form. The microcontroller sends the command register to the request bit TR to set 1, ready to send the message.

(2) Bus arbitration

The CAN controller monitors the bus level, and when the bus has 7 hidden bits, it is determined that the bus is free. At this time all the CAN nodes are hard synchronization and frame start front. When two or more nodes transmit the message at the same time, it causes the bus access conflict. In order to solve the problem of bus access conflict, the arbitration mechanism is introduced into the CAN bus. CAN bus through the message identifier bit by bit comparison to achieve arbitration. During the arbitration period, each transmitter compares the bus level of the monitoring to the transmission bit level, and continues to transmit if the same is consistent. If the monitoring to the bus level is dominant, and the level is about to send hidden, then lose the arbitration, to exit the state. Each message has a unique identifier.
The lower the binary value of the identifier, the higher the priority. First, the message is sent to the identifier and the RTR bit, since the RTR bit of the data frame is 0, and the priority of all data frames is higher than that of the remote frame.

(3) Message transmission

CAN bus in the form of a frame to send messages. In the transmission of the frame of the arbitration field, control field, data field, CRC field, if the transmission node to monitor the sent, will be in the flow of the insertion of a complementary bit.

(4) Error detection

Error detection in the receiving process mainly consists of bit stuffing error, CRC error and response error. Because the frame is inserted into the filling position during the transmission, the next bit will be automatically deleted after receiving the 5 same type of bit. The fill bit must be removed from the previous bit, otherwise it is filled with errors and is marked. The receiving node receives a CRC sequence from the received frame and the computation is carried out. Compared with the received CRC sequence, if the CRC sequence is not consistent with the sequence, and the CRC error occurs and is marked. During the interval, if the level of the bus is not dominant, a response error will be marked. In the event of filling mistakes or response error, the error was detected in a node will send a wrong sign. When an CRC error is detected, the node will send an error flag at the next bit of the reply. The wrong frame will be re sent when the bus is idle.

(5) Receiving response

After receiving the correct message, the receiving node sends a dominant position to the bus during the interval of the response. CAN bus error detection mechanism also provides a response to the error detection\textsuperscript{20}\textsuperscript{21}.

The communication flow of CAN bus is shown in fig 5-13.
5.3 Protocol design of pure electric vehicle based on CAN bus

CAN bus protocol is mainly divided into three layers: physical layer protocol, data link layer protocol and application layer protocol. CAN bus protocol strictly defines the physical layer and data link layer protocol, but there is no strict definition of application layer protocol, users need to design their own needs according to their own needs. There is no unified standard for pure electric vehicle application layer protocol, and therefore need to design pure electric vehicle application layer protocol according to the characteristics of pure electric vehicles. In China, Japan and USA, the standard of GB/T and SAE (include ChadeMO), they both use the CAN bus to communicate when the electrical vehicles in charging, and GB/T and SAE
(include ChadeMO) are almost the same, so in this section topic we just study the SAE to know how the CAN bus works in the electrical vehicles charging.

5.3.1 SAE J1939 protocol

SAE J1939 protocol\(^{[22]}[23]\) is SAE (of Automotive Engineers Society) issued by the CAN bus communication protocol standard serial communication and control protocol standard car network. The J1939 protocol to the CAN2.0B\(^{[24]}[25]\) protocol as the core, according to the OSI hierarchical structure, the CAN bus based on the definition of basic physical layer and data link layer defines network layer and application layer protocol. The following is the main content of the SAEJ1939 protocol:

SAE J1939: Vehicle network serial communication control general standard, the standard gives the standard communication structure, summary the main contents of each sub standard, parameter group number (PGN), source address (SA) and the fault definitions code (DYC) are listed in the appendix.

SAE J1939/01: Truck and bus control sub standard, the sub standard is being drafted, for the J1939 unique, there is no corresponding OSI corresponding.

SAE J1939/11: Physical layer standard and the sub standard provisions of the network hardware should be in line with CAN2.0B standard, the highest network communication rate, maximum number of nodes, the length of bus, communication media such as physical layer network electrical characteristics and physical layer implementation function is defined.

SAE J1939/13: Non - car diagnostic equipment interface sub standard, the sub standard defines the interface format of other diagnostic equipment except the vehicle self - diagnosis equipment.

SAE J1939/21: The data link layer, the sub standard data frame structure (using the CAN 29 bit extended frame format, encoding rules). Including communication priority, bus arbitration, communication format, communication requirements, error detection and processing.

SAE J1939/31: The sub network sub standard, standard connection agreement between different networks.


SAE J1939/5X: Presentation layer standard paper, set aside.
SAE J1939/6X: Session layer paper standard, set aside.

SAE J1939/71: Application layer sub-standard, the sub-standard vehicles commonly prescribed physical parameter data format. Including parameter data length, resolution, and range type, group number, refresh rate, meaning you data field, the default priority and so on.

SAE J1939/73: Diagnostic criteria of the application layer, which is mainly aimed at the diagnostic requirements, provides the information of the 12 diagnostic results, and gives the definition of the 3 types of error patterns in the appendix.

SAE J1939/75: Application level settings and industrial sub standards: the sub standard provides application layer revision and application.

SAE J1939/81: Network management sub standard, the sub standard defines the ECU address management and distribution, processing and ECU naming methods.[26][27]

5.3.2 Physical layer protocols

SAE J1939 physical layer protocol mainly provides the highest transmission rate of the network, the maximum number of nodes, bus length, transmission media, such as the physical layer of the electrical characteristics of the physical layer as well as bit level, bit synchronization and so on[28].

(1) Electrical characteristics

In accordance with the provisions of J1939 protocol, in the same segment within the region, up to a maximum of 30 ECUs are connected, the bus length of up to 100m, the transmission rate set is 250 Kbps. Bus transmission medium for shielding twisted pair, two lines were CAN_H and CAN_L, third lines for shielding line CAN_SHLD. Because the transmission of the CAN bus is the differential voltage signal, the interference of the two line is consistent, so it can effectively avoid or reduce all kinds of electromagnetic interference. At both ends of the bus to match a 120 termination resistor, this can effectively avoid the bus to lose a ECU node and cause the bus network to lose the terminal, improve the network communication reliability[29].

(2) Bit level

CAN bus transmission is a differential voltage signal, the signal value at a certain time, the bus is determined by the difference between the voltage $V_{CAN,H}$ and $V_{CAN,L}$ two lines ,which
is $V_{\text{diff}}$. J1939 protocol provides for two complementary logic state on the CAN bus, the "dominant" status and "recessive" state. $V_{\text{CAN,H}}$ and $V_{\text{CAN,L}}$ was about 2.5V in static, this time $V_{\text{diff}}$ approximately zero, then the state is represented as a logical "1" stands for "recessive" state. When the bus is displayed as "recessive" state, said the bus is idle or bus in a "recessive" state. The voltage amplitude of $V_{\text{CAN,H}}$ is 2.5V~3.5V, the voltage amplitude of $V_{\text{CAN,L}}$ is 1.5V~2.5V, when the $V_{\text{CAN,H}}$ is higher than $V_{\text{CAN,L}}$, $V_{\text{diff}}$ is about 1, the state is represented as a logical "0", on behalf of the "dominant" status. When the bus is displayed as "dominant" status means that there are messages sent on the bus. "Dominant" status can override "recessive" state. When different ECU nodes simultaneously send a "dominant" status and "recessive" state to the bus while the bus is displayed as "dominant" status. The following figure 5-14 shows the physical layer level setting bits\[^{30}\].

![Diagram of bit level](image)

**Figure 5-14** The diagram of bit level

(3) Bit synchronization

Bit synchronization is to ask the CAN bus communication, transmitting and receiving nodes consistent time reference, including the agreement on the start time, the bit boundary, repetition frequency. Bit synchronization can be divided into hard synchronization and re synchronization. Hard synchronization refers to before sending within synchronization forced CAN controller all the time is back, not all frames transmitted in frame start state. Re synchronization refers to the signal transmission process, in order to compensate for signal transmission in the process of time difference adjustment. In a bit of time, can only use a synchronization on the bus when the bus is idle, hidden from the state to the dominant state, hard synchronization would be enforced.
(4) CAN bus standard interface

The standard CAN bus interface\textsuperscript{31} is shown in Fig 5-15:

![Diagram of CAN bus standard interface](image)

**Figure 5-15** The diagram of CAN bus standard interface

The standard CAN bus interface function shown in table 5-1:

<table>
<thead>
<tr>
<th>PIN</th>
<th>SIGNAL</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>CAN_L</td>
<td>CAN_L signal line</td>
</tr>
<tr>
<td>7</td>
<td>CAN_H</td>
<td>CAN_H signal line</td>
</tr>
<tr>
<td>3, 6</td>
<td>GND</td>
<td>Ground</td>
</tr>
<tr>
<td>5</td>
<td>CAN_SHLD</td>
<td>Shielding wire</td>
</tr>
<tr>
<td>1, 4, 8, 9</td>
<td>NULL</td>
<td>NULL</td>
</tr>
</tbody>
</table>

Table 5-1 CAN bus standard interface function

### 5.3.3 Data Link Layer Specifications

The main function of data link layer protocol SAE J1939 protocol provides reliable data transmission for the physical connection, defines the frame format and encoding rules of information frame. Including the node information, communication priority, data definition, bus arbitration and so on\textsuperscript{32}.

(1) Frame format of SAE J1939

The SAE J1939 protocol format using CAN 2.0B protocol as the basis, using the extended frame format of CAN bus, the main difference is that J1939 protocol of 29 bit identifier (ID) is redefined and divided in detail, characteristic of the message identifier can describe the
message more comprehensive and detailed. SAE J1939 protocol identifier by priority (P), the reservation (R), data page (DP), PDU (PF), specific PDU (PS), source address (SA) of 6 parts. SAE J1939 uses a new data format of PDU protocol data unit to implement the data package. PDU protocol data unit is actually composed of 29 bit identifier and data field of two parts[33].

Protocol data unit format is shown in table 5-2:

<table>
<thead>
<tr>
<th>Priority (P)</th>
<th>Reservation (R)</th>
<th>Data page (DP)</th>
<th>PDU (PF)</th>
<th>Specific PDU (PS)</th>
<th>Source address (SA)</th>
<th>Data Field (DA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3bits</td>
<td></td>
<td></td>
<td>8bits</td>
<td>8bits</td>
<td>8bits</td>
<td>0~8bits</td>
</tr>
</tbody>
</table>

Table 5-2 Protocol data unit PDU format

Protocol Data Unit (PDU) of the various parts of the following meanings:

Priority (P): Consists of three bits, said the message priority. The priority from the 0~7, is divided into 8 level, 0 level of the highest priority, said 000B, 7 of the lowest priority, usually expressed as 111B, the emergency alarm message priority is set to 0, some high speed control information, or real-time message priority high, and node state information or message priority request frame is low.

Reservation (R): Accounting for one, are reserved for future expansion left to use. Is set to 0.

Data page (DP): Accounting for one, it represents an additional parameter to select SAE J1939 protocol group directory pages, 0 represents the first 0. 1 represents the first one, the current J1939 uses only the first packet 0, it is set to 0.

PDU (PF): Consists of 8 bits, is part of the set of parameters. PDU format (PF) has two forms: PDU1 and PDU2. PDU1 format PF <240, used for point-to-point communication, the message will be sent to a specified address. The PDU2 format of the PF value of >=240, for broadcast communication, the message will be sent in the form of broadcast to the bus.

Specific PDU (PS): Consists of 8 bits, and reserved bits (R), the data page (DP), PDU format (PF) together form the parameters set. Specific PDU (PS) value depends on the PDU format (PF) value when PF<240 when, PS is the value of the destination address (DA), when PF> time = 240, PS value of extended group (GE).
Source address (SA): Consists of 8 bits, said node sends message. SAE J1939 in the bus protocol, each node has a unique source address.

Data Field (DA): From 0 to 8 bytes. When the data is larger than 8 bytes, a multi-frame format sent.

(2) Message type of SAE J1939

SAE J1939 defines five message types: Command, Request, Broadcast/Response, Acknowledgement, Group Function. Different types of messages through the parameter group number (PGN) to confirm.

Command: Used by the source address destination address or global address to send control commands, all nodes to the command message after receiving control command issued by the need to execute the command.

Request: To a certain address or the global request to send data. The request message is a special PGN to define.

Broadcast/Response: To adopt the way of broadcasting issued in response to the global address of a node to send data or request.

Acknowledgement: The response message is divided into two types: one is provided by the CAN protocol, when at least one node receives the data, it will send a response frame confirmation data has been received, and if there is no error frame, said data are received correctly. Another response message sent by the application layer, clear of a command or request response.

Group Function: For some special functions, such as network management, multi packet transmission. SAE J1939 did not give a detailed definition of the message, as required by the user can define\(^{34}\).

5.3.4 The application layer protocol

The application layer protocol SAE J1939 defines data interpretation rules, for each command is described in detail, gives a detailed explanation of each data signal. The application layer protocol of SAE J1939 is mainly divided into two parts: data definition and parameter value\(^{35}\).
(1) Parameter definition rules

SAE J1939 application layer protocol of the data signal is mainly through the description of parameters, parameters including data length, scope, types and functions of information. The parameters from the function can be divided into measurement parameters and state parameters. From the numerical type can be divided into discrete parameters and continuous parameters.

Discrete parameters usually consists of 2 to 4 bits, measurement-based discrete parameters commonly used to describe the work of the state of a node or module, such as operating mode, start and stop status. Discrete parameter measurement of 2 bit is usually defined as follows: 00 - (work has been started, open etc.), 01 - has stopped (banned, closed etc.), 10 - indicates an error, 11 - the device is not available or not installed.

Discrete parameter status type usually used for a node or module give instructions, work instructions, such as mode switching, equipment start and stop. Two discrete state parameter type is generally defined as follows: 00 - work (start, open, etc.), 01 - Stop (ban, close, etc.), 10 - reservations, 11 - No action or hold. Definition method 3 to 4 discrete parameters can be defined with reference to the method two discrete parameters define your own.

SAE J1939 practical application layer protocol data transmitted continuous parameters = \text{resolution} \times \text{parameter value} + \text{offset}. The actual range of data transmission in J1939 is not equal to the range of numerical transmission parameters, so the actual data transmission for continuous data transmission, and the signal into a digital signal. Therefore, the definition of continuous parameters using the concept of SLOT, so the transmission parameters can be infinitely close to the actual data. SLOT is the Scaling and Limit, Offset, Transfer function. Transfer Function said the function of data transmission; Scaling determines the accuracy of data transmission; Offset determines the initial value in the range of data transmission; Limit is based on the range of data transmission parameters determining the length, and the offset of the resolution.
The table 5-3 below gives a definition of numerical range continuous parameters:\[36]\:

<table>
<thead>
<tr>
<th>Range Name</th>
<th>1bit</th>
<th>2bits</th>
<th>4bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct signal</td>
<td>0<del>250 0x00</del>0xFA</td>
<td>0<del>64255 0x0000</del>0xFAFF</td>
<td>0<del>4211081215 0x00000000</del>0xFAFFFFFFFFFF</td>
</tr>
<tr>
<td>Parameter details</td>
<td>251 0xFB</td>
<td>64256<del>64511 0xFB00</del>FBFF</td>
<td>4211081216 0xFBxxxxxx</td>
</tr>
<tr>
<td>Reserved range</td>
<td>252<del>253 0xFC</del>0xFD</td>
<td>64512<del>65023 0xFC00</del>FDFF</td>
<td>4227858432 00xFC000000~FDFFFFFFFFFF</td>
</tr>
<tr>
<td>Fault</td>
<td>254 0xFE</td>
<td>65024<del>65279 0xFE00</del>FEFF</td>
<td>4261412864 0xFExxxxxx</td>
</tr>
<tr>
<td>Null</td>
<td>255 0xFF</td>
<td>65280<del>65535 0xFF00</del>0xFFFF</td>
<td>4278190080 0xFFxxxxxx</td>
</tr>
</tbody>
</table>

Table 5-3 Definition of the numerical range of a continuous parameter

(2) The parameter set defined rules

Parameter set is a collection of packets in all parameters. Different sets of parameters identified by the parameter group number (PGN). Parameter group number (PGN) is a 24-bit value, the reserved bits (R), the data page (DP), PDU format (PF), specific PDU (PS) and six supplementary zeros. The following table 5-4 shows the format parameter set.

<table>
<thead>
<tr>
<th>Parameter Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Byte 1</td>
</tr>
<tr>
<td>Bit8~3 Bit2 Bit1</td>
</tr>
<tr>
<td>0 R DP</td>
</tr>
</tbody>
</table>

Table 5-4 Recommended SLOT table

Since reserved bits (R) and the data page (DP) is set to 0, so the parameter group number (PGN) entirely PDU format (PF) in combination with a specific PDU (PS). Value of the parameter group number (PGN) is = PF\times 256 + PS.

When PF < 240, in order to PDU1 format, then PS take the destination address (DA), the PS = 0;
When PG >= 240, in order to PDU2 format, then take the PS extension group (GE), then PS = GE.

Therefore SAE J1939 can define up to \((240 + 16 \times 256) \times 2 = 8672\) set of parameters.

Where 240 is the number of available groups PDU1 format, 16 is PDU2 format usable number of groups, 256 for the extension group (GE) of the maximum value, 2 can use up to two data.

### 5.3.5 Message definition

The whole charging session includes four stages: handshake, parameter configuration, charging, and charging completion. The flow chart is shown in Fig 5-15; corresponding message exchange is summarized in Table 5-5, including communication phases, name and description to the parameters, and the communication directions between EVSE and BMS (Battery Management System).

The fig 5-16 of Overall flowchart for charging:

![Flowchart Image](image)

Figure 5-16 The diagram of the flow chart of message definition
<table>
<thead>
<tr>
<th>Phase</th>
<th>Name</th>
<th>Description</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CRM</td>
<td>Charger identification</td>
<td>EVSE -&gt; BMS</td>
</tr>
<tr>
<td></td>
<td>BRM</td>
<td>BMS and vehicle identification</td>
<td>BMS -&gt; EVSE</td>
</tr>
<tr>
<td>2</td>
<td>BCP</td>
<td>Power battery charging parameters</td>
<td>BMS -&gt; EVSE</td>
</tr>
<tr>
<td></td>
<td>CTS</td>
<td>Time synchronization information</td>
<td>EVSE -&gt; BMS</td>
</tr>
<tr>
<td></td>
<td>CML</td>
<td>Maximum output capacity of EVSE</td>
<td>EVSE -&gt; BMS</td>
</tr>
<tr>
<td></td>
<td>BRO</td>
<td>Battery ready for charge</td>
<td>BMS -&gt; EVSE</td>
</tr>
<tr>
<td></td>
<td>CRO</td>
<td>EVSE ready to charge</td>
<td>EVSE -&gt; BMS</td>
</tr>
<tr>
<td>3</td>
<td>BCL</td>
<td>Battery charging requirement</td>
<td>BMS -&gt; EVSE</td>
</tr>
<tr>
<td></td>
<td>BCS</td>
<td>Battery charging overall statues</td>
<td>BMS -&gt; EVSE</td>
</tr>
<tr>
<td></td>
<td>CCS</td>
<td>EVSE charging status</td>
<td>EVSE -&gt; BMS</td>
</tr>
<tr>
<td></td>
<td>BSM</td>
<td>Power battery status information</td>
<td>BMS -&gt; EVSE</td>
</tr>
<tr>
<td></td>
<td>BMV</td>
<td>Battery cell voltage</td>
<td>BMS -&gt; EVSE</td>
</tr>
<tr>
<td></td>
<td>BMT</td>
<td>Battery temperature</td>
<td>BMS -&gt; EVSE</td>
</tr>
<tr>
<td></td>
<td>BSP</td>
<td>Battery reserve</td>
<td>BMS -&gt; EVSE</td>
</tr>
<tr>
<td></td>
<td>BST</td>
<td>BMS stop charging</td>
<td>BMS -&gt; EVSE</td>
</tr>
<tr>
<td></td>
<td>CST</td>
<td>EVSE stop charging</td>
<td>EVSE -&gt; BMS</td>
</tr>
<tr>
<td>4</td>
<td>BSD</td>
<td>BMS statistic data</td>
<td>BMS -&gt; EVSE</td>
</tr>
<tr>
<td></td>
<td>CSD</td>
<td>EVSE statistic data</td>
<td>EVSE -&gt; BMS</td>
</tr>
</tbody>
</table>

Table 5-5  Message exchange during each phase

The central control unit hardware principle diagram and main function: As shown below, the central control unit controller uses a TMS320LF2407 type of DSP, it will receive the CAN bus on the other node to collect the information, the information through the SCI serial port to display the corresponding interface LCD touch screen. At the same time, it also receives
control commands from the LCD touch screen, and then through the CAN bus to the corresponding node controller, execute the command.

Figure 5-17 The diagram of central control unit hardware schematics

The battery management unit hardware principle diagram and main function: As shown below, the battery management unit master controller also uses TMS320LF2407 type of DSP. It will acquire voltage, current, temperature information from the battery pack via the CAN bus to the central control unit displays. While it balances the battery pack voltage.

Figure 5-18 The diagram of battery management unit hardware schematics
5.4 PLC system between the electrical vehicles and charging stations

At present, there is a significant difference in the communication technology between the electric vehicle and the charging pile around the world. In the world, the research on the charging control of electric vehicles is based on two kinds of technical standards: G3 - PLC and Homeplug GreenPHY. At present, Ford, Mercedes Benz, BMW and other large auto manufacturers, Qualcomm Corp and other chip manufacturers are supporting Homeplug GreenPHY standards, the United States letter, and other chip companies are supported G3 - PLC standards.

5.4.1 Research status of PLC technology and its application in charge control communication system

Power line carrier communication technology is a kind of wire communication mode, which uses the existing power line as a communication channel for signal transmission, referred to as PLC. Although power line carrier communication has been the emergence of decades, but the technology has not been known to the public, and even some experts have not thoroughly understand the technology, this is largely because the power line is a very unique transmission medium, it can not only serve as a medium to provide power, but also can transmit communication information. With the rapid development of communication technology and signal processing technology, PLC technology gradually become building automation, remote meter reading, office automation, security monitoring and other areas of important means to communication, in these areas it can replace proprietary networks.

The principle of PLC communication technology and general radio communication is similar, just the carrier signal transmission channel is the power circuit, as shown in fig 5-19:

![Figure 5-19 The diagram of power line carrier signal modulation](image)
As shown in the fig 5-20, the use of power lines as a communication channel to send data, the transmission side of the carrier communication equipment will be modulated to the high frequency carrier signal, the signal power amplification by the signal power line. High frequency signal through the transmission line to the reception side, carrier wave communication equipment by means of a coupling device isolated high frequency signal, signal after filtering the interference of amplification, amplification of the signal after demodulation reduction for the original binary digital signal.

![Diagram of Power Line Carrier Signal Communication](image)

Figure 5-20 The diagram of power line carrier signal communication

Since the PLC technology was put forward in the early 1920s, it has experienced the development process from analog to digital, which can be divided into two stages:

The first generation of PLC Technology: traditional narrow band low speed PLC (1920s - 2000), the main use of ASK, FSK, PSK and other single carrier modulation, typical representative including ST7536, P300 and M1839 chips. Communication rate is lower than 10Kbps, the ability to adapt is low, the reliability is not high, there is a blind spot in the practical application.

The first generation of PLC Technology: High speed broad band PLC (since 2000), the implementation of broad band power line carrier communication using OFDM modulation technology and encoding technology, and high rate of narrow band power line carrier communication technology. Typical broadband carrier main products are the United States Intellon's 14Mbps, 85Mbps and 200Mbps technology and chip, the Spanish company DS2
45Mbps, 200Mbps technology and chip, the typical high rate narrow band carriers products mainly ST7590, LC2000, ADD1020, MAX2992.

PLC technology from the bandwidth can be divided into narrow band PLC Technology (9kHz-500kHz) and broadband PLC Technology (2MHz-34MHz). Narrow band PLC generally used for load control, remote meter reading, intelligent home; broadband PLC is mainly used for transport Internet access, voice, video and other data services. PLC technology can rely on the ubiquitous power lines to play a role, the developed power supply line provides a broad space for the development of PLC technology. The technology has the advantages of no wiring, easy installation, easy maintenance and so on. At present, the typical PLC technology application scenarios are home automation, remote automation meter reading, intelligent community building.

The ISO/IEC 15118 standard drafted by the International Electrical Commission (IEC) provides the communication interface between the electric vehicle and the electric power grid, PLC technology is considered standard communication technique suitable for use herein. ISO/IEC 15118 standard for PLC technology will bring new opportunities for the development of electric vehicles in the field.

ISO/IEC 15118 standard developed by the International Electrical Commission (IEC), aims to unify the communication interface between electric vehicles and the grid, the standard is divided into three parts:

ISO/IEC 15118-1 Introduction to general technology and applications
ISO/IEC 15118-2 To describe the protocol and the requirements of OSI model
ISO/IEC 15118-3 Requirements for physical and data layer

Among them, the communication flow between the communication control unit (EVCC) and the charging equipment communication control unit (SECC) has been defined by ISO/IEC 15118-1. The standard recommended use PLC technology to solve the communication problem between the electric vehicle and charging pile, and possibly in the appendix briefly gives the PLC technology in this system application scenarios, but it did not detail PLC technology solutions. Nevertheless, the introduction of the standard for PLC technology in the field of electric vehicle charging will also play a role.
5.4.2 PLC communication modulation techniques

PLC technology is a low-cost means of communication, but the initial construction of the power line does not take into account factor of communication, so the application of communication will face some challenges. The general design personnel need to pay special attention to the signal attenuation and noise problem, which require complex transceiver. In order to provide the frequency utilization rate, inhibit the signal attenuation, reduce the error rate, the signal modulation technology is very necessary.

The power line channel is complex and changeable, the general communication standard in modulation technology and media access with appropriate modifications can be applied to the power line. Orthogonal frequency division multiplexing (OFDM) modulation and spread spectrum modulation technology are the two technologies mainly used in low-voltage power line carrier communication, the two techniques of strong anti-interference ability, anti multipath interference, so it can be well used in power line communication of special environment.

5.4.2.1 The application of OFDM technology in PLC

OFDM is a multi carrier modulation technique, which can also be seen as multiplexing technology. OFDM technology of high spectrum utilization, can be effective against narrow band interference and frequency selective fading. Therefore, OFDM technology has been widely used in communication technology.

The principle of OFDM is high speed data encoding after assigned to mutually orthogonal and parallel subcarriers, subcarrier modulation rate is low, and the length of modulation symbols are large, so when there is a big distortion or sudden pulse interference, the use of OFDM technology can effectively protect the digital signal. As shown, OFDM technology allows sub carrier spectrum overlap, which greatly improves the utilization of the spectrum, as long as each subcarrier meet between orthogonal, data signal can be obtained from the overlapping subcarriers. Therefore, OFDM technology is actually a high-speed serial data into parallel low-speed data transmission technique.

As shown in the fig 5-21, with the increase in the number of carriers, carriers gradually superimposed together, the spectrum is very close to rectangular, this theory bandwidth utilization rate can reach the limit Shannon value of information theory.
The principle of OFDM system: Parallel digital signal after modulation through serial parallel conversion into N in the transmitter serial data (can use phase shift keying quadrature amplitude modulation) to get a bunch of complex data flow. Digital modulation used in each sub channel can be different according to the channel condition of sub carrier to decide. After the number of each sub channel flow modulation of the respective channel carrier, the modulated signal superposition can be obtained by the OFDM symbol:

\[
s(t) = \sum_{i=0}^{N-1} d_i \text{rect}(t - ts - t/2) \exp(j 2\pi f_i(t - ts)) \quad t_s \leq t \leq t_s + T
\]

Where N is the number of subcarriers, \(d_i\) is the i-th channel symbol, T is the OFDM symbol duration, \(\text{rect}(t)\) is a rectangular function, \(|t| \leq T/2\); \(f_i\) of the i-th sub-carrier frequency, frequency difference between adjacent carriers is \(\Delta f = 1/T\).

At the receiving end of the k-th subcarrier demodulated, and the integral formula can be obtained within a period of time:

\[
\hat{d}_k = \frac{1}{T} \int_{t_k}^{t_k+T} s(t) \cdot \exp(-j 2\pi \frac{k}{T} (t - t_k))dt = \frac{1}{T} \sum_{i=0}^{N-1} d_i \exp(j 2\pi \frac{i - k}{T} (t - ts))dt = d_k
\]

As can be seen from the above equation, if desired symbol can restore the K-Subcarrier is demodulated, and for other sub-carriers, due to the frequency difference in the integration interval \(\frac{i - k}{T}\) produces an integral multiple of the cycle, the result is 0 points. Separated from the OFDM signal \(s(t)\) in the signal sub-carriers, and then digital demodulation to restore the complex signal into a real signal, and then revert to the parallel-serial conversion data. Thus, the carrier signal N channel modulation required are generated by the sinusoidal signal.
generator, the receiving end of the carrier synchronization requires strictly. So when the channel number is large, the system will be difficult to achieve, resulting in difficulties in application.

IN 1971, Weinstein and Ebert using the discrete Fourier transform and inverse discrete Fourier transform to modulate and demodulate of the baseband signal, so that this method replace sinusoidal signal generator and demodulator, which greatly reduces the complexity of multi-carrier system.

The basic realization of OFDM: First, the sender via the serial data stream and converted into N parallel signals; then, various signals are baseband modulation, each signal can choose different digital modulation schemes (such as FSK, PSK, QAM, QPSK); the output signal do inverse fast Fourier transform. Then, the sub-carrier signals cyclic prefix is inserted, parallel to serial conversion; finally, the signal after D/A conversion, the signal transmitted out by the RF transmitter. The power line channel signal, at the receiving end, the signal is processed by the receiver set opposite process can recover the original data. In order to improve the system better anti-interference ability, can also use interleaving, equalization and channel encoding technology.

Powerline channel exists frequency selective fading obviously, big noise, electromagnetic compatibility and other complex issues, OFDM technology can solve these problems. OFDM will flow high-speed serial data transmission technology into parallel data stream processing speed, which makes the realization of self adaptive technology more simple, can realize the signal transmission in the different frequency band under certain error rate conditions. The receiver measured in each sub carrier signal to noise ratio, SNR feedback to the transmitter in a certain way, the sender can choose reasonable modulation according to the sub carrier of SNR in frequency band signal. For the EMC problem in the PLC, can reduce or close the transmission power of the corresponding band subcarrier, to make the carrier power spectrum density is zero or reduced to meet the requirements of EMC standard.

5.4.2.2 The application of spread spectrum modulation technology in PLC

The so-called spread spectrum communication is brand the information bandwidth, so that data can be transmitted in a wide frequency range, a technology to recover the original information through receiving bandwidth at the receiving end. Spread spectrum communication system for anti-interference ability to decrease the bandwidth, enhance the

82
reliability of information transmission. There are four kinds of spread spectrum modulation:
DSSS - direct sequence spread spectrum, FHSS - frequency hopping spread spectrum,
THSS - time hopping spread spectrum, HSS - hybrid spread spectrum.

The basic theory of spread spectrum communication is the Shannon channel capacity formula:

\[ C \approx W \log_2 (1 + \frac{S}{N}) \]

C: Channel capacity (bit/s)
W: Signal bandwidth (Hz)
N: Noise power
S: The average signal power

When the signal to noise ratio is very small (S/N<=0.1), you can get:

\[ W = \frac{C \cdot N}{1.44 \cdot S} \]

According to the formula shows that if you want to increase the information transmission rate (ie, channel capacity), can be achieved by increasing the bandwidth of the transmitted signal or improving the signal to noise ratio. If the channel capacity C is a constant, you can increase the transmission signal bandwidth by reducing the need for the system signal to noise ratio, the system can also reduce the bandwidth requirements by increasing the signal power. It should be noted that, when the system bandwidth is increased to a certain level, the capacity of the channel can not continue to increase the limit.
Figure 5-22 The block diagram of power line spread spectrum communication

Pictured on the power line spread spectrum modulation techniques in the application schematic. The sender generates a digital signal after signal coding; After spreading code spreading sequence generator can generate the digital signal after the modulation frequency band spreading code obtained broadening. Broadening of the signal by the RF generator for processing after coupling to the power line. The receiver will first broadband RF signal to an intermediate frequency processing; Then, the transmitter and the locally generated synchronous spread spectrum sequences will signal despreading; Finally, after demodulation, restore to the original signal[37].

Compared with the conventional communication systems, spread spectrum communication system has a strong anti-interference ability, when applied to the power line carrier communication, can effectively reduce the signal attenuation, decreasing degeneration, the anti-interference ability is enhanced. Therefore, the spread spectrum modulation is widely used in PLC communication.

5.4.3 Power line carrier communication standard

At present, the PLC modulation technology is based on the OFDM technology, which has been adopted by most of the business alliance and the standardization organization in the world because of its high adaptability and performance. Narrow band PLC standard has Prime series, G3-PLC. Currently the most influential standardization organizations include ITU G.hn, Homeplug[38], HD-PLC, IEEE P1901 and so on, Broadband PLC standard mainly has
Homeplug series standard, UPA series standard, HD-PLC standard and so on. The main technical standards of power line communication are listed in the table 5-6. This section will respectively introduce the G3-PLC and Homeplug GreenPHY standards\(^\text{[39]}\).

<table>
<thead>
<tr>
<th>Working frequency band</th>
<th>G3</th>
<th>Prime 1.3</th>
<th>Prime 1.4</th>
<th>HomePlug AV</th>
<th>Homeplug Green PHY</th>
<th>HD-PLC</th>
<th>DS-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-490kHz/40-90kHz</td>
<td>OFDM</td>
<td>OFDM</td>
<td>OFDM</td>
<td>FODM</td>
<td>2-30MHz</td>
<td>2-28MHz</td>
<td>2-33MHz</td>
</tr>
<tr>
<td>Modulation technique</td>
<td>convol utional code</td>
<td>convoluti onal code</td>
<td>RS code+ convoluti onal code</td>
<td>Turbo code</td>
<td>Turbo code</td>
<td>RS code+ convoluti onal code</td>
<td>RS code+4 DTCM code</td>
</tr>
</tbody>
</table>

Table 5-6 The main technical standards of power line communication

### 5.4.3.1 G3-PLC narrow band communication standard

G3-PLC\(^{[50]}\) is initiated by the French power grid transmission company, Maxim and Sagem Communications jointly developed the standard, which is designed for smart grid communications and the design of the global power line communication open protocol. G3-PLC narrow band power line carrier communication (NB-PLC) standard, commonly used in automatic meter reading (AMR), the energy control and grid monitoring low-speed data communication applications.

Technical principle:

G3-PLC physical layer uses the OFDM technology, working in the frequency range of 10kHz~490kHz. As OFDM technology has high efficient channel coding technology, a strong error correction mechanism and a reliable mode of operation, so it is considered to be the most cost-effective, most secure and reliable means of communication in the smart grid.

G3-PLC specification, in conjunction with a series of advanced technology to build a strong physical layer (PHY) and one based on IEEE802.15.4 standard MAC (medium access control) layer in the layer and the network layer, transport layer and is compatible with the COSEM system application layer. It includes work in CENELEC, ARIB, FCC predetermined NB-PLC bands, can provide 20~240kb/s data transfer rate.
(1) Physical layer

The goal of the G3-PLC physical layer design is to ensure the correct transmission of the data in a very poor NB-PLC environment. It only uses 36 and 72 sub carriers in the CENELEC-A band and FCC band, it reduces the requirement of data transmission rate in theory, and adds more error correction coding and robustness measures, which can achieve the ideal effect in the actual environment test. The PHY layer includes splitting the data frame from the MAC layer and the physical structure of a layer protocol data unit, and based on the received sub carrier signal to estimate the channel signal to noise ratio, calculate the link quality indicators, used as a physical layer adaptive frequency mapping and transmission power control reference and the closure of some not suitable for data transmission frequency channel, and select the appropriate transmission mode.

(2) MAC layer

The MAC G3-PLC layer actually includes two sub layers, which are based on the 802.15.4 MAC type IEEE sub layer and the 6LoWPAN suitable for supporting the IPv6 network.

The MAC sub layer consists of two modules: MAC common part sub layer and MAC layer management entity. The generic MAC sub layer is responsible for neighboring nodes of the communication, the main functions include produce MAC protocol data unit, management CSMA/CA mechanism access mode, guarantee between adjacent nodes direct communication data reliable transmission (ASK mechanism) and data security (AES-128 encryption) and not the same node network selection and addressing mode. MAC layer management entity is through MAC layer information database, a storage has all the information (including the MAC layer and PHY layer and the adjacent nodes two-way communication required for the MAC sub layer protocol state information database) to be responsible for sub layer management service. Its main function is the active scanning for adjacent nodes, MAC layer parameters management, the initialization of MAC layer and PHY layer. With IEEE 802.15.4 MAC sub layer has the advantages of low cost, low complexity, low power consumption advantages, very suitable for the NB-PLC transmission requirements.

6LoWPAN adaptive layer. 6LoWPAN suitable for the use of the sub layer, the network layer for the G3-PLC technology to introduce the IPv6 network technology, which has a wider range of application. It mainly consists of 3 modules: Common processing operation module, Mesh mode routing function module, security and initialization configuration function
module. The public handling module is mainly responsible for handling the transmission frame from the IP network, and the security and initialization configuration function module is responsible for the security of the network. Because the MAC sub layer based on the 802.15.4 IEEE type is used, it is able to provide and support for the topology of the point to point tree, star, and Mesh network. But because the MAC sub layer provides only relevant functional operation primitives, it does not complete the formation of the topology, thus the upper layer protocol must also be responsible for calling the relevant primitives in the appropriate order, complete the formation of network topology. So the technique in 6LoWPAN suitable gametes layer add a mesh mode routing function module, it through LOAD protocol calculated LAN node "overhead", to select the optimal routing path between two points, and thus to establish a complete network.

(3) Network layer and application layer

Connected to the 6LoWPAN is the network layer, which contains the compression of the IPv6 network layer and IP component transport layer, can support a wide range of Internet applications, to ensure the high flexibility of the G3-PLC system architecture. Due to the PLC technology is mainly used in measurement, so the OSI model made some simplifications, used to adapt the application of measurement and generalized to ensure that the measurement and management of the application, and the current application of all are UDP dependent, does not rule out future may depend on TCP. In the metering applications, COSEM interface model introduced and support IPv6 UDP/COSEM package, the standard can be used by different manufacturers production of (with IEC62056 standard) smart metering applications, enhanced interoperability with existing application COSEM metering equipment.

5.4.3.2 HomePlug GreenPHY communication standard

HPA (Home Plug Power Line Alliance) is composed of CISCO, Intel, HP and other companies, is committed to the development of domestic power line communication technology standards organization. 2010 HPA issued a HomePlug GreenPHY (referred to as the HomePlug GP) specification, with support smart grid and electric vehicle applications features. HomePlug GreenPHY standard is a narrow band power line carrier communication standard, usually used in smart home, electric vehicle charging control and other low speed data communication occasions. HomePlug supports HAN (home local area network) within the smart grid devices. HomePlug alliance through GreenPHY HomePlug technology, looking for a means to reduce investment and energy consumption, on the basis of ensuring the
reliability of HomePlug AV/P1901. HomePlug GreenPHY will not affect the existing HomePlug IPTV, video and broadband services. The HAN device can access the smart grid conveniently through HomePlug GP. GreenPHY HomePlug is a simplified version of AV HomePlug standard, which can meet the communication needs of various devices in smart grid, can provide enough bandwidth for existing power grid and the future smart grid devices. In order to describe the basic principles of GP HomePlug, we should first understand the AV HomePlug.

1. HomePlug AV technology principles

HomePlug GreenPHY is a simplified version of HomePlug AV, 2010 HomePlug Smart Energy Technical Working Group organization to make amendments to the HomePlug AV standard, developed the HomePlug GreenPHY standard. HomePlug AV standard includes the MAC layer and the physical layer, HomePlug AV standard uses OFDM technology of IEEE P1901-2010 OFDM standard. The following table 5-7 is some important properties of the HomePlug AV standard physical layer.

<table>
<thead>
<tr>
<th>Physical layer</th>
<th>Modulation frequency band</th>
<th>Modulation technique</th>
<th>Number of sub carriers</th>
<th>Carrier spacing</th>
<th>Sub carrier modulation mode</th>
<th>Forward error correction</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2MHz~30MHz</td>
<td>OFDM</td>
<td>1155</td>
<td>24.414kHz</td>
<td>BPSK, QPSK, 16QAM, 256QAM, 1024QAM</td>
<td>Turbo code, code speed 1/2 or 16/21</td>
<td>ROBO Technology: 4Mbps~10Mbps</td>
</tr>
</tbody>
</table>

Table 5-7 Important properties of the HomePlug AV standard physical layer

HomePlug AV has a bandwidth of 28MHz, frequency range 2MHz~30MHz. The physical layer of HomePlug AV uses the OFDM technology to allocate spectrum, and the spectrum resources are divided into multiple sub carriers to carry out the signal transmission.

(1) Adaptive bit loading and spectrum allocation

Any broadband signal transmitted over the power line will occur in multipath fading. When the transmit signal reaches the receiver through a number of paths, the multipath fading can be generated. The signal in the transmission process, due to different transmission paths, resulting in different signal delay, signal attenuation is also different. When the signal reaches
the receiver at the same time, different paths, different signal attenuation, different delay superposition signal generated by causing multipath fading.

OFDM is the most important modulation technology of HomePlug AV. It has strong robustness, and can restrain the frequency selective fading and multipath fading. OFDM sub carriers with different frequency and different fading characteristics, they have different voltage levels at receiver, OFDM can independently manage these subcarriers.

HomePlug AV uses adaptive bit loading technique. Adaptive bit loading technique allows different sub carriers to use different modulation techniques, thus enabling the carrier channel to be able to transmit the information flexibly. For the transmission characteristics of bad sub carriers, can be used BPSK (binary phase shift keying modulation), each sub carrier symbols only carry 1bits data, so that can enhance the ability to resist interference. Good transmission characteristics of the sub carrier can be used 1024QAM modulation technology, each sub carrier symbol can carry 10bits data.

Adaptive bit loading allows each sub carrier to carry as much as possible according to the different levels of data channel. In the process of communication, the transmitter sends a data packet to the receiver by receiving the data packet to obtain in the sub carrier transmission signal strength. HomePlug AV devices in the same network will send data packets intermittently, the system records and updates the channel information in the form of the received signal spectrum.

Figure 5-23 The diagram of adaptive bit loading technique to optimize data throughput
The received signal spectrum depicts the intensity of each sub carrier signal that contains the OFDM symbol. HomePlug AV standards are divided into a total of 1155 sub carriers. The magnitude of each frequency point is recorded by the receiver at the frequency point to receive the signal strength. In AVLN (HomePlug AV logical network), each device is unique, will not be confused with other devices, each HomePlug AV client must maintain the acceptance signal spectrum of all the devices in the same network, so as to select the appropriate subcarrier modulation technology to ensure the best communication quality.

If a AVLN has N devices, each HomePlug AV device must have a N-1 received signal spectrum (except for the spectrum of all the other devices). For example, AVLN has 25 devices, each client must have 24 real-time signal spectrum. This seems to be very complex, but it can still achieve the physical layer transmission rate of 200Mbps, so the adaptive bit loading technology is a good use of power line communication technology. Taking into account the requirements of the smart grid is not high, reasonable to make the HomePlug AV is entirely possible to make.

(2) The MAC layer and the central coordinator of HomePlug AV

The MAC layer of HomePlug AV uses CSMA technology as the basic access technology of the channel, TDMA as an alternative technology. Each is controlled by a central coordinator (CCo) in the network. CCo with reference to the power frequency signal periodically to send the beacon synchronization network, but also will send some management information. Beacon interval is two power frequency period (60Hz power frequency, the beacon interval is 33.3ms, 50Hz power frequency, the beacon interval is 40ms).

(3) CSMA and channel access priority

HomePlug AV uses the CSMA technology as the basic multi access technology, it will be divided into four different business priorities, priority from low to high in order for CAP0, CAP1, CAP2, CAP3. CSMA is usually described as "first listen to say", each device in the network before sending data will be listening to the network, only when the transmission medium is in idle state, it can send a signal to the transmission medium. When the transmission medium is free, there are a number of devices ready to send a signal, it should first solve the high priority access business.

2. HomePlug GreenPHY technology
HomePlug alliance with the development background smart grid, electric vehicles, to have some standard HomePlug AV streamline developed HomePlug GreenPHY agreement. HomePlug GreenPHY device is fully compatible with HomePlug AV, the two do not interfere. The following describes HomePlug GreenPHY standard physical layer and data link layer.

(1) HomePlug GreenPHY physical layer

HomePlug GreenPHY and HomePlug AV use the same frequency band (2MHz~30MHz), modulation (OFDM) and error correction (FEC Turbo Codes). The following table 5-8 is the comparison of technical parameters between HomePlug GreenPHY and HomePlug AV.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>HomePlug AV</th>
<th>HomePlug GreenPHY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrum</td>
<td>2MHz~30MHz</td>
<td>2MHz~30MHz</td>
</tr>
<tr>
<td>Modulation mode</td>
<td>OFDM</td>
<td>OFDM</td>
</tr>
<tr>
<td>Number of sub carriers</td>
<td>1155</td>
<td>1155</td>
</tr>
<tr>
<td>Carrier spacing</td>
<td>24.414kHz</td>
<td>24.414kHz</td>
</tr>
<tr>
<td>Sub carrier modulation mode</td>
<td>BPSK, QPSK, 16QAM, 256QAM, 1024QAM</td>
<td>QPSK</td>
</tr>
<tr>
<td>Forward error correction FEC</td>
<td>Turbo code Code speed 1/2 or 16/21</td>
<td>Turbo code Code speed 1/2</td>
</tr>
<tr>
<td>Speed</td>
<td>ROBO: 4Mbps<del>10Mbps Adaptive bit loading; 20Mbps</del>200Mbps</td>
<td>ROBO: 4, 5 or 10Mbps</td>
</tr>
</tbody>
</table>

Table 5-8  Comparison of technical parameters between HomePlug GreenPHY and HomePlug AV

The biggest difference between HomePlug GreenPHY and HomePlug AV is that the maximum transmission rate of the physical layer. HomePlug AV supports the maximum transmission rate of the 200Mbps in physical layer, which is a luxury for the construction of smart grid. After adjusting the HomePlug GreenPHY in the HomePlug AV based on the appropriate reduction of the transmission rate, but also cut the cost of equipment and product power consumption.

(2) HomePlug GreenPHY MAC layer

HomePlug GreenPHY MAC layer is a simplified version of the HomePlug AV/P1901 MAC layer, HomePlug GreenPHY layer uses the same CSMA technology and the layer priority technology with AV/P1901 MAC layer, but HomePlug GreenPHY does not support TDMA technology. In addition, the HomePlug GreenPHY physical layer does not support adaptive
bit loading technology, so that the HomePlug GreenPHY MAC layer does not need to record and manage the spectrum of the received signal. The table 5-9 below compares the HomePlug GreenPHY and HomePlug AV.

<table>
<thead>
<tr>
<th>Function</th>
<th>HomePlug AV</th>
<th>HomePlug GreenPHY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel access method</td>
<td>CSMA/CA, TDMA</td>
<td>CSMA/CA</td>
</tr>
<tr>
<td>CCo</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Channel estimation</td>
<td>Adaptive bit loading</td>
<td>ROBO</td>
</tr>
<tr>
<td>Shared Bandwidth</td>
<td>null</td>
<td>ROBO</td>
</tr>
</tbody>
</table>

Table 5-9 Compares the HomePlug GreenPHY and HomePlug AV

5.5 Adaptive charging control method of electric vehicle based on PLC

Electric vehicle driving regional uncertainty, power on charging facilities load control and the rate of around in various periods of different makes the electric vehicle charging when they face different charging facilities, the use of different charging parameters, so the charging process of the electric vehicle need achieve the adaptive control. This section presents a realization method of adaptive control of electric vehicle. This method uses the PLC connection, SDP charging equipment, automatic acquisition and automatic connection, the parameters are transferred through the communication of electric vehicles and charging facilities, in order to achieve adaptive charging control. In IEC 62196, it defined the PLC as a method to communicate, so in this section, we mostly talk about the PLC communication in charging process in Europe.

5.5.1 Adaptive charge control strategy

The electric vehicle is connected with the charging pile through the charging cable, and automatically monitors and obtains the address of the other party to establish a communication connection with each other, so as to achieve the self adaptation of different equipment. After the establishment of communication electric vehicle automatically obtain charging pile to provide the service and charging parameters, the demand curve calculated with the demand weighted, supplied to the charging pile control, charging process does not stop acquiring charging parameters to modify the calculation demand curve, so as to achieve the charging parameter adaptive. According to the communication and data exchange between electric vehicle and charging pile, the adaptive control of charging is realized. PLC (power line carrier communication) is a kind of communication mode that uses power line as the medium to transmit information. Using PLC communication is one of the biggest advantage is
can make use of existing transmission medium power line as the communication physical layer, without re-wiring, installation and simple and flexible settings, for the user to achieve network communication brings much convenience. The rapid development of PLC technology, has been able to meet the needs of the user with a relatively high bandwidth requirements.

(1) Charging control communication architecture

Adaptive charging control realization foundation for electric vehicle and charging pile of data interaction, hierarchical structure of communication as shown in the figure, is divided into 7 layers:

The physical layer of the charging cable based on power line carrier;

The link layer adopts PLC control module carrier;

The network layer using the Internet Protocol IPv6;

TCP/IP, UDP and TLS protocol using transport layer;

The session layer using V2GTP technology;

The presentation layer uses EXI to carry out efficient data compression;

The application layer uses the SDP technology to carry on the automatic acquisition, the communication automatic connection and carries on the data exchange.
The following figure 5-24 is the communication layer structure of electric vehicles and charging piles:

Figure 5-24 The diagram of communication layer structure of electric vehicles and charging piles

(2) Charge control device adaptation

Before the establishment of communication between electric vehicle and charging pile, each other's communication address is unknown, if the manual preparation method is not only a
waste of time, but also difficult to operate. Using SDP (automatic access to services) technology can be very convenient for both sides to automatically obtain each other's address to establish a communication connection.

SDP technology using the table below the V2GTP (car to power transmission protocol) message format, through the interaction of the message header can be informed of the other side of the use of the protocol version, to determine whether to establish a higher level of communication. After charging cable connection is reliable, the electric car vehicle controller using V2GTP format to send multicast packets for charging pile acquisition request and charging pile in response to the request, the message containing the local IP address, TCP port information. After receiving the message, the electric vehicle can establish a network connection between the TCP layer and the charging pile by acquiring the information, thereby realizing the automatic acquisition of the charging pile, and the charging control device is adaptive.

The following table 5-10 represents the V2GTP message format:

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Length</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol version</td>
<td>0</td>
<td>1</td>
<td>Version of V2GTP protocol</td>
<td>0x01: Version 1.0</td>
</tr>
<tr>
<td>Version check</td>
<td>1</td>
<td>1</td>
<td>V2GTP protocol version to take the back, can be used as a synchronization with the version of the word</td>
<td>0xFE</td>
</tr>
<tr>
<td>Frame type</td>
<td>2</td>
<td>2</td>
<td>Specific types of message content</td>
<td></td>
</tr>
<tr>
<td>Frame length</td>
<td>4</td>
<td>4</td>
<td>Length of message content</td>
<td>0~0xffffffff</td>
</tr>
<tr>
<td>Frame content</td>
<td>8</td>
<td>...</td>
<td>Interactive data</td>
<td></td>
</tr>
</tbody>
</table>

Table 5-10  The V2GTP message format

(3) Parameter adaptation of charge control

After the establishment of network communication between electric vehicle and charging pile, the electric vehicle can obtain the service and charging parameters of charging pile, and determine whether the charging pile can be charged and the charging demand curve can be calculated; During the charging process, the electric vehicle and the charging pile are
constantly interacting with the data, and the demand curve of the charging correction is calculated and the control is carried out in real time; in charging process, the electric car and charging pile detect the end of each of the conditions, to meet the conditions of the data exchange to each other, and then automatically terminate the charge.

Before charging, as shown below, the electric car from the charging pile access can provide service, choose their own services, continue to from the charging pile get charging parameters, including charge rate table, grid can provide the maximum charge current and other charging parameters. According to these parameters, the parameters of the battery capacity and the residual capacity, the battery characteristic curve and the charging time can be used to calculate the optimal charging curve, during the charging process, the parameters such as demand current and voltage are sent to the charging pile to get the best charging.
The following figure 5-25 for the electric vehicle automatic access to services and charging parameters of the process:

Charging process, as shown in the diagram below, the electric car continuously from the charging pile gets the maximum charging current, if the grid load limit changes and electric vehicles will be according to the maximum allowable charging current and its parameters of the current re-weighted optimum charging curve, send appropriate to the needs of current and voltage for charging pile real-time adjustment.

The following figure 5-26 is the process of automatic adjustment of electric vehicle charging process:
Output in the process of charging, electric vehicles have been testing the SOC of battery and charging schedule, check whether to achieve the predetermined goal; charging pile kept detection grid limit orders, the user end operating instructions and charging system with and without abnormal downtime. Detected to meet the end conditions, as shown in the figure will be the data to each other, automatically stop charging.
Throughout the communication process, the electric car and charging pile will continue to interact with each other to each other, in order to make decisions for each other, in order to ensure the safety and reliability of charging, at the same time to provide data for the remote monitoring and management system, to provide the possibility of value-added services. Keep the parameters of interaction between the two sides, in the whole process of the implementation of the parameter adaptive charging.

5.5.2 Charging pile on implementation

(1) Interface circuit

The charging interface as shown in the fig 5-27, L1, N for power line, PP and CP for navigation control line, PE to ground. L2 and L3 as backup contacts, when necessary, can provide three-phase AC charging, or can also provide DC output, charging the charging pile by informing electric vehicles, electric vehicles to choose from.

Figure 5-27 The diagram of charging interface
Guidance and control through CP, PP and PE, the control mode of PWM in CP and PE. By monitoring the voltage each detection point value and the duty ratio of PWM, electric vehicle and charging pile can detect the current state of cable: Not connected and connected. To detect the cable will be able to start PLC for reliable communication connection.

The cable is connected with the charging of electric vehicles and charging pile with power line L1, N to power transmission, there are CP, PE navigation control. The PLC signal can be coupled in the main power line L1 and N, also can be coupled in the navigation control line CP, PE. There is a big noise and interference on the mains power line, in order to reduce the interference and improve reliability must reduce the communication rate, through the main power carrier also has certain problem of crosstalk. We consider PLC control signals are coupled in the guide line, compared to the main power line as the PLC channel, the guide line of control channel is very clean, small interference, high reliability of communication. PWM frequency of 1 kHz for low frequency signal, and the work frequency of PLC in 2 ~ 30 MHz, the two will not constitute interference.
(2) Control system

The electric vehicle and charging pile by connection as shown below, the PLC carrier signal coupling module will be in CP, PE, charging controller and vehicle controller network signal is transmitted to the PLC module, to realize the network connection through PLC carrier module.

Figure 5-28 The diagram of communication connection between electric vehicle and charging pile
In charging controller is responsible for data exchange with the electric car, the inside of each function module as shown below, including:

![Diagram of charging pile controller hardware function connection](image)

Figure 5-29 The diagram of charging pile controller hardware function connection

The main control CPU: responsible for the electric vehicle charging system scheduling, data processing and control;

The power module: the power supply device provides power communication control unit;

Sampling module: acquisition of voltage and current, and send the voltage and current information to the main control CPU;

Human-computer module: interface for display and keyboard input;

I/O module: collection volume switch, to the control of the main CPU on the state quantity, while performing control of the main CPU of the control command;
Guided control module: monitoring the state of the guide line of control, and on to the control of the main CPU;

PLC control module: the control of the main CPU communication data into a carrier signal.
Chapter 06: Conclusion

This topic based on the charging standard compared to the world's major countries, that all the standard although there is a big difference between, also has the relative relationship. For example, the United States, Japan and China are using the same CAN bus system to communicate. As well as China and Europe, DC charging interface is very similar, while the United States and Europe, mixed charging interface is also very similar. So when electric vehicles manufacturers want to transnational sales, can use additional charging socket in order to solve the problem that the interface is not uniform.

In this paper, we focus on the comparison of CAN bus and PLC, two ways of communication systems, the two communication methods have their own advantages and disadvantages, but I prefer to choose CAN bus system. In my opinion, as the Bosch group in the global auto parts market accounted for a large share, and based on the CAN bus communication system reliability and high performance, the vehicles in the future must tend to more electronic and more intelligent, so the bandwidth and the speed of communication will have higher requirements, CAN bus system compared in PLC is more qualified for these problems.

As the new industry standard in the early stages of development will encounter complex and incompatible, the electric car industry is no exception. Thus, the global different charging interface standards will still exist for a long time, but with the popularity of electric vehicles, more and more people will consider standards compatibility problems, even charging port countries and regions can not be formed in the shape of the structure unified, but the control, communication may eventually reach an agreement.
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