

Comprehensive Analysis of Power Systems for Hybrid Electric Vehicles

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Abstract. Now the pollution problem is becoming more and more serious, and the gas emitted by cars has seriously affected the environment. In order to reduce environmental pollution and Strength conservation and emission discount, sell the first-rate sustainable development of China's new electricity automobile industry, accelerate the development of vehicle strength, and the study of new energy vehicles is inevitable. New power vehicles are designed to use unconventional energy sources or indirectly use gasoline energy in a way that differs from conventional automotive internal combustion engines. The new power vehicle is the superior technology to complete the power control and driving of the vehicle which transcends the traditional technology and way. It is a vehicle with new technology as well as new structure. This paper mainly analyzes the energy conversion of hybrid electric vehicles, the advantages and disadvantages of the power system of hybrid electric vehicles, and also discusses the actual application of technology and the plate and management mode of power battery.

Keywords: Hybrid Electric Vehicle, energy conversion, application, power battery.

1. Introduction

Since the beginning of the continuous promotion of the industrial revolution, the exploitation and utilization of fossil energy has worsened the global environment. Today, with highly developed industry, energy reserves are also decreasing year by year. For this reason, the world is currently imposing increasingly strict restrictions on vehicle energy consumption and emissions. In order to reduce pollutant emissions, reduce energy consumption, and save the use of energy, more and more automobile enterprises began to study the corresponding new energy vehicles. In this context, in addition to all kinds of new energy vehicles, still use gasoline as the main energy of hybrid cars, by joining the higher efficiency at low-speed motor, cannot change the premise of user habits, improve fuel economy and environmental protection, at the same time in improving dynamic performance and driving quality also has great potential. Pure electric vehicles although relatively more environmental protection and energy saving, but now the cost is still relatively high, battery range is short, supporting facilities construction is need to invest a lot of manpower and money, in a short time is difficult to put into use, so hybrid cars because considerable fuel saving and appropriate price become the main force of new energy vehicles, and can be used as the transition of traditional cars and pure electric cars.

As shown in Figure 1, a hybrid electric vehicle (HEV) is a complementary technology that uses the engine as the primary power source and is then equipped with a battery as a secondary power source. Hybrid electric vehicle is developed based on the traditional fuel oil technology, usually refers to the oil, electric hybrid power, using two different power sources of the vehicle technology. Hybrid cars to a great extent, reduce the fuel consumption, in the car start, acceleration, uphill, battery auxiliary engine produce powerful power, on the one hand, the driver in the process of driving will experience better driving feeling, on the other hand, hybrid cars can achieve higher fuel economy [1], improve the utilization rate of energy.

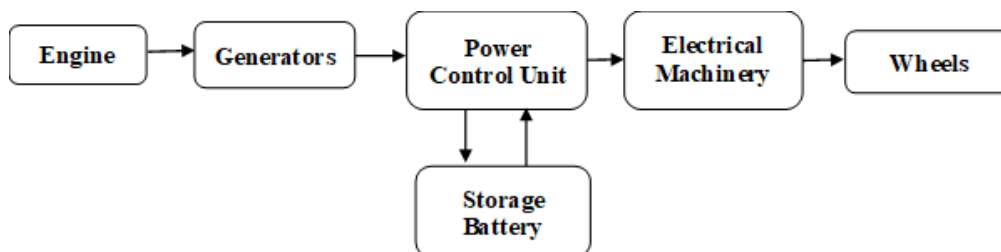


Figure 1. System diagram of a typical hybrid electric vehicle

There are roughly three types of HEVs, namely Series Hybrid Electric Vehicles, Parallel Hybrid Electric Vehicles and Parallel-Series Hybrid Electric Vehicles, this classification is roughly based on the connection of the power system to decide. In terms of structure, the series hybrid model is an extended range hybrid model. Its power device is composed of engine, generator as well as motor, and its power system is formed in series. The internal combustion engine of a SHEV does not directly provide the vehicle power, but is used to charge the battery, provide the power of the motor operation, and finally, the car [2] is driven by the variable speed mechanism. Parallel hybrid cars this power system structure is simple, low cost, closer to the traditional car drive system, its engine and motor drive car and they belong to two sets of system. Both of them can provide torque to transmission system independently, in different road can drive together and can drive separately. Parallel-Series hybrid electric vehicles combines the characteristics of both SHEVs and PHEVs. Engines, generators as well as electric motors can all be found in its powertrain. There are two power forms of motor and engine to start the car, these two forms have different power auxiliary devices. The two power units can either drive the vehicle alone or work together. At the same time, because the hybrid system has a separate generator, it no longer uses the motor as a generator like the parallel system, so the engine can also charge the battery pack when working together with the motor.

Battery also has applications in fuel cars, generally only for car all kinds of electric device power supply, not power the car, and the battery in the application of new energy vehicles, efficacy and the engine, have the effect of power output [3], including traditional lead-acid batteries, nickel metal hydride batteries and emerging lithium ion power electric lithium battery. A 4200 mAh power battery can discharge the power in just a few mins, however the ordinary battery can not do it, so the release capacity of the everyday battery can not compare with that of the power battery. The largest distinction among strength battery and everyday battery is that its discharge energy is massive and better than its precise energy. Because the principle use of strength battery is car power supply, it need to have higher discharge energy than regular batteries. New electricity vehicles are specially composed of battery drive device, motor machine and electronic manipulate device and meeting components. The motor, electric control and assembly are basically the same as the conventional automobile, and the motive for the price difference lies inside the battery drive system. Look from the price of latest energy motors, battery force device occupies 30-forty five% of the price of latest energy vehicles, and strength lithium battery and battery drive system approximately 75-85% of the fee, so the excessive charge of latest strength motors is greater from the price of energy battery, reduce the value of energy battery has been the enterprise needs to clear up the hassle.

This paper mainly analyzes the energy conversion of hybrid electric vehicles, the advantages and disadvantages of the power system of hybrid electric vehicles, and also discusses the actual application of technology and the types, plates and management modes of power batteries.

2. Classification of HEV

Hybrid power is a combination of more than two power sources, and recently, the definition of HEVs is basically referring to the vehicle equipped with internal combustion engine, generator, power battery at the same time. As mentioned above, SHEV, PHEV PSHEV are the three commonly classified types [4].

2.1. Series hybrid electric vehicle

SHEVs' power system, as showed in Fig. 2, is relatively simpler compared with parallel type, and the its technology is relatively more mature and durable. It is first used in various places where HEV power is applied, such as city buses or private cars.

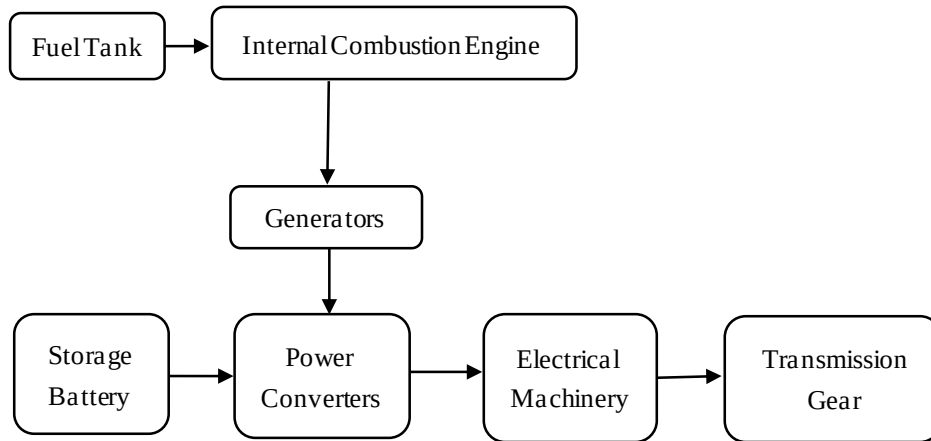


Figure 2. System diagram of the series hybrid electric vehicles

The head and front of SHEV power system consists of engine, generator, inverter, energy storage device and traction motor device of transmission system. Compared with traditional automobile, the HEV power system is different from its traction motor and energy storage device. As for the application of energy storage device, lead-acid battery is generally the most widely used, it also has an immensely mature technology. However, the limitation of energy density makes it hard to apply in HEV power system. NI-MH battery has a higher specific power, on the other hand, the economic cost is increased accordingly So it quite has not a high application rate. At present, lithium battery is the most used battery in commercial HEV. It has a good complementarity with super capacitor, so that it not only has a long endurance but also can meet the requirements of high instantaneous power. How to maximize the energy saving or recovery in SHEV power system has always been a problem that needs to be studied, among which energy recovery is easy to associate with. The braking is mainly reflected in about power recovery of HEV, and the braking system is firmly linked with the safety. Hence what a qualified recovery module should achieve is to recover the energy lost during braking to capacity extent under the condition of fully guaranteeing the safety of the vehicle and the driver. Nowadays the braking energy recovery system is usually divided into different levels for the sake of safety and the intensity of electric recovery braking is lower than that of mechanical braking. It needs to be reasonably distributed to meet the corresponding requirements.

2.2. Parallel hybrid electric vehicle

In fact, the PHECs' power system, as demonstrated in Fig. 3, is to install a set of electric driving system, namely, motor and power battery based on the ordinary power system [5,6]. Both the engine as well as motor can drive the vehicle individually or together. Besides, the engine can also turn the motor into a battery to charge when the power battery runs low. The parallel operation of the internal engine and the motor while providing energy to the vehicle is one of the traits of PHEVs' power system. In general, in order to ensure the efficiency, the engine may also be required to generate power for the energy storage device. The efficiency and controllability of the ICE are improved and the service life of the engine is prolonged. The similarity with the tandem power system lies in that the core of the parallel power system is still the internal combustion engine. In addition, its power transmission efficiency is theoretically higher than that of ordinary SHEV power system. And its power requirements on the engine are relatively low hence its development degree is higher than the latter.

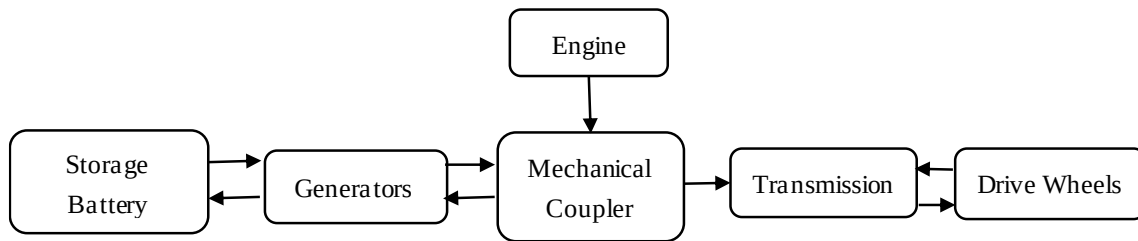


Figure 3. System diagram of the parallel hybrid electric vehicles

The PHEV's power system mainly consists of two sets, namely single-axis and dual-axis PHEV power system, and there are many different types of patterns and variants on the basis. The single-axle system connects the motor to the engine by a torque compound, while two-axle system has two sets of transmissions compared to the single-axle system. The dual-shaft system is effectively combined and connected with the engine and has the participation of planetary gear group. The advantage is that the speed ratio between the motor and the engine can be adjusted more freely to optimize the power structure. Comparing with the SHEV power system, there is no other obvious energy loss direction except friction loss in the power transmission process. That's why its energy transmission efficiency is higher than the latter. The PHEV power structure can combine the power of two kinds of energy, which is able to ensure the motion load of the power group while exceeding the SHEV power. Because of this, the engine power requirements are lower, the mass as well as the volume of the power system are smaller, so that the weight is reduced, but also reduce the loss of energy. However, the power core ICE of PHEVs' power system has a larger time ratio in the high efficiency zone compared with SHEV system, so the displacement is more than the latter.

2.3. Parallel-Series hybrid electric vehicle

Recently, the PSHEVs' power system has the highest application rate. The system diagram of the PSHEV is showed in Fig. 4. The gain of this shape is that it is simple to govern, however, the disadvantage are its excessive price and complex struct. Theoretically, the PSHEV energy device can recognize the working mode of collection. Compared with the PHEV gadget, the PSHEV system can modify the power output of the ICE and the operation of the motor extra flexibly in keeping with the operating situations.

The PSHEV power system is mainly composed of battery, transformer, generator, engine, motor, power transmission system and differential. The motor and internal combustion engine can drive the power system separately, or one of them can be the main way to drive the other as a supplement. The PSHEV power system can be started by mixing two kinds of energy in a relatively free ratio [7]. Therefore, the economy and power performance of the PSHEV power system are much stronger than that of the SHEV and PHEV, but at the cost of complex structure and high manufacturing and research and development costs. In the PSHEV system, the ICE and the motor system have their own mechanical variable speed mechanism, which is combined by the gear train or planetary gears, to make comprehensive adjustment. The participation of the planetary gear group in the power transmission makes the power output of a single power source controllable. In many PSHEV power systems such as Toyota Hybrid System, the coupling of the engine and generator requires the planetary gear group. This combination can realize the normal operation of the generator in the case of sufficient battery [8].

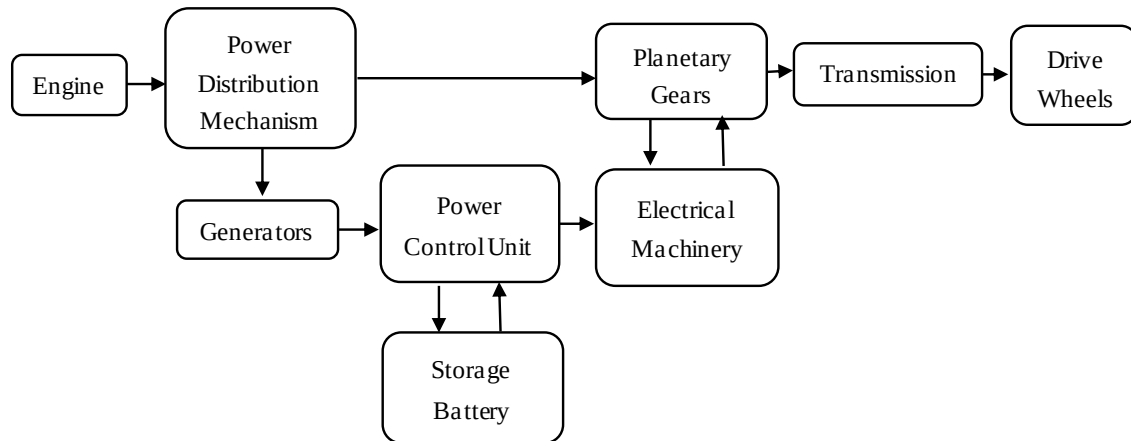


Figure 4. System diagram of the parallel-series hybrid electric vehicles

2.4. Recent applications of hybrid power systems

Commercial brands of hybrid electric vehicles circulating in the modern market also have relatively unique designs for the power system. Its basic purpose is to improve efficiency and save energy. Taking Toyota's THS-II hybrid core system control as an example [9], the system controls the engine operation with mathematical model, to measure speed or incorporate into a capacitor battery to generate or discharge in conjunction with the engine to maximize energy by detecting the engine rotor efficiency. Inge the planetary gear set to adjust the power sources as described previously. In that way, not only can it be applied to multiple complex situations, also improves fuel and transmission efficiency.

BYD DM-i super hybrid system is a hybrid technology with electric power as its core [10]. The difference between its power source and the traditional system is that it is a power system with the electromotor and capacitor energy, as well as the engine power as the auxiliary work. What is more novel is that the multi-gear transmission is not necessary because of the highly controllable speed of the electromotor. That is to say, the structure and transmission direction of the whole power system will be clearer and tidier. Besides DM-i system has a variety of different power supply solutions, including engine direct drive mode, series and parallel mode, pure electric mode and so on, which can have different road conditions and power requirements in a variety of forms.

3. Power battery system

3.1. Control system and composition of power battery

Power battery is the main energy supply storage system of HEV, namely ESS. The ESS is composed of module, battery management system, electrical system, thermal management system and other structural parts.

3.1.1. Module

Module refers to the combination of power battery cells that can directly provide electric energy through the series and connecting mode with the protective circuit board and shell. It is one of the secondary structures of the power battery system. The cell, namely the power cell, mainly including lithium cobalt oxide, lithium iron phosphate, lithium manganese oxide as well as lithium nickel cobalt manganese oxide ternary materials according to the cathode material.

3.1.2. Battery management system

Battery management system is the core fittings of the power cells, it can determine the status of the entire system by detecting the local battery status. It can also control and adjust the battery by detecting the condition of system, to realize the energy management of each unit in the power battery system and ensure the security and stability. There are three basic functions of the battery

management system: detection, management together with protection, including data collection, status monitoring, balance control, thermal management, safety protection, information management and other functions. It must have the ability of real-time monitoring and adjusting the battery management status, working synchronously with multiple parallel subsystems. In the actual running, acceleration and deceleration are always constantly alternating, so the system must be able to accept dynamic feedback and adjust its monitoring and management mode constantly.

3.1.3. Electrical system

Overvoltage jumpers or high voltage wiring harnesses, low voltage wiring harnesses and relays make up the general structure of the electrical system. High voltage cable can be regarded as the principle machine of the battery, which constantly transmits the strength of the coronary heart of the power battery system to the diverse required additives. The low voltage cable may be appeared because the subsystem, which transmits detection indicators and manage signals in real time. The gadget may also be equipped with overload protector, that is to save you the electrical system from overheating because of overload. Overload protector has complete features, dependable action, robust anti-interference potential. It can work stably in relatively harsh environments, that is why it is widely used in diverse electrical circuits of electric vehicle.

3.1.4. Thermal management system

Battery thermal management device is used to make certain that the battery gadget works within the right temperature variety. It is composed of battery container, warmness switch medium, tracking gadget and other additives. There are four primary kinds of thermal control system: air cooling, water cooling, liquid cooling as well as phase change materials, a good way to devour the warmth generated via the chemical response in the battery. It is one of the key technologies to make certain the performance, protection, and toughness of the electricity battery. The battery thermal management machine has the following essential functions: real-time accurate measurement and monitoring of battery temperature; strong heat dissipation and airflow; fast heating to make the battery work normally; powerful air flow of harmful gasoline area; therefore, the temperature field of the battery is evenly distributed.

3.2. Typical power battery

Electronic energy storage devices are made of batteries or ultracapacitors. All the batteries or supercapacitors are in series, parallel or series-parallel to achieve the voltage or capacity required to drive the motor in the battery pack. The main types of HEV power batteries are: lithium-ion battery, nickel-metal hydride battery, fuel cell, lead-acid battery, and sodium-sulfur battery.

3.2.1. Lithium-ion battery

Lithium-ion power battery has high working voltage, large specific energy, small volume, light mass as well as long cycle life, no memory effect of the battery; no pollution, etc. Lithium-ion battery is one of the most technical and advanced batteries in the world. The battery has high energy density, long cycle life, which means more electricity, more charge and discharge times, and long service life. Lithium-ion batteries used in cars are mainly divided into two types: iron phosphate lithium-ion battery and ternary lithium-ion batteries. Both are positive electrode materials for power lithium batteries, which are significant in improving battery energy density.

(a) *Lithium iron phosphate ion battery*: Lithium iron phosphate ion battery, whose full name is lithium iron phosphate lithium-ion battery. It takes lithium iron phosphate material as the positive, carbon series graphite and other materials as the negative electrode, separated by a diaphragm, and through the transfer of lithium ions through the organic electrolyte battery. Lithium iron phosphate ion battery has good thermal stability, high security, low cost, and long service life. On the other hand, it has low energy density and fear of low temperature at the same time. Its thermal stability is the best among the power lithium-ion batteries. Its internal chemical components begin to decompose only when its temperature is 500-600°C. Also, the puncture, short circuit as well as high temperature will

not make it burn or explode. But low energy density leads to heavier, larger batteries and average range. The biggest problem is the low temperature charging. With the decrease of temperature, its charging efficiency will decrease. Especially at minus 5 degrees Celsius, the reduced efficiency makes it no longer easy to use, so it is not suitable to use this kind of battery in winter in the north

(b) *Ternary lithium-ion battery*: Ternary lithium-ion battery is a battery who use nickel cobalt manganese as positive cathode. It completely integrates the coolest movement overall performance of lithium cobalt oxide, the excessive specific capability of lithium nickel acid and the excessive safety and low cost of lithium manganese oxide. High energy density is one of the characteristics of ternary lithium-ions, lengthy cycle existence and excessive bloodless resistance; but insufficient balance at warmness. It has the highest energy density by far, however it is low-resistant to high temperatures, whereas it behaves considerable at low temperatures, which means it is suitable for northern climates. Low security has been a major obstacle to its large-scale deployment and integration. Many experiments show that the ternary battery with large capacity is difficult to pass the safety tests such as acupuncture and overcharge. And it is easy to cause combustion or explosion in the case of internal damage or short circuit [11]. Ternary lithium-ion batteries can also easily shorten their service life at high temperatures, the cycle life is short.

3.2.2. NiMH rechargeable battery

NiMH rechargeable battery, which can speed up the charging and discharging process. When at high speed, the electricity generated by the generator can be stored in the nickel metal hydride battery, when at low speed, usually consume a lot of gasoline than the high-speed state, in the range is lower than the lithium-ion battery. It has large energy density, poor safety and has the corresponding battery memory effect, and the battery will pollute the environment after waste.

3.2.3. Fuel cell

Fuel cell has a fantastic electrode which include oxygen electrode, and the terrible electrode is the gas electrodes together with hydrogen or hydrocarbons or ethanol. At gift, the complete electricity conversion price of most hydrogen gasoline cells is far less than that of natural electric cells. If it's miles a renewable approach, the performance is usually a spinoff of pollutants manufacturing system. If it's miles hydrogen power, a process that reasons power loss is elevated in vain. Combined, the energy intake of riding by myself won't be as environmentally friendly as natural electric or plug-in hybrid economy.

3.2.4. Lead-acid battery

Lead acid battery is widely used as the starting energy supply of inner combustion engine automobiles. It has exact reliability, easy raw materials, and reasonably-priced fee. Its electricity can essentially meet the electricity necessities of the car. However, the disadvantage is that the service life is too short, the volume is large, the specific energy is inefficient, it will also produce certain pollution.

3.2.5. Sodium-sulfur storage battery

Sodium sulfur battery is sodium as negative electrode, sulfur as positive electrode, in the electrolyte to form a battery. It can be discharged with high current as well as high power. 3 times of its inherent energy can be released instantaneously, which means its efficiency is high. But the biggest disadvantage of sodium sulfur battery is that it is less secure, because the raw materials are particularly flammable. Therefore, safety problem should pay more special attention to. In addition, the other conditions that need to be met are external heating, vacuum insulation technology is even better.

3.2.6. Supercapacitor

Supercapacitor has the advantages of high-power density and long cycle life; it plays a significant role in new energy vehicles. Electrode is a significant part of the capacitor; it largely determines the overall electrochemical performance. However, the high cost of lithium-ion ultracapacitors and the

immature technology limit the large-scale application of it [12]. Compared with chemical battery, super capacitor has three obvious advantages. First, it can be recharged and discharged hundreds of thousands of times, the longevity is much higher than chemical battery; second, supercapacitors have high power density during charging and discharging and can release a large amount of electric energy instantly, which can meet a wider range of electric power needs of vehicles, third, its working environment adaptability is better, it can work stably usually when the outdoor temperature is -40°C -65°C . But the disadvantage of supercapacitor is that its energy density is low, and its storage power cannot meet the needs of power battery of electric vehicles. And the discharge current is more difficult to control. Therefore, it is mainly used in the vehicle starting system, military, and a small number of bus vehicles recently.

3.3. Factors affecting the efficiency of power batteries

Temperature has a relatively clear influence of temperature on diffusion. In general, the temperature increase helps to ion diffusion, that is, reduces the migration resistance. Therefore, the migration rate of ions will also increase, which is likely to make the first efficiency higher. As a result, at the high temperature the electrochemical reaction inside the power battery will be more active and the efficiency will be higher; but on the contrary, the electrochemical reaction will decrease, and the efficiency will be reduced.

Solid electrolyte interface (SEI) membrane will consume a part of charged ions in the process of initiation, and the negative electrode reaction process is a process of ion embedding and detachment in the interlayer structure of carbon. So, the formation of SEI membrane will reduce the first circulation efficiency of the negative electrode.

Another factor that affects the efficiency of a power cell is current. The charging current or discharge current should not be too large. The thermal effect brought by the large discharge current will further expand the influence range of the large current discharge. The heat dissipation capacity cannot keep up hence the temperature of battery is too high. It could probably happen that the electrolyte breaks down and the diaphragm melts. Therefore, in addition to the impact of lithium-ion on the internal microstructure, the effect of current on the battery is mainly manifested through the effect of heat [13].

4. Summary

This paper mainly analyzes the energy conversion of HEVs, the traits and strong and weak of their power system, also discusses the actual application of technology and the types, plates, and management modes of power batteries. Generally, the production technology, the optimization of the new energy vehicles control system, the optimization of power battery, braking system and distribution control technology are the keys to the development of hybrid vehicles. Moreover, related technical problems about pure electric vehicles or will be a breakthrough. For instance, battery is one of the power sources of hybrid vehicles, continuously optimize its performance can improve energy efficiency. It is believed that under the promotion of government policy and market demand, hybrid technology will usher in a more long-term development. And in the context of the global call to promote the reduction of carbon emissions, it will be more and more positive to promote the iterative upgrade of hybrid technology. For the country, in order to accelerate the improvement of endurance and other technical levels, the state should increase the support to produce new energy vehicle enterprises of charging piles and other facilities, reduce the production costs of enterprises, increase the financial subsidies for such enterprises, and then encourage the competent enterprises to enter the ranks of charging pile production. On the other hand, further planning can be made for parking lots, high roads, and gas stations to build charging infrastructure, and both in price and quality.

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