Chapter 1
Overview of Battery and Its Management

Developing energy-saving and new energy vehicles industry is an international consensus, which is also an emerging industry in China and a key filed established by "Made in China 2025". The battery technology is the bottleneck of the development of electric vehicles (EVs), while the battery management system (BMS) is not only the key to ensure efficiency and safety of the EVs, but also the focus of national core technology competition. In 2017, the medium and long-term development plan for the vehicle industry was jointly issued by the Ministry of Industry and Information Technology, the National Development and Reform Commission, and the Ministry of Science and Technology of the People's Republic of China. They pointed out that the annual production and sales of new energy vehicles in China would reach 2 million, the specific energy of cells would exceed 300 Wh/kg, striving to reach 350 Wh/kg; the specific energy of the system would strive to reach 260 Wh/kg, and the cost would be reduced to less than 1 yuan/Wh by 2020. The annual sales of global new energy passenger vehicles have reached 1.22 million by 2017 with a growth rate of over 55%. According to the statistics of China Association of Automobile Manufacturers, China's annual production and sales of new energy vehicles in 2017 reached 794,000 and 777,000, respectively, ranking first in the world for 3 consecutive years. From January to May 2018, the production and sales of new energy vehicles in China both reached 328,000 with an increased rate of 122.9 and 141.6%, which shows that China is becoming an important role in the development of the international new energy vehicle market.

However, as an alternative for fuel, the battery has the characteristics of low cycle life, slow charging, poor low-temperature discharging capability, and difficult to predict the degradation state, which causes the users' anxiety about driving range and concerns about performance at low temperatures. When the cells used in groups on the EVs, the degradation rate and trajectory of the cells are different and the inconsistency between the cells is particularly obvious due to the differences in the manufacturing and operating environment, which makes it hard to estimate the accurate state of the battery system. When the state of health (SOH) of some batteries degrades sharply, the performance of the whole system will be affected, which will aggravate lifetime decay and even cause safety problems. As a result, it is important

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for BMSs to strengthen the battery energy management, reduce heating time at low temperature, improve remaining useful life (RUL) prediction accuracy, slow performance degradation, and guarantee the expected service lifetime. They are not only the keys to guarantee the vitality and sustainable development of the new energy vehicles market, but also the basic requirements to establish the confidence of the market.

1.1 Developing Plan for the New Energy Vehicle in China

The traditional vehicles driven by internal-combustion engine system, which have dominated the vehicle industry for a long time, are facing a huge transition. In order to seize the opportunity of technology and market, countries all over the world compete to develop technologies of EVs, and actively promote the investment and expansion of the new energy vehicle industry.

As early as the 1960s, China began to trial-produce EVs, due to the limitations of technical conditions and social environment, no breakthroughs were made in technology at that time. It was not until the "overall design of EVs" for National Key Technologies R&D Program of China during the 8th Five-Year Plan Period was approved in 1992 that the R&D of China's EV industry was officially started [1].

During the 10th Five-Year Plan period, China began large-scale organized R&D of EV technology. The layout of "three vertical and three horizontal" was established by the Electric Vehicle Key Project under the 863 Program in 2011. The vehicles including fuel-cell electric vehicles (FCEVs), hybrid electric vehicles (HEVs), and EVs are named as "three vertical", and three key technologies including multi-energy powertrain control system, driven motor, and battery are named as "three horizontal". China launched extensive studies on EV technology, laying a technical foundation for the development of EVs.

During the 11th Five-Year Plan period, China organized the Energy Savings and New Energy Vehicle Key Project, sticking to the layout of "three vertical and three horizontal". China carried out research on key technologies and large-scale industrialization of the electric vehicles, and successfully carried out the demonstration projects such as Beijing Olympics, Shanghai World Expo, Shenzhen Universiade, the ten thousands of new energy vehicles and so on. It is worth mentioning that the Rules on the Production Admission Administration of New Energy Automobiles, published by the National Development and Reform Commission in China, officially defined the new energy vehicles for the first time. The new energy vehicles refer to the vehicles that use the unconventional vehicle fuel as an energy source (or use the conventional vehicle fuel with new vehicle energy device) and integrate the advanced technologies of vehicle energy control and drive. According to the definition, the new energy vehicles can be divided into HEV, battery electric vehicle (BEV), FCEV, hydrogen internal-combustion engine vehicles, and other vehicles with new fuels such as dimethyl ether and high-efficient energy storage capacitors,

which indicates that China has begun to implement management and access systems for new energy vehicles and their production enterprises.

The key component technology, the vehicle integration technology, and the public platform technology should be improved, deepened, and upgraded, forming the strategic focus of "three vertical, three horizontal and three platforms". It is pointed out in the 12th Five-Year Plan that breaking through the bottleneck of battery technology is the main task, but the three key technologies including the battery, the electric motor, and the electric control system were also needed to be broken through [2, 3]. In 2015, the new energy vehicles were included in "Made in China 2025", and the target that the battery energy density would reach 350 Wh/kg by 2026 was proposed. In the same year, the emission reduction commitment made by President Xi Jinping at the Climate Conference in Paris was reflected in the 13th Five-Year Plan.

In November 2016, the State Council in China officially issued the National Strategic Emerging Industries Development Plan for the 13th Five-Year Plan, where the strategic position of green and low-carbon industries such as the new energy vehicles, the new energy, and the energy conservation and environmental protection had been clarified once again. As one of the eight major tasks in the 13th Five-Year Plan, the development of the new energy vehicles is the priority of the State Council. The Plan calls for a large-scale application of the new energy vehicles and the overall improvement of the quality and performance of the EVs. Moreover, it requires promoting the R&D of the battery technology, breaking through the technology of battery grouping and system integration, and boosting the cascade utilization of battery. It also emphasizes that the R&D of the battery system should be improved, and the technical targets of the lithium-ion batteries such as high safety, long lifetime, and high-energy density should be realized. It can be seen that China is constantly making efforts in the application and development of the batteries in the EVs, striving to improve the quality of the battery management to promote the successful transformation from a big country to a powerful country in automobile industry.

1.2 Application Requirements for Batteries and BMS

The performance of the EV highly depends on the performance of the battery and BMS. In order to meet the requirements of dynamic performance, safety, economy, and environmental friendliness of the EVs, the battery system should meet the following requirements:

(1) High specific energy. Improving the specific energy of the battery can greatly improve the driving mileage of the EVs, and also reduce the mass and volume of vehicles.
(2) High specific power. Improving the specific power of the battery can effectively improve the vehicle dynamic performance of EVs so that it has excellent acceleration performance.

(3) Long service lifetime. About 50% of the cost of EVs comes from the battery system, so extending the battery lifetime can greatly reduce the use and maintenance cost, thus reducing the cost of the vehicle.
(4) High safety. The high safety of the battery can reduce the probability of dangerous accidents such as fire and explosion of the vehicles which are caused by liquid leakage, short-circuit, collision, and so on.
(5) High reliability. Improving the adaptability of the battery to complex working conditions can effectively prevent the sudden change in battery characteristics caused by drastic changes in the working environment and false operation.
(6) Excellent high/low-temperature performance. The battery is supposed to have strong adaptability to the change of vehicle operating environment and can work normally in a wide temperature range.
(7) Low self-discharge rate. Low self-discharge rate can reduce the capacity degradation rate of the battery and extend its service lifetime.
(8) Low cost. Reducing the cost of the battery can effectively reduce the cost of the vehicles and improve the product competitiveness of the EVs.
(9) Environmental friendliness. The battery will help to establish battery recycling standards and prevent secondary pollution to the environment.

At present, the commercialized batteries used in the EVs can be divided into three categories according to their capacity and output power, namely, the energy-type batteries, the power-type batteries, and the energy/power-type batteries.

(1) The energy-type battery usually has a large capacity and can supply energy continuously, which is often used in BEVs and HEVs. The total energy of this type batteries takes up a large proportion in the vehicle energy configuration, generally exceeding 10 kWh, which is not only beneficial to recover the energy from the vehicle braking feedback, but also can increase the driving range of BEVs and reduce the pollutants emission.
(2) The capacity of the power-type battery is generally small but can meet the instantaneous high power supply, which is often used in light HEVs. This type of battery is mainly used to absorb the energy of the braking feedback, while providing instantaneous extra energy for the starting and accelerating condition of the vehicle.
(3) The energy/power-type battery has high energy density, high power output capability in a low state of charge (SOC) range and high power acceptability in a high SOC range. It gives consideration to both high energy and high power characteristics, which is often used in plug-in hybrid electric vehicles (PHEVs).

To be specific, different EV types have different configurations and working modes, leading to different requirements for the batteries. The following describes the specific requirements for the batteries in the BEVs, HEVs, and PHEVs.

1.2.1 Battery Electric Vehicle

BEV is a new energy vehicle that only uses the battery as the energy storage source. The battery provides the electric energy to the motor through the battery and driving the motor, and thus propel the vehicle. The driving mileage of BEV completely depends on the capacity of the battery. The larger the capacity of the battery is, the longer the driving mileage of the vehicle will be, while the volume and mass of the battery will also increase accordingly. Therefore, the choice of the corresponding battery used in BEV depends on different design goals, road conditions, and driving conditions. The specific requirements can be summarized as follows:

(1) The battery pack should have enough energy and capacity to ensure that the rate of continuous discharge generally does not exceed 1C (C represents the battery charge or discharge current rate. For example, a rate capacity of a cell is 3 A h, and 3 C indicates the value of the charge or discharge current is 3 times of the rated capacity, i.e., $3 \times 3 = 9$ A.), and the peak discharge rate generally does not exceed 3C. For BEV with regenerative braking energy, the battery pack must be able to withstand the pulse charging current of 5C.
(2) The service of the battery should not be affected by deep discharging, and it can support full load discharging when necessary.
(3) BMS is required to feedback and control the real-time states of the battery pack to ensure the safety and efficiency of the battery pack.
(4) The space layout and installation of the battery box require targeted research and design due to the large volume and mass of the battery pack.

1.2.2 Hybrid Electric Vehicle

HEV is an energy-hybrid new energy vehicle that combines the traditional internal-combustion engine system with the electric propulsion system. In general, the battery is the main energy source of the electric propulsion system in HEV. Therefore, during the development process of the HEV, the relevant design of the battery also needs to be considered in detail.

Generally speaking, the battery on HEV does not need a large capacity, but needs to meet the instantaneous high power demand of the vehicle. Different from BEV, HEV has three different structural configurations: series, parallel, and series–parallel leading to different battery design requirements.

(1) The series HEV is powered jointly by the engine, the generator and the battery, and the SOC of the battery system is usually at a high level. Therefore, the requirement of the battery is similar to that of the BEV, but the requirement of the capacity specification is relatively low.
(2) The engine and motor of the parallel HEV can directly provide the driving force, and different power combinations can meet the different power demands

of the vehicle, which means that the vehicle can adapt the battery with a small capacity, but the maximum discharging current of the battery should be more than 20C to meet the instantaneous high power demand of the vehicle when HEV accelerates or climbs.

(3) The series–parallel HEV composed of a series HEV and a parallel HEV, which has all the working modes of the series HEV and parallel HEV. Therefore, it is necessary to comprehensively consider the battery design requirements of series HEV and parallel HEV according to the actual situation.

Although different types of HEV have different requirements for the batteries, there are still some common requirements:

(1) The state of power (SOP) of the battery should be large enough to meet the demand for high power charging and discharging in a short time.
(2) The service lifetime of the battery should be as long as possible to reach about 1000 deep discharge cycles and 400,000 shallow discharge cycles.
(3) The battery SOC should be kept within the range of 50–85% as far as possible.
(4) BMS is required to control and feedback the real-time state of the battery pack to ensure the safety and efficiency of the battery pack.

1.2.3 Plug-in Hybrid Electric Vehicle

PHEV is a kind of HEV that can be charged from the power grid. It has both BEV and HEV operating modes, which can be simply understood as a combination of BEV and HEV. Such vehicles are usually expected to drive dozens of kilometers in the BEV operating mode, and can meet highway driving requirements in the HEV operating mode, while having high-power output capacity in low SOC range. Therefore, the energy density requirement of PHEV batteries is close to that of BEV batteries, and the power density requirement is close to that of HEV batteries. In fact, the price of PHEV is generally higher than BEV and HEV due to the higher requirement of PHEV battery.

1.2.4 Relevant R&D Indicators

The 13th Five-Year Plan of China has clearly defined the relevant indicators for the battery and BMS. In December 2017, the Guidelines for the Application of New Energy Vehicles for Key Special Projects in 2018 issued by the Ministry of Science and Technology clearly stated:

(1) New energy passenger vehicle

The design of the battery and BMS needs to meet the requirements of high safety and high specific energy. The specific energy of the battery system should be more