Overview of Key Technologies of Battery Management System

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Abstract—The research of energy storage battery provides time and space support for the development and utilization of renewable new energy. For the efficient utilization of energy storage battery, special battery management system is needed. This paper introduces the function, composition and development status of battery management system. Combined with the current engineering application and research situation, this paper summarizes the methods and approaches to realize its various functions (state detection, SOC estimation, balanced control and heat management), and compares and analyzes the advantages and disadvantages of the battery management system. Finally, the development trend of battery management system is prospected.

1.Introduction
With the increasing demand for energy consumption in human society, the exploitation and utilization of traditional fossil energy has brought a series of environmental and resource depletion problems, prompting countries to explore and develop renewable new energy and promote energy reform. Especially after the development of large-scale power system, thanks to the development and utilization of new energy and the promotion of smart grid, the research of energy storage technology has entered people's field of vision[1]. Electrochemical energy storage is widely used in power system, electric vehicle, rail transit, uninterruptible power supply and other fields because of its high energy conversion efficiency, convenient and flexible use and no geographical restrictions. However, after a large number of single batteries are connected in series and parallel to form an energy storage system, due to the differences in the working characteristics of the batteries and the single batteries, the performance of the batteries becomes worse, the service life is shortened, and the potential safety problems occur[2]. In view of the series connection problem of energy storage batteries, it is necessary to monitor the working state of batteries in real time and carry out relevant management. Therefore, battery management system (BMS) is produced. By controlling the working state of batteries through battery management system, the service life of batteries is extended, the efficiency of batteries is improved, and the economic cost of system operation is reduced, to achieve the purpose of safe operation of the battery pack.

2.General Situation of Battery Management System
Battery management system is a necessary device for all kinds of electrochemical energy storage systems. It can not only optimize the management and protection of the battery, but also improve the efficiency, reliability and safety of the battery.
2.1. Composition and Function

In a broad sense, battery management system is a device to manage and control the battery in a certain way, which can realize battery detection, battery state estimation, battery performance maximization, battery protection, and feedback to users and external devices[3]. Specifically, it is to detect the operation status of each single battery and battery pack in the battery pack, and control the battery pack according to the collected status data, so as to complete the tasks of battery pack energy balance, temperature control, safety protection and charge discharge management.

Generally speaking, the main functions of battery management system are:

(1) State of charge (SOC) estimation: battery state parameters are the basis for the system to perceive the operating state of the battery pack and conduct corresponding control. Accurately collecting the data of current, voltage and working temperature of each battery is the premise of accurately estimating SOC of the battery, and also an important index to grasp the battery performance state at any time.

(2) Balanced control: the inconsistency between the cell units cannot be eliminated in the actual work. With the continuous accumulation of use, the inconsistency between the cells will be increased continuously, which will affect the overall performance and life of the battery pack. Therefore, in the battery charging and discharging, the system should have the ability of equalization, make each battery in the battery group reach the equilibrium and consistent state, and prevent the battery overcharge and waste of capacity.

(3) Charge discharge management and safety protection: protect the battery pack according to the detected battery operation status data and charging and discharging conditions to improve the safety of the system. In the battery work, the battery parameters are collected in real time, and reasonable fault diagnosis and protection strategies are adopted to prevent the battery from overcharge, over discharge, over temperature and over current.

(4) Communication control: the communication control of battery management system is embodied in not only ensuring the real-time communication between internal modules, but also communicating with superior energy management controller and human-computer interface, so as to effectively improve the stability and security of the whole system.

(5) Status display: through the human-computer interface, the information related to the battery pack can be monitored in real time, and the communication with the display part can be realized to display the battery charge and discharge status, the display of residual power, and the current battery voltage, temperature, current and various fault information.

2.2. Development Status at Home and Abroad

Battery management system has been studied for a long time abroad, especially with the development of electric vehicles, many kinds of battery management system products have been developed, mainly including the EVI battery management system of general motors, which can manage 26 cells in series at the same time, realize the detection of battery pack current and cell voltage, over discharge alarm, over discharge alarm Power off protection and other functions. BADICHEQ battery management system developed in Germany can collect the total current of battery pack, voltage and temperature of single battery in real time, and realize the functions of equalization charging control, data communication, data display, safety alarm, etc[4]. The SAMSUNG SDI battery management system developed in South Korea can monitor the voltage, current and temperature of 40 single batteries at the same time, and use the collected data to manage the batteries in a balanced way. In addition, the battery management system of Prius hybrid electric vehicle developed by Toyota in Japan and the battery management system of electric vehicle developed by Tesla in the United States can realize the management and control of 7000 single batteries.

Domestic research on battery management system started late, and Beijing Traffic University has committed to its research, and has improved the insulation detection system, battery dispersion evaluation system in system function, and used charger communication to control safe charging, and
applied double Kalman filter prediction method to practice in SOC estimation. The distributed battery management system developed by BYD automobile company can collect the voltage of single battery, current and total voltage of battery pack, estimate SOC, protect safety and manage heat. Tsinghua University has developed a special battery management system for EV-6580 light electric bus, which has real-time acquisition of current, voltage, temperature and other parameters, and is equipped with a special charging control system for the battery pack to control the degree of charging and discharging and prevent overcharging and discharging.

In terms of battery management system of energy storage power station, some domestic institutions have also carried out relevant work. For example, the battery management system of energy storage power station developed by energy technology Co., Ltd. can be used in large, medium and small wind and solar energy storage power stations. The system adopts three-layer modular system, namely battery array management module (BAU), battery cluster management module (BCU) and battery pack management module (BMU) to manage the battery. It can monitor the voltage, temperature of single battery and the charge / discharge current of battery cluster in real time, and realize multi-level alarm and fault diagnosis, fault isolation, fault detection, fault detection and fault diagnosis Fault recovery and other protection measures[5]. In general, the research on battery management system at home and abroad mainly focuses on the power management of hybrid electric vehicles, pure electric vehicles and other vehicles. With the development and utilization of renewable energy in recent years, large-scale energy storage technology has been developed, especially the development of electrochemical energy storage, which promotes the research and development of battery management system for energy storage.

3. Key Technologies of Battery Management System

Whether it is the battery management system or the energy storage battery management system, the key points of the research have been focused on the research and development of battery parameters detection, SOC estimation, health status estimation, charge discharge management, balanced control, heat management and fault warning.

3.1. Battery Status Detection

Battery state detection is the basis of the realization of various functions of battery management system. Only by online monitoring of battery voltage, current and temperature, can battery SOC be accurately estimated, battery balanced regulation controlled reasonably and battery protection implemented in time.

3.1.1. Voltage measurement

Voltage measurement can be realized by voltage acquisition circuit and AD conversion. The common measurement methods are: voltage direct sampling method[6], which is composed of linear operational amplifier, analog switch, voltage follower and so on. This method has good real-time performance and high measurement accuracy, but there are some shortcomings in the circuit, such as resistance matching and leakage current, the calculation of output voltage is too complicated, which is suitable for the case of few single batteries in series. Differential mode measurement method[7], that is, using electronic components to gate a single battery for measurement, has the advantages of simple structure, low cost and good performance. Integrated chip detection method[8] uses special integrated chips for voltage measurement, such as LTC6803/04, AD7280, ATA6870 and other chips. The advantages of this method are high integration, small size, high detection accuracy, but it also has the disadvantage of high cost. Other measurement methods include linear optical coupling amplifier circuit acquisition method, common mode measurement method, switch matrix measurement method and so on.

3.1.2. Current measurement

Hall current sensor, current transformer and optical fiber sensor can be used for current measurement,
and series resistance detection and shunt detection can also be used. Hall current sensor has stable performance and is widely used, such as WP050E, ACS712, CSM300B, LT108-S7 and so on. It has the advantages of wide measurement range and high precision, and is widely used in engineering practice; current transformer is only suitable for AC measurement; the application of optical fiber sensor is limited because of its high economic cost; series resistance method requires high precision of resistance, and its circuit design is also complex, and it is easy to produce large measurement error.

3.1.3. Temperature acquisition
Temperature acquisition can be measured by thermistor, thermocouple and temperature sensor[9]. Thermistor method is to use the resistance value of the resistance changes with the temperature characteristics, through the voltage divider circuit, the temperature is converted into a voltage signal, and then through the analog-to-digital conversion to get the temperature data. This method has low cost, but it has the problems of poor linearity and low measurement error. The principle of thermocouple method is that bimetallic body will produce different thermoelectric electromotive force at different temperatures, and the corresponding temperature value can be obtained by collecting the value of electromotive force. This method has high measurement accuracy, but the signal of thermoelectric electromotive force is millivolt level, so it needs amplification, and the external circuit is complex, so it is only suitable for high temperature measurement. The collection method of integrated temperature sensor is more and more used in daily production and life. The common models are DS18B20, BQ76930, etc. these sensors are easy to use, with high measurement accuracy and direct output of digital quantity, so they are very suitable for use in digital systems.

3.2. SOC estimation
In order to display the remaining capacity of the battery in real time, it is necessary to accurately estimate the state of charge of the series parallel battery pack.

3.2.1. Open circuit voltage method
According to the working characteristics of the battery model, there is a one-to-one mapping relationship between the open circuit voltage and the remaining capacity of the battery[10]. According to this corresponding relationship, according to a certain charge and discharge rate, the SOC value of the battery can be obtained by measuring the open circuit voltage. This method is simple and easy to measure. Due to the existence of internal polarization resistance of battery, it needs to stand for a period of time to get the open circuit voltage of battery. Therefore, this method can only be applied to battery modeling research or provide rough SOC initial value for ampere hour integration method, which is not suitable for on-line real-time measurement.

3.2.2. Ampere hour integration method
When the capacity of the battery is known at a certain time, the charge and discharge of the battery in a period of time are accumulated to obtain the state of charge of the battery at the next time:

\[ SOC(t) = SOC(t_0) - \frac{1}{Q_n} \int_{t_0}^{t} \eta(t)I(t)dt \]

Where \( SOC(t_0) \) is the SOC of the moment \( t_0 \); \( t \) is the charge discharge time; \( Q_n \) is the rated capacity of the battery (capacity under standard state); \( I(t) \) is charge discharge current, charge is negative, discharge is positive; \( \eta(t) \) The coulomb efficiency is used to correct the influence of temperature, charge discharge rate and self discharge rate on SOC estimation[11]. This method is relatively simple in practical application. Because the algorithm is the integration of current in time, it has high requirements on the accuracy of initial power estimation, and there are accumulated integration errors, so it needs to be corrected and referenced[12]. In reference [13], the modified open circuit voltage method is combined with the modified ampere hour integration method to improve the accuracy of SOC estimation.
3.2.3. Kalman filter method

The core idea of Kalman filter theory is to make the optimal estimation of the state of the power system in the sense of minimum variance. Battery SOC estimation is based on the optimal control algorithm of battery model. Battery is regarded as a power system. SOC is a state variable in the system, so as to observe the state of battery.

The general mathematical form of battery model is as follows:

**Equation of state:** \( x_{k+1} = A_k x_k + B_k u_k + w_k \)

**Output equation:** \( y_k = c_k x_k + D_k u_k + V_k \)

The discrete SOC calculation formula is as follows:

\[
SOC_{k+1} = SOC_k - \frac{\eta_i \Delta t}{C}
\]

The input vector of the system usually includes battery current, temperature, residual capacity and internal resistance. The output of the system is the working voltage of the battery, and the SOC of the battery is included in the state variable of the system.

Kalman filter method can not only estimate the SOC of battery, but also calculate the corresponding error. It has low requirements for the initial SOC, and is suitable for electric vehicles with large current amplitude variation. However, it has high requirements for the accuracy of battery model, and it is difficult to model the battery, so it is not suitable for the nonlinear battery system[14]. On the basis of classical Kalman filter, scholars have developed extended Kalman filter, unscented Kalman filter, adaptive Kalman filter and other SOC estimation algorithms. These algorithms have been widely used in nonlinear system estimation.

3.2.4. Neural network method

Neural network method uses a large number of basic neurons to connect with each other to form a complex computer network system, which can simplify and imitate the parallel processing, information storage and learning ability of human brain. Battery SOC estimation is a nonlinear dynamic process. Neural network can deal with nonlinear problems better. The SOC value can be predicted by using the relationship among input layer, hidden layer and output layer of neural network. The input quantity is generally the influence factor of SOC, such as voltage, current, temperature, etc; the number of hidden layer neurons depends on the complexity and accuracy of the problem model; the output is SOC value. Neural network is suitable for any battery model calculation, but the disadvantage is that the accuracy is affected by the choice of input quantity, which requires a large number of sample data to train, and the estimation error is greatly affected by the data and training methods[15].

3.3. Equilibrium control

In the application of microgrid, distributed generation and electric vehicle, the capacity of energy storage battery is large and the voltage of battery pack is high. Thousands of batteries need to be used in series to improve the voltage and capacity of battery pack. However, the differences of production process, materials and use environment are easy to cause the inconsistency between batteries, mainly in the following aspects: different voltage, different capacity, different internal resistance, different charging and discharging efficiency[16]. In the process of use, the inconsistency of batteries will lead to overcharge and overdischarge of some single batteries, which will reduce the performance and service life of single batteries and battery packs, and even cause safety problems.

Battery management system through the balance control is to improve the overall performance of the battery pack, and extend the service life of the battery. At present, the main types of equalization control include active equalization, passive equalization and other equalization. The commonly used equalization technologies are active equalization and passive equalization. There are three kinds of variable parameters for equalization control: residual capacity, terminal voltage and state of charge[17]. Among them, passive equalization is also called energy dissipation equalization, which releases the
energy higher than other monomers by connecting with the resistance of the single cell. The typical passive equalization control is shunt resistance equalization. The advantages of this method are less components, low cost, high reliability and simple control. However, the battery energy is consumed in the equalization process, which leads to the decrease of energy utilization rate of energy storage system. At the same time, the resistance shunt generates a lot of heat energy, which is easy to cause thermal management problems. Active equalization, also known as non energy dissipation equalization, uses topology switch and algorithm fusion to transfer power from high-voltage cell to low-voltage cell through some medium, so as to realize the energy consistency of battery pack. The commonly used active equalization control methods include inductance type, capacitance type and converter type. Active equalization circuit structure is complex and difficult to control, but it can reduce the consumption of electricity and reduce the calorific value of battery, which is the focus of current battery balancing management research[18].

3.4. Thermal management

Thermal management is to detect the real-time temperature of the battery box and the battery, and take the active heating or cooling method to make the battery work in the appropriate temperature range as far as possible, so as to give better play to the performance of the battery. Because the working environment temperature of the battery is too high or too low, it will have an important impact on the performance and safety of the battery, when the temperature is too low, the battery activity will be reduced, and the available capacity will be reduced. When the battery is charged at low temperature and high current, the safety accident of thermal runaway will occur. Therefore, the energy storage battery system needs cooling devices such as fans or heating devices such as thermal resistance to keep the battery at the appropriate working temperature. Air cooling, liquid cooling, phase change material cooling, heat pipe cooling and composite cooling can be used for battery cooling[19]. The battery can be heated by thermal resistance heating and liquid heating. In low temperature environment, the battery can be charged with small current first, then self heated by the heat generated by the chemical reaction of the battery, and then charged in normal mode.

4. Conclusion

To sum up, with the development of electric vehicle industry and large-scale energy storage technology, the research and development directions of battery management system are as follows:

(1) Modular integration. With the development of large-scale energy storage, the demand for the number of batteries in series is increasing day by day; improving the integration can effectively reduce the volume, power consumption and economic cost of each module[20].

(2) SOC estimation is fast and accurate. On the basis of building a high-precision battery model and studying the estimation algorithm, it is necessary to improve the estimation accuracy and efficiency, especially the online correction ability of estimation[21].

(3) The balance control will develop in the direction of active balance, and constantly improve the balance current and efficiency. At the same time, the intelligent algorithm and big data storage should be used to integrate the voltage balance and capacity balance in the balance control strategy, so as to make the balance more accurate and efficient.

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