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RESEARCH ARTICLE

Energy Balance Control of Multi Group Lithium Ion Batteries Under Internet of Things Technology

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ABSTRACT Due to the different capacity, internal resistance, electrochemical characteristics and other parameters between different lithium-ion battery cells, the energy consumption and collection speed of the battery are inconsistent during the charging and discharging process, resulting in uneven energy distribution, resulting in excessive discharge of the battery. In order to eliminate the inconsistencies of lithium-ion batteries and improve the utilization rate of groups, a control method for energy balance of multi-group lithium-ion batteries under the Internet of Things technology was proposed. Under the layered architecture of the Internet of Things, voltage information from each lithium battery is collected by the sensing layer. Subsequently, the collected data is weighted and fused using an adaptive weighted multi-sensor data fusion algorithm to enhance the accuracy and stability of the voltage information. The Controller Area Network (CAN) bus is used as the communication medium to upload the voltage information after fusion. In the application layer, multiple sets of lithium-ion battery equalization control circuits are designed. The capacitance of the capacitor is calculated using supercapacitors. Through the remote monitoring module based on Android operating system, combined with 4G Internet of Things technology, the remote monitoring of lithium-ion battery status information is realized. Experiments show that the method can effectively control the energy balance of the lithium-ion battery pack, when the experiment reaches 50 seconds, the end time of the lithium battery balance control is about 540 seconds, the balance efficiency is greater than 98%, the battery voltage standard deviation is always less than 10 mV, to ensure the balanced distribution of energy in the battery pack, and further promote the application and promotion of renewable energy.

INDEX TERMS Battery energy, battery voltage, equilibrium control, Internet of Things technology, multiple sets of lithium ion batteries, remote monitoring.

I. INTRODUCTION

With the development of science and technology and the enhancement of economic level, the car has become an indispensable tool in people's life, but widely used car consumes a lot of oil resources, but also produce a lot of pollution [1]. Affected by the energy crisis, environmental protection concerns, and other factors, electric vehicles, as a novel means of transportation, have become a significant research area in the automotive industry due to their advantages of high energy utilization, zero emissions, low noise, and diverse energy sources [2]. According to relevant data, an electric vehicle can save about 1.5 to 1.9 tons of oil a year, so the use of electric vehicles is conducive to controlling environmental pollution and saving energy [3]. At present, lithium-ion batteries are the most widely used power batteries in electric vehicles. This type of battery has the characteristics of high energy density, high working voltage, no memory effect, long cycle life, no pollution, light weight, small self discharge, etc., but the positive and negative electrode materials determine that

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the current single lithium-ion battery has a low electrode voltage, which cannot meet the demand for driving voltage of electric vehicles. Therefore, multiple single lithium-ion batteries need to be connected in series to drive electric vehicles [4]. When multiple lithium-ion batteries are connected in series, the differences among each lithium-ion battery will become more obvious. This inconsistency between the batteries will lead to a reduction in the usable capacity and performance of the lithium-ion battery pack, thus affecting the driving range of electric vehicles [5]. That is to say, the inconsistency of lithium-ion battery packs will have a series of impacts on batteries. If this problem is not solved, it will increase the use cost of electric vehicles and affect the promotion of electric vehicles. Therefore, it is very important to control the energy balance of multiple sets of lithium-ion batteries [6]. In response to this issue, energy balance control of lithium-ion batteries has become an important field of research. In recent years, with the advancement of technology, especially the rapid development of the Internet of Things, new possibilities have emerged for energy balance control of lithium-ion batteries. Internet of Things technology enables the real-time monitoring of battery operating conditions, temperature, voltage, and other parameters, facilitating efficient management and optimized control of battery packs, thereby enhancing energy utilization and extending battery life [7], [8]. Therefore, to gain a deep understanding and solve the issue of inconsistency in lithium-ion battery packs, it is crucial to control the energy equilibrium of multiple battery packs. In future research, combined with the latest advancements in Internet of Things technology, exploring more intelligent and efficient energy balance control strategies will provide robust support for the sustainable development of electric vehicles [9], [10].

II. LITERATURE REVIEW

In recent years, many scholars have conducted a lot of research on the energy balance control of lithium-ion battery packs, and have achieved certain research results. For example, Ananda and others built a general estimation energy balance (GAGE-EB) model driven by a genetic algorithm according to the characteristics of open circuit voltage (OCV), internal resistance (Rint), coulomb counting, and other parameters. This model estimates the deliverable capacity and internal resistance by accurately matching the battery terminal voltage, so as to check the new battery load and balance the power generation profile energy. However, this method has the problems of low efficiency and long balancing time [11]; Tarhan et al. designed a battery management system by using Altium program. The system measures and checks the voltage, temperature, current, SOC (state of charge), SOH (state of health) and other indicators of the battery pack and battery cell, real-time grasps the operating status of lithium batteries, and judges whether there is inconsistency in battery energy. The lithium battery with low energy is balanced through a separate port, but this method has the problem of slow energy conversion between batteries and is easy to produce more energy consumption [12]; Uno et al. proposed a modular equalization system using a dual phase (DPS) controlled capacitor isolated dual active bridge (CIDAB) converter. The system has two modules, each of which contains a CIDAB converter. The converter is used to directly convert the energy of each battery. The exchange branches of the CIDAB converters of adjacent modules are connected to each other through LC slots. The switching branch of CIDAB converter acts on the equalizer within and between modules to achieve the balance control between batteries. However, the balance current generated by this method is small, and the effect is not ideal in the battery discharge balance process [13]. Cheng et al. achieved homogenization of active material utilization by implementing composition gradient design on the electrode at the microscale, thereby expanding the energy-power characteristics while balancing the degradation rate of the battery. However, this method still faces issues of degradation and capacity fade during long-term cycling of the battery, which requires further improvement to enhance the cycling life and stability of the battery [14]. Qian and Liu proposed the MSCA-DEKF method, which optimizes SOC/SOH estimation through a second-order RC model and pulse discharge, open circuit voltage testing. Online estimation of Ohmic resistance and capacity reduces computational costs, improves SOC estimation accuracy, and Ro-based SOH is more robust and accurate than capacity-based SOH. The implementation of this method relies on accurate model parameter acquisition, including parameters obtained through pulse discharge testing and open circuit voltage testing, which, if erroneous, will directly affect the accuracy of SOC/SOH estimation [15]. Shang et al. designed a liquid cooling system for lithium-ion batteries that changes the contact surface. By optimizing the inlet temperature, cooling plate width, and mass flow rate, efficient cooling and reduced pump power can be achieved, which can be widely applied in battery thermal management to improve battery performance. The difficulty of this method lies in balancing the cooling effect with energy consumption, accurately controlling the cooling plate contact area, addressing the nonlinear impact of temperature on thermal performance, and ensuring the reliability and stability of the cooling system in practical applications [16]. Yu et al. established for vehicle active and passive suspension. To avoid experience value of uncertain weight coefficient affecting the LQG control, analytic hierarchy process (AHP) is adopted to determine the weighting coefficient of vehicle performance evaluation index. And the LQG controller of vehicle active suspension is designed based on optimal control theory. Compared with the analysis results of passive suspension, the effectiveness of active control scheme is verified [17]. Ouyang et al. proposed a predictive control method for battery efficiency, studied the influence of vanadium REDOX flow batteries on energy storage of microgrids, and adopted biomass fuel cells as a power generation system to achieve battery energy control. However, the operation mode of the microgrid will affect the charging and discharging strategy of the battery, so it is necessary to design a flexible control system to adapt to different operating conditions [18]. Guo et al. introduced a trust evaluation scheme for federated learning in digital twin mobile networks (DTMN), which enhances the accuracy and resistance to attacks of user trust evaluation by considering direct trust evidence and recommended trust information, and conducting fine-grained trust calculation based on a multi-attribute user behavior model. Due to the use of a trust calculation method based on a multi-attribute user behavior model, the computational complexity of this scheme may be relatively high, which could impact the accuracy of the entire trust evaluation system [19].

The Internet of things (IOT) refers to the deployment of embedded hardware and software system equipment in the physical environment that has certain networking communication capabilities, physical environment detection capabilities and action execution capabilities, and the access of these intelligent equipment to the Internet through wired or wireless access, to achieve data transmission, data fusion and distributed collaborative computing, so as to realize the network connection and data exchange between things [20]. The Internet of Things is based on the Internet. It is possible to use this technology to directly communicate data between things. The Internet of Things integrates embedded system application technology, intelligent perception technology, computer communication technology, etc., and has the characteristics of overall perception, reliable transmission and intelligent processing [21]. Therefore, an energy balance control method for multiple sets of lithium-ion batteries under the Internet of Things technology is proposed in this paper. The weighted fusion of data is processed by an adaptive weighted multi-sensor data fusion algorithm, which improves the accuracy and stability of voltage information and realizes efficient and reliable data transmission. The balance control circuit of Li-ion battery is designed to realize the balance control and energy management of battery state by using supercapacitor. Combined with 4G Internet of Things technology, remote monitoring of lithium battery status information is achieved, which improves the convenience and intelligence level of battery management. On the whole, this research combines a number of key technologies and innovative thinking in the battery management system, providing an efficient, accurate and intelligent solution for battery condition monitoring and energy management, which can effectively control the energy balance of lithium-ion battery packs, and has strong application value. This method uniquely combines IoT technology to achieve efficient balancing control of the energy of multiple sets of lithium-ion batteries through adaptive data fusion, CAN bus communication, and remote monitoring, significantly improving the utilization and lifespan of battery packs. Experimental verification has demonstrated outstanding performance of the proposed IoT-based lithium-ion battery energy balancing control method. By real-time monitoring of battery status and precise data processing using IoT technology, this method achieves effective battery energy balancing control. Under different conditions, its voltage standard deviation is lower than the comparative methods, demonstrating high balancing efficiency and battery pack adaptability. Additionally, this method accurately reflects the internal state and inconsistency of the batteries, providing strong support for battery management. Overall, this method is not only highly innovative but also has significant practical value.

III. ENERGY BALANCE CONTROL OF MULTIPLE SETS OF LITHIUM ION BATTERIES

Lithium-ion batteries mainly rely on lithium ions inside the battery to embed and deembed between the positive and negative electrodes in a round robin cycle to achieve energy storage and release [22]. The operating voltage, maximum usable capacity and other characteristic parameters of each single lithium-ion battery in an ideal lithium-ion battery pack should be consistent [23], so the detection of an ideal lithium-ion battery pack can be transformed into the detection of a single lithium-ion battery, but it is difficult to ensure the consistency of all aspects of performance of a lithium-ion battery pack when it leaves the factory. And with the increase of charge and discharge times of the lithium-ion battery pack, the inconsistency of the lithium-ion battery pack will increase, which will reduce the maximum usable capacity of the entire battery pack. When the difference of each battery in the battery pack is large, the capacity of the entire battery pack is greatly affected by the smaller battery, thus reducing the utilization rate of the total capacity of the battery pack. At the same time, these inconsistencies reduce the available power of the lithium-ion battery pack, so that the lithium-ion batteries with different performances are in different charge and discharge depths during the charging and discharging process, which cannot meet the requirements of high-power electric vehicles. Therefore, it is necessary to develop a method to balance the energy of the lithium-ion battery pack. By achieving energy balance, the service life and performance stability of the entire battery pack can be improved, and the problems caused by the power imbalance of a single battery can be effectively avoided, which makes an important contribution to the reliability and safety of the battery pack application field and promotes the sustainable development of battery technology.

A. CONSTRUCTION OF BALANCED CONTROL MODEL ARCHITECTURE BASED ON INTERNET OF THINGS TECHNOLOGY

IoT technology can achieve real-time monitoring of multiple sets of lithium ion battery and data collection, including battery respective parameters such as voltage, temperature, current, to achieve balance between multiple sets of lithium ion battery control, guarantee the balanced distribution of electricity in the battery pack, reduce voltage fluctuation and difference, to further improve the stability of the system. This

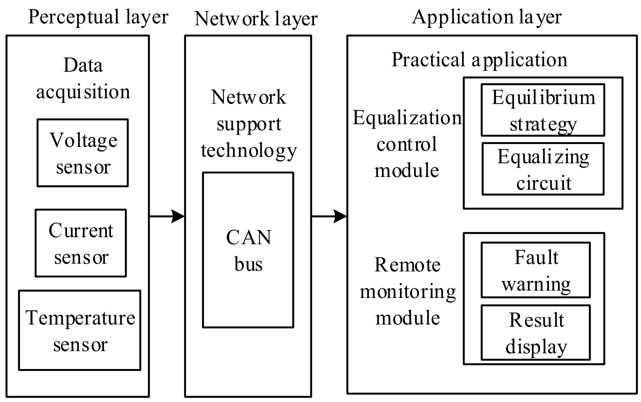

FIGURE 1. Multi-group lithium-ion battery energy balance control platform.

real-time performance can help to find the energy difference of each unit in the battery pack in a more timely manner, judge the energy state of the battery more accurately, and reduce the occurrence of energy imbalance. Therefore, the balanced control model architecture based on the Internet of Things technology provides important technical support and innovative direction for the research of multi-group lithium-ion battery energy balance control. The network architecture of the Internet of Things can generally be divided into three parts, namely, the perception layer, the network layer and the application layer [24]. The energy balance control model architecture of multiple sets of lithium ion batteries using the Internet of Things technology is shown in Fig. 1.

According to Fig. 1, the core of the multi-group lithium-ion battery energy balance control platform lies in its Internet of Things (IoT) technology architecture, consisting of the perception layer, network layer, and application layer. The perception layer is located at the bottommost layer, composed of intelligent perception devices responsible for collecting key parameters such as voltage and current of the battery pack. It serves as a crucial link connecting the lithium-ion battery pack to the management system. These devices not only support traditional human-to-device communication but also enable autonomous communication, connection, and intelligent management between devices. Sensor technology, as the core of the perception layer, senses the measured parameters through sensitive components, while transducer components convert this data into usable output signals for further processing. The network layer is responsible for transmitting the data collected by the perception layer to the application layer, which designs and executes energy balance control strategies based on this data, such as controlling supercapacitors to achieve energy balance, thereby ensuring stable operation and extending the lifespan of the battery pack. The entire platform leverages the advantages of IoT technology to achieve real-time monitoring and intelligent management of the battery pack's status, greatly improving energy utilization efficiency and battery pack reliability.

The network layer in the control model mainly uses the communication network to interact and share the data information collected by the perception layer with the Internet. The medium of information transmission is CAN (Controller Area Network, CAN) bus. CAN is an ISO international standardized serial communication protocol, which has the characteristics of good reliability, complete functions and low cost. CAN bus network can be divided into high-speed network and low-speed network. The battery pack in this paper uses high-speed CAN bus network. Each controller and equipment on the electric vehicle can be connected to the CAN bus to form a network, and all nodes on the network can communicate with each other, which can effectively improve the practical performance and save wiring harness and cost. Through the CAN bus of the network layer, the data information of each battery collected by the sensing layer in real time can be uploaded to the application layer.

The application layer utilizes the energy balance control module and the remote monitoring module to analyze and process the information of each battery transmitted by the network layer, enabling the status monitoring, energy management and fault warning of the lithium-ion battery pack.

B. BATTERY VOLTAGE FUSION BASED ON ADAPTIVE WEIGHTED DATA FUSION ALGORITHM

Using the sensor technology of the sensing layer of the Internet of Things, connect the voltage sensor to each lithium-ion battery, and collect the instantaneous voltage of each battery in real time. However, during the operation of Li-ion batteries, due to various reasons (such as manufacturing process, use environment, etc.), the performance of different battery cells will vary. This difference makes the voltage distribution in the battery pack uneven, affecting the service life and performance of the battery pack. Adaptive weighted multi-sensor data fusion algorithm is a common algorithm used to process multi-sensor data. Its core idea is to assign different weights to the data collected by different sensors according to the reliability and accuracy of the data, and then carry out weighted fusion, so as to obtain more accurate results. The adaptive weighted data fusion algorithm can adaptively adjust the weight of each cell voltage in the final fusion value according to the difference between cells, so as to obtain more accurate battery voltage information. By weighted fusion of voltage data of different battery cells, the algorithm can reduce the uncertainty and error of data of a single sensor, improve the accuracy of voltage information of the entire battery pack, help to monitor the state of the battery more accurately, ensure the safe and stable operation of the battery pack, and thus improve the accuracy and stability of energy balance control of multiple sets of lithium-ion batteries. It provides strong support for the optimal management and safe use of battery packs.

The accuracy of each voltage sensor is different, so the credibility of the voltage sensor cannot be unified. The adaptive weighted multi-sensor data fusion algorithm is used to adaptively find the corresponding weight of the measured results of each voltage sensor, and finally achieve the optimization of the fusion results. The core of the adaptive

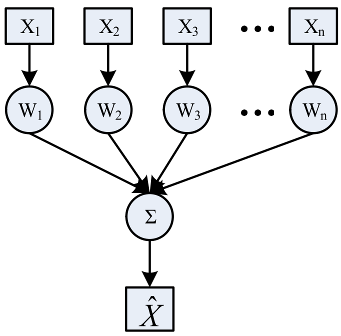

FIGURE 2. Structure of adaptive weighted fusion algorithm.

weighted multi-sensor data fusion algorithm is to obtain more accurate and reliable results by weighting the data collected by different sensors. The algorithm itself is not specific to one type of battery or application scenario, but has a wide range of applicability. At the same time, the algorithm does not depend on a specific type of battery structure or chemical composition, and should be designed with universality in mind, so it can be easily applied to on-board batteries, whether lithium-ion batteries, lead-acid batteries or other types of automotive batteries. The adaptive weighted data fusion algorithm model is shown in Fig. 2.

According to Fig. 2, in this model, X_1, X_2, X_3 to X_n represent voltage data collected from different sources or at different times, forming the input variable set X. Meanwhile, W_1, W_2, W_3 to Wn are elements of the weight vector W associated with each input data, used to adjust the importance of each input data in the fusion process. These input data and weights are combined through a summation function. Ultimately, this function fuses the elements of X and W into a single output value, which is the result of fusing the battery voltage data.

As shown in Fig. 2, the battery voltage data fusion result is expressed by (1):

$$\hat{X} = \sum_{i=1}^{n} W_i X_i \tag{1}$$

wherein, the i weighting factor of voltage sensor is W_i, and $\sum_{i=1}^{n} W_i = 1$; the total mean square error is $\sigma^2 = \sum_{i=1}^{n} W_i^2 \sigma_i^2$; the i voltage sensor variance is expressed as σ_i.

To minimize the mean square error, when the weighting factor is (2). σ^2 has a minimum value. The minimum value is (3):

$$W_i = \frac{\hat{X}}{\sigma_i^2 \sum_{i=1}^{n} \frac{1}{\sigma_i^2}} \tag{2}$$

$$\sigma_{\min} = \frac{W_i}{\sum_{i=1}^{n} \frac{1}{\sigma_i^2}} \tag{3}$$

Thus, the measured variance determines the weight coefficient of each sensor. By optimizing the weight coefficient, the inaccurate or incomplete energy balance control caused by the battery voltage estimation error can be better avoided, and the energy balance control effect can be effectively improved. If the weight coefficient is in line with (2), the total mean square error can be minimized, and accurate battery voltage data fusion update results can be obtained, and the energy state of each lithium-ion battery pack can be more accurately determined, and the corresponding energy balance control strategy can be made. The updated fusion result of battery voltage data is as follows (4):

$$\hat{X}' = \sigma_{\min} \frac{\sum_{i=1}^{n} \frac{X_i}{\sigma_i^2}}{\sum_{i=1}^{n} \frac{1}{\sigma_i^2}} \tag{4}$$

To sum up, based on the average value of each batch, we assign weights to them for valuation, which is called batch valuation; Weighted valuation is to assign weights to each sensor. The same calculation formula can be used for these two valuation methods. To determine which algorithm is more effective, the variance of adaptive weighted estimation can be used. Set n sensors with different accuracy to detect the same data as $X_1, X_2, \ldots, X_n$, sensor variances are $\sigma_1, \sigma_2, \ldots, \sigma_n$.

The variance of the available mean is $\sigma = \frac{1}{n^2} \frac{1}{\sum_{i=1}^{n} \frac{1}{\sigma_i^2}}$; the variance of adaptive weighted estimation is $\sigma = \frac{1}{\sum_{i=1}^{n} \frac{1}{\sigma_i^2}}$. According to Schwarz inequality finally get $\sigma^2 = \left(\sum_{i=1}^{n} \frac{1}{\sigma_i^2}\right)^{-1} \leq \sigma_{\bar{X}}^2 = \frac{1}{n^2} \sum_{i=1}^{n} \sigma_i^2$.

Combining the above formula, it can be concluded that only when the variance of each sensor is completely the same, the estimation fusion of the two methods will be completely consistent. But this kind of situation basically does not exist. Therefore, the adaptive weighted estimation is more effective and is a more effective battery voltage fusion method.

C. BATTERY DATA TRANSMISSION BASED ON CAN BUS COMMUNICATION

CAN bus communication is an efficient and reliable data transmission mode with high transmission rate and anti-interference ability. In the battery energy balance control system, each battery module needs to exchange voltage and status data information in real time. CAN bus can provide stable and fast data transmission channel to ensure real-time and reliability. Therefore, the network layer uses CAN2.0B protocol to send information to complete CAN bus communication from the battery voltage data collected by the sensing layer to the application layer. The data format is formed by expanding frames, and the data frame message status is described in Table 1. The CAN bus transmits two types of data through two mechanisms, completes the flight control data bus output through the response sending function, and completes the bus transmission of battery data through the time-sharing sending

TABLE 1. State of CAN2.0B protocol data frame message.

Start frame	One-bit
Arbitration component	A remote end sends a response request, 18-bit extension ID (D0-D17), The 2-bit extension, 11-bit base ID (D28-D18)
Control section	4-bit data format with 2 reserved bits
Data part	All 64 bits, 0 to 8 bytes of data
CRC part	1-bit locator, 15-bit cyclic redundancy check
Response part	Two-bit
Closing section	7-bit

function. Among them, it is strictly prohibited to output data that is not in accordance with the specified time period, and the battery data must be output through the specified time intervals. If a node remains occupied for an extended period within the specified time period, or if battery data has not been received beyond the specified time limit, the fault report will be output.

D. CALCULATION OF CAPACITANCE VALUE BASED ON SUPERCAPACITOR

The application layer uses the remote monitoring module to analyze and process the battery voltage information transmitted by the network layer communication, so as to realize the status monitoring and energy management of the lithium-ion battery pack. In multiple sets of lithium-ion battery packs, due to differences in battery materials, temperature, aging and other factors, there is an energy imbalance, resulting in some batteries overcharged or overdischarged. Supercapacitors can be used as auxiliary energy storage devices for energy balance control because of their high capacity and fast charging and discharging. By calculating the capacitance value of the supercapacitor, the energy balance control can be accurately adjusted, the safety risk caused by overcharge or overdischarge of the battery can be avoided, and the reliability and safety of the system can be improved. Since the measurement of battery terminal voltage is relatively convenient and the measurement accuracy is high, the battery energy balance strategy based on voltage has been widely used in many practical projects [25]. Using the balanced management technology of the battery pack, based on the battery voltage information transmitted by the communication layer, first compare the voltage of each single lithium-ion battery, according to the results of the comparison, control the high voltage single lithium-ion battery, and transfer part of the energy to the low voltage single lithium-ion battery to achieve the energy balance of the lithium-ion battery, Further, the inconsistency of the single lithium ion battery can be improved.

In this paper, supercapacitors are used as equalization devices, and a multi group lithium ion battery equalization

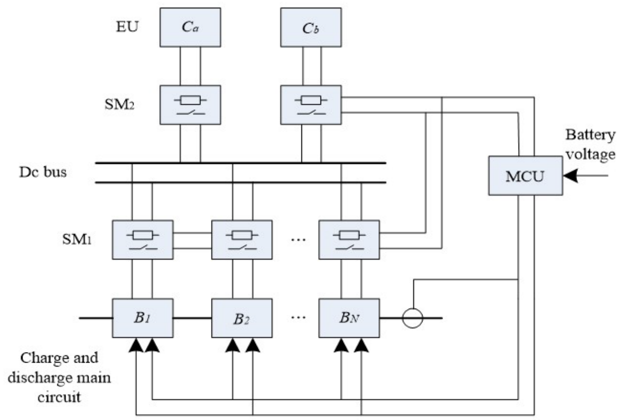

FIGURE 3. Multi-group Li-ion battery equalization control circuit based on supercapacitor.

circuit based on supercapacitors is designed to build multi group lithium ion battery energy equalization control module. The equalization circuit has simple structure and is easy to be modularized. It can conduct real-time energy equalization control in any process such as charging and discharging of lithium ion batteries. The multi group lithium ion battery equalization control circuit based on super capacitor is shown in Fig. 3.

The circuit is an energy transfer circuit mainly composed of supercapacitors, mainly including an equalization unit EU switch matrix SM, controller MCU. Super capacitors have large capacity, high power density, fast charging and discharging speed, wide operating temperature range and long cycle life. They are very suitable for the balance control of lithium ion batteries. Among them, C_a and C_b stands for supercapacitor, $B_1, B_2, \cdots, B_N$ represents a lithium-ion battery.

Multiple sets of lithium batteries used in electric vehicles include M cells, each containing N single battery in series. The design is fixed in each cell to N the balance control is implemented by the controller MCU Judge the conditions for starting and stopping the equalization control, and the energy equalization control can be realized at any time when the battery is used, without additional switching. MCU according to the battery voltage information transmitted by the communication layer, judge the current status of the lithium-ion battery, such as the charging and discharging voltage, whether it is working, and the battery pack equilibrium status. When the pressure difference of a single lithium-ion battery exceeds the preset value, MCU will start in the equalization circuit, by controlling SM, discharge the battery with high voltage and charge the battery with low voltage. Further, the voltage of each single battery is consistent, and the energy balance control of multiple sets of lithium ion batteries is realized.

The synchronization of data ensures the stability of the energy transmission circuit. If the data collected by different sensors are not synchronized, there will be instability, such as the mismatch between voltage and current, which will cause

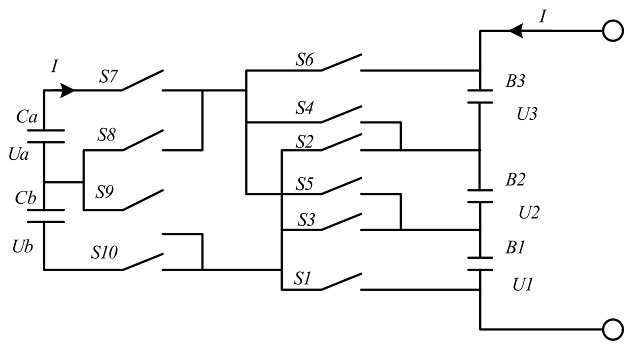

FIGURE 4. Main circuit diagram of lithium-ion battery energy balance control.

the energy balance control system to fail to work properly. In the lithium-ion battery energy balance control system, a timestamp based synchronization mechanism is used to ensure the time synchronization of the data collected from the voltage sensor and the current sensor. This mechanism ensures that the system can accurately monitor the voltage signal and current signal of each battery during the charging and discharging process, and provides reliable data support for energy balance control. Synchronization of sensor data is ensured through time stamps. Each sensor records a timestamp at the time of data acquisition. In this way, even if there is a small time difference between the sensors, their data can be synchronized according to the time stamp, ensuring the timing consistency of the data. With lithium ion battery B_1, B_2, B_3 the battery pack formed in series is taken as an example for correlation analysis, and its main circuit is shown in Fig. 4.

In Fig. 4, the voltages of the three lithium-ion batteries are collected by the sensing layer voltage sensor of the Internet of Things, respectively U_1, U_2, U_3, a single capacitance voltage is also acquired by the Internet of Things sensing layer voltage sensor, which are U_a, U_b, the current is represented by I, the super capacitor C_a and C_b form EU, S represents relay, where $S_1 \sim S_6$ form SM_1, $S_7 \sim S_{10}$ is used to select capacitance. DU mainly detects the voltage signal of each battery and the current signal in the process of charging and discharging. It mainly uses the switch array composed of optocoupler relays to select the voltage of a single battery and transmit it to the A/D converter, then transmit to MCU.

Set the equivalent resistance in the circuit to R, subscript for capacitor series equivalent capacitance parameter c indicates that the equalizing capacitor obtains energy from the lithium ion battery with high voltage, and its current I_1 indicates that the current used for charging the low voltage lithium ion battery I_2 to express. If lithium ion battery B_1 with minimum voltage, B_3 with the highest, the initial voltage of the capacitor is the same, and the capacitance value is the same. At this time, the working process of the equalization circuit can be divided into three stages, specifically described as:

Phase 1 $[t_0 \sim t_1]$: S_5, S_6 close, S_7, S_9 close, current I_1 at the time points of t_0 and t_1 can be described as (5) and (6):

$$-(U_3 - U_a)/R\,\big|_{t_0} = I_1(t_0) \tag{5}$$

$$-(U_3 - U_a)/R\,\big|_{t_1} = I_1(t_1) \tag{6}$$

Set power consumption is represented by Q, according to $C = \frac{Q}{U}$, available capacitance C_a the Q_a of electricity transferred from the battery is described as (7):

$$Q_a = C_a \Delta U_a \tag{7}$$

wherein, differential pressure ΔU_a described as (8):

$$\Delta U_a = U_a(t_1) - U_a(t_0) \tag{8}$$

The whole process, the voltage and current of capacitance C_a are (9) and (10):

$$U_a(t) = U_3(t)(1 - e^{\frac{-t}{\lambda_1}}) \tag{9}$$

$$I_1(t) = -\frac{U_3}{R} e^{\frac{-t}{\lambda_1}} \tag{10}$$

where, $\lambda_1 = RC_a$.

In this process, C_b will occur self discharge, and its voltage drop is $\Delta U_b = U_b(t_1) - U_a(t_0)$, the voltage of B_3 will also decrease, and its voltage drop is $\Delta U_3 = U_3(t_1) - U_3(t_0)$.

Phase 2 $[t_1 \sim t_2]$: S_5, S_6 close, S_8, S_{10} Close, battery charge to C_b. The working principle is the same as phase 1. At this stage, the pressure rise of C_b is approximately equal to pressure rise of 1 C_a. Therefore, the amount of electricity transferred to the capacitor is approximately equal. Due to C_a self discharge, the voltage will drop, and the voltage of B_3 will also drop, and the voltage drop is $\Delta U_3' = U_3(t_2) - U_3(t_1)$.

Phase 3 $[t_2 \sim t_3]$: S_1, S_2 close, S_7, S_{10} Close, equivalent capacitance C_c discharge to B_1. It can be seen that (11) and (12):

$$C_c = (C_a C_b)/(C_a + C_b) \tag{11}$$

$$U_c = U_a + U_b \approx 2U_a \tag{12}$$

At this time, the discharge current I_2 at the time points of t_2 and t_3 can be described as (13) and (14s):

$$(U_c - U_1)/R\,\big|_{t_2} = I_2(t_2) \tag{13}$$

$$(U_c - U_1)/R\,\big|_{t_3} = I_2(t_3) \tag{14}$$

The amount of electricity with the capacitance transferred to B_1 can be described as (15):

$$Q_c = C_c \Delta U_c = [(C_a C_b)/(C_a + C_b)]\,\Delta U_c \tag{15}$$

At this stage voltage $U_c(t)$ and current $I_2(t)$ of capacitance of C_c respectively described as (16) and (17):

$$U_c(t) = U_c(t_2) e^{\frac{-t}{\lambda_2}} \tag{16}$$

$$I_2(t) = \frac{U_c(t_2) e^{\frac{-t}{\lambda_2}}}{R} \tag{17}$$

where, $\lambda_2 = RC_c$.

The voltage of B_1 rise is (18):

$$\Delta U_1 = U_1(t_3) - U_1(t_2) \tag{18}$$

The equalization efficiency is the ratio of the power absorbed by the capacitor to the power charged by the capacitor. By calculating equalization efficiency, the performance of energy equalization control of lithium-ion batteries can be evaluated. When the equalization efficiency is high, it indicates that the energy equalization control strategy can effectively transfer the electricity from the capacitor to the battery, and achieve a better equalization effect. This index can be used to measure the energy balance degree of the lithium-ion battery, and the equalization efficiency ∂ can be described as (19):

$$\partial = \frac{C_c \Delta U_c}{2C_a \Delta U_a} \tag{19}$$

If the energy in the lithium-ion battery is unbalanced to a large extent, and the battery voltage cannot be balanced by one equalization, the process needs to be repeated for many times. If the remaining battery power is linearly associated with the terminal voltage U_{ocv}, according to the capacity of lithium ion battery C_n and the maximum amount of electricity that can be transferred by the equalizing capacitor at one time Q, obtaining lithium ion battery B_m and B_n the differential pressure of is ΔU, then the number of times the lithium ion battery pack needs to be equalized can be described as (20):

$$N = \frac{3600C_n(\Delta U/2)}{(4.2 - 2.75)Q} \tag{20}$$

In addition, the selection principle of super capacitor is that the capacitance, self discharge rate and withstand voltage of the capacitor are equal. The voltage that can equalize the lithium ion battery each time the equalizing circuit acts is called the maximum equalizing voltage U_ℓ, by calculating the capacity of supercapacitors, sufficient storage capacity can be provided to achieve energy balance between batteries. Supercapacitors can act as energy storage devices, quickly absorbing and releasing energy when needed, helping to achieve a balanced transfer of energy between battery modules. The capacitance value of the capacitor can be described as (21):

$$C = (3600C_n U_\ell)/\left[(4.2 - 2.75)(U'/2)\right] \tag{21}$$

where, the capacity unit of capacitance C_n is Ah. The available voltage range of lithium ion battery is 2.75-4.2 V. U' that is the highest voltage that the capacitor can charge in the equalizing circuit.

According to the energy balance control strategy of multiple groups of lithium-ion batteries, based on the battery voltage value transmitted by the communication layer, the energy balance control of multiple groups of lithium-ion batteries can be realized through the lithium-ion battery balance control circuit.

E. MULTIPLE SETS OF LITHIUM ION BATTERY STATUS REMOTE MONITORING

1) THE BATTERY STATUS REMOTE MONITORING MODULE WAS BUILT BASED ON ANDROID

In order to facilitate real-time monitoring of the status of multiple sets of lithium-ion batteries, mobile phone clients can be used to monitor the information of each single battery in the battery pack in real time. The mobile device Android [26], which has good software compatibility and strong open source, is used to build a remote monitoring module for multiple sets of lithium-ion battery status on the mobile phone.

Since the running environment of the function library of the Android system depends on the Java language, the Java environment needs to be configured before building the Android development environment. This article selects the intelligent integrated development environment for development and Eclipse as the development platform. The intelligent integrated development environment is equipped with the ADT plug-in on the development platform, connecting Eclipse and the Android SDK (the Android SDK provides the application development interface library and debugging functions required for developing Android applications). The plug-in can complete clear breakpoint settings, so as to facilitate the observation of the status information of lithium ion batteries at various stages. The design of the entire mobile phone client is carried out under the Windows operating system.

2) ELECTRIC VEHICLE WIRELESS COMMUNICATION TECHNOLOGY BASED ON 4G INTERNET OF THINGS

Short distance wireless communication technology is mainly used in electric vehicle network, which mainly includes 4G Internet of Things (Wireless Fidelity), Bluetooth, Zig Bee and other technologies [27]. These wireless communication technologies are applied in different fields due to different modulation methods, suitable frequency bands, operating range and data rates [28]. The high-speed, high-bandwidth and low-delay 4G network IoT technology is used to connect and manage a large number of IoT devices and realize the interconnection among devices [29].

4G IoT technology can realize remote monitoring and management. Through real-time communication with remote server, electric vehicle can remotely view and control vehicle status, such as battery power, charging status, vehicle position, etc. With 4G Internet of Things technology, electric vehicles can be interconnected with other intelligent devices and cloud platforms to achieve Internet of Vehicles services. For example, the vehicle can be connected with the navigation system, smart home devices, etc. to achieve intelligent navigation, remote control and other functions. Taking 4G Internet of Things as the wireless communication technology on electric vehicles can meet the needs of users [30], while reducing costs and improving work efficiency. Therefore, this paper selects 4G Internet of Things for information transmission between the battery management system of electric vehicles and mobile phone clients. The system uploads the collected lithium-ion battery data to the network server through MQTT (Message Queue Telemetry Transmission) protocol, then establishes a database on the server side, and saves the sent battery data in the database. When the customer views the battery data through the mobile

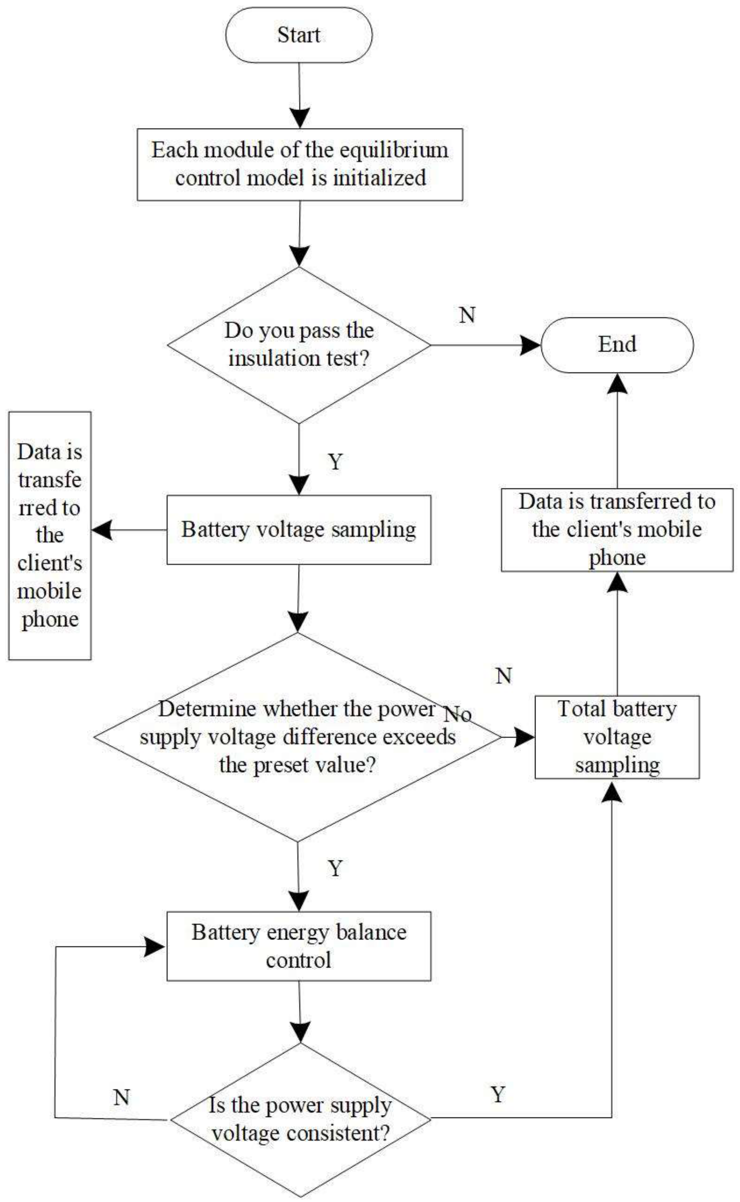

FIGURE 5. Energy balance control flow of multiple groups of lithium-ion batteries.

phone, the mobile phone APP communicates with the server through the HTTP (hypertext transmission) protocol, so that the customer can monitor the data information of each cell in the lithium-ion battery pack through the mobile phone.

F. REALIZATION OF ENERGY BALANCE CONTROL FOR MULTIPLE SETS OF LITHIUM ION BATTERIES

Using the energy balance control model of multiple sets of lithium ion batteries, the flow chart of energy balance control of lithium ion batteries is shown in Fig. 5.

Using the energy balance control model of multiple sets of lithium ion batteries, the specific process of energy balance control of multiple sets of lithium ion batteries is described as follows:

(1) Initialize each module in the multi group lithium ion battery energy balance control model.

(2) Carry out insulation test on the battery pack. If the test passes, use the sensing layer of the battery management system to collect the voltage of each single battery in the battery pack; If the insulation test is not passed, it indicates that the battery pack has leakage, and the program is over.

(3) On the one hand, the collected voltage data of each single battery can be transmitted to the mobile phone client through data transmission technology for monitoring, and on the other hand, the voltage difference of each lithium-ion battery can be calculated.

(4) According to the voltage difference of the lithium-ion battery, judge whether the battery needs to carry out

energy balance control. If it is found that the battery voltage difference does not reach the preset threshold, that is, the voltage difference between individual battery cells is small, the total voltage of the battery pack can be directly sampled. This can simplify the operation process, improve detection efficiency, and reduce interference with the battery system. If the voltage difference exceeds the preset value, start the single battery voltage equalization control, and set the number of times the lithium ion battery needs equalization control. Then judge the consistency of the single battery after the equalization control. When the battery consistency standard is not met, return to the battery energy balance control link, and re conduct the energy balance control of the battery until the battery consistency requirements are met, and then enter into the battery pack total voltage sampling link.

(5) Transfer the collected total voltage information to the mobile client to achieve remote monitoring of the battery pack.

IV. EXPERIMENTAL ANALYSIS

Taking a brand of electric vehicle as the experimental object, the motor power of the vehicle is 4/5 KW; the driving mode is rear drive; the braking mode is front disc and rear drum; the steering mode is mechanical power assistance; the power battery type is lithium battery; and the charger is an intelligent built-in charger, with a maximum speed of 55-60 km/h. The main parameters of lithium battery are shown in Table 2.

TABLE 2. Main parameters of lithium battery.

Serial number	Parameter name	Data
1	Charging voltage	72 V
2	Charging current	20 A
3	Standard capacity	200 ah
4	Load voltage	24 V
5	Discharge current	200 A
6	Protection function	Short circuit protection
7	Storage temperature	29°
8	Charging time	10/h

The energy balance control method algorithm is as follows:

(1) Sensor data acquisition: Real-time monitoring of the voltage of each cell in the battery pack using the Lime LV25-P/SP2 voltage sensor.

(2) Setting voltage range threshold: Choose an appropriate voltage range threshold, which is the difference between the maximum and minimum voltages of each cell in the battery pack. Set to 30mV to ensure timely initiation of energy balancing operations without causing excessive intervention.

(3) Initiate energy balancing operation: Initiate energy balancing operation when the voltage difference between any two cells exceeds the set threshold.

(4) Energy balance control: Use balancer devices to control the energy balance of the battery. Balance the voltages of individual cells by discharging cells with higher voltages and charging cells with lower voltages.

(5) Stop balancing operation: Stop energy balancing operation when the voltage difference between all cells is less than the set value (10 mV). Within this range, battery pack stability can be effectively maintained.

In order to verify the effectiveness of the method in this paper, the experiment carried out energy balance control on the lithium-ion battery pack of the electric vehicle. The Lyme LV25-P/SP2 voltage sensor was used to collect the battery voltage data. When the voltage difference (that is, the difference between the maximum and minimum voltage of each cell in the battery pack) was set to 30 mV, the energy balance operation was started. When the voltage difference was less than 10 mV. The equilibrium stops and the experimental results are obtained, as shown in Fig. 6.

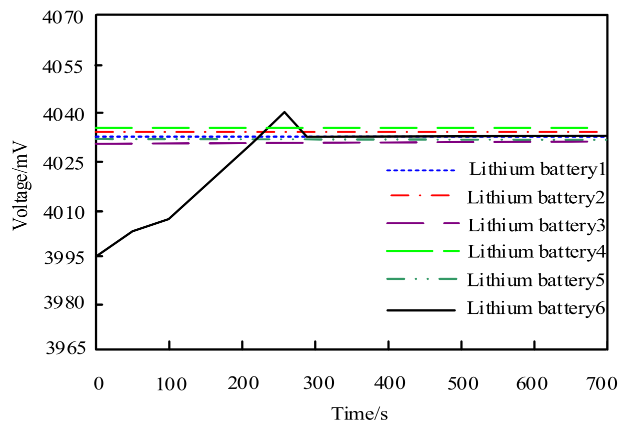

FIGURE 6. Energy balance control of lithium-ion battery pack.

It can be seen from Fig. 6 that the battery pack contains six lithium-ion batteries, of which the highest voltage is lithium battery 4, and the lowest voltage is lithium battery 6. The pressure difference between the two is nearly 40 mV, which meets the energy balance starting conditions. After the equalization operation starts, the voltage of lithium battery 6 gradually rises, and the difference between the voltage of lithium battery 6 and that of lithium battery 4 is less than 10 mV at about 200 s, reaching the set end of equalization condition. At this stage, the voltage of lithium battery 6 will continue to rise for a period of time. When the relay is closed, the voltage of lithium battery 6 begins to fall back, then slowly decreases, and finally is almost the same as the voltage of lithium battery 1. Its voltage difference with lithium battery 4 is only about 2 mV, which better realizes the goal that the voltage difference set in the experiment is less than 10 mV. This shows that the method in this paper is effective.

In order to further measure the performance of the method in this paper, when the lithium-ion battery pack is discharged, the method in this paper is used to control the energy balance of the battery pack, and it is set to turn on the balance control

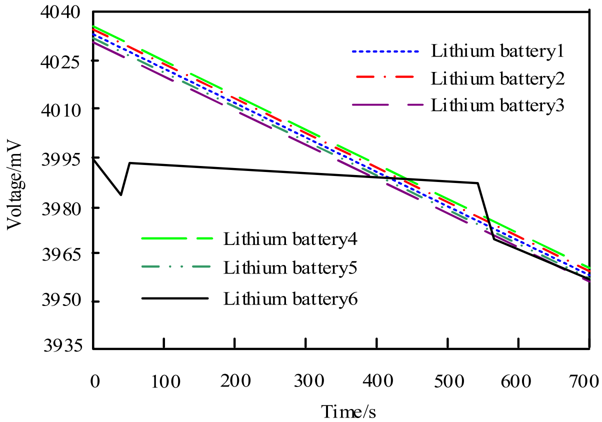

FIGURE 7. **Balance control of battery pack in discharge state.**

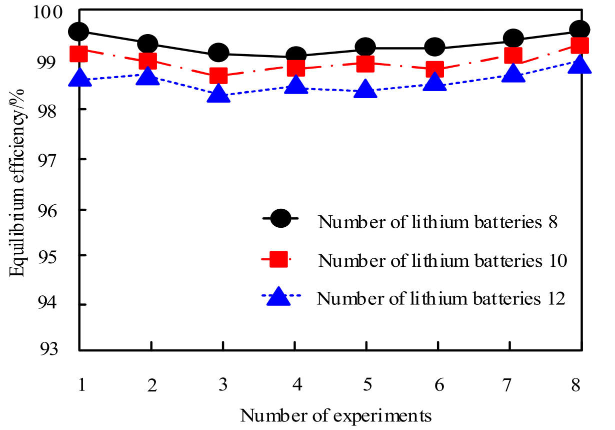

FIGURE 8. **Balance efficiency of battery packs under different quantity of lithium batteries.**

when the experiment runs to 50 s. The final results are shown in Fig. 7.

It can be seen from Fig. 7 that with the start of discharge, the voltage of all lithium batteries decreases to varying degrees. When the experiment reaches the 50 s, the equalization control of lithium battery 6 is enabled, and the end time of the equalization control is about 540 s. Then the voltage of lithium battery 6 drops rapidly and gradually tends to the other five batteries and voltages. After 20 s, the pressure difference between lithium battery 6 and lithium battery 4 was reduced to 5 mV, realizing the goal of balancing control of lithium battery 7.

The energy balance degree of lithium-ion battery can usually be evaluated by the balance efficiency index. The larger the value, the stronger the ability of the balance battery, the stronger the ability to restrain the expansion of voltage difference and prevent thermal runaway. Therefore, the experiment uses the method in this paper to implement the balance control on the battery packs with different number of single lithium batteries, and evaluates the results through the balance efficiency index, as shown in Fig. 8.

It can be seen from Fig. 8 that after using the method in this paper to control the balance of the battery packs with different number of single lithium batteries, the balance efficiency is good. The balance efficiency under three conditions is more than 98%, especially for the battery packs with 8 lithium batteries, the balance efficiency is less than 99%. It can be seen that the method in this paper has a stronger ability to balance the battery energy. The adaptability to the battery pack is also good.

The open circuit voltage (OCV) can show the microscopic chemical reaction state inside the battery from the macroscopic physical quantity, so the inconsistency of each cell in the battery pack can be reflected through the external parameter of the battery, the open circuit voltage. The battery SOC (State of Charge) refers to the state of charge, which reflects the residual capacity of the battery. Its value is defined as the ratio of residual capacity to battery capacity. The relationship between OCV and SOC of lithium battery measured by experiment is shown in Fig. 9.

From the curve in Fig. 9, it can be observed that when the SOC value of the lithium-ion battery changes, the OCV value of the battery also changes accordingly, and the two show a positive correlation trend. Specifically, when the SOC value is low (less than 20%) or high (greater than 80%), the change in OCV value is significant; When SOC is in the middle range (20% to 80%), the change in OCV is relatively gentle. This phenomenon indicates that the open circuit voltage of lithium batteries varies at different SOC stages. Therefore, by monitoring the open circuit voltage of the battery pack, the state of the battery and the inconsistency of each individual battery can be understood. By studying the relationship between SOC and OCV of lithium batteries, estimation methods and online monitoring strategies for SOC of battery packs can be provided. This is of great significance for ensuring the stable operation of the battery system, achieving battery management and performance optimization. In summary, the open circuit voltage of lithium batteries can serve as a status indicator of the battery, reflecting the SOC of the battery and the inconsistency of individual batteries.

In order to further measure the excellent performance of the method in this paper, the method of lithium ion battery energy balance based on genetic algorithm in literature [7], the method of battery energy balance based on battery management system in literature [8], and the method of battery energy balance based on modular equalization system in literature [9] are used as the comparison method of the method in this paper, and the standard deviation of voltage is used as the evaluation index. Under different signal-to-noise ratio conditions, the performance of these four methods in the energy balance control of lithium ion batteries was analyzed. The voltage standard deviation can reflect the statistical average value of the deviation from the average voltage of each cell in the battery group. The smaller the voltage standard deviation is, the better the balance of the battery group is. After testing, the results are shown in Fig. 10.

It can be seen from Fig. 10 that these four methods can achieve the energy balance control of lithium ion battery pack. Under the signal noise ratio of 10 dB, the standard

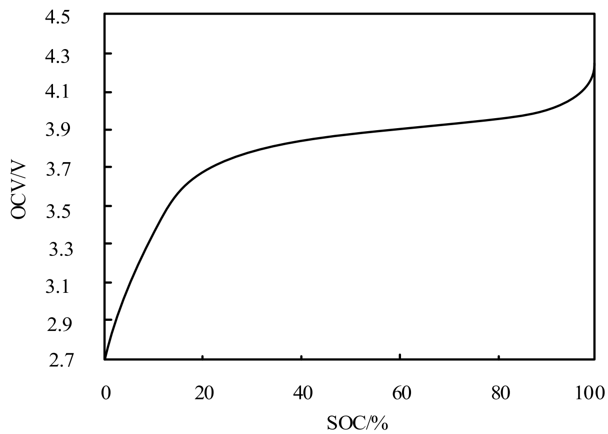

FIGURE 9. The relationship between OCV and SOC of lithium battery.

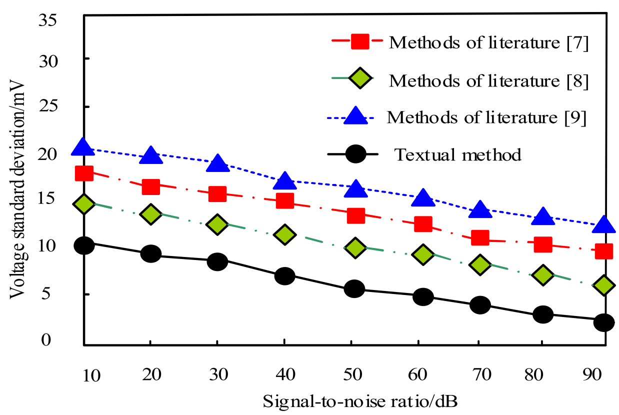

FIGURE 10. Standard deviation of lithium-ion battery voltage after equalization.

TABLE 3. Comparison of stability results under different working conditions and loads.

Condition/load	Battery system stability index /%	PPRU	TFL-DT	Proposed method
Static low load	Voltage fluctuation	90	91	95
	Temperature difference	7	8	5
Dynamic medium load	Voltage fluctuation	89	87	92
	Temperature difference	10	11	8
High speed high load	Voltage fluctuation	88	87	92
	Temperature difference	15	14	8
Extreme conditions (rapid charge and discharge)	Voltage fluctuation	85	84	91
	Temperature difference	16	15	10

deviation of voltage is below 20 mV, while the method in this paper is 10 mV. With the increase of the signal to noise ratio, the voltage standard deviation of the four methods gradually decreases. When the signal to noise ratio is 90 dB, the voltage standard deviation of all methods drops below 15 mV, especially the method in this paper has dropped to about 2 mV at this time. Throughout the whole experimental process, the voltage deviation of the other three methods is always higher than that of the method in this paper, because the method in the literature [7] estimates the deliverable capacity and internal resistance based on the open-circuit voltage characteristics. If the OCV model adopted is not accurate or does not match the actual situation, the estimated voltage will deviate greatly from the real value. The method in reference [8] used the battery management system to measure and check the voltage of the battery pack and battery cell. The sensor's low accuracy will lead to certain deviation of the measured voltage. The method in reference [9] used CIDAB converters to convert and equalize control energy, but the reference voltage is not accurately calibrated, resulting in a large deviation in voltage measurement. The performance of this method in terms of voltage standard deviation is always better than the other three methods. This is because the proposed method uploads the voltage information after fusion processing through the CAN bus, which has high reliability and anti-interference ability, and helps to reduce the errors and fluctuations in the data transmission process. In addition, multiple sets of lithium-ion battery equalization control circuits are designed in the application layer. By using supercapacitors to balance the energy between multiple sets of batteries, the voltage of each battery unit in the battery pack can be kept in a relatively stable and balanced state, thus reducing the voltage fluctuations and differences in the entire battery pack. It can be seen that this method can better achieve the energy balance control of lithium ion battery pack. These experimental results demonstrate that the proposed method has high accuracy and precision, and can achieve good energy balance control for lithium-ion battery packs under different signal-to-noise ratio conditions. This is of great significance for improving the overall performance of lithium-ion battery packs, extending battery life, and ensuring battery safety.

In order to strengthen the universality of research methods and experimental results for energy balance control of multi-group lithium-ion batteries under the Internet of Things technology, the current cutting-edge methods such as privacy protection Reputation Update scheme (PPRU) of cloud-assisted vehicle network and digital twin joint Learning Trust Assessment Scheme (TFL-DT) of mobile network are selected as comparison methods. The stability of the battery system under different working conditions and loads is taken as the evaluation index. Among them, the voltage fluctuation indicates the fluctuation degree of the voltage of each cell in the battery system under specific working conditions and loads, and the smaller the fluctuation, the better the stability; The temperature difference indicates the temperature difference of each cell in the battery system under a specific working condition and load, and the smaller the difference, the better the stability. Multiple sets of lithium-ion batteries are connected to the iot energy balance control system, initial parameters are set, and experimental data is collected and analyzed. The results are shown in Table 3.

From the experimental results, it can be seen that the proposed method is superior to PPRU and TFL-DT in terms of battery system stability under various operating conditions and loads. Especially at high speed and high load and extreme conditions (rapid charge and discharge), the advantages of the proposed method are more obvious, and the voltage fluctuations and temperature differences are kept at a low level, which means that the battery system can maintain better stability and reliability under these conditions. These results validate the effectiveness of the proposed method in lithium-ion battery energy balance control, especially with the support of the Internet of Things technology, it can achieve accurate control and optimization of multi-group lithium-ion battery energy, and improve the overall performance and stability of the battery system.

V. CONCLUSION

As an efficient energy storage device, lithium-ion battery is more and more widely used in the electric vehicle industry. The traditional equalization control is usually carried out at the battery pack level. In this paper, an energy equalization control method for multi-group lithium-ion batteries under the Internet of Things technology is proposed. The adaptive weighted multi-sensor data fusion algorithm is used to process the voltage information of each lithium battery collected by the sensing layer, which improves the accuracy and stability of the voltage information. This data fusion algorithm can effectively eliminate the inconsistencies of lithium-ion batteries and improve the reliability of the whole system. The CAN bus is used as the communication medium, and the high transmission rate and stability of CAN bus are used to upload the voltage information after data fusion to the application layer, which realizes the transmission and sharing of information. In the application layer, according to multiple sets of lithium-ion battery equalization control circuit, the energy of multiple sets of lithium-ion battery is balanced and controlled, which realizes the balanced distribution of electric energy in the battery pack, and improves the utilization rate and life of the battery pack. The remote monitoring module based on the Android operating system is built, and combined with 4G Internet of Things technology, the battery status information can be obtained in a real-time and remote way to realize the remote monitoring of the status information of lithium-ion batteries, and the voltage of each battery unit in the battery pack is kept in a relatively stable and balanced state, thus reducing the voltage fluctuation and difference in the entire battery pack. The experimental results show that the method is based on the Internet of Things technology to realize the energy balance control of lithium-ion battery packs, and has high practicability and feasibility. The research method can be applied to energy management and health monitoring of lithium-ion batteries in electric vehicles, energy storage systems, drones and other fields, and can be further studied and expanded to a wider range of fields in the future.

From the perspective of practical applications, the superior performance demonstrated by the method in this article implies that lithium-ion battery packs can operate more efficiently, reducing performance degradation and shortened lifespan caused by energy imbalance. Additionally, the lower standard deviation of voltage also signifies an improvement in the safety of the battery pack, reducing the safety risks associated with overcharging or over-discharging. However, the method presented in this article also has certain limitations. Firstly, the method requires retrofitting or upgrading existing battery management systems, which increases implementation costs and complexity. Secondly, under extreme operating conditions (such as high temperatures, low temperatures, or high loads), the performance of the method in this article may be affected, requiring further research and validation. Furthermore, the method in this article primarily focuses on the evaluation indicator of voltage standard deviation, while the performance of lithium-ion batteries is also influenced by various other factors, such as internal resistance, capacity, etc. Therefore, future research needs to comprehensively consider additional evaluation indicators.

Looking into the future, with the continuous expansion of the electric vehicle market and the constant advancement of technology, the demand for battery energy management systems will also increase. Future research directions could further explore how to utilize more advanced Internet of Things (IoT) technology and big data analytics to optimize battery energy balance control algorithms, improve energy utilization efficiency, and extend battery lifespan. Additionally, research can also focus on how to apply this method to a wider range of electric vehicles and energy storage systems, such as hybrid electric vehicles, smart grids, etc., in order to expand their potential application scenarios.

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