Hindawi
Mathematical Problems in Engineering
Volume 2019, Article ID 8075453, 9 pages
https://doi.org/10.1155/2019/8075453

Research Article

Switch Matrix Algorithm for Series Lithium Battery Pack Equilibrium Based on Derived Acceleration Information Gauss-Seidel

Yewen Wei,[1,2] Shuailong Dai ,[1,2] Jiayu Wang,[1] Zhifei Shan,[1] and Jie Min[1]

[1] *College of Electrical Engineering & New Energy China Three Gorges University, China*
[2] *Hubei Province Collaborative Innovation Center for New Energy Microgrid, CTGU, China*

Correspondence should be addressed to Shuailong Dai; daishuailong@126.com

Received 4 December 2018; Revised 10 January 2019; Accepted 28 January 2019; Published 10 February 2019

Academic Editor: Zhen-Lai Han

With the rapid development of energy internet and new energy-related industries, lithium-ion batteries are widely used in various fields due to their superior energy storage characteristics. To reduce the influence of the inconsistency of the individual cells in the battery pack, a switch array DC equalization circuit together with an acceleration information Gauss-Seidel (DAIGS) method is proposed. The aging factor is added in the system state matrix considering the battery time effect. In this method, the energy transfer path can be optimized by updating the switch control matrix in each iteration. Hence, it can avoid the repeated charging and discharging of the battery and also reduce energy loss in rapid equalization. A four-cell battery string equalization model simulation was built in the PSIM and the experiment was also carried out to prove the feasibility of the proposed method. It was verified that the DAIGS had better performance under the same precision or number of iterations.

1. Introduction

As the constant deterioration of the global natural environment, new energy vehicles are increasingly being used because of their environment-friendly characteristics. The battery string, power source for electric vehicles, plays an important role in the generalization of new energy vehicles [1]. However, the individual inconsistency caused during the manufacturing process and intensified during the service of the battery pack will result in excessive charging and discharging problems [2]. An equalization circuit is needed to improve overall performance and prolong the service life of the battery string.

Depending on the storage and energy transmission components, equalization on series battery pack is mainly divided into resistor equalizer [3], capacitor equalizer [4], LC oscillating circuit equalizer [5], transformer equalizer [6], and inductor equalizer [7–9]. Among them, the resistor equalizer [3] consumes energy and dissipates heat, which cannot meet the requirements of energy saving and environmental protection; the capacitor equalizer relies on the voltage difference between the cells, and when the voltage difference between the cells is small, it cannot be effectively balanced [4]; in [5], the proposed topology will increase the capital cost. What is more the transformer itself has drawbacks such as large volume and low energy transfer efficiency; LC oscillator circuit equalizer was proposed in reference [6], the capacitor voltage is increased by LC oscillation, the energy is transferred in the form of voltage, and the controllability is poor; the inductor equalizer is used in [7–9], the energy is transferred in the form of current with high controllability. Meanwhile, existed control methods are especially important in the control of equalization circuits. In [10], a novel algorithm was proposed in this paper to manage battery charging operations by a model-based control approach. In [11], it developed a polarization-based charging time and temperature rise optimization strategy for lithium-ion batteries. An enhanced thermal behavior model was introduced to improve the calculation accuracy at high charging current, in which the relationship between polarization voltage and charge current is addressed. In [12], the paper addresses the optimal bidding strategy problem of a commercial virtual power plant (CVPP), which comprises of distributed energy resources (DERs), battery storage systems (BSS), electricity consumers, and participates in the day-ahead (DA) electricity market. In [13], The focus of this paper is a presentation of the latest distributed, centralized, and multiagent control designed to coordinate distributed microgrid ES systems.

The Gauss-Seidel method is an iterative method in numerical linear algebra that can be used to find the approximate solution for a group of linear equations [14]. This method is also widely used in engineering practice, such as modulated filter bank [15], employ cloud-based computation offloading [16], motion analysis [17], etc. In [18], the algorithm based on outlier detection was proposed to solve the problem that present cell-balancing algorithms cannot identify the unbalanced cells in the battery pack. The unbalanced cells were identified by the proposed balancing algorithms and balanced by the shunt method using switches. In [18], the strong tracking cubature extended Kalman filter can achieve more accurate SOC prediction compared to other Kalman-based filter algorithms, which improved the accuracy of battery energy balance. Reference [19] focuses on exploiting the supercapacitor characteristics to prolong the battery lifetime and improve system efficiency. In terms of the performance, the structure complexity, and the cost-effectiveness of the system, a semiactive hybrid one is usually a good choice. The equalization scheme proposed in [20] adopted inductor equalizers to transfer energy from the overcharged cells to the overdischarged ones in the battery pack. The inductor is used to temporarily store the energy transfer capability of the capacitor. And the direction of the current through the inductor can be controlled by a thyristor. It overcame the disadvantages of several other equalization strategies, such as heat dissipation, energy waste, and roundabout energy transfer and also avoided the introduction of additional power source or transformers, hence improving the equalization efficiency. However, to control the thyristors in the equalizer, a complicated drive circuit is required.

According to the disadvantages of abovementioned circuits and strategies, an equalization circuit based on a switch array is proposed in this paper. By controlling the bridge switch matrix, energy from the overcharged cell can be transferred to the overdischarged cell. The battery aging factor parameters are introduced while matrixing the energy variation in the equalization process so that the derived acceleration information Gauss-Seidel algorithm is used to save the time of the equalization process. Finally, the battery model and equalization circuit models were built in PSIM. The advantages of the proposed circuit topology and its control were verified by simulation and experiments respectively. This paper focuses on the algorithm for solving the on-time of switch array in equalization circuit. Our contributions are as follows. (1) A novel flexible interlaced converter is proposed for lithium battery balancing. (2) The energy exchange in the equalization is matrixed while considering the aging factor interference of the battery self-discharge so that a more reliable switch-on time solution can be obtained. (3) For the characteristics of the energy exchange matrix, the derived acceleration information Gauss-Seidel (DAIGS) algorithm is optimized to improve the convergence speed in dynamic equalization process.

This paper is organized in the following sequence. The operation principle of the complementary equalization topology and its control algorithm are explained in Section 2. The addition of the aging factor and its mathematical description is illustrated in Section 3. Considering that the system state matrix is a square matrix, the DAIGS is proposed and verified by simulation and experiment results in Section 3. Finally, conclusions and key research content for future work are provided in Section 4.

2. Interleaved Converter and Its Working Principle

The diode in the conventional buck-boost circuit structure is replaced by a MOSFET for energy bidirectional transmission in continuous current mode (CCM). To make it more suitable for the battery pack, a novel multiphase interlaced converter is proposed and shown in Figure 1. For the multiphase interleaved converter, MOSFETs are driven in a complementary mode. The circuit is composed of n-1 subconverters and n batteries, wherein the inductor of the i^{th} equalization module is connected to the cathode of the i^{th} battery. For each equalization circuit (EC) module, the drain of the upper switch tube is connected to the positive bus of the battery pack, and the source of the lower switch tube is connected to the negative bus of the battery pack. Each subconverter is used to equalize the energy of the battery pack on both sides separated by the inductor.

2.1. Basic Working Principle. The basic working principle of the submodule in the multiphase interleaved equalization circuit is illustrated in Figure 2. Assuming that the battery $\mathrm{B_i}$ is overcharged, it is required that the excess energy of $\mathrm{B_i}$ should be transferred to other cells in the battery pack.

When the switch $\mathrm{S_{L(i-1)}}$ is turned on, the current flows through the inductor $L_{\mathrm{(i-1)}}$ and switch $\mathrm{S_{L(i-1)}}$ from battery $\mathrm{B_i}$ to battery $\mathrm{B_n}$. In the state I, the inductor $L_{\mathrm{(i-1)}}$ absorbs the energy from $\mathrm{B_i}$ to $\mathrm{B_n}$; subsequently, the switch $\mathrm{S_{L(i-1)}}$ is turned off and the current direction of the inductance stays the same due to freewheeling. Followed by, the current flows from $\mathrm{B_1}$ to $\mathrm{B_{(i-1)}}$ through the diode $\mathrm{D_L}$ and the batteries absorb the energy released by the inductor. The working principle of state II is similar and will not be described here.

Combining the two states, the excess energy belonging to $\mathrm{B_i}$ can be transferred to the remaining cells. Specific instructions are as follows: assuming that the difference between $\mathrm{B_i}$ and average of the battery pack is Q_i^{extra}. Under state I, the energy released by each battery from $\mathrm{B_i}$ to $\mathrm{B_n}$ is set to be $\Delta\varepsilon_1$, which is temporarily stored in the inductor $L_{\mathrm{i-1}}$ and then released to the battery $\mathrm{B_1}$ to battery $\mathrm{B_{n-1}}$; under state II, the energy released by the batteries from battery $\mathrm{B_1}$ to battery $\mathrm{B_i}$ is set to be $\Delta\varepsilon_2$, which is temporarily stored in the inductor L_{i} and then released to the batteries $\mathrm{B_{i+1}}$ to $\mathrm{B_n}$. The states I and II can be operated simultaneously.

The on/off switching of each state during the equalization process is shown in Table 1. During one switching cycle,

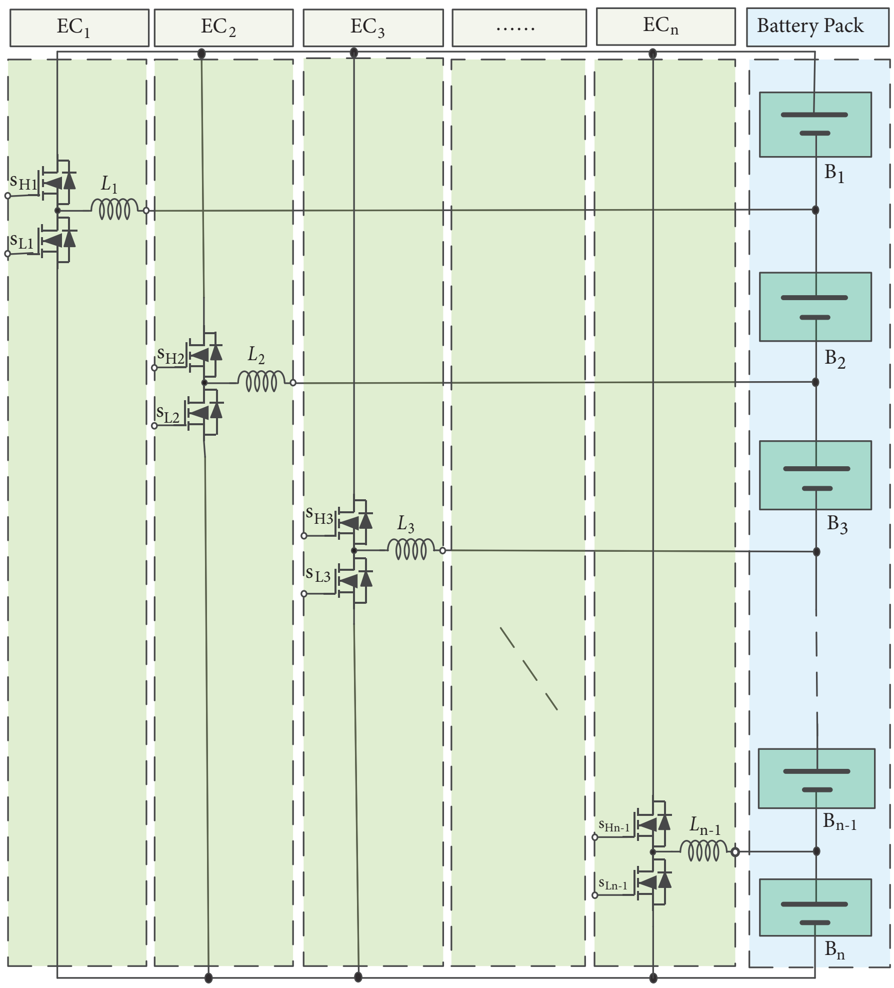

FIGURE 1: Multiphase interleaving converter.

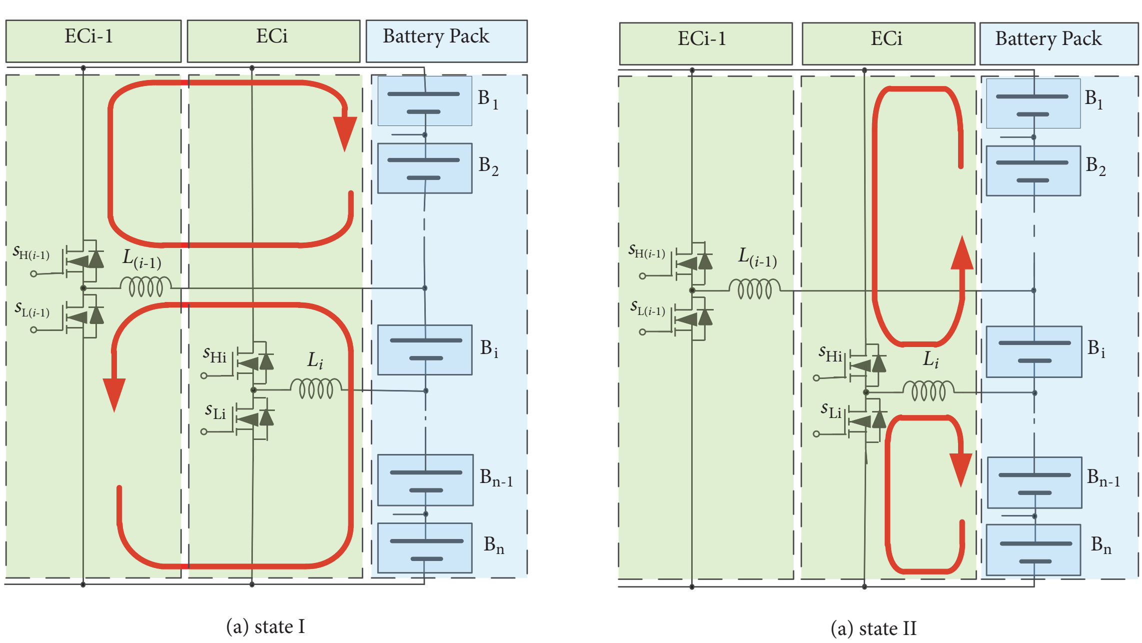

FIGURE 2: Energy transfer from the overcharged B_i to the remaining.

Table 1: Switching state under the equalization.

Switch	*State I*		*State II*	
	Counterclockwise arrow	Clockwise arrow	Counterclockwise arrow	Clockwise arrow
$S_{H(i-1)}$	off	off	off	off
$S_{L(i-1)}$	on	off	off	off
$S_{H(i)}$	off	off	on	off
$S_{L(i)}$	off	off	off	off

energy absorbed and released by the inductor is equal. Accordingly, the following formulas can be derived.

Formula (1) describes the energy exchange from B_1 to $B_{(i-1)}$ batteries; formula (2) describes of the energy released from the battery B_i in quality; formula (3) describes energy exchange from $B_{(i+1)}$ to B_n.

$$\frac{(n-i+1)\,\Delta\varepsilon_1}{(i-1)} - \Delta\varepsilon_2 = \frac{Q_i^{extra}}{n} \quad (1)$$

$$Q_i^{extra} - \Delta\varepsilon_1 + \Delta\varepsilon_2 = \frac{Q_i^{extra}}{n} \quad (2)$$

$$-\Delta\varepsilon_1 + \frac{i\Delta\varepsilon_2}{(N-i)} = \frac{Q_i^{extra}}{n} \quad (3)$$

The simultaneous equations are solved as follows:

$$\Delta\varepsilon_1 = \frac{(i-1)\,Q_i^{extra}}{n} \quad (4)$$

$$\Delta\varepsilon_2 = \frac{(n-i)\,Q_i^{extra}}{n} \quad (5)$$

The multiphase interleaved converter proposed herein easily transfers the energy of overcharged battery to the remaining battery with only two switching tubes controlled (this function can be achieved by controlling only one switch tube when the overcharged battery is in the first or last position of the series battery pack).

2.2. Switching Array and Battery Aging Factor. In engineering practice, there is usually more than one battery that needs to be balanced, a comprehensive consideration of the overall equilibrium and partial equilibrium control is proposed. Due to the highly symmetric of multiphase interleaved converters, the battery pack equalization is considered as an integral process, starting with a matrix of variable energy in the battery pack. Define $Q_{\overline{B}}$ as the average energy of battery after equalization, as shown in formula (6). The turn-on time of the switch is matrixed in formula (7), in which the element t_i is the operating time of the EC_i. When it is positive, variable t_i stands for the turn-on time of the upper switch tube S_{Hi}. Otherwise, it is time for S_{Li}.

$$Q_{\overline{B}} = \frac{\sum_{i=1}^{n} Q_{B_i}}{n} \quad (6)$$

$$T = \left[t_1, t_2, \ldots, t_{n-1}\right]^T \quad (7)$$

$$Q_\Delta = \left[Q_{B_1} - Q_{\overline{B}} \;\; Q_{B_2} - Q_{\overline{B}} \;\; \cdots \;\; Q_{B_i} - Q_{\overline{B}} \;\; \cdots \;\; Q_{B_{n-1}} - Q_{\overline{B}} \;\; Q_{B_n} - Q_{\overline{B}}\right]^T \quad (8)$$

$$\Delta q_n = \begin{bmatrix} -1 & -\frac{1}{2} & -\frac{1}{3} & \cdots & -\frac{1}{n-1} & -\Delta_a \\ \cdots & -\frac{1}{2} & -\frac{1}{3} & \cdots & -\frac{1}{n-1} & -\Delta_a \\ \frac{1}{n-1} & \cdots & -\frac{1}{3} & \cdots & -\frac{1}{n-1} & -\Delta_a \\ \frac{1}{n-1} & \frac{1}{n-2} & \cdots & \cdots & -\frac{1}{n-1} & -\Delta_a \\ \frac{1}{n-1} & \frac{1}{n-2} & \frac{1}{n-3} & \cdots & -\frac{1}{n-1} & -\Delta_a \\ \frac{1}{n-1} & \frac{1}{n-2} & \frac{1}{n-3} & \cdots & \cdots & -\Delta_a \\ \frac{1}{n-1} & \frac{1}{n-2} & \frac{1}{n-3} & \cdots & 1 & -\Delta_a \end{bmatrix} \quad (9)$$

$$\Delta q_n T = Q_\Delta \tag{10}$$

Each element in formula (8) Q_Δ is the difference between the initial energy of the battery and the final energy after equalization. Formula (9) is the energy variation of each battery by per unit when the equalization modules are working during one switch cycling. Taking equalization circuit one (EC_1) as an example, in matrix Δq_n, $q_{(1,1)}$ = -1 indicates that one unit energy is transferred from battery B_1 to inductor L_1 and $q_{(2,1)} = q_{(3,1)} = \ldots = q_{(n,1)} = 1/(n-1)$ indicates the 1/(n-1) of one unit energy is absorbed by the batteries from battery B_2 to battery B_n. Similarly, in the matrix q_Δ, $q_{(2,1)} = q_{(2,2)} = -1/2$ indicates that the battery B_1 and the battery B_2 transfer one-half of the one unit energy to the inductor L_2 and $q_{(3,2)} = q_{(4,2)} = \ldots = q_{(n,2)} = 1/(n-2)$ indicates that the 1/(n-2) of one unit energy is absorbed by the batteries from the third one to the n^{th} battery. Based on the same principle, the turn-on time of the switching matrix can be obtained according to formula (10), in which Q_{Bi} is the initial charge of the battery and $-\Delta_a$ is an aging factor. Regarding the switch array as an integral whole, it is feasible to solve the problem in a plurality of battery energy abnormal states. Compared with the methods that sequentially equalize individual energy anomalies, it saves a lot of equalization time and reduces the on-state loss of the switch.

2.3. Derived Acceleration Information Gauss-Seidel Method. The element-wise formula for the Gauss-Seidel method is extremely similar to that of the Jacobi method. The computation of $x_{i(k+1)}$ uses only the elements of $x_{i(k+1)}$ that have already been computed and only the elements of $x_{(k)}$ that have not yet to be advanced to iteration k+1. This means that unlike the Jacobi method, only one storage vector is required as elements can be overwritten as they are computed, which can be advantageous for complex problems.

However, unlike the Jacobi method, the computations for each element cannot be done in parallel. Furthermore, the values at each iteration are dependent on the order of the original equations. Decompose the coefficient matrix shown in

$$\Delta q_n = L + D + U \tag{11}$$

where $\boldsymbol{L}$ is a strictly lower triangular matrix, $\boldsymbol{D}$ is a diagonal matrix, and $\boldsymbol{U}$ is a strictly upper triangular matrix, which is

$$L = \begin{bmatrix} 0 & & & \\ a_{21} & 0 & & \\ \cdots & \cdots & \ddots & \\ a_{n1} & a_{n2} & \cdots & 0 \end{bmatrix},$$

$$D = \begin{bmatrix} a_{11} & & & \\ & a_{22} & & \\ & & \ddots & \\ & & & a_{nn} \end{bmatrix},$$

$$U = \begin{bmatrix} 0 & a_{12} & \cdots & a_{1n} \\ & 0 & \cdots & a_{2n} \\ & & \ddots & \vdots \\ & & & 0 \end{bmatrix} \tag{12}$$

Gauss-Seidel method is a common method for iteratively solving linear equations by computer. The iterative format is shown in

$$t_i^{k+1} = \frac{\left(Q_\Delta - \sum_{j=1}^{i-1} q_{ij} t_j^{(k+1)} - \sum_{j=i+1}^{n} q_{ij} t_j^{(k)}\right)}{q_{ii}} \tag{13}$$

Its matrix form is

$$t^{k+1} = D^{-1}\left(b - Lt^{(k+1)} - Ut^{(k)}\right) \tag{14}$$

The method proposed which is called derived acceleration information Gauss-Seidel (DAIGS) has a fundamental difference from successive overrelaxation (SOR) method. The iteration formula using DAIGS is

$$t^{k+1} = D^{-1}\left\{b - Lt^{(k+1)} - U\left[(1-w)\, t^{(k)} + wt^{(k+1)}\right]\right\} \tag{15}$$

The speed effect DAIGS acceleration depends on the selection of factor w. Under the premise of allowing the error to be constant, reducing the value of w increases the weight of the input quantity, and finally accelerates the convergence speed. Further increase the operational weight of the updated element, thereby accelerating the approximation of the exact value.

3. Simulation and Experiment

3.1. Circuit Model. A simulation model of the equalization circuit was built in the software PSIM to verify the feasibility and effectiveness of the proposed principle. Set the capacity of a lithium battery to be 3AH, rated voltage to be 3.7 V, the switching frequency to be 10 kHz, and the value of inductance to be 100 uH. In the simulation, the initial voltage of the batteries B_1, B_2, B_3, and B_4 was set to be 4 V, 3.8 V, 3.6 V, and 3.4 V. The schematic of the equalization circuit is as shown in Figure 3.

Under the forced active equalization control, it is necessary to control the equalization module one (EC1) and the equalization module two (EC2) to transfer the excess energy from B_2 to other cells in the battery pack. During state I, the

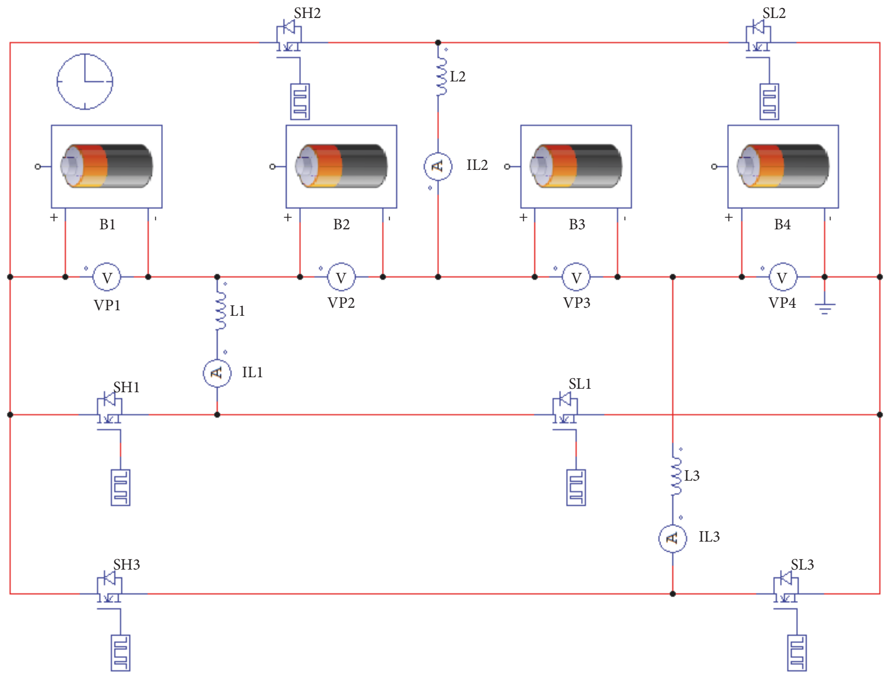

Figure 3: Equalization circuit simulation in PSIM.

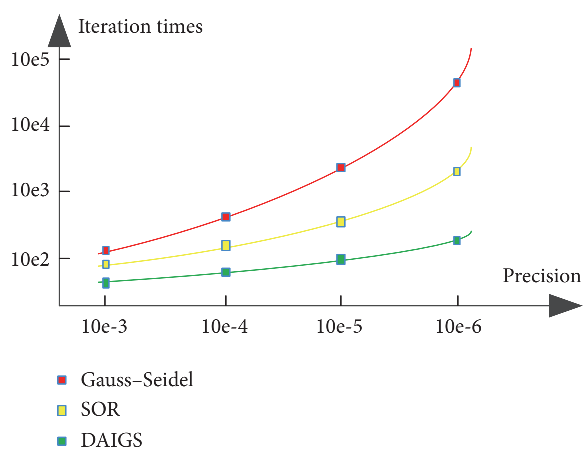

Figure 4: The iteration times and error relationship of the algorithm.

energy from B_1 and B_2 is transferred to B_3 and B_4. When switch S_{H2} is turned on, the energy from batteries B_1 and B_2 is transferred to inductor L_2; when switch S_{H2} is turned off, the energy stored in the inductor L_2 is released to batteries B_3 and B_4. Hereafter the balancing energy is transferred from B_2, B_3, and B_4 to B_1 in state II. When switch S_{L2} is turned on, the balancing energy is transferred from batteries B_2, B_3, and B_4 to inductance L_1; then switch S_{L2} is turned off, inductor L_1 transfers energy to battery B_1.

3.2. Algorithm Example. According to the component parameters in the experiment, the energy transfer matrix of the switch array can be described by (16), and the final battery energy difference is shown in (17). The information is collected and transmitted to the single-chip microcomputer which solves the conduction time matrix of the equalization module switch group, thereby controlling the drive circuit to send the corresponding PWM signal to control the switch tube.

$$\Delta q_{n=3}\left(p.u.\right) = \begin{bmatrix} -1 & -\frac{1}{2} & -\frac{1}{3} & -\Delta_a \\ \frac{1}{3} & -\frac{1}{2} & -\frac{1}{3} & -\Delta_a \\ \frac{1}{3} & \frac{1}{2} & -\frac{1}{3} & -\Delta_a \\ \frac{1}{3} & \frac{1}{2} & 1 & -\Delta_a \end{bmatrix} \tag{16}$$

$$Q_{\Delta} = \left[-0.3 \quad -0.1 \quad 0.1 \quad 0.3\right]^{T} \tag{17}$$

Further, the iterations of the three methods are compared with different precisions in the example, and the comparison results are shown in Figure 4. It can be seen from Figure 4 that the superiority of the DAIGS algorithm is not obvious at lower precision, but when the accuracy is further improved, the increase in the number of iterations is slower. Meanwhile, the iterative convergence effect of DAIGS is compared. In comparison, assuming that the Gauss-Seidel algorithm has no acceleration effect, the effect of the contrast acceleration factor W on the convergence speed of the algorithm is shown in Figure 5. When the acceleration factor w is constant, the acceleration or deceleration effect of the DAIGS algorithm is better than the successive over relaxation (SOR).

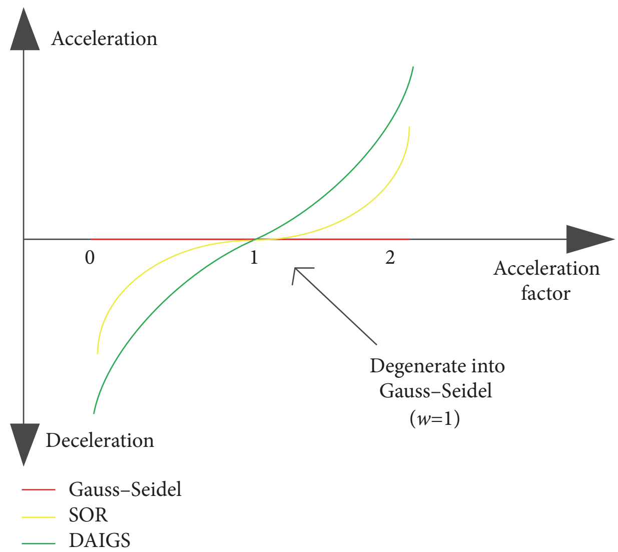

FIGURE 5: Acceleration factor and its effect on the convergence rate.

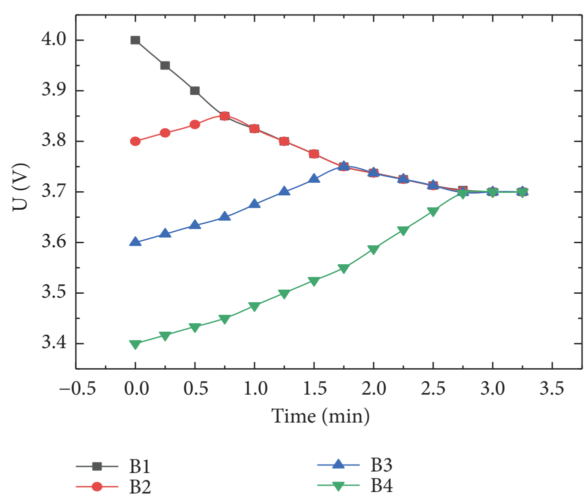

FIGURE 6: OCV of traditional equalization.

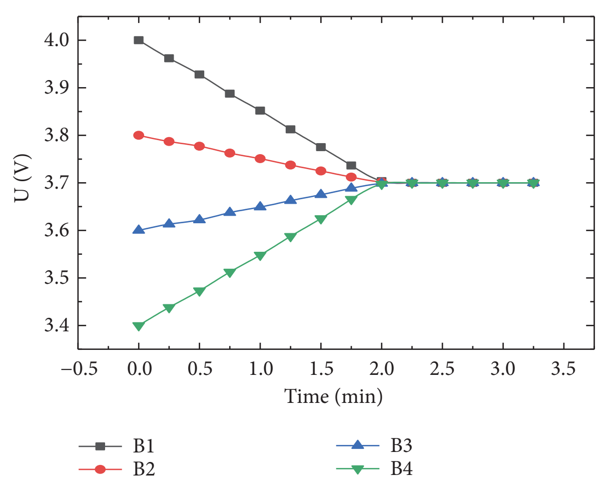

FIGURE 7: OCV of DAIGS equalization.

3.3. Results Analysis. In order to further verify the feasibility and effectiveness of the proposed design theory, a small-scale experimental circuit was built. In the experiment, the battery voltage was collected every 15 seconds and plotted as shown in Figure 6. Voltage changes of each battery under traditional equalization and proposed matrix equalization are shown in Figures 6 and 7, respectively. It can be seen in Figure 6 that batteries B_2 and B_3 are repeatedly charged and discharged (first charged, then discharged) under the control strategy, which may cause damages to the battery. In the contrast, according to Figure 7, not only the time consumed by the equalization process is reduced, but also the repeated charging and discharging are avoided, thus reducing the negative effects brought by the equalization circuit.

In the experiment, it is verified that both the multiphase interleaved converter and the matrix equalization control strategy can achieve the energy balance of each monomer in the battery pack. The matrix equalization is advantageous apparently in the aspect of shortening equalization time. In order to further illustrate the advantages of the circuit topology and its control strategy, a dissipative energy equalization circuit is also built through the parallel battery pack. Despite the simple control, the energy consumed by the resistor is rather considerable.

4. Conclusion and Future Work

In this paper, a multiphase converter based on switch array for battery pack active balancing is proposed. The switching state is matrixed to optimize the battery equalization control, which shortened the equalization time while avoiding the repeated charge and discharge of the battery during the equalization process. Finally, the proposed design is verified by simulation and a small-scale experiment. The experimental results illustrate that the circuit and DAIGS method have the following advantages:

(1) An n-phase interleaved equalization circuit topology is proposed based on the Buck-Boost converter. The superiorities of innovation converter are mainly for simple structure and easy expansion and work independently by each equalization subcircuit, thus making it possible to work synchronously and reduce the time consuming of the equalization process.

(2) The switching state matrix processing in the control avoids the problem of the batteries to be repeatedly charged and discharged while achieving rapid equalization and meanwhile reduces the damage caused by the operation of the equalization circuit, thus extending the working life of the battery.

(3) Considering the effects of battery self-discharge and equalization circuit loss, aging factor was added to the state matrix. The derived acceleration information Gauss-Seidel algorithm is optimized to achieve faster convergence.

The main task of energy internet is to achieve easy access to renewable energy and distributed energy. More specifically, it is a huge project for realizing the optimization and complementation of various energy forms such as cold, heat, gas, water and electricity, thereby improving energy efficiency and realizing the two-way flow and sharing of information, energy, and energy. For that, in the energy internet, power network act as the hub platform and Internet Technology act as the tool to implement wide-area optimization and coordination of renewable energy and distributed energy infrastructure through energy regulation system. Energy, the main load of the energy Internet, is mainly distributed in the natural world in the discounting and unstable form such as wind energy, solar energy, and other clean energy. Energy storage technology can solve the randomness and volatility of new energy power generation to a large extent. It can achieve a smooth output of new energy power generation and enable large-scale renewable energy power to be reliably integrated into the power grid. However, the object of this study is the energy balance of lithium batteries; the characteristics of the energy Internet new energy generation end are not well reflected. In the future research, the energy carriers of energy storage systems will be expanded and the energy characteristics of such as wind power and photovoltaics will be taken into account to achieve more effective and reliable equalization control.

Data Availability

The PSIM11 simulation data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

Shuailong Dai proposed a novel battery pack equalization system and DAIGS method. Jiayu Wang and Zhifei Shan designed and implemented the balancing circuit and its control. Jie Min drafted the manuscript and Yewen Wei finalized and polished the manuscript.

Acknowledgments

This research work is supported by the Excellent Young and Middle-aged Science and Technology Innovation Team of Hubei Education Department T201504 and National Innovation and Entrepreneurship Training Program for College Students 201711075009.

References

[1] Z. P. Cano, D. Banham, S. Ye et al., "Batteries and fuel cells for emerging electric vehicle markets," *Nature Energy*, vol. 3, no. 4, pp. 279–289, 2018.

[2] R. Guo, L. Lu, M. Ouyang, and X. Feng, "Mechanism of the entire overdischarge process and overdischarge-induced internal short circuit in lithium-ion batteries," *Scientific Reports*, vol. 6, article 30248, 2016.

[3] L. McCurlie, M. Preindl, and A. Emadi, "Fast model predictive control for redistributive lithium-ion battery balancing," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 2, pp. 1350–1357, 2017.

[4] Y. Shang, N. Cui, B. Duan, and C. Zhang, "Analysis and optimization of star-structured switched-capacitor equalizers for series-connected battery strings," *IEEE Transactions on Power Electronics*, vol. 99, p. 1, 2017.

[5] S. Jeon, M. Kim, and S. Bae, "Analysis of a symmetric active cell balancer with a multi-winding transformer," *Journal of Electrical Engineering & Technology*, vol. 12, no. 5, pp. 1812–1820, 2017.

[6] A. M. Imtiaz and F. H. Khan, "Time shared flyback converter based regenerative cell balancing technique for series connected Li-Ion battery strings," *IEEE Transactions on Power Electronics*, vol. 28, no. 12, pp. 5960–5975, 2013.

[7] S.-W. Lee, K.-M. Lee, Y.-G. Choi et al., "Modularized design of active charge equalizer for li-ion battery pack," *IEEE Transactions on Industrial Electronics*, vol. 99, p. 1, 2018.

[8] Y. Ma, P. Duan, Y. Sun, and H. Chen, "Equalization of lithium-ion battery pack based on fuzzy logic control in electric vehicle," *IEEE Transactions on Industrial Electronics*, vol. 65, no. 8, pp. 6762–6771, 2018.

[9] X. Cao, Q.-C. Zhong, Y.-C. Qiao, and Z.-Q. Deng, "Multilayer modular balancing strategy for individual cells in a battery pack," *IEEE Transactions on Energy Conversion*, vol. 33, no. 2, pp. 526–536, 2018.

[10] C. Zou, X. Hu, Z. Wei, and X. Tang, "Electrothermal dynamics-conscious lithium-ion battery cell-level charging management via state-monitored predictive control," *Energy*, vol. 141, pp. 250–259, 2017.

[11] C. Zhang, J. Jiang, Y. Gao et al., "Charging optimization in lithium-ion batteries based on temperature rise and charge time," *Applied Energy*, vol. 194, pp. 569–577, 2016.

[12] E. G. Kardakos, C. K. Simoglou, and A. G. Bakirtzis, "Optimal offering strategy of a virtual power plant: a stochastic bi-level

approach," *IEEE Transactions on Smart Grid*, vol. 7, no. 2, pp. 794–806, 2016.

[13] T. Morstyn, B. Hredzak, and V. G. Agelidis, "Control strategies for microgrids with distributed energy storage systems: an overview," *IEEE Transactions on Smart Grid*, p. 1, 2016.

[14] Z. Tian, M. Tian, Z. Liu, and T. Xu, "The Jacobi and Gauss–Seidel-type iteration methods for the matrix equation AXB=C," *Applied Mathematics and Computation*, vol. 292, pp. 63–75, 2017.

[15] J. Jiang, F. Zhou, and S. Ouyang, "Design of oversampled interleaved DFT modulated filter bank using 2block Gauss-Seidel method," *Circuits, Systems and Signal Processing*, vol. 33, no. 2, pp. 549–564, 2014.

[16] E. Meskar, T. D. Todd, D. Zhao, and G. Karakostas, "Energy aware offloading for competing users on a shared communication channel," *IEEE Transactions on Mobile Computing*, vol. 16, no. 1, pp. 87–96, 2017.

[17] L. Wang, R. Li, and Y. Fang, "Energy flow: image correspondence approximation for motion analysis," *Optical Engineering*, vol. 55, no. 4, Article ID 043109, 2016.

[18] C. Piao, Z. Wang, J. Cao, W. Zhang, and S. Lu, "Lithium-ion battery cell-balancing algorithm for battery management system based on real-time outlier detection," *Mathematical Problems in Engineering*, vol. 2015, Article ID 168529, 12 pages, 2015.

[19] Z. C. Gao, C. S. Chin, W. D. Toh, J. Chiew, and J. Jia, "State-of-charge estimation and active cell pack balancing design of lithium battery power system for smart electric vehicle," *Journal of Advanced Transportation*, vol. 2017, Article ID 6510747, 14 pages, 2017.

[20] Q. Zhang, W. Deng, S. Zhang, and J. Wu, "A rule based energy management system of experimental battery/supercapacitor hybrid energy storage system for electric vehicles," *Journal of Control Science and Engineering*, vol. 2016, Article ID 6828269, 17 pages, 2016.