A Fast Equalization Method for Series Batteries based on Cuk Converters

Qinghai Meng and Zhou Zhang
North China University of Technology, Shijingshan, Beijing, China

Keywords: Cuk converters, SOC, Series batteries, Equalization

Abstract: In series battery packs, the accumulated differences among every single battery could significantly decrease the performances of the packs. Consequently, equalization circuits are very necessary for series batteries. Based on Cuk converters, this paper introduces a fast equalization method considering SOC (State of Charge) differences of series batteries. The method increases equalization current as large as possible, and simultaneously, achieves fast equalization and low consumption. The experimental platform is constructed, and the results verify the validity of the proposed fast equalization method.

1 INTRODUCTION

With the development of technology, the energy storage system composed of batteries is widely applied in the fields of microgrids and new energy vehicles(Zhang and Wang, 2019). The production and working environment may lead to the differences among serial batteries, which could significantly decrease the performance of the whole pack(Liu and Zou, 2018). It is of great significance to apply equalization methods to eliminate the differences, so as to ensure the high-efficiency of utilization of energy in the battery pack(Zhiliang and Xiang, 2018).

The Cuk converter topology is widely used to perform equalization function(Rui and Lizhi, 2015). Literature(Yan and Cheng, 2015) surveys the battery equalization using a fuzzy controller. Literature(Ouyang and Chen, 2018) researches quasi-sliding mode control based on Cuk converters to balance the batteries. Literature (Samadi and Saif, 2014) discusses the predictive control for cell balancing in Li-ion battery packs. Unfortunately, the control methods mentioned above are too complicated to perform an equalization function, and the balancing speed may not be so fast. This paper introduces a fast equalization method considering SOC (State of Charge) differences of series batteries based on Cuk converters, and simultaneously, achieves fast equalization and low consumption. The experimental platform is constructed, and the results verify the validity of the proposed fast equalization method.

2 TOPOLOGY ANALYSIS

This paper adopts the bidirectional DC/DC circuit based on the Cuk converters, as shown in figure 1. The equalization circuit is divided into two parts, the left part is a double-layer bridge, mainly used for selecting the single cell needed to be balanced, and the right half performs an equalization function, controlling energy flowing in both directions.

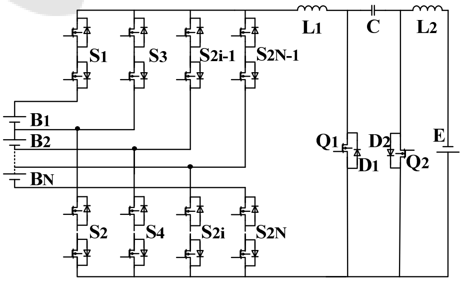

Figure 1. Topology based on the Cuk converter.

3 EQUALIZATION BASIS AND ITS ESTIMATION

The battery's state of charge (SOC) is selected as the equalization basis, which is of more significant

Meng, Q. and Zhang, Z.
A Fast Equalization Method for Series Batteries based on Cuk Converters.
DOI: 10.5220/0011104800003355
In *Proceedings of the 1st International Joint Conference on Energy and Environmental Engineering (CoEEE 2021)*, pages 18-21
ISBN: 978-989-758-599-9

advantages than the terminal voltage of batteries. Because the relationship between SOC and the terminal voltage is nonlinear. SOC can directly reflect a battery's state, which can help to obtain a more accurate result.

After the selection of the equalization basis, the more important part is to estimate SOC in a proper way. This paper is based on extended Kalman filter (EKF) to complete this. The core of EKF is the use of Taylor expansion for partial linearization. This paper builds an equation of second-order RC battery model, as shown in figure 2. The state variables are the SOC、electrochemical polarization voltage U_1 and concentration polarization voltage U_2, controlling variable I. Hence the equation can be derived as formula (1).

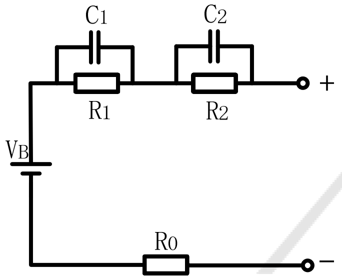

Figure 2. The second-core RC battery model.

$$\begin{bmatrix} SOC_{\mathrm{k+1}} \\ U1_{\mathrm{k+1}} \\ U2_{\mathrm{k+1}} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \mathrm{e}^{-\frac{T}{\tau 1}} & 0 \\ 0 & 0 & \mathrm{e}^{-\frac{T}{\tau 2}} \end{bmatrix} \times \begin{bmatrix} SOC_{\mathrm{k}} \\ U1_{\mathrm{k}} \\ U2_{\mathrm{k}} \end{bmatrix} + \begin{bmatrix} \frac{\eta T}{Q} \\ R1 \times \left(1-\mathrm{e}^{-\frac{T}{\tau 1}}\right) \\ R2 \times \left(1-\mathrm{e}^{-\frac{T}{\tau 2}}\right) \end{bmatrix} \times I + W(k) \tag{1}$$

where η is the Cullen Coefficient, which can be obtained from battery discharging experiment. Generally, when the battery is charging, η equals to 1, and less than 1 when discharging.

The observation equation is expressed as:

$$U_{\mathrm{k}} = U_{\mathrm{OCV}}(SOC) + U1_{\mathrm{k}} + U2_{\mathrm{k}} + IR_0 + V_{\mathrm{k}} \tag{2}$$

The Kalman Filter is initialized as:

$$\begin{aligned} & k = 0 \\ & \hat{x}_0^{\,+} = E(x_0) \\ & \sum x_0 = E\left[\left(x_0 - \hat{x}_0^{\,+}\right)\left(x_0 - \hat{x}_0^{\,+}\right)^T\right] \\ & \sum w = E\ (w \times w^T) \\ & \sum v = E\ (v \times v^T) \end{aligned} \tag{3}$$

and recursived as:

$$\begin{aligned} & \hat{x}_k^{\,-} = f(\hat{x}_{k-1}^{\,+}, u_{k-1}) \\ & \sum x_k^{\,-} = A_{k-1} \sum x_k^{\,+} A_{k-1}^{\;T} + \sum w \\ & L_k = \sum x_k^{\,-} C_k^{\,T} \left(C_k \sum x_k^{\,-} C_k^{\,T} + \sum v\right)^{-1} \\ & \hat{x}_k^{\,+} = \hat{x}_k^{\,-} + L_k\left[y_k - g\left(\hat{x}_k^{\,-}, v_k\right)\right] \\ & \sum x_k^{\,+} = \left(E - L_k C_k\right) \sum x_k^{\,-} \end{aligned} \tag{4}$$

According to the Hybrid Pulse Power Characteristic (HPPC) test presented in the Freedom Car manual(FreedomCar, 2003) and existing data obtained before, the time constant τ_1 、τ_2 and polarization resistance R_1、R_2 can be received from the MATLAB curve fitting toolbox using the parameter identification means.

4 CONTROL STRATEGY

In this paper, constant current method is used for equalization, and the loss can be expressed as

$$Q_1 = I_1^{\,2} R t \tag{5}$$

where I_1 is the equalizing current, R is the equivalent resistance during the process, and t is the time needed for equalizing. Another equalization method is to use a rectangular wave with a duty cycle α. If the two types of equalizing currents start in the same time, the amplitude of the rectangular wave current needs to be increased. Therefore, the loss of the rectangular wave current balanced in one switching cycle can be derived as

$$Q_2 = I_2^{\,2} R \alpha t = \frac{I_1^{\,2}}{\alpha} R t \tag{6}$$

where I_2 is the rectangular wave current. The duty cycle varies from 0 to 100%, so the conclusion is

$$Q_2 > Q_1 \tag{7}$$

Only when the SOC imbalance degree of the battery group reaches a certain degree, the equilibrium control begins, and the balance is judged by the variance of the SOC to open the equilibrium.The control policy flowchart is shown in figure 3.

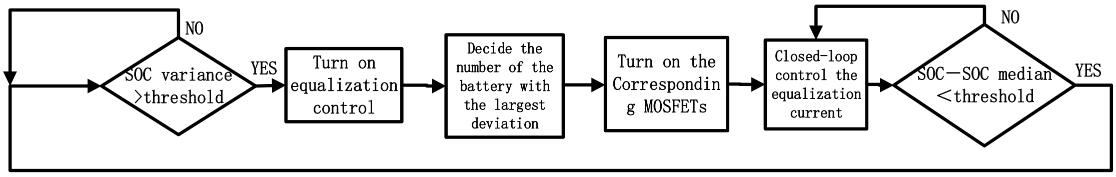

Figure 3. The control strategy flow chart.

5 SIMULATION AND EXPERIMENT

5.1 Simulation Verification

First, the rated capacity of each single battery in the simulation is 60Ah, and the rated voltage is 3.3V. In order to get the results faster, the initial SOCs are set to 65.502%, 65.503%, and 65.500% respectively. Figure 4 shows the simulation result using the proposed control strategy to equalize three batteries. The SOC of the first battery was set as the median. The initial SOC deviation of the third battery was bigger than that of the second one. Hence the third battery needs to be charging equalized first, where sets the charging current as 5A. Then the second battery needs to be completed discharging equalization, where sets the discharging current as 10A. Figure 5 shows the current of serial battery packs and the assisting battery respectively.

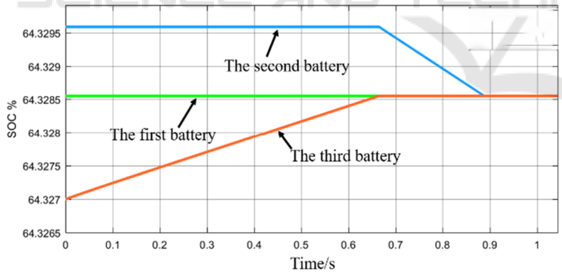

Figure 4. Simulation result of the equalization process.

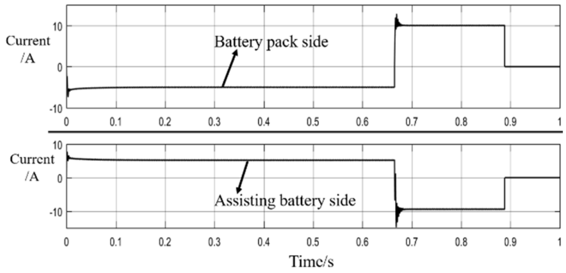

Figure 5. The current wave of both sides.

5.2 Experimental Verification

An experimental platform is built for the battery equalization, as shown in figure 6. Firstly, the battery pack is discharging equalized, and the reference values of the discharging currents are 2A, 4A, 6A, 8A, and 10A, respectively. The wave when the current value is 10A are shown in figure 7. Then the battery pack is charging equalized, and the reference values of the charging currents are 2A, 3A, 4A, and 5A, respectively. All the experiments are successfully realized quantitative control of the currents. The waves when current value is 5A are shown in figure 7. And the results verify that method could achieve fast equalization and low assumption.

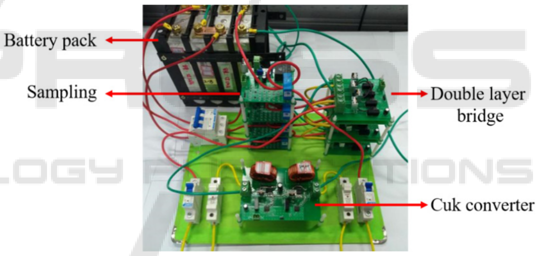

Figure 6. The experimental platform.

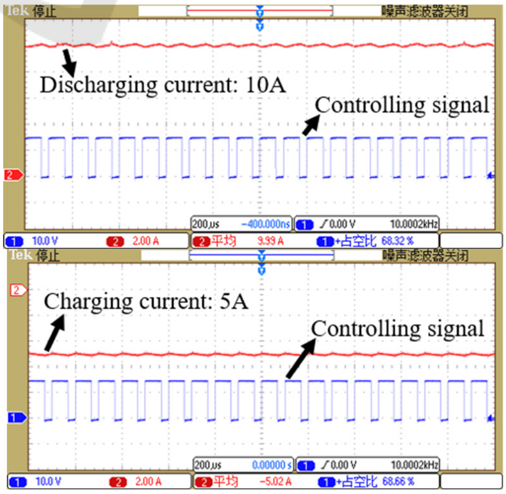

Figure 7. Discharging and charging current wave.

6 CONCLUSION

This paper introduces a fast equalization method considering SOC (State of Charge) differences of series batteries based on Cuk converters. The method increases equalization current as large as possible, and simultaneously, achieves fast equalization and low consumption. The experimental platform is constructed, and the results verify the validity of the proposed fast equalization method.

ACKNOWLEDGMENTS

I'd like to thank all the teachers and students who helped me to finish this paper. Without their help, the work can not be completed successfully.

REFERENCES

H. Zhang, Y. Wang, H. Qi and J. Zhang, Active battery equalization method based on redundant battery for electric vehicles[J], *IEEE Transactions on Vehicular Technology*, 2019, 68(8), p 7531-7543.

X. Liu and Y. Zou, The proportional current control strategy for equalization circuits of series battery packs, *ICEMS*, Jeju, 2018, p 846-849.

Z. Zhang, X. Cheng, Z. Lu and D. Gu, SOC estimation of lithium-ion battery pack considering balancing current, *IEEE Transactions on Power Electronics*, 2018, 33(3), p 2216-2226

L. Rui, W. Lizhi, H. Xueli, D. Qiang and Z. Jie, A review of equalization topologies for lithium-ion battery packs, *CCC*, Hangzhou, 2015, p 7922-7927.

J. Yan, Z. Cheng, G. Xu, H. Qian and Y. Xu, Fuzzy control for battery equalization based on state of charge, *IEEE 72nd Vehicular Technology Conference - Fall*, Ottawa, ON, 2010, p 1-7.

Q. Ouyang, J. Chen, J. Zheng and Y. Hong, SOC estimation-based quasi-sliding mode control for cell balancing in lithium-ion battery packs, *IEEE Transactions on Industrial Electronics*, 2018, 65(4), p 3427-3436.

M. F. Samadi and M. Saif, Nonlinear model predictive control for cell balancing in Li-ion battery packs, *2014 American Control Conference, Portland*, OR, 2014, p 2924-2929.

Freedom Car Battery Test Manual For Power-Assist Hybrid Electric Vehicles. 2003: p 13-16.