SOC-based Sequencing Equalizer for Parallel-connected Battery Configuration using ANFIS Algorithm

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ABSTRACT

Battery cells are connected in parallel to enlarge the system capacity. However, cell inconsistency may reduce the overall system capacity and cause the over-charging or over-discharging issue. This paper proposes a SOC-based sequencing equalizer for parallel-connected battery configuration that uses the ANFIS (adaptive neuro-fuzzy inference system) algorithm to make the switching decision. Depend on the load current and the SOC (state-of-charge) rate of cells, the switching decision is made to equalize the SOC of the battery cells. The simulation results show that the system capacity is maximized and the controller is adaptive for a large number of parallel-connected in dynamic load profile.

Keywords: parallel-connected battery, ANFIS, SOC-based sequencing equalizer.

1. INTRODUCTION

The quantity of electric vehicle is increasing dramatically which demand a long term working battery system. To enlarge the system capacity, the batteries are connected in parallel. Unfortunately, the characteristics of the battery are different in impedance and voltage which may lead the system to the over-charging or over-discharging problem. The cell inconsistency of the battery becomes more serious due to the long working time which is reported in [1].

To mitigate the unequal current sharing due to cell inconsistency, a power resistor is connected to each battery [2]. Although the current is shared equally, the available capacity of the battery system is non-optimal due to the difference in the initial SOC rate and the power loss of the resistor is very high. To reduce the power loss and maximize the system capacity, two resistors and one switch are used to equalize the battery in [3]. Using the SOC comparison algorithm, the current sharing ratio of branches is controlled and the cell inconsistency is overcome. However, there is a trade-off between the equalization performance and the power loss in the equalizer circuit. In [4], fuzzy logic control (FLC) is used to control the switch as in Figure 1. Depend on the load demand and the actual SOC rate of cells, the switches decision is made. Although the equalization performance is good, the unequal current sharing issue still exists between parallel branches. The combined ANFIS network and KF (Kalman Filter) [5] proved to be effective when estimating the "averaged SOC" of a battery pack based on the difference of the cells and the load current, however, this method is only applicable to a series battery pack.

This paper proposes a control algorithm that uses the cells logically based on the ANFIS algorithm to solve the limitation of the conventional works. The proposed algorithm is described in section 2 and verified in section 3. The conclusion is made in section 4.

2. PROPOSED METHOD

The proposed algorithm is developed based on the control topology in Figure 1 when one battery (B_i) is controlled by a switch (S_i), i = 1,…,4. The flowchart of the proposed method is shown in Figure 2 with the description of the ANFIS algorithm is illustrated in Figure 2. The working principle is described as follows: First, the SOC of all cells and the load current will be measured and arranged in ascending. If the SOC of any cell is close to SOC_{min}, the system will disconnect that cell. The ANFIS algorithm then measu

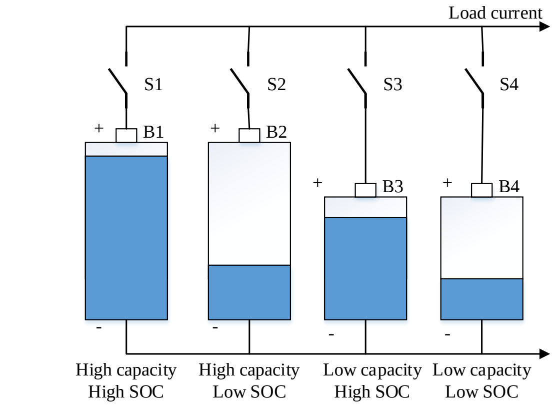

Figure 1: The topology of Parallel-connected system with 4 cells under different SOC and different capacity [1]

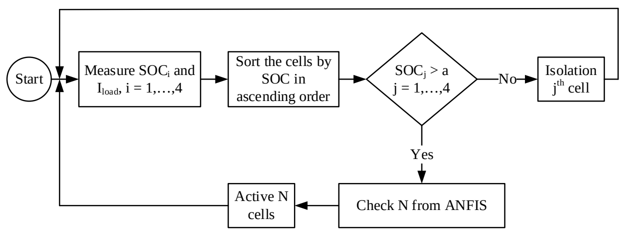

Figure 2: The flowchart of the proposed method in discharging

SOC and load current to calculate the appropriate number of remaining cells to be connected to the load.

The ANFIS network has 2 inputs, which is the SOC pack defined in [1] and the load current. The membership functions of input SOC pack is built with 3 values (L, M, H) that represent the three input states (low level, medium level, high level), respectively and 5 values of the load current (VH, H, M, L, VL) that represent the five input states (very high, high, medium, low, very low) as shown in Figure 3 and Figure 4. The value of output N and control rules are constructed is shown in Figure 5. The data is trained with 3 training cycles. The final error achieved via the ANFIS-GUI interface in Matlab is 3.1895×10^{-8}.

3. VERIFICATION SIMULATION

To verify the proposed method, a simulation for four parallel-cell connected Li-ion 18650 family battery cells (ICR18620 3.7V/2Ah) has been implemented in MATLAB. The profile of the load current is shown in Figure 6. The SOC of 4 cells of the proposed method is compared with the fixed-resistor method [2] with the same topology is shown in Figure 7, it is easy to see that depending on the load current, higher SOC cells will be connected to the pack and lower SOC cells will be disconnected. As a result, the PCCP system will be automatically balanced and the SOC of all cells will be equal, thereby reducing loop current and power loss. The current of 4 battery in discharge is shown in Figure 8, with the fixed-resistor method, all cells are always connected to the pack and provide load current. However, when the SOC of the cells with lower SOC is exhausted, the SOC of the cells is not equal, which leads to the appearance of the loop current between cells. For the proposed method, cells with different SOC are automatically arranged and adjusted to connect to the pack. This results in an equal discharge current of the cells when the SOC of all cells is

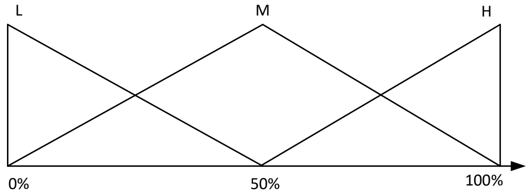

Figure 3: Membership functions of the input SOC

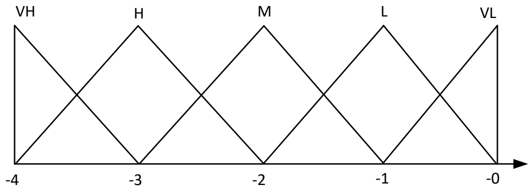

Figure 4: Membership functions of the input I_{load} (A)

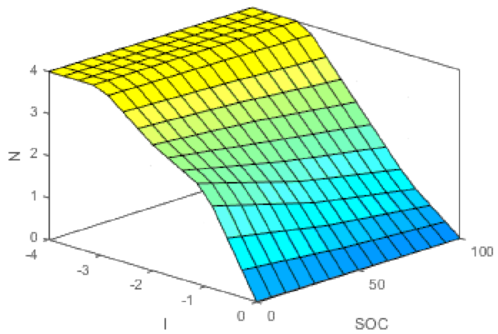

Figure 5: Membership functions of the output N

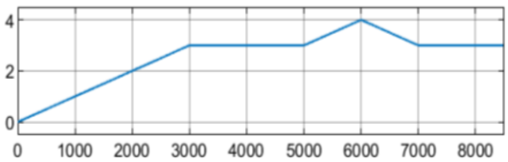

Figure 6: The Profile of load current

equal.

4. CONCLUSION

This paper proposes a SOC-based sequencing equalizer for parallel-connected battery configuration that uses the ANFIS algorithm to reduced loop current and maximizes the SOC utilization. The proposed method adjusts the number of cells for better results. The simulation results show advantages when compared to the fixed-resistor method.

5. REFERENCE

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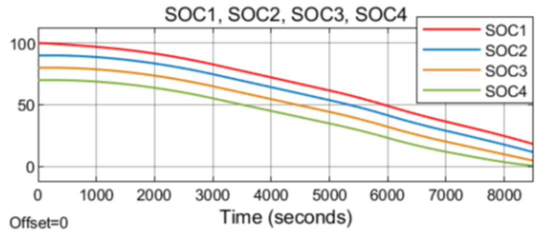
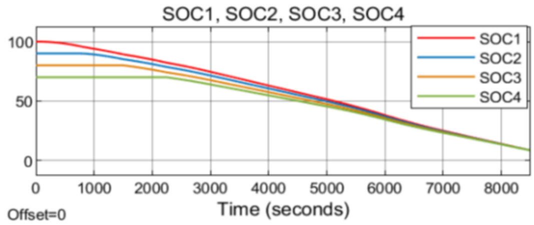
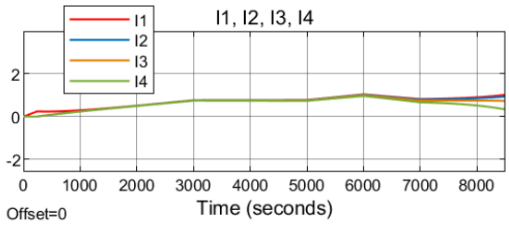


a. Fixed-resistance method



b. Proposed method

Figure 7: The SOC of 4 battery in discharging



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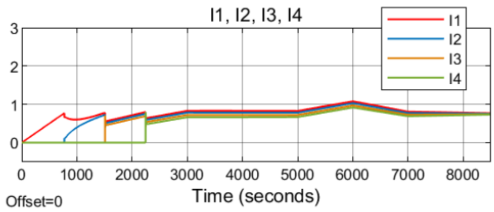

b. Proposed method

Figure 8: The current of 4 battery in discharging

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