A Novel Half-Bridge Converter for Battery Charging-Discharging

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***Abstract*—Charging-discharging converter for battery cells is widely used in modern industry to measure the performance of the battery. With the rapid development of the technology of switching power supply today, converters with high efficiency and small size are becoming more and more important. This paper proposes a novel half-bridge converter for battery charging-discharging based on Thevenin equivalent model with high efficiency and simplified structure. The control circuit and detecting circuit are also analyzed in the main system. The simulation results from two series of 28V, 800Ah lead-acid battery cells are given to verify the stability and reliability of the converter.**

***Index Terms*—battery, charging-discharging, half-bridge converter**

I. Introduction

With the increasing demand for energy, Battery as a power source equipment or emergency back-up power, plays an irreplaceable role in the process of modern industry. In the daily use of the battery, it is often necessary to repeat charging and discharging tests in order to estimate the performance of the battery. By detecting the battery charge and discharge process, parameters can be used to accurately measure the status of the battery.

Many switching power supply circuits have been commonly used in the battery charging-discharging machines now. During the charge mode, the external power supply provides a constant current or voltage for charging through a power conversion. Also during the discharge mode, resistive load is added to form a loop for discharging, and the status of the battery can be detected in this process. However, this type of circuit is relatively complex, and makes a lot of loss of power because the charging and discharging processes are separated, the power cannot be recycled.

In this paper, to detect performance of the battery, a novel half-bridge converter for battery charging and discharging based on Thevenin equivalent model is proposed. The converter can realize the bi-directional charging-discharging process of the battery cells, the power can be recycled during the process and the circuit can be simplified [1].

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II. Anaysis of Charging-Discharging Circuit

Charging-Discharging circuit of the battery cells includes battery model, LC filter and the half-bridge circuit part. Fig. 1 shows the whole framework of the system. Control circuit can change the state of the switches in half-bridge circuit to ensure the work of charging-discharging process. Detecting circuit can detect the different parameters of the system in real time.

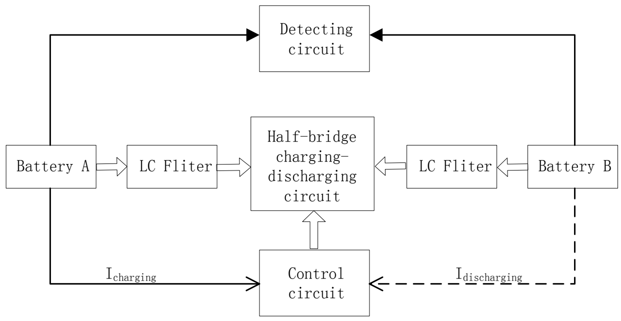

Figure 1. General framework of the system

A. Battery Model

Thevenin equivalent model is commonly used on lead-acid battery, the model is shown in Fig. 2: E is an internal ideal voltage source, r is internal resistance of the battery, R is polarization resistance and C is polarization capacitor [2]. In this model, the value of E is determined by measuring the open-circuit voltage before the connection of charging-discharging circuit and represents the initial voltage of battery. The parallel circuit of R, C is considered to describe the polarization effect of battery cells. Typically, the value of the capacitance C is 1.31.7F per 100Ah.

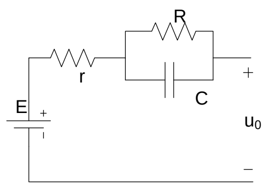

Figure 2. Thevenin equivalent model of battery

According to the model, it can be obtained:

$$\begin{cases} C\dfrac{du_C}{dt} = i_0 - \dfrac{u_C}{R} \\ u_0 = E - i_0 r - u_C \end{cases} \tag{1}$$

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For simplicity, u can be expressed as:

$$u_0 = E - \mathrm{r}\cdot C\frac{du_C}{dt} - (1+\frac{r}{R})u_C \quad (2)$$

B. Half-Bridge Charging-Discharging Circuit

Half-Bridge circuit proposed in this paper can achieve bi-directional charging-discharging process on two groups of batteries. Fig. 3 is the main circuit of the half-bridge converter. In order to facilitate analysis, make the following assumptions: 1) All devices are ideal components; 2) Terminal voltage of battery is constant during one cycle.

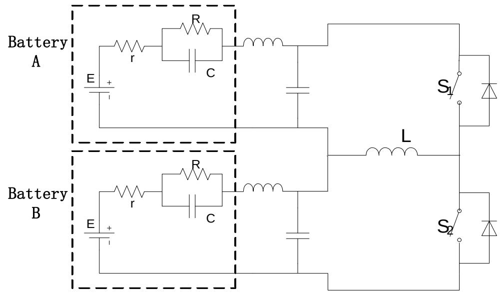


Figure 3. The main circuit of the converter

The converter is operated at the continuous conduction mode (CCM) and has two working modes: mode 1 is Battery A discharging to Battery B, mode 2 is Battery B discharging to Battery A, and it can be adjusted by control circuit. When the terminal voltage of battery changes, the duty ratio of converter will also change within a range. Therefore the converter can work at both buck and boost states.

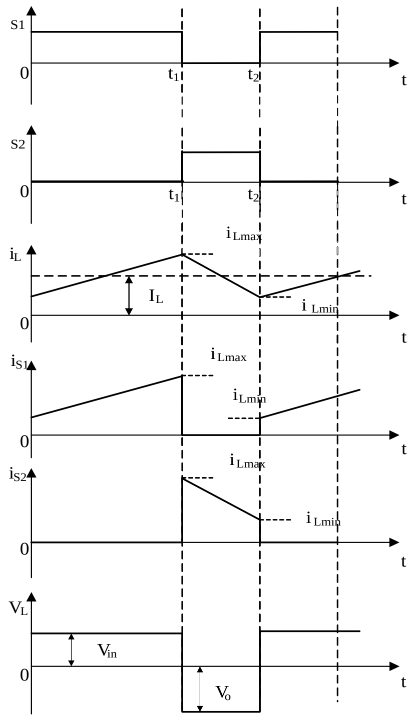


Figure 4. The main waveforms of the converter

Fig. 4 is the main waveforms of the converter during one cycle in mode 1. At this time, it is assumed that the Battery A is fully charged and Battery B is the weakest charged [3]. The gate pulses of Switch S_1 and Switch S_2 are shown in Fig. 4. Switches in the half-bridge circuit are turned on alternately during one cycle, while the current of inductor L is continuous and changes linearly between the maximum and minimum value.

During [t_0-t_1] in mode 1, Switch S_1 is turned on and Switch S_2 is turned off, the terminal voltage of Battery A is applied to inductor L and the current in *L* is built up with constant slope from the minimum to the maximum value. The circuit transfers the energy of Battery A to inductor *L* for discharging. Equation (3) indicates the current increased in inductor L. V_{in} is the voltage applied to inductor *L*, D_1 is the duty ratio of Switch S_1 and T_s means the time of one switching cycle.

$$\Delta \mathrm{i}_{L[\mathrm{t}_0-\mathrm{t}_1]} = \frac{V_{in}}{L} D_1 \cdot T_S \quad (3)$$

At the same time, because the Switch S_2 is turned off, Battery B discharges through the connected LC filter. The energy of Battery B can be stored in the filter temporarily.

During [t_1-t_2], both S_1 and S_2 change the switch status, the energy stored in inductor *L* flows to Battery B for charging until the end of one cycle. The current in L falls to the minimum value linearly. Equation (4) indicates the current decreased in inductor L. V_o is the output voltage on Battery B and D_2 means the duty ratio of Switch S_2.

$$\Delta \mathrm{i}_{L[\mathrm{t}_1-\mathrm{t}_2]} = \frac{V_o}{L} D_2 \cdot T_S \quad (4)$$

In inductor *L*, the current increased during [t_0-t_1] is equal to the current decreased during [t_1-t_2], so it can be obtained:

$$V_{in} D_1 = V_o D_2 \quad (5)$$

Also during this time, the Switch S_1 is turned off, so Battery A can only discharge through the connected LC filter to store energy waiting for the next switching cycle.

The equivalent circuits during one cycle in mode 1 are shown in Fig. 5. On the other hand, the working process of the converter is similar in mode 2.

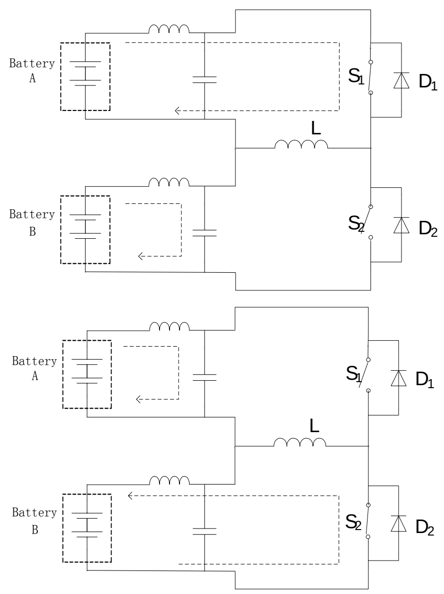


Figure 5. The equivalent circuits during one switching cycle

C. LC Fliter Circuit

According to the analysis of main circuit, the current of discharging from Battery A exists when the Switch S_1 is turned on, but it falls to zero immediately when S_1 is turned off. Similarly, the current of charging to Battery B is also discontinuous and determined by the status of Switch S_2. In order to smooth the charging and discharging current of battery cells to provide a constant and continuous current, LC filter is connected for the filtering purpose. Fig. 6 is the filtered waveforms of charging and discharging current.

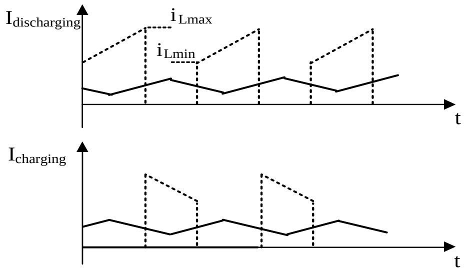


Figure 6. The filtered waveforms of charging and discharging current

III. Anaysis of Control Circuit and Detecting Circuit

A. Control Circuit

To realize closed-loop control, current mode PWM control method is adopted in this circuit. In this converter, we want to control the discharging current to be constant and continuous. According to the parameters sampled of charging-discharging circuit, the control circuit can regulate the duty ratio of PWM signal to drive the switches in half-bridge converter. Fig. 7 shows the control circuit. In addition, we can also take the charging current under control if it is necessary. This control method is more accurate and has a better dynamic performance.

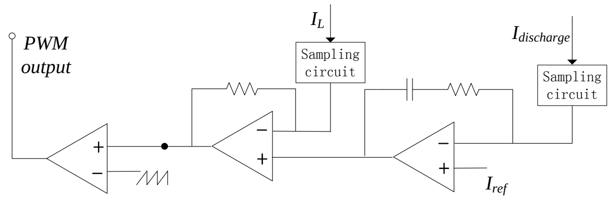


Figure 7. The schematic of control circuit

B. Detecting Circuit

In order to measure the performance of battery in real time, detecting circuit is used to detect the parameters such as terminal voltage of battery, charging and discharging current, internal resistance etc. Detection of internal resistance is the most difficult but essential part.

The internal resistance can effectively measure the state of charge (SOC) of the battery. With the decrease of discharge capacity, the resistance of the battery becomes larger. To detect the internal resistance directly, we take the AC signal injection method [4], [5]. By injecting a AC signal into the battery circuit, we can get the voltage U, current I and the phrase difference φ. The internal resistance R can be worked out according to the following equation.

$$R = \frac{U}{I}\cos\varphi \tag{6}$$

The selection of the AC signal frequency is very important in order to eliminate the main interference of external noise sources. In this system, a 1kHZ AC current signal is added into the battery circuit, and the amplitude of injected current is only 1A, so it hardly has effect on the performance of battery.

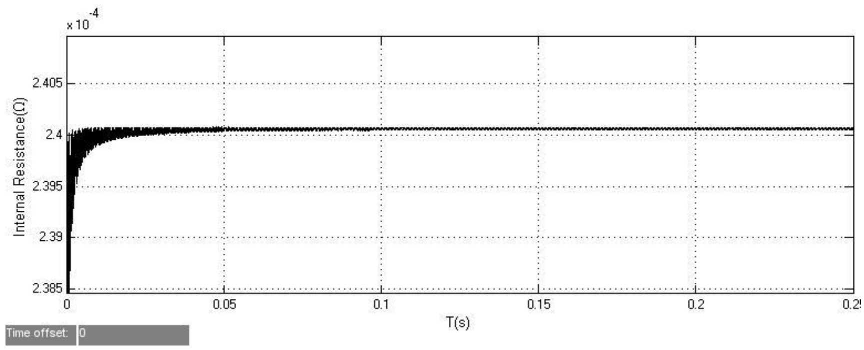


Figure 8. The waveform of internal resistance

To verify the accuracy of this method, we use a 2V, 800Ah battery to simulate, the rated internal resistance at fully charged is 0.24mΩ. Fig. 8 is the waveform we obtained by this method. The result shows that it is very close to the rated value and can indicate the value of internal resistance in a very short time.

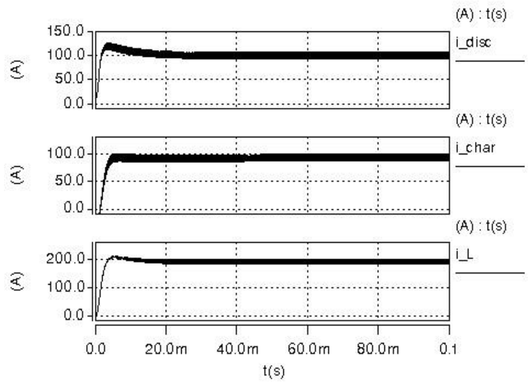
IV. Simulation Results

To verify the above analysis, the proposed half-bridge converter for battery charging-discharging is simulated using SABER software. The parameters are shown in Table I.

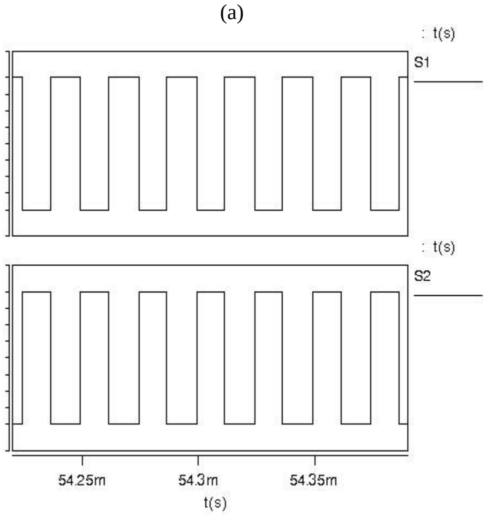
TABLE I. The Parameters of Simulation

Component	Parameter
Battery cells	28V, 800Ah
Discharging current	100A
Switching frequency	40kHz
Inductor L	20μH
Filter inductor	0.1μH
Filter capacitor	5000μF

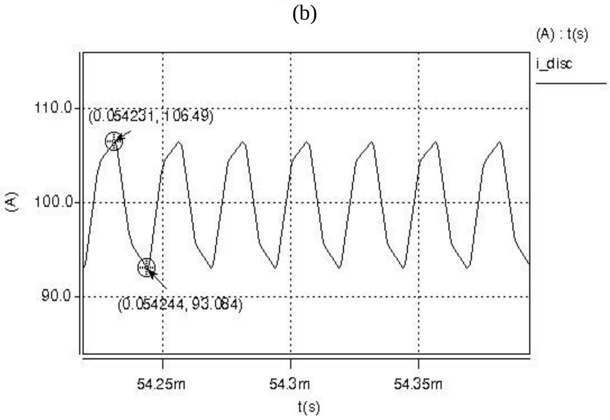
The simulation results are shown in Fig. 9.



(a)



(b)

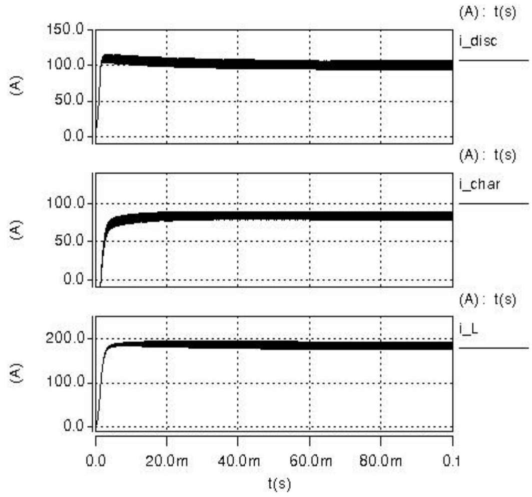


(c)

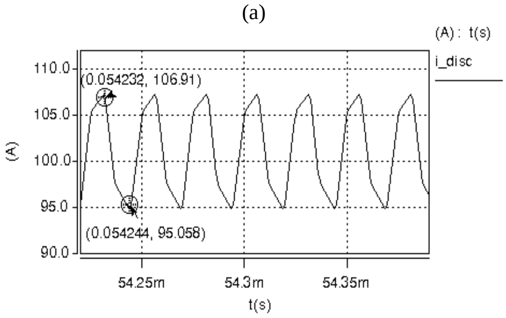
Figure 9. Initial waveforms in simulation: (a) current of discharging, charging and the inductor; (b) gate pulses of the switch S_1 and S_2; (c) the amplified waveform of discharging current

Fig. 9 shows the current of discharging and charging, the inductor current and the gate pulses of the switches in the converter. The terminal voltage of Battery A is 28V in simulation. When Battery A discharges to Battery B, the average discharging current can hold steady around 99.79A (from 93.08A to 106.49A, very close to the set value 100A) and has a small current ripple (the ripple rate is about 13.4%) in simulation.

Fig. 10 shows the current of discharging and charging, the inductor current when the terminal voltage of Battery A drops from 28V to 26V. With the decreasing of voltage in the discharging process, the average value of discharging current is about 100.98A and it is still very stable and accurate. At the same time, the current of charging and the inductor current have also been decreased, it is because the change of terminal voltage has regulated the duty ratio of gate pulses and according to the principle of conservation of energy, the current drops gradually.



(a)



(b)

Figure 10. Waveforms when the terminal voltage of Battery A drops to 26V: (a) current of discharging, charging and the inductor; (b) the amplified waveform of discharging current

With the decreasing of the terminal voltage of Battery A from the fully charged voltage to the lowest, the average discharging current changes in the range from 99.49A to 101.25A and the ripple rate is always ≤15%. The value of current can also be adjusted according to different demands to provide a constant current for discharging.

In addition, charging current and the inductor current in simulation can also get steady rapidly, and the results are determined by the change of the terminal voltage of battery cells. Similarly, we can also adjust the control method to make the charging current hold steady and constant while the discharging current will be changed.

V. CONCLUSIONS

In this paper, a novel half-bridge converter for battery charging-discharging based on Thevenin equivalent model is proposed. The proposed converter can realize the bi-directional energy transfer during charging and discharging process of the battery cells. At the same time, this converter also leads to advantages in high efficiency and simplified structure.

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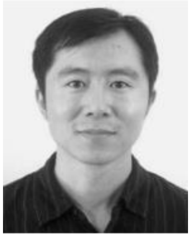

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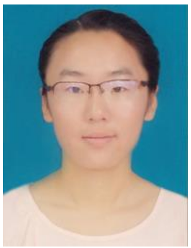

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