새로운 시분할 다중 제어 기법을 이용한 소프트 스위칭 다중 출력 충전기

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Soft Switching Multiple Output Charger By Using Novel Time Division Multiple Control Technique

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ABSTRACT

Multiple output converters (MOCs) are widely used for applications which require various levels of the output voltages due to their benefits in cost, volume, and efficiency. However, most of the MOCs developed so far can regulate only one output tightly and require as many secondary windings in the transformer as the number of the outputs. In this paper, a novel Time Division Multiple Control (TDMC) method to regulate all the outputs in high precision is proposed and applied for the multiple output battery charger based on the phase shift full bridge topology to charge a multiple number of batteries at one time. The proposed converter can charge three different kinds of batteries or same kind of batteries in different state of charges (SOCs) by using constant current/constant voltage (CC/CV) charge mode independently. At the same time it can provide an even degree of tight regulation for each output to satisfy the strict ripple requirement of the battery. The validity and feasibility of the proposed method are verified through the experiments.

Index Terms – Time division multiple control, Multiple output battery charger, Phase shift full bridge, and ZVS-ZCS

1. Introduction

Recently novel Time Division Multiple Control (TDMC) method which can precisely and independently regulate the multiple outputs with only one secondary winding for the multiple outputs has been proposed and applied to the double ended forward converter [1]. However, it has limitations in power rating and efficiency. In order to overcome those problems, a multiple output charger based on the phase shift full bridge converter with TDMC method is proposed in this research. The proposed converter can charge three different kinds of batteries or same kind of batteries in different SOCs by CC/CV charge mode independently and also satisfy the ripple limits of the Li-Po battery.

2. Proposed TDMC method and operation principle of the multiple charger

Fig.1 shows the proposed multiple charger based on the phase shift full bridge converter including R-C model of the Li-Po batteries with TDMC method. As shown in the figure, the proposed converter was developed by modifying the conventional phase shift full bridge converter, in which three different output circuits shares the secondary winding of the transformer and an active switch is added to each output in order to perform the TDMC method.

Fig. 2 shows the overview of the PWM scheme of the proposed converter with TDMC method. As shown in the figure, the PWM is performed at the frequency of f_s for the primary switches and at $f_s/3$ for each of the secondary switches. The proposed method can regulate all of the outputs in one sampling time (3Ts). Each output is controlled independently and precisely during one switching period T_S (interrupt cycle) by way of the secondary switches. In one switching period T_S, just one secondary switch is turned on to allow the primary side to control each output by shifting the phase between the leading and lagging switches. Similarly, another output is regulated in the next switching period. As a result, all of the outputs are controlled in one sampling time (3Ts) sequentially. Since each output is regulated independently within one switching cycle (T_S), there is no cross regulation problem. Thus it is possible to provide an even degree of the tight regulation for all the outputs.

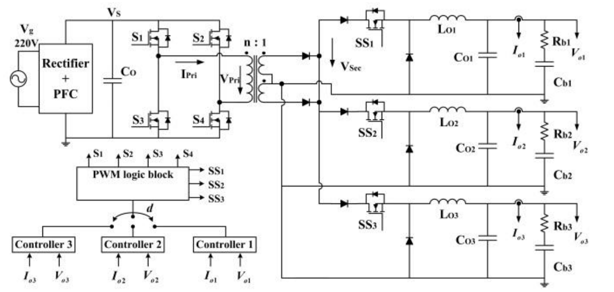

Fig. 1. Proposed multiple charger based on Time Division Multiple Control method for three Li-Po batteries

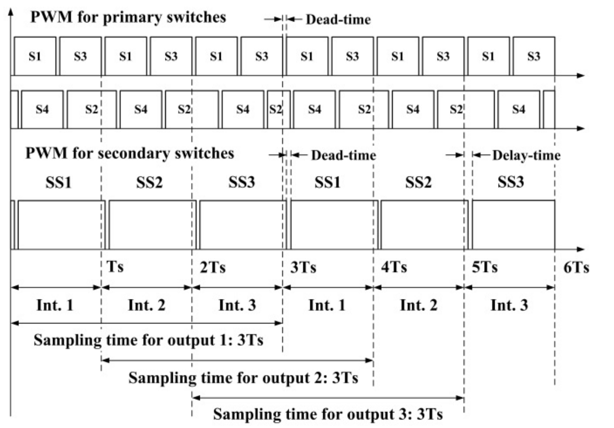

Fig. 2. Switching waveforms of the primary and secondary switches in the proposed charger with TDMC method

3. Steady state analysis and control-output-transfer functions of the proposed charger

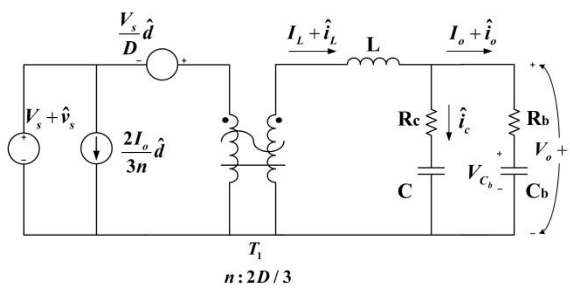

Fig. 3. State space average modeling of the proposed multiple charger for each secondary output

As shown in Fig. 1, three secondary circuits have the same configuration. Since the same control method can be applied to each secondary circuit in a time-shared basis, the control-to-output transfer functions with only one output need to be derived.

The battery load is modeled by a resistor R_b in series with a capacitor C_b having an initial voltage, V_{Cb}. The state space average model of the proposed multiple charger at each output including R-C equivalent circuit model of the Li-Po battery is shown in Fig. 3, where D is the effective duty cycle between the leading and lagging legs. Some steady state equations can be obtained as in (1) to (3) in continuous conduction mode (CCM).

$$V_o = \frac{2}{3} \times \frac{D}{n} V_s \quad (1)$$

$$V_o = R_b I_o + V_{C_b} \quad (2)$$

$$I_s = \frac{2}{3} \times \frac{D}{n} I_o \quad (3)$$

The control-to-output voltage and control-to-output current transfer functions can be found based on small signal modeling of the state space average circuit as (4) and (5), respectively.

$$G_{vd} = \left.\frac{\hat{v}_o}{\hat{d}}\right|_{\hat{v}_s=0} = \frac{V_o}{D} \times \frac{(1+a_1 s)(1+a_2 s)}{s^3 b_3 + s^2 b_2 + s b_1 + 1} \quad (4)$$

$$G_{id} = \left.\frac{\hat{i}_o}{\hat{d}}\right|_{\hat{v}_s=0} = \frac{V_{C_b} + I_o R_b}{D R_b} \times \frac{(1+a_1 s)(1+a_2 s)}{s^3 b_3 + s^2 b_2 + s b_1 + 1} \quad (5)$$

where,

$$a_1 = R_b C_b;\; a_2 = R_c C;\; b_1 = R_c C + R_b C_b$$

$$b_2 = LC + LC_b + R_b R_c C C_b;\; b_3 = R_b L C C_b + R_c L C C_b$$

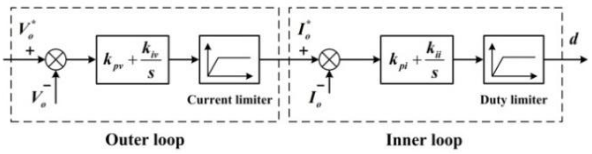

Fig. 4. Block diagram of the dual control loop for each output

In this application, CC/CV mode charge is performed by using a dual control loop with PI compensator for each loop, where the inner control loop serves for the output current control loop and the outer loop serves for the output voltage control as shown in Fig. 4.

4. Experimental results and discussions

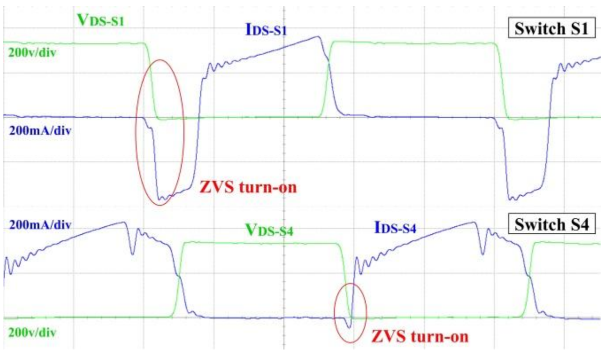

Fig. 5. Voltage and current waveforms of the switches S1 and S4

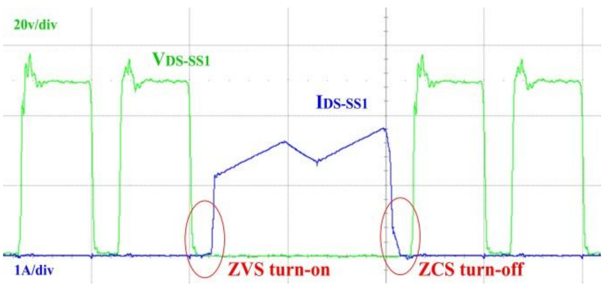

Fig. 6. ZVS turn-on and ZCS turn-off waveforms of the secondary side switch SS1

Fig. 5 shows the voltage and the current waveforms of the switch S1 and S4 captured at the end of CV charge mode. As shown in Fig. 5, ZVS turn-on is achieved at the switches S1 and S4 under the light load condition. The ZVS turn-on is also achieved at the switches S2 and S3 similarly though it is not shown here. As a result, ZVS turn-on of the primary switches can be achieved all over the charge process.

Fig. 6 shows the ZVS turn-on and ZCS turn-off waveforms of the secondary switches at the outputs. As shown in the figure, since ZVS turn-on and ZCS turn-off can be easily achieved at each secondary switch all over the charge process, there are no switching losses at the secondary switches.

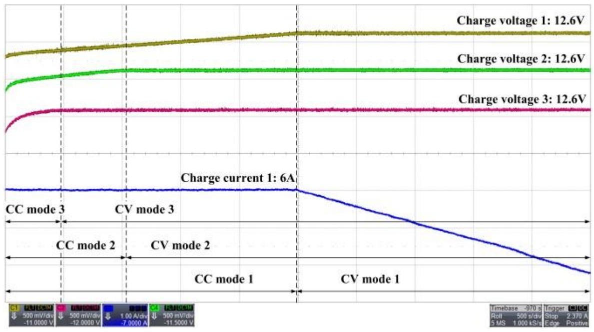

Fig. 7. Charge voltage and current profiles of three Li-Po batteries by using the proposed charger and TMDC method

Fig. 7 shows the charge current and voltage profiles of the three Li-Po batteries in different SOCs during the charge process by the proposed multiple converter respectively. The figure shows that the proposed charger and the TDMC method work properly to charge three Li-Po batteries independently and precisely by CC/CV charge modes. It is also shown that all three batteries can be successfully charged with no cross regulation problem simultaneously.

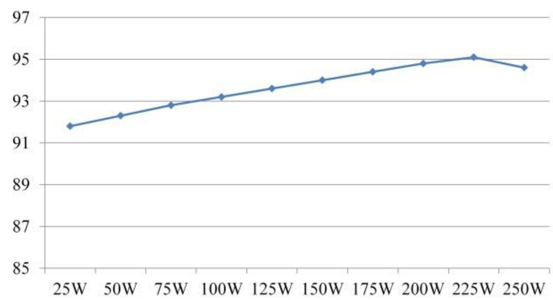

Fig. 8. Efficiency plot of the proposed multiple output charger

As shown in the Fig. 8, the efficiency plot of the proposed charger varies from 91.8% to 95% according to the load and the maximum efficiency is 95% at 90% load.

5. Conclusion

In this paper, a multiple output battery charger based on the novel TDMC technique is applied to the phase shift full bridge topology to charge for three Li-Po batteries precisely and independently. The ZVS turn-on at the primary switches and ZVS turn-on and ZCS turn-off of the secondary switches are achieved all over charge process thereby reducing the switching losses. With the help of a digital signal processor capable of high speed operation, the TDMC method can be simply implemented. If the proposed method is applied for the EV charger, it can provide advantages in terms of volume, cost and efficiency. Also the installation area can be saved significantly.

References

[1] Van-Long Tran and Woojin Choi, "*Novel Time Division Multiple Control Method for Multiple Output Battery Charger*", IEEE Transaction on Power Electronics, Early Access Article 2014.