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A novel synchronous buck topology for battery charger

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Abstract

This paper introduced a novel synchronous buck converter with soft-swithcing (ZCS and ZVS) for battery charger. The converter structure is simple and easy control.New converter combines synchronous retification and soft-swithing (ZCS and ZVS) to decrease circuit losses. Moreover, the circuit is designed to make current never pass through body diode of synchronous rectifier. Thus,the circuit avoids diode recovery effects which happened frequently in sycnchronous converter topologies. The operating modes of the converter and equivalent circuits are identified by analyzing the operating principles of the charger circuit. Simulation results reveal the theoretical effectiveness of novel battery charger with little voltage ripple and circuit losses, fast dynamic reponse and high efficiency.

*Keywords:*battery charger;converter;synchronous; buck;soft-swithcing;

1. Introduction

Batteries are extremely convenient energy devices that can be used repeatedly many times.Moreover,batteries cause less pollution than traditonal dry cell.Batteries are utilized in many domains,such as dialy life and seafaring[1][2].Batteries depend strongly on charger circuit,besides materials and craftsmanship.Efficent charging shortens charging time and prolongs battery cycle life[3].

Conventional buck battery chargers employed hard-switching PWM converter to regulate output voltage.In these circuits,the voltage and current waveforms of switches are presented square,it caused serious losses that decrease efficiency of battery chargers[4].Moreover,Conventional battery chargers with linear power regulators can handle only low power levels, having a very low efficiency, and have a low power density,since they stipulated low-frequency filters.Modern battery chargers require high quality, small size, light weight, high reliability, and highly efficient energy conversions.The most efficient solution is to increase operation frequency. However, Traditional hard-switch resulted in more

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switch losses and caused electromagnetic interference when converters operated under high-frequency. In order to keep high-efficiency under high-frequency operation, the soft-switching technique were employed in conventional battery chargers.Zero-current-switch(ZCS) and zero-voltage-switch(ZVS)techniques are two conventionally employed soft-switching methods[5].These techniques lead to either zero voltage or zero current during switching transition, significantly decreasing the switching losses and increasing the reliability for the battery chargers.

Traditional ZCS/ZVS converters operated with constant on-time control,circuits need to operate with a wide switching frequency range, when given wide input source and load range, making the filter circuit design difficult to optimize.Many high-efficiency battery charging topologies have been proposed.However, the maximum charging efficiency is just 60%-77%[6][7].The resonance of the novel converters is dominated by the auxiliary switch, which generates resonance and temporarily stops a period that can be regulated.Thus, buttering the disadvantages of fixed conduction or cutoff time in a traditional resonant power converter, the efficiency also get improved.Recently, most battery chargers are low voltage and large current output.In this case, the commutation losses of converter is not to be neglected,the commutation losses would influence efficiency of converter.This paper developed a novel synchronous buck battery charger with soft-swithcing.More Simple circuit structure,easy control,low switching losses and commutation losses, high charging effiency.The remainders of this paper is organized as follow.The second Section describe the circuit topology and illustrates; The third Section presented Simulation results. Conclutions are drawn in final section.

2.Circuit configuration and operation principle

2.1.Circuit configuration

Fig. 1 shows the circuit structure of novel synchronous buck converter with soft-switching for a battery charger, capacitor Cr is parallel with auxiliary switch, the commution diode is replaced by auxiliary switch S2, thus it make circuit more simple. when auxiliary switch S2 is off, capacitor Cr absord extra current. The resonant between the auxiliary inductor and paralleled capacitor generates a sinusoidal voltage waveform on S2, which is different from the conventional square waveform in the PWM synchronous buck converter. Auxiliary switch S2 can be turned on when its voltage resonates back to zero. As a result, the body diode D2 never conducts current. Hence, the commutation losses is decreased and recovery effect of diode is averted. Because of the period of the resonant voltage pulse across S2 is mainly determined by the parameters of inductor Lr and capacitor Cr, the turn-on timing of S2 can be almost fixed. Co and Io is output filter, because the value of Co and Lo are large enough, the output current Io deemed as constant value.

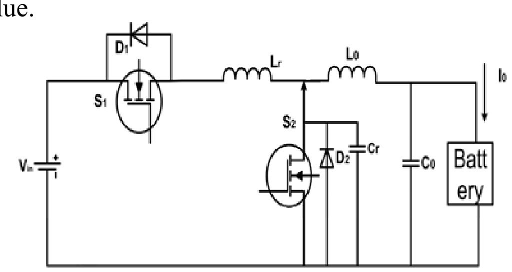


Fig. Novel converter for battery chargers

2.1.Analysis of circuit

The ideal main waveforms of circuit are described as Fig 2. Several assumptions are made for analysis:

i) All semiconductor elements are ideal and have no time delay during switching.

ii) The inductance and capacitance in the resonant circuit have no internal resistance.

iii) The filter inductance Lo is much greater than the resonant inductance Lr. The filter capacitance Co is much larger than the resonant capacitance Cr. The output stage of the filtering circuit can be regarded as a constant current Io compared to the resonant circuit.

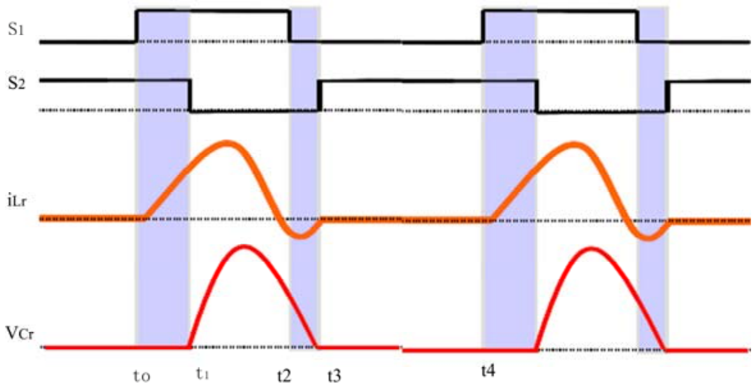


Fig 2. Conceptual waveforms of circuit

The circuit operation in one cycle can be divided into four stages. The operating pricinples are analyzed as follows:

Mode 1 [t0-t1]: before t_0, main switch S1 is off and auxiliary switch S_2 is on. Auxiliary switch S_2 freewheel current,theoutput current $I=I_0$.At the time of t=to, main switch S_1 is on. Vin charges inductance Lr, the inductance current iLr rise linearly until I_0. Fig.3.(a) show this mode.The current i_{Lr} can be described by equation (1):

$$i_{L_r}(t) = L_r \frac{V_{in}}{L_r} \tag{1}$$

Mode 2 [t1-t2]: In this mode, iLr= Io at t = t1, and auxiliary switch S_2 is turned off. The main power switch S_1 remains on during this period. Fig. 3 (b) shows the equivalent circuit. In this mode, the current pass through Lr and Cr, causing the inductor Lr and capacitor Cr to resonate. The equations describing the current i_{Lr} during this mode are by equation (2):

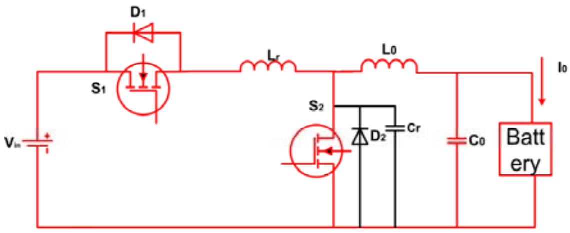
$$i_{Lr} = V_{in}\sqrt{\frac{C_r}{L_r}}\sin[\frac{1}{\sqrt{L_r \times C_r}}(t-t_1)] + I_0 \tag{2}$$

At $t=t_2$, the current i_{Lr} of inductance Lr decrease to zero, main switch S_1 is turned off under ZCS. At this time, mode 2 ends.

Mode 3 [t2-t3]: At t=t2, main switch S_1 is turned off under ZCS, auxiliary switch S_2 remains on ,inductance Lr remain resonant with capacitor Cr. On this period, the current i_{Lr} of inductance Lr is reverse, which pass through body diode D_1. Fig. 3(c) shows the equivalent circuit.At t=t3, the voltage V_{Cr} of capacitor Cr decrease to zero, auxiliary switch is turned on under ZVS. Voltage V_{Cr} can be described by equation (3):

$$V_{Cr}(t) = \frac{0-(I_o + i_{Lr})}{C_r}(t - t_2) + VCr(t_2) \qquad (3)$$

Mode 4 [t3-t4]: At t=t4, main switch S1 is turn on, and auxiliary switch S_2 remains on, the operation returns to Mode 1 in the next switching cycle. Fig. 3.(d) shows the equivalent circuit.



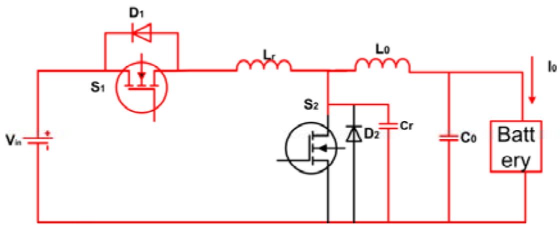
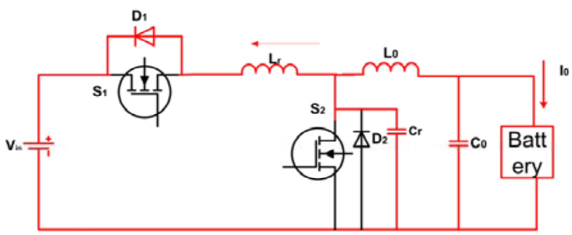


Fig 3(a) . Mode 1 Fig 3(b) Mode 2

3.Simulation results

A prototype buck converter with ZCS PWM topology was established to verify the functions.The developed charging circuit was connected to a 12V-48Ah lead-acid battery. Table1 presents the experimental circuit parameters for new converter.

The simulation was conducted with Simulink tool. Fig.4(a) depict the trigger signal on the switch S1 and S_2 respectively.Fig.4(b)plots the waveform of current i_{Lr} voltage Vcr. The current iLr decreased to zero when the main switch S_1 was cut off. And,the voltage VCr decrease back to zero when auxiliary



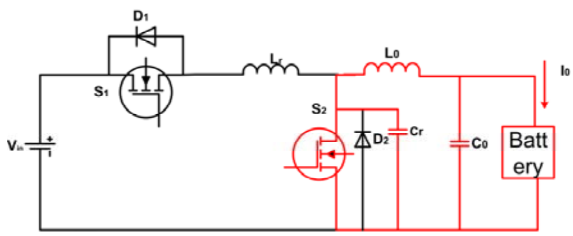


Fig 3C Mode 3 Fig 3(d) Mode 4

switch S_2 was turned on. Accordingly, the main switch S1 can realise ZCS, auxiliary switch S_2 can realize ZVS with low switching losses. Fig.4(c) describes the waveform of body diode D2.As description refered,when S_2 is off, the capacitor Cr absorbed current. Thus, D_2 never conduct current and recovery effect was averted. Fig.4(d) plot waveform of output voltage.It show Ripple of output voltage is very small.

Table 1. Parameters of main elements

Parameter	Column
Input voltage Vin	20V
Output voltage Vout	16V
Main frequency f	100k Hz
Resonant frequency fr	127k Hz
Resonant inductance Lr	3.2uH
Resonant capacitor Cr	0.49uH
Output inductance Lo	32uH
Output capacitor Co	4.9uH

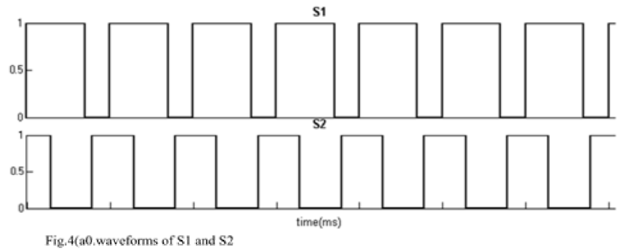


Fig 4(a) waveforms of S1 and S2

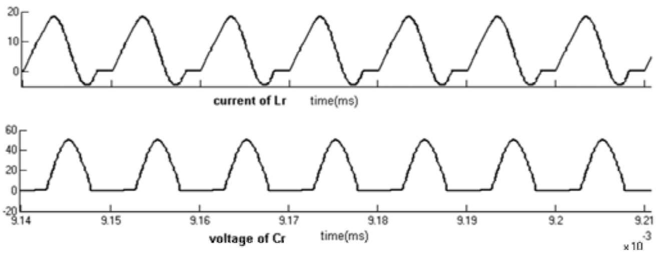


Fig (b) Waveforms of reonant L_r and C_r

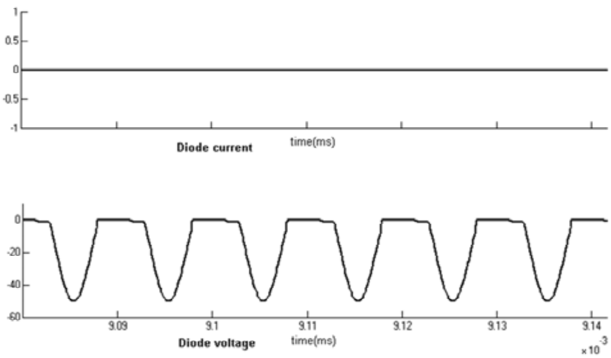


Fig . 4 C waveforms of D

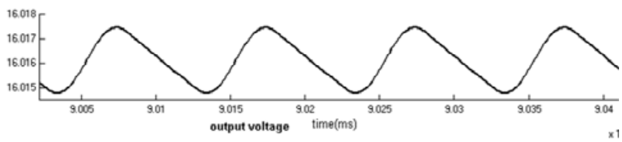


Fig 4(d) waveforms of output voltage

4. Conclusion

This paper developed a high-efficiency battery charger with a synchronous buck converter with soft-switching (ZVS and ZCS) to improve the performance. The experimental results obtained by charging a lead-acid battery indicate the effectiveness of the proposed approach, revealing that the main switch S_1 and auxiliary switch S_2 in the developed novel charger is indeed operated with ZCS and ZVS respectively.Constant-frequency operation, reduced resonance time, small components and small circuit volumes can be realised. A large decrease in the working temperature of the switches, a considerable decrease in the heat loss and a substantial increase in the charging efficiency are realised by reducing the resonant time. The charging efficiency of the circuit is 93.1%, revealing high charging efficiency and fast charging.

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