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Research on Compensating Power Converter used for Artillery

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Abstract: Aiming at the low efficiency shortage of traditional power supply converter used for artillery, a novel compensating power converter used for artillery was proposed, and its work mode was analyzed. The current expression of inductor was given and work statuses under two working modes were analyzed. Finally an experimental prototype based on DSP was built, the results indicate that the compensating power converter own low current and voltage stress and high efficiency because only part of power pass through the converter, thus, the converter own large potential application value. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Compensating power converter, Current stress, Voltage stress, Power plant.

1. Introduction

As demand of artillery dynamic increases, the requirements on the generator and power level of the post power converter are more and more stringent [1-4].

Demand of the self-propelled artillery is divided into two types [4, 5]: low-voltage DC power on the control appliances and computer system, and three-phase AC power on the servo system. To meet the above electricity demands, medium-frequency alternators in the dual-voltage system are usually used as generators. The generator owns double-windings and double-channels output, one is low-voltage AC; and the other is high-voltage AC to the servo system. Through power converter, low-voltage AC can be transformed to variable DC to supply the DC equipment. However, the post power converter of the generator is mainly traditional chopper [6, 7]. For the power transformation, paper [8] turns the hollow magnetic inductance to adjust the voltage using the hollow electromagnetic induction principle; paper [9] conducts a research on the DC-DC convertor to achieve power transformation; paper [10] uses a Buck-Boost DC-DC convertor to transform DC-voltage. Above-mentioned power convertors are all full-power converters, in which all power passes through chopper, along with the high stress of voltage and current, which lead to large volume, low efficiency, and serious heating of the entire device, thus the device is not fitful for high level power supply of the artillery.

Aimed at the above shortages, a compensating power converter is proposed in this paper, its work mode is analyzed and the parameters of inductor and capacitor are computed and verified. Only part of power passes through the converter, thus the stress of voltage and current is reduced. The novel compensating converter is especially suitable for middle and high power fields.

2. Circuit Topology

The circuit topology is shown in Fig. 1, which is composed of uncontrolled rectifier circuit, input filter circuit, compensated boost converter and output filter circuit. The three-phase AC produced by generators can be converted to DC by uncontrolled rectifier circuit, and then supplied to the chopper after filters. Chopper is composed by power inductors, power switches and diodes, whose output voltage is the sum of voltage of output capacitor C_1 and voltage of input capacitor C_2, that is, the sum of the boost part of chopper and input voltage.

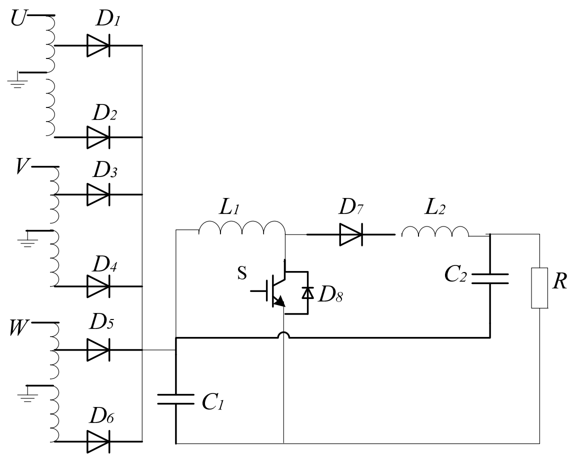


Fig. 1. Topology of compensating converter.

In Fig. 1, U_A, U_B, U_C are three-phase AC produced by generators, C_1 is filter capacitor, L_1 is power inductor, $S_1$is power switches, and diodes D_1 is power diode, L_2 is filter inductor and C_2 is filter capacitor.

3. Research on Working Modes

In order to facilitate the analysis, the compensating converter shown in Fig. 1 can be simplified as Fig. 2. The converter has 2 working modes, which are continuous conduction mode (CCM) and discontinuous conduction mode (DCM).

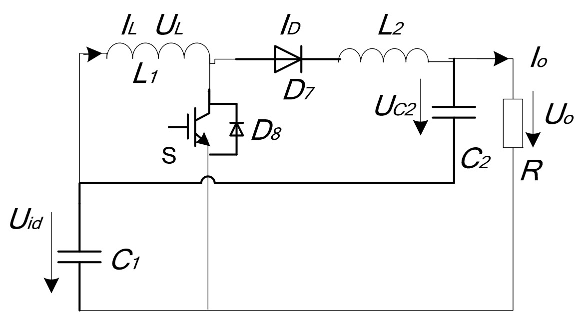


Fig. 2. Equivalent circuit of compensating converter.

3.1. CCM

The inductor current waveform within one switching period under CCM is shown in Fig. 3. In this mode, diode D_7 is cutoff while switch S is on and a loop is formed by capacitor C_1 and boost inductor L_1. At this point, capacitive energy storage begins, inductor current I_L increases from zero with slope equal to U_{id}/L, finally, the inductor voltage equals to the capacitor voltage when stable, that is,

$$U_L = U_{id}, \tag{1}$$

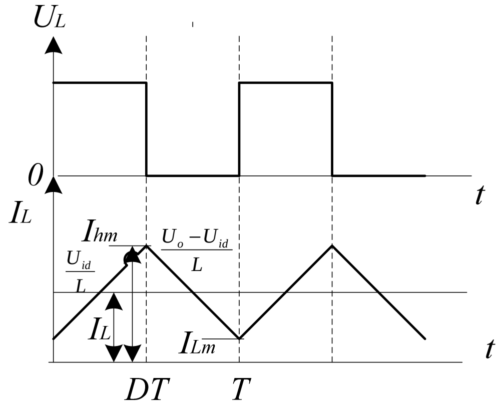


Fig. 3. Waveform of inductive voltage and current under CCM.

Current I_L passes through diode D_7 when S is off, L_2 is filter inductor and its value is ignored for analyzing, inductor L_1 and capacitor C_2 form a loop. At this point, inductive energy storage of capacitor C_2 begins, inductor current I_L increases with slope equal to（U_o –U_{id}）/L, finally, the inductor voltage of L_1 equals to the capacitor voltage of C_2 when stable, that is,

$$U_{C2} = U_L, \tag{2}$$

Output voltage equals capacitor C_1 voltage plus capacitor C_1 voltage at this time, since the voltage of capacitor C_1 are always equal to input voltage U_{id}, thus following equation can be obtained:

$$U_o = U_{C2} + U_{id}, \tag{3}$$

When output voltage clamps to input voltage, only part of voltage which is higher than input is transformed by chopper, thus the output power partly passes through. Compared with the traditional full-power boost converter, the switch power, stress of voltage and current and wastage are all reduced, thus efficiency is improved.

To analyze the power inductive current of clamp converter, following equations are obtained by Fig. 2 and Fig. 3:

$$I_{hm} - I_{Lm} = \Delta I_L = \frac{U_{id}DT}{L_1}, \quad (4)$$

$$I_{hm} + I_{Lm} = 2I_L, \quad (5)$$

By (4) and (5), we can obtain

$$I_{hm} = I_L + \frac{1}{2}\Delta I_L = I_L + \frac{U_{id}DT}{2L_1}, \quad (6)$$

$$I_{Lm} = I_L - \frac{1}{2}\Delta I_L = I_L - \frac{U_{id}DT}{2L_1}, \quad (7)$$

where I_{hm} is the maximum of I_L and I_{hm} is the minimum, I_L is the average of inductor L_1, D is the duty ratio of switching, T is the switching period.

Based on equation (6), the pulsating quantity ΔI_L of I_L is inversely proportional to L_1 and related to duty ratio D, and beyond that, I_{Lm} is related to I_L and ΔI_L, since I_L is increase and ΔI_L is decrease, I_{Lm}=0 when I_L=0.5ΔI_L, input current is under continuous mode at the time, hence

$$I_L = \frac{U_{id}DT}{2L_1}, \quad (8)$$

It can be seen from (8) that I_L is the continuous critical value of power inductive current and the continuous critical value of output current I_o is

$$I_o = \frac{U_{id}DT}{2L_1}(1-D), \quad (9)$$

When D=0.5, the maximum of output current is

$$I_{om} = \frac{U_{id}T}{8L_1}, \quad (10)$$

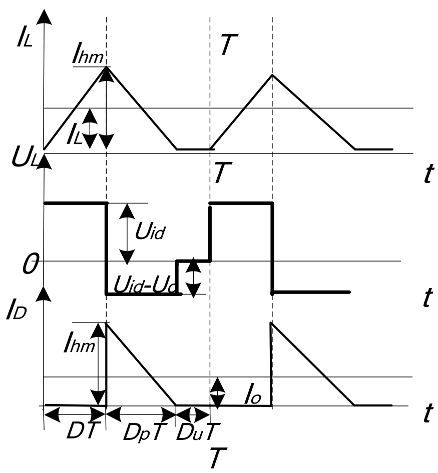


Fig. 4. Waveform of Inductive voltage and current and diode current under DCM.

From the waveform of I_D in Fig.4, the following equation can be obtained:

$$I_D T = I_o T = \frac{1}{2} I_{hm} D_p T, \quad (11)$$

Hence

$$I_o = \frac{1}{2} I_{hm} D_p, \quad (12)$$

where I_{hm} is the maximum of I_L, D_{pT} is the conducting time of D_7, D_p and I_{hm} can be obtained from Fig. 4.

From the waveform of U_L in Fig. 4, obtaining

$$D_p = \frac{U_{id}}{U_o - U_{id}} D, \quad (13)$$

And from the waveform of I_D, I_{hm} is

$$I_{hm} = \frac{U_{id}DT}{L_1}, \quad (14)$$

According to (12) and (14), it can be seen that output current I_o depends on D, D_p, inductor L_1 and input voltage under CDM, in which D_p subjects to values of input voltage $U_{id,}$ output voltage U_o and D.

4. Simulation and Experiment Results

To verify the correctness and effectiveness of compensating converter, simulation experiments on traditional Boost converters and clamped converters were conducted by MATLAB, and an experiment prototype based on DSP was manufactured. The system parameters are shown in Table 1.

Table 1. System parameters.

Main Circuit Parameters	Value
Input Voltage	10 V/ 20 V /50 V
Power inductor L1	500 uH
Controller	DSP:TMS320F2812
Load	Resistance :100 Ω/150 Ω
Switching Element	K15H1203
Diode	DSEI30-10

When testing the stress of, the input voltage was 50 V and other parameters remained the same.

Fig. 5 and Fig. 6 show the inductive current waveform of traditional boost converters and compensating converter, and spike current are 65.8 A and 56.4 A respectively. Comparing with traditional boost converters, the inductive current stress of compensating converter is smaller. Since the current of switching tube and backward diode is related to the inductive current, the current of switching tube and backward diode is also smaller.

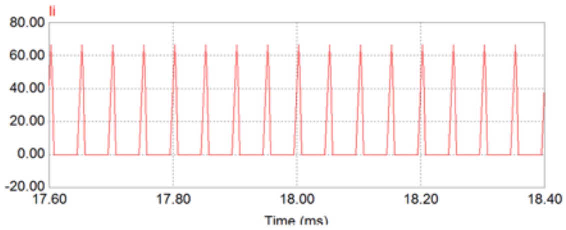


Fig. 5. Inductor current waveform of traditional boost converter.

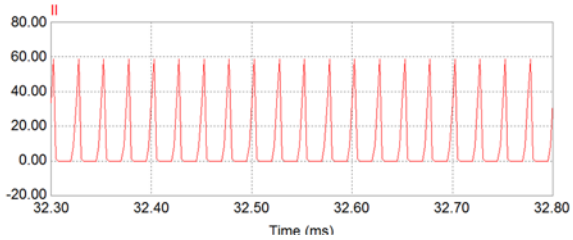
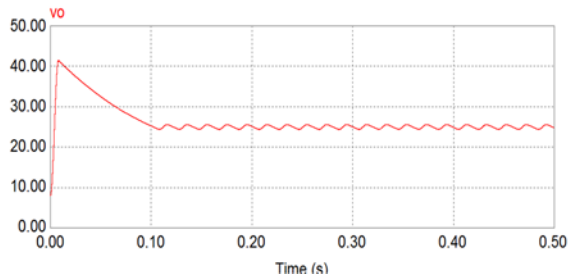
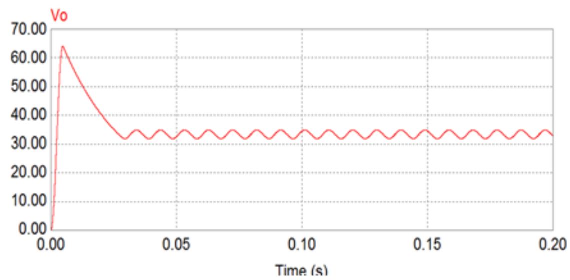


Fig. 6. Inductor current waveform of compensating converter.

When verifying the Boost capacity of traditional boost converter and compensating converter, input voltage was 10 V. Fig. 7 and Fig. 8 show the output voltage waveform of the two types of converters, when duty ratios are 0.5 and 0.9 respectively and D=0.5, the voltage gain of traditional boost converter is higher under the same input voltage [10].



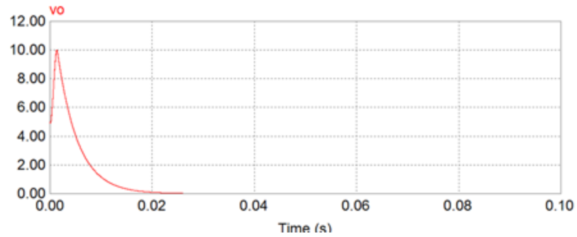
(a) Traditional Boost Converter



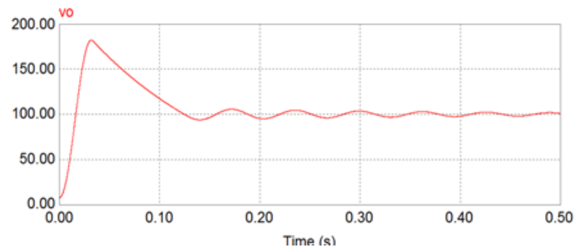
(b) Compensating Converter

Fig. 7. Output voltage waveform under D=0.5.

According to Fig. 7, the output of traditional boost converter is 25 V at this point, while the compensating converter is 34 V, which is higher; if the duty ratio increases to 0.9, the output of traditional boost converter is lower when D=0.9, that dual to the relatively higher boost ratio when D=0.4~0.5 [10]. Fig. 8 indicates that, at this point, the output of compensating converter is nearly 100 V and boost ratio is about 10, and the boost capacity was higher. The above analyses indicate that the boost capacity of compensating converter is better.



(a) Traditional Boost Converter



(b) Compensating Converter

Fig. 8. Output voltage waveform under D=0.9.

Fig. 9 is the waveform of switching tube control signals, PWM signal produced by DSP whose duty ratio is 0.6 passed through driven reverse, and the actual driving signal's duty ratio is 0.4,

Fig.10 is the output voltage waveform of the two types of converters. CH1 is the output voltage waveform of traditional boost converter under 10 V input voltage, the result shows that the output voltage is 12 V, while CH2 is the output voltage waveform of compensating converter, in which the output voltage is 16.5 V and the boost ratio is 1.62, hence the boost capacity of compensating converter is better.

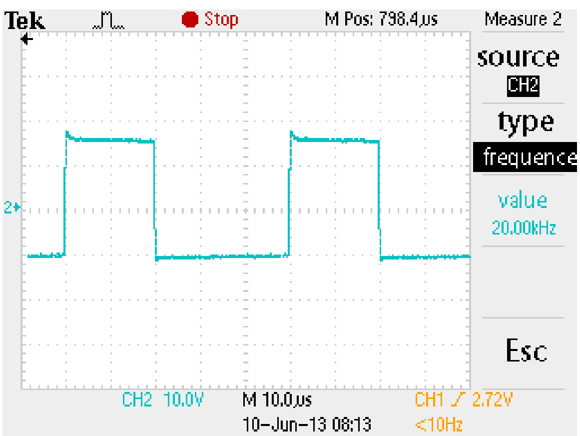


Fig. 9. Waveform of switchingtube control signal.

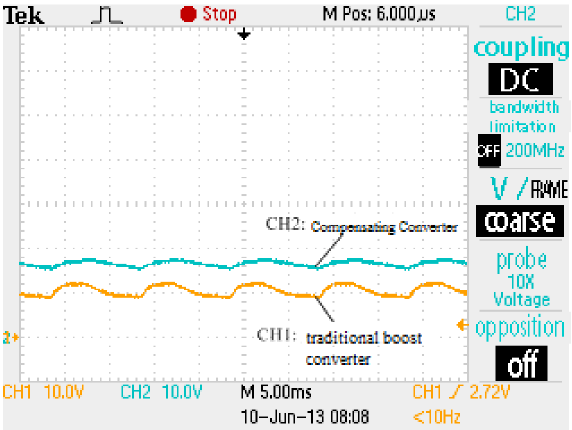


Fig. 10. Output voltage waveform of compensating and traditional boost converter.

5. Conclusions

The complex construction vehicles often use a dual-voltage power supply system, if the design of compensating converter could be applied, not only could reduce the voltage of power elements and current stress, and simplify the power supply structure, but also could reduce system cost and improve system reliability, so the design in this paper is worth to reference and promotion.

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