EMI Reduction and Frequency Stabilization in Ripple Injection Type Hysteretic Controlled Switching Converter

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Abstract: This paper describes a ripple injection type hysteretic controlled switching converter to meet the requirement for the fast response, such as in high-speed digital processor applications; it is one of hysteretic and nonlinear control methods. We have investigated the problem that when its output current is decreased, the operating frequency is decreased. We have found that its operation becomes in current discontinuous modes and the operating period becomes longer when the output current is decreased. Also, the constant operating frequency range can be expanded by controlling the injection ripple waveform by the periodic detection. Finally, we introduce a phase modulation method to reduce EMI.

Keywords: hysteretic controlled switching converter, ripple injection, discontinuous current mode, continuous current mode, EMI Reduction, Frequency Stabilization

1.Introduction

Many DC-DC converters are widely used in electronic devices. Hysteretic controlled switching converter is known as a typical control method for high-speed control. This method does not use a fixed frequency clock, but directly compares the output voltage with the reference voltage to enable high-speed switching control. This control method has the disadvantage that the control frequency fluctuates significantly due to changes in the load current.

In this paper, first we introduce the principle of ripple injection type hysteretic control switching converter. Then we introduce that when the output current decreases, its operation becomes discontinuous mode and the duty cycle becomes longer. Also, it is analyzed that the constant operating frequency range can be expanded by controlling the injection ripple waveform by the periodic detection. Finally, we discuss a circuit that uses phase modulation to reduce EMI.

2 Hysteretic control switching converter

2.1 Characteristics of hysteretic controlled switching converter

The basic configuration of the step-down hysteretic controlled switching converter is shown in Fig.1. The current flows from the switch or the diode to the inductor L and is provided into the output capacitor C to obtain the low ripple output voltage V_o.　As shown in Fig.1, the circuit consists of switch, freewheel diode D_i, energy storage inductor L, filter capacitor C and associated circuits. When the switch is ON, the hysteretic controlled converter supplies power to the load through the switch and the inductor L, and stores part of the electric energy in the inductor L and the capacitor C. After a certain period of time, the switch is turned off, due to the self-inductance of the inductor L, the current in the circuit will remain unchanged. By controlling the time when the switch is ON and OFF, the output voltage V_o can be controlled. If the output voltage is detected to control the on and off time to keep the output voltage constant, it will achieve the purpose of voltage stabilization [3].

The comparator compares the output voltage directly with the reference voltage V_{ref} to control the switch output, and the PWM signal is generated.

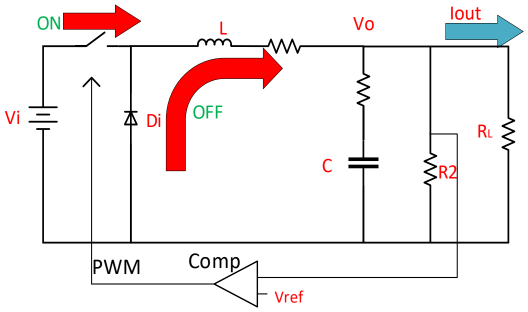
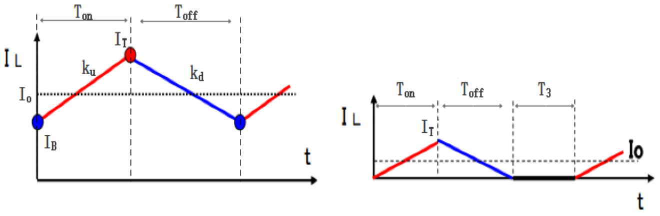


Fig. 1 Basic hysteretic controlled converter

The disadvantage of this basic hysteretic controlled switching converter is that the change of the output current greatly changes the operating frequency and that the comparator needs a certain amount of ripple.

In order to alleviate these problems, a large output capacitor with a series of equivalent series resistance (ESR) and a hysteresis comparator are used, so that the ripple injection type hysteretic controlled and constant-on-time (COT) control switching converter can be configured.

2.2 Operation of the hysteretic switching controlled converter



(a) CCM state (b) DCM state

Fig.2 CCM state and DCM state

The operation modes of the switching converter are classified into continuous conduction (current) mode (CCM) and discontinuous conduction mode (DCM) depending on the current flowing through the inductor current. The Inductor current is shown Fig2 :

Due to the self-inductance of the inductor L, after the switch is turned on, the current increases relatively slowly.

The inductor current is shown as below：

$$I_{out} = \frac{1}{T}\int_0^T I_L(t)dt \tag{1-1}$$

Output current in CCM state is given by

$$I_{out} = (I_B + I_T)/2 \tag{1-2}$$

Output current in DCM state is given as follows:

$$I_{out} = (I_T/2)/\{1+T_3/(T_{on} + T_{off})\} \tag{1-3}$$

3 Hysteretic controlled switching converter with ripple injection

3.1 Method of ripple injection

The configuration of the ripple injection type hysteretic controlled switching converter is shown in Fig.3. The intended ripple is injected into the input of the comparator by connecting the ripple generating circuit CR to both ends of the inductor L, so that the operating frequency in response to the change of the load current can be held almost constant.

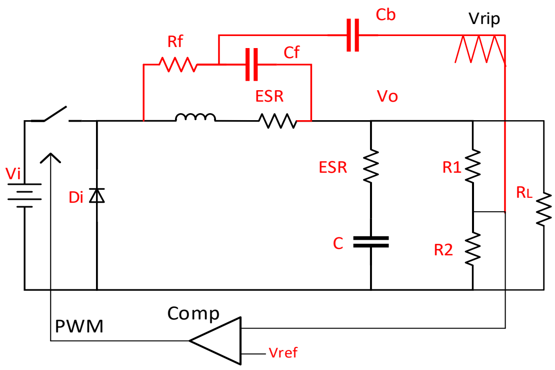


Fig. 3 Hysteretic controlled converter with ripple injection.

3.2 Relationship between output current and operating frequency

In the circuit of Fig.3, the values of the main circuit elements are set as follows: input voltage V_{in} = 10 V, output voltage V_{out} = 3 V, inductor L = 10 mH, output capacitor C = 220 uF, ESR = 5 mΩ, R_1 = 3.9 kΩ, R_2= 470 kΩ, R_f = 470 kΩ, C_f = 5 nF, C_b = 20 uF. Here, when the output current is 200 mA, the output ripple ΔV_{out} becomes 0.05 mV, and the operating frequency F_{op} becomes 1.3MHz. Fig.6 shows the relationship between the operating frequency Fop and the output current I_{out} when I_{out}.is small. We see that the range of DCM is ~ 100 mA and the operating frequency F_{op} becomes lower by decreasing the output current.

Here SAW shows change of period, SAW∝T

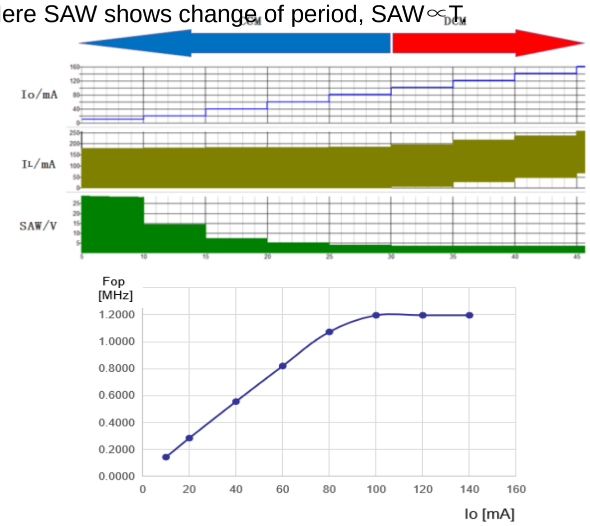


Fig. 4. Operation frequency and output current

4 Improvement of operating frequency in DCM state

4.1 Stabilization circuit for ripple injection

When the output current decreases at DCM state, the operating period T increases to keep the switch on-time constant.If the switch on-time is controlled in accordance with the change of the operation period, the operation period will be controlled constantly by the frequency-to-voltage (F/V) conversion circuit.

The proposed circuit is shown in Fig.9. Using the PWM waveform, the voltage V_H is detected which is in proportion to the operating cycle. This voltage is amplified to generate a modulation voltage V_m which is injected into the ripple area by the resistance Rm. V_m is used to modulate the ripple waveform and control the on- time.

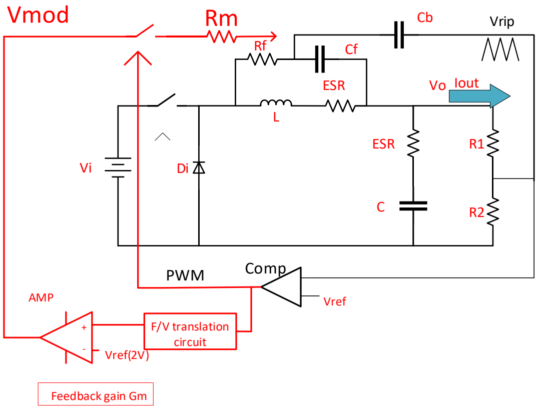


Fig. 7. Proposed circuit for modulation method of time

4.2 Result of simulation

In the above condition, the relationship between I_{out} and the change of the operating frequency is shown in Fig.12. Simulation result of proposed circuit in Fig. 9 is shown in Fig.11.We see that the constant operating frequency range is approximately equal to that of I_{out} = 60 mA, while the frequency change width is improved from ⊿F=1.0MHz to 0.3MHz, and the frequency change rate is improved from α=85% to 20%.

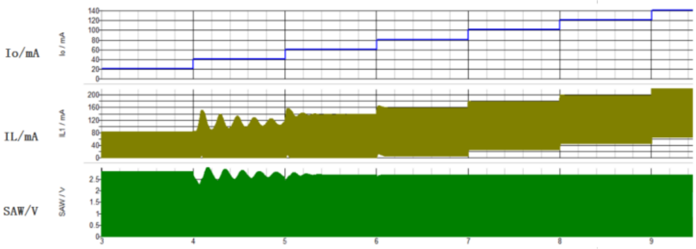


Fig. 8. Output current, inductor current and SAW voltage

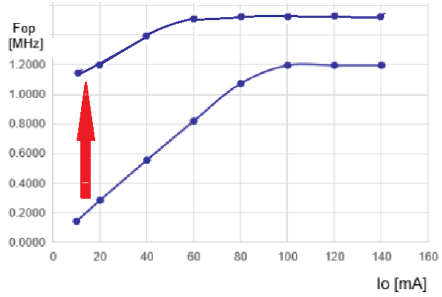


Fig. 9. Operating frequency before and after correction.

5 EMI Reduction in ripple injection type hysteretic control switching converter

In this section we will introduce phase modulation method in ripple injection type hysteretic controlled switching converter.

The proposed circuit shown in Fig.10 is uses phase modulation method and the clock phase modulation circuit is shown in Fig.11.it uses CR to delay the Pos edge of the input PWM signal and generates a delay pulse compared to the modulation voltage V_m. AND the output resistance terminal with Di to generate an output PWM signal.

The peak level of the frequency spectrum decreases from 2.6V to 342mV which is -17.6dB reduction which is shown in Fig.12.But the ripple of output voltage is from 1mV to 2mV so we should improve the circuit to reduce ripple.

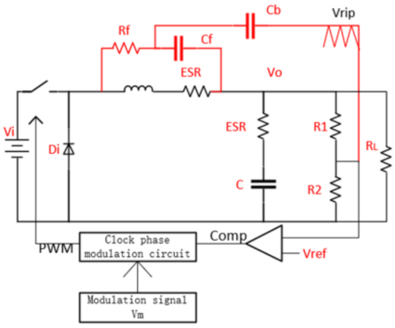


Fig. 10.Phase modulation method in ripple injection type hysteretic controlled switching converter.

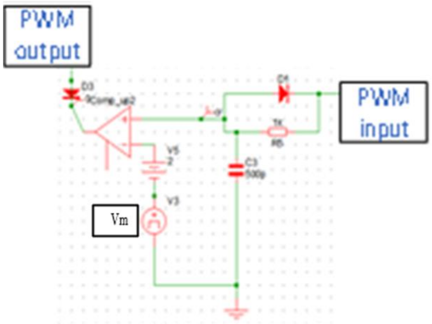


Fig. 11.Phase modulation method circuit

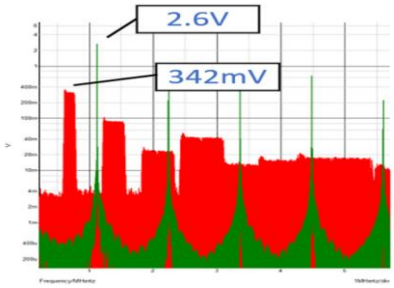
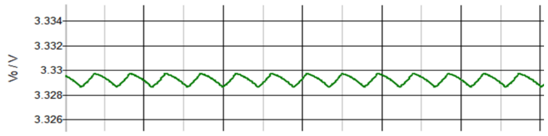
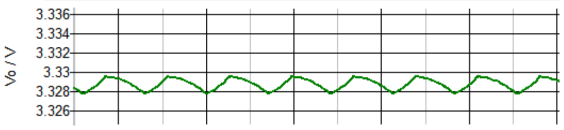


Fig. 12.Spectrum of PWM



Before phase modulation



After phase modulation

Fig. 13.Ripple of output voltage

6 Improvement of ripple of output voltage

In the above discussion, we can see that the ripple is Larger.We use the same method as how to improve operating frequency in DCM state , injecting V_{mN} into the ripple generating circuit.

V_m and V_{mN} get same frequency but opposite phase.

We obtain lower ripple 1mV from 2mV which is shown in Fig.15.

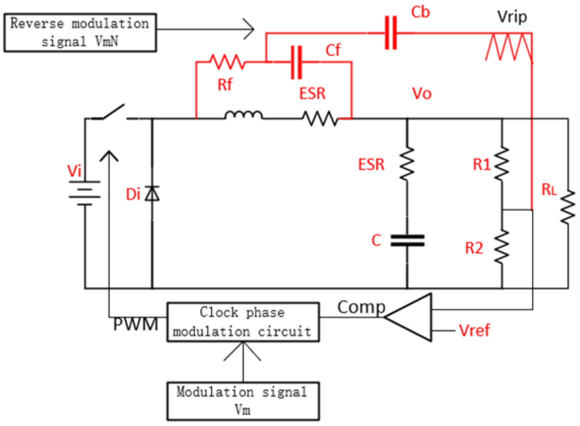
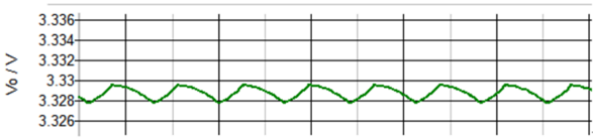
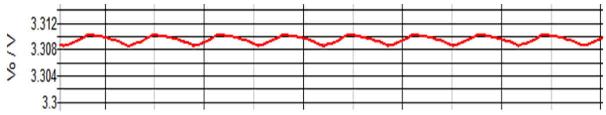


Fig. 14. Proposed circuit for EMI reduction with ripple



Before ripple suppression



After ripple suppression

Fig. 15. Output voltage ripple of proposed circuit

7 Summary and future challenge

This paper describes a ripple injection type hysteretic controlled switching converter for fast response and constant operating frequency. We verified the frequency modulation method in hysteretic controlled switching converter and discussed the feasibility of modulating the reference voltage. Finally, we analyzed the circuit using phase modulation method in ripple injection type hysteretic controlled switching converter，

Our future research is to stabilize the frequency even under 40mA for the output current, and to analyze ripple injection type hysteretic controlled switching converter using the transfer functions.

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