Independent Regulation of Multiple Output Flyback Converter with Pulse-Train Control

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Abstract

A family of independent-regulation multiple-output (IRMO) dc-dc flyback converters was researched in this paper, and its control in discontinuous conduction mode (DCM) was achieved by using pulse-train (PT) control method. To avoid cross-regulation between each output of multiple output flyback converters, time-multiplexing scheme is used to determine which output is controlled in the time interval of time-multiplexing signal. Error amplifier and corresponding compensators as required by conventional pulse width modulation (PWM) technique were not used in PT control. The multiple output flyback converters with PT control proposed in this paper is simple and enjoys fast dynamic response. It can achieve constant voltage output, and can also achieve constant current output, which provides an effective solution for multiple constant current output application, especially in LED backlight application.

Keywords: *Independent-regulation multiple-output, pulse train control technique, timing-multiplexing, discontinuous conduction mode, LED backlight*

1. Introduction

Isolated multiple independent outputs of power supply are usually required by equipment and devices such as LED backlight system, power adapter device and so on. Development of low cost and uncrossed regulation multiple output power supplies has thus attracted much attention recently [1]. Using N different switching converters is the most straightforward implementation [2]. However, this method requires too many components, including controllers and power devices, thus increase system complexity and cost. If it is not required to control N different outputs individually, a transformer with one primary winding and N secondary windings could be used. But this solution cannot control individual outputs precisely [3],Single-inductor multiple-output (SIMO) converter with only one inductor benefits in significant overall cost saving, small size and light weight of equipment and device, which make it as one of the most suitable and cost-effective solution for multiple output power supplies [6]. But research is focus on the topology and control method in non-isolated application.

In this paper, a family of independent-regulation multiple-output (IRMO) dc-dc flyback converters was researched, and its control in discontinuous conduction mode (DCM) was achieved by using PT control method. "Blank pulse" is adopted to improve its transient performance and light load efficiency. The time-multiplexing scheme is adopted for the control of IRMO flyback converter in DCM to prevent cross-regulation

between each output. PT control IRMO flyback converters, which can achieve constant voltage output, and can also achieve constant current output, provides an effective solution for multiple constant current output application, especially in LED backlight application.

2. Independent Regulation of Multiple Output Flyback Converters

Considering two conventional flyback converters switching at a frequency of f_s ($=1/T$) and working in DCM with duty ratios D_{1a} and D_{1b}, the schematics and waveforms of their inductor currents are shown in Figure 1. For converter A, the inductor current ramps up during $D_{1a}T$, ramps down during $D_{2a}T$, and stays zero during $D_{3a}T$, which is similar to the characteristics of converter B. If $D_{1a}+D_{2a}<0.5$ and $D_{1b}+D_{2b}<0.5$, the two converters can be operated in complementary phases Φ_a and Φ_b. And then, two independent flyback converters can be combined into an independent-regulation dual-output (IRDO) flyback converter which has a single magnetic element as shown in Figure 2. Using time-multiplexing (TM) scheme [8], each output of this flyback converter can be regulated independently. When $S_{oa}=1$, output A will be regulated, when $S_{ob}=1$, output B will be regulated [9-13].

Time multiplexing can be extended to multiple (N) outputs, and each output should occupy a time slot of T/N for charging and discharging the inductor.
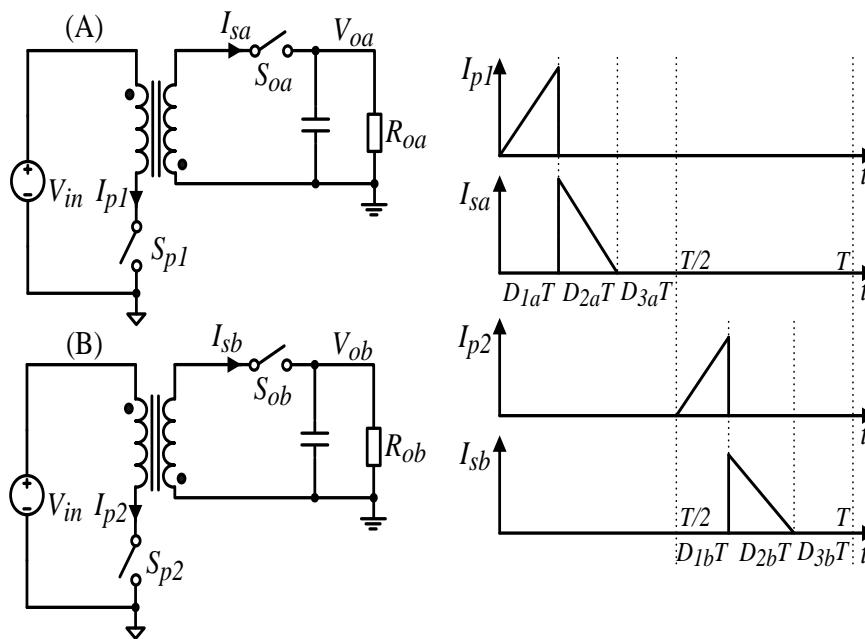

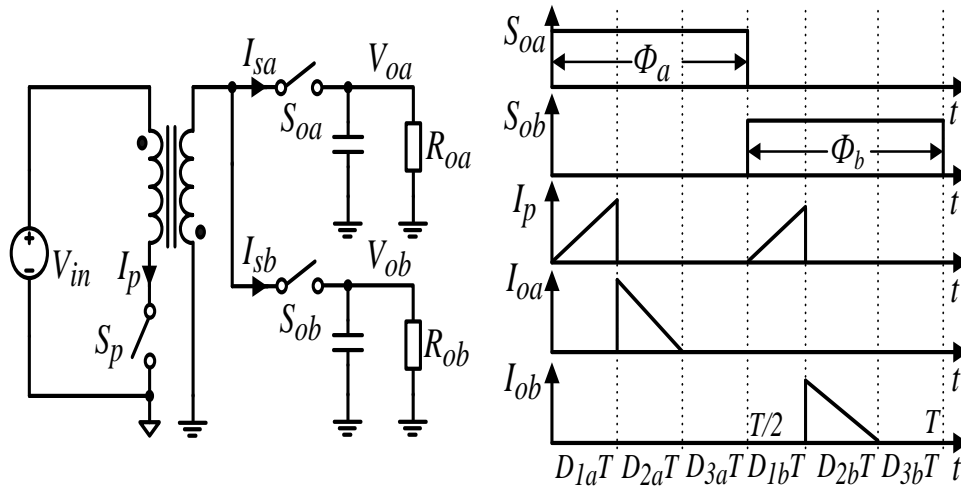**Figure 1. Two Independent Regulated Flyback Converters and their Switching Current in DCM**

Figure 2. Independent Regulated Dual Output Flyback Converter and It's Switching Current in DCM

3. PT Control of IRDO Flyback Converter

The block diagram of the proposed PT control IRDO flyback converter operating in DCM is shown in Figure 3 and its corresponding timing diagrams are shown in Figure 4 High-power pulse, low-power pulse and blank pulse are selected as active control signals of power switch according to the relation between output voltage and reference voltage.
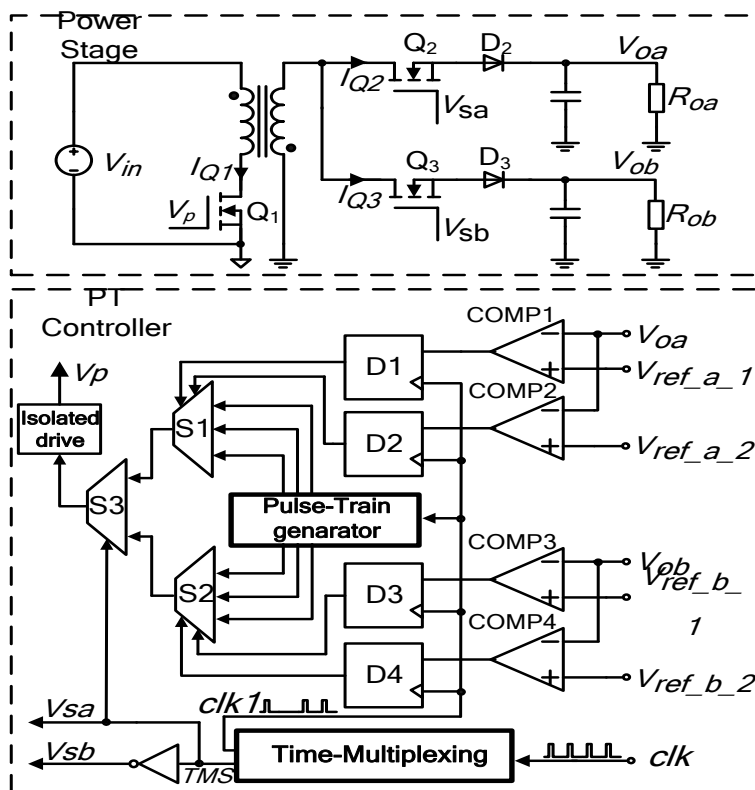

Figure 3. Block Diagram of Proposed Voltage-Mode PT Control IRDO Flyback Converter

The TM control signal *TMS* in Figure 4 is used to determine which output is controlled. When *TMS* = 1, the output voltage v_{oa} is regulated, and when *TMS* = 0, the output voltage v_{ob} is regulated.

Figure 4 show the timing diagram of IRDO flyback converter when $T_A/T_B=1$, where TA is the control time of output A in a switching period, and TB is the control time of output B in a switching period. The ratio of T_A to T_B is determined by the ratio of maximum power of each output, and applying the maximum power of each output to determine T_A/T_B can improve the utilization rate of inductor [8].
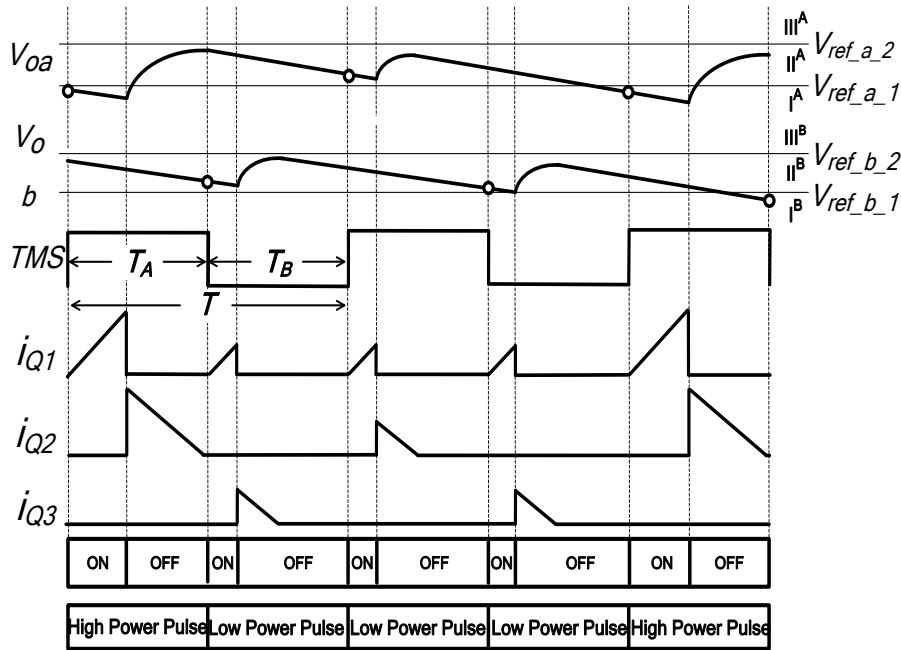

Figure 4. Sequence Diagram of SIDO Buck Converter with Time-Multiplexing Voltage Mode PT Control (T_A/T_B = 1)

By using two predefined reference voltage $V_{ref\_a}1$ and $V_{ref\_a}2$ ($V_{ref\_a\_1}<V_{ref\_a\_2}$), the output voltage V_{oa} is divided into three regions I[A], II[A] and III[A]. These two predefined reference voltage must ensure that the output voltage is regulated within the tolerance.

In the region IA, V_{oa} is lower than the reference voltage $V_{ref\_a\_1}$. Hence, high-power pulse is needed to deliver more power to the load to make output voltage increase. During the high power pulse, the energy drawn from the input power source is

$$\Delta E_{in\_H\_A} = \frac{V_{in}^2 T^2}{2L_p} D_{1a\_H}^2 \tag{1}$$

In the region II[A], V_{oa} is higher than the reference voltage $V_{ref\_a\_1}$, but lower than the reference voltage $V_{ref\_a\_2}$. Low-power pulse is employed as control pulse. The energy drawn from the input power source during low-power pulse is

$$\Delta E_{in\_L\_A} = \frac{V_{in}^2 T^2}{2L_p} D_{1a\_L}^2 \tag{2}$$

If the load is lighter than the power providing by a low power pulse, V_{oa} will increase to the region III[A]. Blank pulse is employed to discharge the output filter capacitor. The controller enters skipping-cycle mode controlled by the combination of low-power pulses and blank pulses. The number of the skipping-cycle increases with the decreasing of the load.

From the above analysis we can conclude that the duty ratio of high-power pulse D_H determines the maximum power of output A. The duty ratio of low-power pulse D_L determines the maximum load power of skipping-cycle mode. When the output A is under heavy load, the minimum value of V_{oa} will fall in the region I^A or II^A. With the decreasing of the load, the minimum value of V_{oa} will increase to III^A.

It is the same for the regulation of output voltage V_{ob}. When the converter operates in DCM, the charging time of lower power pulse on the inductor is less than high-power pulse. The pulse train pattern can be set as low-power pulse and blank pulse if the maximum power of output B can be satisfied by the combination of low-power pulse and blank pulse, thus the operating time $_{TB}$ can be decreased. Therefore, we can increase the maximum power of output A. This method can improve the utilization rate of inductor, while the load power of output B is satisfied.

In DCM, a continuous high power pulse train can achieve the voltage gain M_a of output A as

$$M_a = \frac{V_{oa}}{V_{in}} = \frac{D_{1a\_H}}{N D_{2a\_H}} \tag{3}$$

Where, D_{1a_H} and D_{2a_H} are the duty ratios of inductor current rise and fall time respectively of output A. During the operating time T_A, in order to make sure the inductor current operating in DCM, the value of D_{1a_H} must be lower than

$$D_{1a\_H\_max} = \frac{N V_{oa} D_A}{V_{in} + N V_{oa}} \tag{4}$$

Where, D_A is the duty ratio of output A multiplexing time in one switching cycle. Similarly, in order to make sure the inductor current operating in DCM, the value of D_{1b_H} must be lower than

$$D_{1b\_H\_max} = \frac{N V_{oa}(1 - D_A)}{V_{in} + N V_{ob}} \tag{5}$$

According to (4), the maximum output power of output A is

$$P_{oa\_max} = \frac{V_{in}^2 T D_{1a\_H\_max}^2}{2 L_p} \tag{6}$$

Correspondingly, the maximum output power of output B is

$$P_{ob\_max} = \frac{V_{in}^2 T D_{1b\_H\_max}^2}{2 L_p} \tag{7}$$

If the voltage of output A is the same as output B, the relationship between maximum output power of each output and D_A is shown in Figure 6. The less multiplexing time of each road can be used, the less power of each road can output. When D_A=0.5, the total output power of the converter reaches to the minimum value.
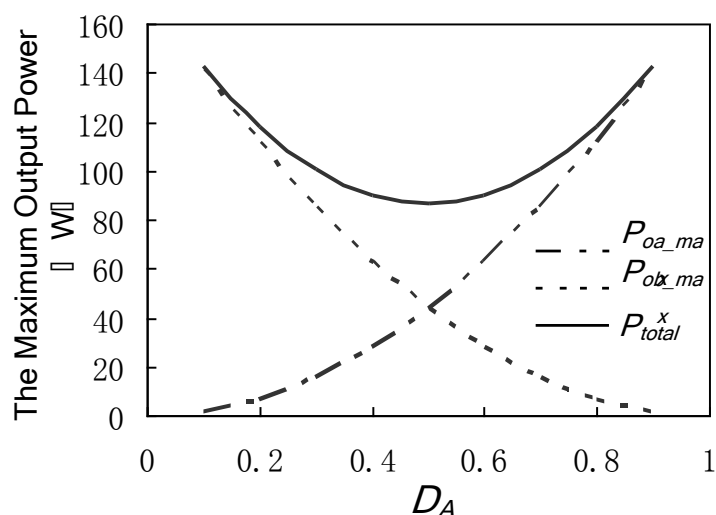
Figure 5. The Relationship between Maximum Output Power of Each Output and DA

4. Conclusion

In this paper, a family of isolated IRMO dc-dc flyback converters was researched, and used flyback converter as an example to achieve its control in DCM by using PT control method. The time-multiplexing scheme is adopted for the control of IRMO flyback converter in DCM to prevent cross-regulation between each output. PT control IRMO flyback converters, which can achieve constant voltage output and also can achieve constant current output, provide an effective solution for multiple constant current output application. Besides the simplicity of design and uncrossed regulation, this control method enjoys a fast dynamic response.

Acknowledgments

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