SIDO converter with variable control time duty

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Abstract—In this paper, we proposes a new control method for Single Inductor Dual Output (SIDO) DC-DC converter. Most of SIDO are controlled with fixed control cycle. We propose a new control method for SIDO converters by implementing variable control time ratio, which enables the converter to operate in a steady state even when the load current ratio is large.

Keywords—Power circuit, SIDO switching power supply, Buck converter, DC-DC converter

1 INTRODUCTION

DC-DC converter is one of the most widely used electronic devises, as it supplies various required DC voltage to each of the electronic circuits of the system in order to conserve energy. Furthermore to minimize the volume and reduce the cost of electronic device, it is very important to downsize the DC-DC converter.

In a conventional system, for the each output of the DC-DC converter, one inductor is required. Hence, for multiple outputs, a numerous number of inductors are required in order to establish the entire system. In order to reduce the cost and volume of the system, it is necessary to reduce the number of required inductors. Single inductor multi output(SIMO) converters, especially dual output(SIDO) converters have been recently introduced in the industry. However, these circuits have a drawback of limited load current supply ratio due to its fixed control cycle.

In this paper, we propose a new control method for SIDO converters by implementing variable control time ratio, which enables the converter to operate in a steady state even when the load current ratio is large. Comparing the simulation results of the proposed method with those of the conventional method, we have confirmed that the operation of the proposed control method at high load current supply ratio is much more stable.

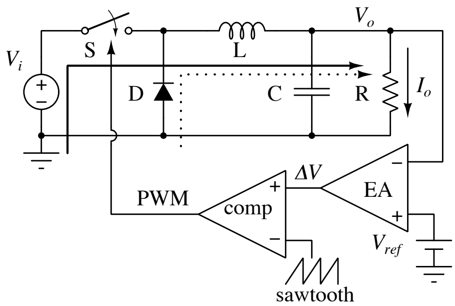

Fig. 1. Schematic diagram of the circuit configuration of the basic buck converter

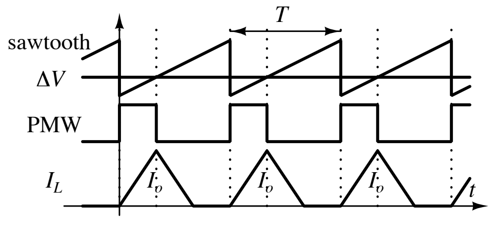

Fig. 2. Waveforms of sawtooth, ΔV, PWM signal, I_L

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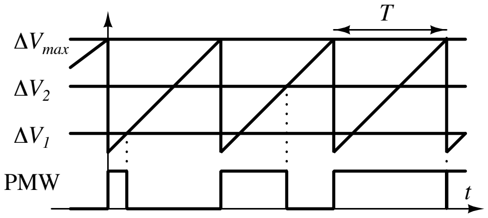

Fig. 3. Relation between ΔV and width of PWM signal

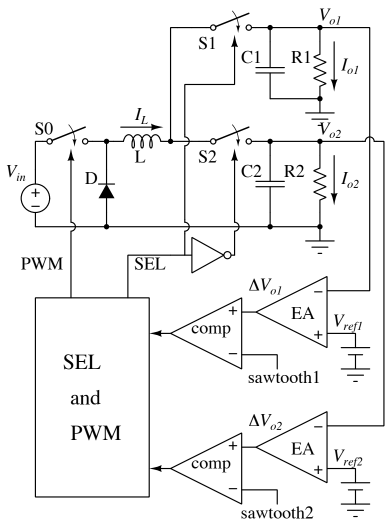

Fig. 4. Schematic diagram of the circuit configuration of the basic buck-buck SIDO converter

2 Buck-Buck SIDO converter

2.1 Buck DC-DC converter

The schematic diagram of the circuit configuration of the basic buck converter is shown in Fig. 1. Waveforms of sawtooth wave, ΔV, PWM signal, I_L of Fig. 1 are shown in Fig. 2 respectively.

When PWM signal (Fig. 2) is High, then Switch S (Fig. 1) turns ON. Thus the electric source supplies energy to the output through the route shown with solid line in Fig. 1. In this case inductor current increases linearly and inductor charges energy. When PWM signal is Low, then switch S turns OFF. In this case the inductor supplies its stored energy to output through the route marked with dot line. In this time, inductor current decreases linearly.

Load current is determined by area, which

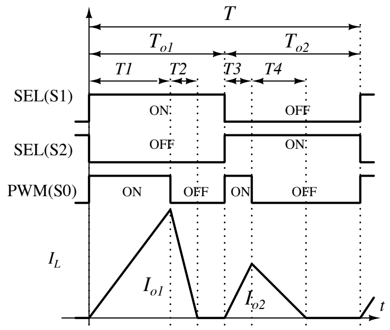

Fig. 5. Waveforms of SEL, PWM signal, and I_L

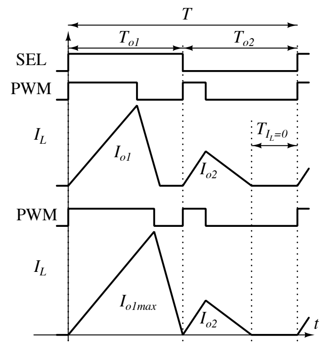

Fig. 6. Maximum value of I_{o1} in conventional method

acquired from increase and decrease of I_L. Output voltage V_o is supplied to error amp, and it is compared with reference voltage, Error voltage ΔV is obtained. Error voltage ΔV is compared with sawtooth in comparator and we get PWM signal that controls output voltage and load current.

The width of PWM signal varies due to value of ΔV. The relation between ΔV and width of PWM signal is shown in Fig. 3. In Fig. 3, the width of PWM signal is max when ΔV is max(ΔV_{max}), and the maximum width of PWM signal depends on cycle T.

2.2 Conventional SIDO converter

The schematic diagram of the circuit configuration of the basic buck-buck SIDO converter is shown Fig. 4, and waveforms of SEL, PWM signal, I_L of Fig. 4 is shown in Fig. 5. SEL is signal controlled S1, S2 and makes them work exclusively. As Fig. 4 shows, we only use one inductor, and there are two output parts and

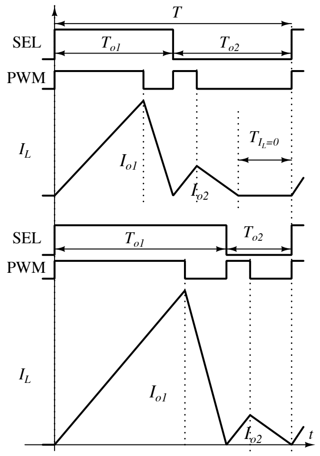

Fig. 7. Change of I_{o1max} by increasing T_{o1}

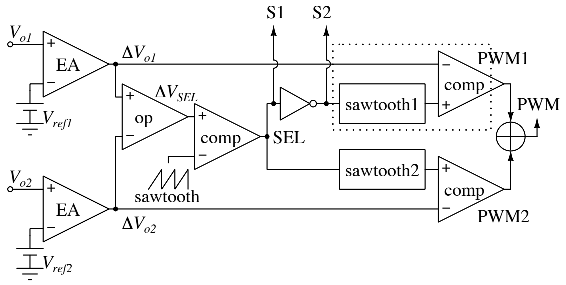

Fig. 8. Block diagram of the proposed control circuit

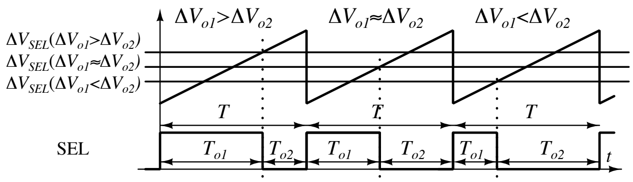

Fig. 9. Relation between the value of ΔV_{o1}, ΔV_{o2} and control time ratio(T_{o1}:T_{o2})

two control parts in the buck converter which is shown in last section. And we connect them in parallel.

As Fig. 5 shows, from the waveforms of inductor current and SEL signal, we can find that load current I_{o1} of high side converter is larger than load current I_{o2} of low side converter. Then the width of PWM pulse produced by I_{o1} is large, and the width of PWM pulse produced by I_{o2} is small. T_{o1} is control time of high side converter, while T_{o2} is control time of low side converter. For the SIDO, inductor current is controlled with Discontinuous Current Mode(DCM).

Now we discuss basic operation of the circuit. In $T1$, S0 and S1 is ON, in this region, power source supplies energy through inductor to high side converter. In $T2$, S0 turns OFF, the inductor supplies its stored energy to high side converter. In $T3$, S0 and S2 is ON, power source supplies energy through inductor to low side converter. In $T4$, S0 turns OFF, the inductor supplies its stored energy to low side converter. Two output voltages V_{o1} and V_{o2} are obtained by repeating of above mentioned operation. Two load currents I_{o1} and I_{o2} are determined by area, which acquired from increase and decrease of I_L.

Now we consider that high side converter need much more load current. The state of I_{o1} before increase is shown in the upper part of Fig. 6, while the state of I_{o1} after increase is shown in the lower part of Fig. 6. In Fig. 6, since the width of PWM signal is broadened and I_{o1} increase, but the maximum value of load current is still limited by T_{o1}, because the ratio $T_{o1} : T_{o2}$ in conventional control method is fixed. In T_{o2}, there is moment of time that I_L is 0. By using this moment, it is possible to supply a larger load current to high side converter in T_{o1}, and the operation range will become larger.

2.3 Basic composition and work principle of proposal method

The control time ratio was fixed in the conventional method, but it becomes variable in proposed method, and compared with conventional method, proposed method makes possible the stable operation even with large load current. As shown in Fig. 7, we use $T_{I_L=0}$ which could not be used in conventional method and the expense of operating range is implemented by increasing T_{o1} and increasing the maximum width of PWM signal. The control time ratio changes responding to two output voltage error ratio.

The block diagram of the proposed control circuit is shown in Fig. 8. In Fig. 8, the two output voltages V_{o1} and V_{o1} are supplied in error amp and the error voltages ΔV_{o1} and ΔV_{o2} are obtained respectively. By comparing the difference with ΔV_{SEL} which is increased in op-amp and sawtooth in comparator, the SEL signal responding to two output voltage error ratio is obtained. In Fig. 9, If ΔV_{o1} is larger than ΔV_{o2} then T_{o1} is larger than T_{o2}. If ΔV_{o1} is approximately equal to ΔV_{o2} then T_{o1} is approximately equal T_{o2}. In the case of ΔV_{o1} is less than ΔV_{o2} then T_{o1} is less than T_{o2}. The sum T of control time of two converters is constant. Two sawtooth waves (sawtooth1 and sawtooth2) are generated with matching the High/Low time width of SEL signal. By comparing that with ΔV_{o1}, ΔV_{o2} in comparator respectively, we obtain PWM1 and PWM2 signals. PWM1 and PWM2 are synthesized and PWM signal is obtained. Due to above mentioned operation, by using error ratio of two output voltages, proposed control method of variable control time ratio is achieved.

3 THE SAWTOOTH WAVE GENERATOR CIRCUIT

3.1 The basic sawtooth wave generator circuit

We explain the operation of the area enclosed by dotted line in Fig. 8. The diagram of basic sawtooth wave generator circuit and waveforms of SEL signal and sawtooth1 are shown in Fig. 10.

In Fig. 10, when SEL signal is High, then switch SW turns ON, in this period, capacitor voltage V_c is 0. And when SEL signal is Low, switch turns OFF. In this case, capacitor C is charged by current from current source, and V_c increases linearly. Again when SEL signal is High, switch SW turns ON, and V_c becomes 0. By repeating this operation, sawtooth wave is obtained. In the basic sawtooth wave generator circuit, the current value of current source is constant.

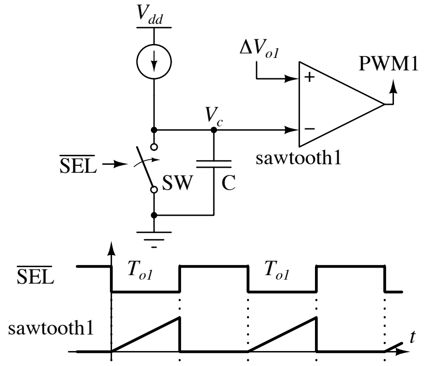

Fig. 10. The basic sawtooth wave generator circuit

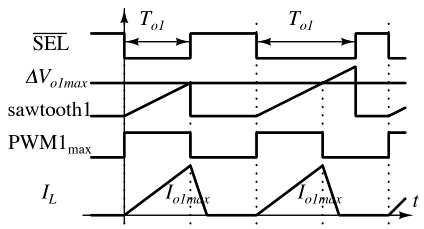

Fig. 11. The relation between peak value of sawtooth wave and maximum width of PWM signal

3.2 The sawtooth wave generator circuit with variable pulse width

In proposed control method, because control time ratio of two converters is variable, the maximum width of PWM signal increases. As a result, compared to conventional control method, it becomes possible to supply a load current of a much larger value. Fig. 11 shows the waveform of sawtooth produced when T_{o1} is increased for basic sawtooth wave generator.

We can find in Fig. 11, that despite increasing control time T_{o1}, maximum value PWM1max of PWM signal remains unchanged, resulting inability to increase load current I_{o1max}. To solve this problem, we have used a sawtooth generator circuit with variable pulse width, which can maintain a constant peak value of sawtooth signal regardless of any change in SEL signal High/Low time.

Fig. 12 shows the circuit diagram of the sawtooth wave generator circuit with variable pulse width, which contains the Peak Hold

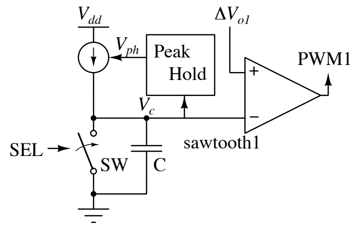

Fig. 12. The sawtooth wave generator circuit with variable pulse width

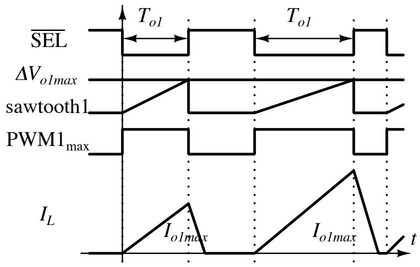

Fig. 13. Increase of PWM signal due to constant peak of sawtooth wave

TABLE 1
Simulation conditions

input voltage: V_{in}	10V
output voltage: V_{o1}	5.0V
output voltage: V_{o2}	4.0V
load current: I_{o1}	5.0A
load current: I_{o2}	0.5A
inductor:L	0.5μH
output capacitor:C	470μF
operating frequency: f	200kHz

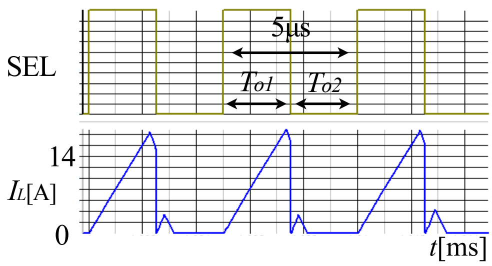

Fig. 14. Waveforms of SEL signal and inductor current in conventional method

circuit that searches the peak voltage of sawtooth wave. By controlling the current value of current source based on this peak voltage, constant peak value of sawtooth signal can be maintained regardless of any change in SEL signal High/Low time. By this method, as shown in Fig. 13, it becomes possible to increase maximum value of PWM signal by simply increasing the control time. Using this circuit, we can successfully implement the proposed control method.

4 Simulation Results

Parameters used in simulation are shown in Table 1. Load current ratio of two converters is I_{o1}:I_{o2}=5A:0.5A so load current of I_{o1} is 10 times of I_{o2}.

First, we compare proposed method with the conventional method. Using conditions shown in Table 1, waveforms of SEL signal and inductor current of conventional method and proposed method are shown in Fig. 14, Fig. 15 respectively.

In Fig. 14, before inductor current reaches 0, SEL signal High/Low is switched, which is not a correct operation. However as shown in Fig. 15, control time ratio changes, indicating the inductor current operating in correct DCM mode. So we can confirm that the proposed method is operating in a much wider range of operation than a conventional control method.

Output voltage waveforms are shown in Fig. 16. The target output voltage is steady. Fig. 17 shows steady state output voltage ripple characteristics. Ripple voltage of V_{o2} is 3mV, which is 0.1% for the output voltage and the Ripple of V_{o1} is 16mV, which is 0.3% for the output voltage.

Next, the load response characteristics is shown in Fig. 18 and Fig. 19. Fig. 18 shows the change in characteristics when load current I_{o1} is changed from 2.5A to 5.0A. In Fig. 18, undershoot self regulation voltage of V_{o1} is 18mV, while cross regulation voltage of V_{o2} is 3mV. Next, Fig. 19 shows the change in characteristics when load current I_{o2} is changed from 0.25A to 0.5A. In Fig. 19, ripple voltage of V_{o1} is less than 1mV, and ripple voltage of V_{o2}

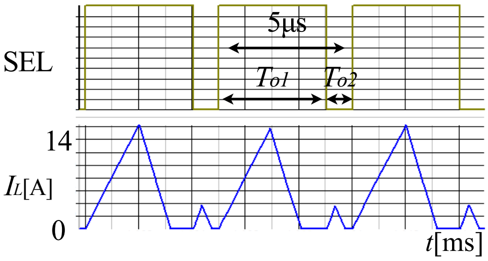

Fig. 15. Waveforms of SEL signal and inductor current in proposed method

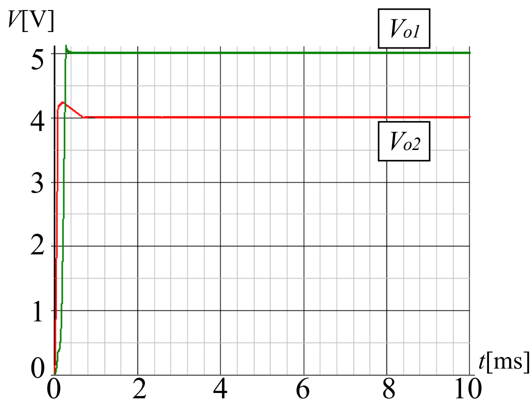

Fig. 16. Output voltage waveforms

is 3mV.

Lastly, when load current ratio (I_{o1}:I_{o2}) is 1:1, and when load current ratio (I_{o1}:I_{o2}) is 10:1, waveforms of SEL signal, inductor current, sawtooth wave are shown in Fig. 20, Fig. 21 respectively. From Fig. 20 we can find that, when load current ratio (I_{o1}:I_{o2}) is 1:1, control time ratio (T_{o1}:T_{o2}) is almost equal to 1:1. However, when load current ratio is 10:1, from Fig. 21 we can see that, , control time ratio is changed, control time of the larger load current side increases. By this operation, it is possible to supply a much larger load current in a stable way. Also, the peak values of sawtooth wave are constant despite any variation in the value of control time ratio.

5 Conclusion

In this paper, for SIDO power supply circuit, we have proposed a new control method that works in case of a large load current ratio, and confirmed the basic characteristics.

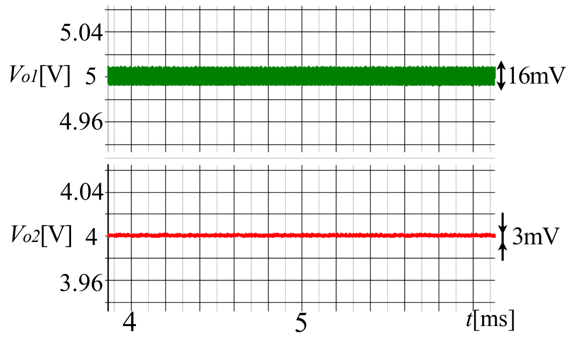

Fig. 17. Steady state output voltage ripple characteristics

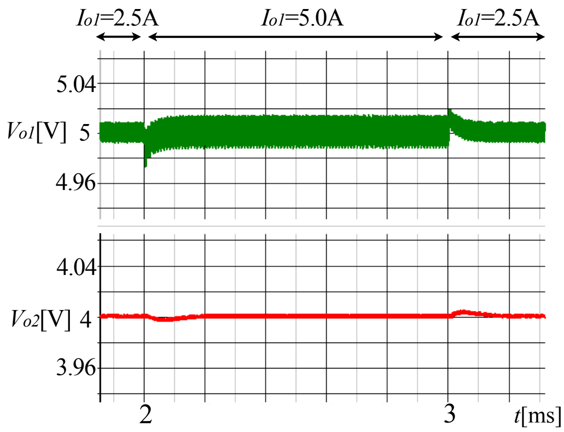

Fig. 18. Load response characteristics when I_{o1} changed

By varying control time ratio of two converters, we have confirmed the operation of the proposed method in case of the load current ratio I_{o1}:I_{o2}=5.0A:0.5A that is 10:1. At the time, steady state output ripple voltage is less than 1% of the output voltage.

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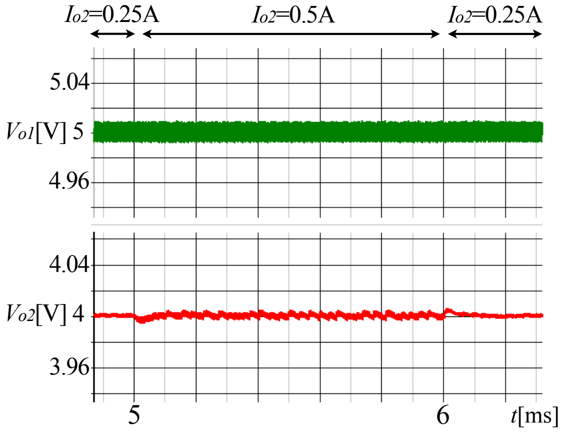

Fig. 19. Load response characteristics when I_{o2} changed

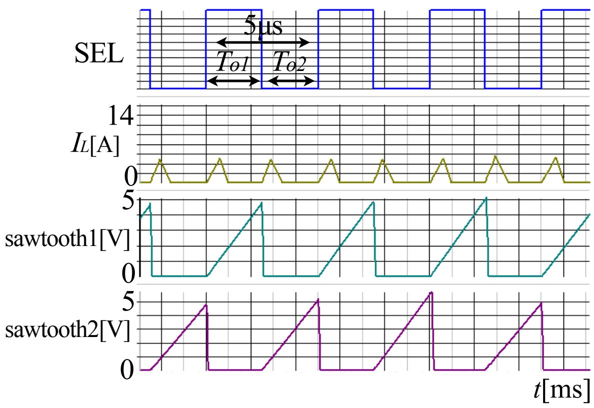

Fig. 20. Waveforms of SEL, I_L, sawtooth1(I_{o1}:I_{o2}=0.5A:0.5A)

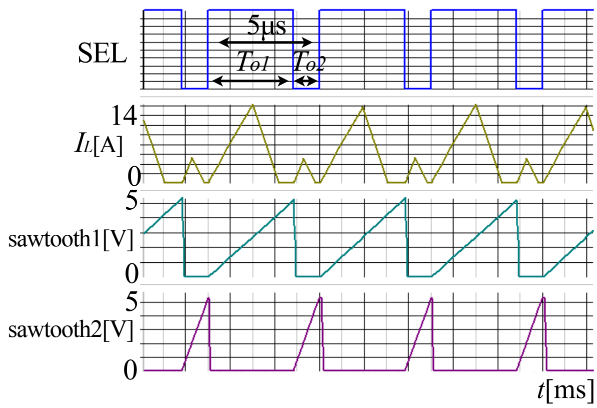

Fig. 21. Waveforms of SEL, I_L, sawtooth1(I_{o1}:I_{o2}=5.0A:0.5A)

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