MULTIPHASE BUCK DC-DC CONVERTER WITH ZERO VOLTAGE SWITCHING

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Abstract – In the present paper, a control algorithm of multiphase buck DC-DC converter with zero voltage switching (ZVS) is proposed. It allows combining the advantages of ZVS and multiphase converters. ZVS allows efficiency increasing of the DC-DC converter. The usage of the multiphase buck DC-DC converter leads to increasing of the value of output current and its frequency of pulsations, as well as to decreasing the amplitude of these pulsations. The problem is solved for ensuring a constant phase shifting when the amplitude of the output current is changing.

Keywords – Power Electronics/Switch Mode Power Supply/Multiphase Buck DC-DC Converters/Zero Voltage Switching

1. INTRODUCTION

In recent years, the development of technology in microelectronics led to a significant increase in operating frequency of the microprocessors in the computers. As a result, a change followed in the requirements to the power supply devices: low supply voltages with a large value of the consumed by them current. This led to the development of Multiphase Switch Mode Power Supply (MPh-SMPS). A number of specialized ICs of leading companies are based on this principle of operation: TPS400090-Texas Instruments, ICL6564-intersil, MAX1887-MAXIM, FAN53168-FAIRCHILD and others. They are built on connected in parallel phase shifted synchronous BUCK DC-DC converters working at continuous conduction mode (CCM) of operation. In this way, minimal conductive losses are achieved.

A number of publications and monographs are devoted to MPh-SMPS [1,2,3]. The reducing of the switching losses in the BUCK power transistors by zero voltage switching (ZVS) is not considered. CCM does not allow switching of the transistors in a ZVS mode.

It can be achieved easily by the BUCK DC-DC converters. For this purpose, a synchronous BUCK converter is used, in which the bottom transistor is turn-on while the current in the filter inductor changed its direction for a short time from the output to the input source [4,5].

In this way an improvement of the efficiency is achieved, as shown in Fig.1 [7].

In this paper, a circuit solution is proposed, which allows working of the Multiphase BUCK DC-DC converter in ZVS mode of operation.

2. MULTIPHASE BUCK DC-DC CONVERTER WITH ZVS

2.1. ZVS BUCK DC-DC converter

The circuit of the ZVS BUCK DC-DC converter is shown in Fig.2. The principle of operation of ZVS is described in [4]. In summary, one can say that it is reduced to hysteresis current mode control. The specific issue here is that the low current level is fixed to a constant minimum value (I_{min}), while the high current level (I_{peak}) is changing depending on the output current value. Consequently, the switching frequency of the transistors is a function of output current (Fig. 3).

The control system of the BUCK DC-DC converter consists of the following elements: comparators U1 and U2; logical elements U3 and U4 (RS flip-flop); logical elements U5 and U6 (Run / Stop gates of pulses for Top and Bottom transistors of the DC-DC converter).

Fig. 1. Efficiency of ZVS Buck step down 24 V – 2.5 V @ 10A (Picor Semiconductor Solutions, Vicor Corporation)
The comparator U2 sets the RS trigger in state U4 = 1 and U3 = 0 when the output current has the value $I_{\text{min}}$, wherein $V_{gT} = 1$ and the transistor QT is turned on. When the output current reaches the value $I_{\text{peak}}$, the comparator U1 changes the state of the RS trigger (U4 = 0 and U3 = 1). The transistor QT is turned off and the transistor QB is turned on.

The elements of the control system: voltage control switch - S1; voltage controlled current source G1 and analog behavior model ABM realize generator of sawtooth voltage whose maximum value $V_{tr}$ remains constant regardless of the frequency of the switching transistors.

Frequency-independent generator of sawtooth voltage is described below.

In order to implement the circuit of the multiphase BUCK DC-DC converter, it is necessary to form triangular voltage with a period $T_{sw}$ equal to the switching period $T_{sw}$ and with constant amplitude $V_{tr}$. Such amplitude of the triangular voltage allows constantly phase shifting of the switching between BUCK DC-DC converters, at variable operating frequency (Fig. 3). This can be achieved by appropriate mathematical tools, which will be presented, based on the equality of the switching period and the period of the triangular voltage (Fig. 4).

The switching period is composed of two time intervals: $t_r$ - interval during which the transistor $T_{op}$ is turned on and wherein the current through the inductor increases to the value $I_{\text{peak}}$, and $t_f$ - interval during which the bottom transistor is turned on and the current through the inductor decreases to the value $I_{\text{min}}$. As a result

$$T_{sw} = t_r + t_f,$$

where

$$t_r = L \frac{\Delta I}{V_{i} - V_{o}},$$

$$t_f = L \frac{\Delta I}{V_{o}},$$

$$\Delta I = I_{\text{peak}} - I_{\text{min}}.$$

The period of the sawtooth voltage is:

$$T_{tr} = \frac{C_i V_{tr}}{I_c},$$

where: $I_C$ is the charging current for the capacitor, forming the sawtooth voltage.

From (1) - (4) the following relationship is obtained:

$$I_C = \frac{V_{o}(V_{i} - V_{o})C_i V_{tr}}{V_{o} L \Delta I}$$
Equation (5) is applied to the circuit in Fig. 2 and its validity is confirmed by the stimulation results shown in Fig. 3 and Fig. 4.

2.2. Simulation model and simulation results of Multiphase BUCK DC-DC Converter with ZVS

The circuit of multiphase BUCK DC-DC converter consisting of four DC-DC converters is shown in Fig. 5.

Simulation using Cadence PSpice [8] is performed. The control circuit is shown in Fig. 6. It is conditionally divided into two parts. The part named Master repeats the circuit in Fig. 2, except that the triangular voltage is buffered by the elements Gain1-Gain3. The buffered signals Vg1-Vg3 are applied at the non-inverter inputs of the comparators U9, U19 and U27 from the second part of the control system named Slaves. There they are compared with the reference phase shifted voltages Vphsh1, Vphsh2 and Vphsh3. The value of Vphsh1 is equal to one quarter of the maximum value of the sawtooth voltage Vo.

The increment of Vphsh2 and Vphsh3 is equal to the same value. This leads to the same phase shifting between the four BUCK DC-DC converters.

The amplitude of Vo is frequency-independent, as demonstrated above. As a result, a constant phase shifting is obtained when the value of dI/dt changes.

The RS triggers U13-U14; U22-U23 and U31-U32 realize successive starting (with the same phase shifting) of the second, third and fourth DC-DC converters, by the initial run of the Multiphase converter (Fig. 7). Through the logical elements U5-U6; U15-U16; U24-U25; and U33-U34, a Run/Stop Multiphase BUCK DC-DC converter is realized.

The waveforms, illustrating the operation of Multiphase DC-DC Converter with ZVS, are shown in Fig. 7. It is seen that the currents through the four inductors I1-I4 have the same phase shifting.

The output current is a sum of the above currents and its frequency of the pulses is four times higher than the frequency of the pulses of its constituent currents.

The proposed principle of control of Multiphase DC-DC Converter with ZVS could be realized on chip [4,7].
3. ACKNOWLEDGEMENT

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4. CONCLUSION

A control algorithm of multiphase buck DC-DC converter with zero voltage switching (ZVS) has been developed. The principle of operation of the proposed control system is described in details. The developed approach combines the advantages of ZVS and multiphase converters. Mathematical expressions describing the dependence between the period of the sawtooth voltage and the amplitude of the output current are derived in order to ensure a constant phase shifting. Simulation using Cadence PSpice is performed and the waveforms of the sawtooth voltage and output current with different amplitudes are presented. The obtained simulation results confirm the validity of the proposed approach.

5. REFERENCES


