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Review of Step down Converter with Efficient ZVS Operation

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ABSTRACT

This paper presents the review of step down converter with efficient ZVS operation. The designed buck converter uses ZCS technique and the function is realized so that the power form is converted from 12V DC 5V DC (1A). A detailed analysis of zero current switching buck converters is performed and a mathematical analysis of the mode of operation is also presented. In order to reduce the switching losses in associated with conventional converters; resonant inductor and resonant capacitor (LC resonant circuit) is applied which helps to turn on-off the switch at zero current. The dc-dc buck converter receives the energy from the input source, when the switch is turned-on. The buck–buck converters have characteristics that warrant a more detailed study. The buck converters under discontinuous conduction mode /continuous conduction mode boundary.

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I. INTRODUCTION

In step converter case, the operation with small duty cycle influences the performance of both steady state and transient state. This small duty cycle degrades the power efficiency and the transient dynamics with the effect of the minimum pulse width of MOSFET gate drivers. In order to remove these problems, the increase of duty cycle is introduced by employment of a transformer. This converter improves the conventional critical conduction mode (CRM) buck converter that has a ZVS operation range extended. The main parameters that impose limits on a buck converter with high-frequency pulse width modulation (PWM) operation are the junction capacitances of the semiconductors, parasitic inductances, and the reverse recovery of the diodes. To minimize these effects, many soft-switching techniques have been presented in the literature. Soft-switching techniques typically increase the current and/or voltage stresses in the semiconductor devices. This topology contains an extra switch compared to the conventional buck converter. However, this topology allows for ZVS in the turn-off switches, thus providing a higher efficiency at higher switching frequencies.

In PWM buck converters under discontinuous conduction mode (DCM)/continuous conduction mode (CCM) boundary, power switches may be turned on at ZVS condition like those in QR converters. Resonant components are not required, and voltage stress of the power switch during its OFF time is just the same as that in conventional PWM converters.

The switching frequency of switches should be higher to diminish the size of a converter (*LC* filter). As a result, losses (e.g., switching loss of switchers) in connection with frequency may increase, which would cause to the decrease in the efficiency of the converter. Many techniques have been proposed to reduce the losses arising from switching frequency. Pulse frequency modulation (PFM) control and double-mode control combination of pulse width modulation (PWM) and PFM have been widely applied.

II. STEP DOWN CONVERTER

The basic operation of the buck converter has the current in an inductor controlled by two switches (**usually a transistor and a diode**). In the idealized converter, all the components are considered to be perfect. Specifically, the switch and the diode have zero voltage drop when on and zero current flow when off and the inductor has zero series resistance. Further, it is assumed that the input and output voltages do not change over the course of a cycle.

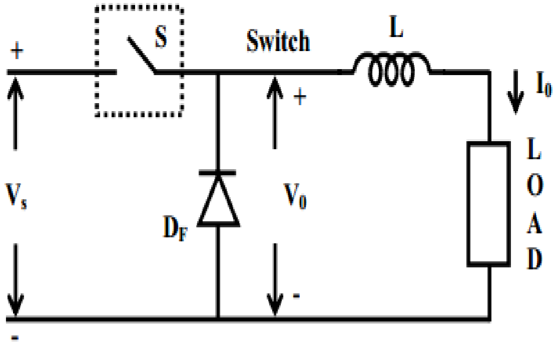

Fig.1 Step down converter

III. BUCK CONVERTER OPERATION

The original concept of a “Buck Converter” requires that the input voltage is chopped, in amplitude and develops the lower amplitude voltage at the output. A buck converter has switch-mode dc-dc conversion with the advantages of simplicity and low cost. The fig.1 shows a simplified non-isolated buck converter, which allows a dc input and employs pulse-width modulation (PWM) of switching frequency to control the output of an internal power MOSFET. An act in concert external diode, external inductor and output capacitor, produce the regulated dc output. A Buck or step down converters are designed to produce an average output voltage lower than the input source voltage.

A. *Continuous Conduction Mode*

A buck converter operates in continuous mode if the current through the inductor (I_L) never falls to zero during the commutation cycle. In this mode, the operating principle is described by the plots.

- When the switch pictured above is closed (on-state, top of figure 2), the voltage across the inductor is

$$V_L = V_i - V_o.$$

The current through the inductor rises linearly. As the diode is reverse-biased by the voltage source V, no current flows through it;

When the switch is opened (off state, bottom of figure 2), the diode is forward biased. The voltage across the inductor is

$$V_L = -V_o$$

(neglecting diode drop). Current I_L decreases

The energy stored in inductor is

$$E = \frac{1}{2} L * Il2$$

B. *Discontinuous Conduction Mode*

In some cases, the amount of energy required by the load is too small. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle.

We still consider that the converter operates in steady state. Therefore, the energy in the inductor is the same at the beginning and at the end of the cycle (in the case of discontinuous mode, it is zero). This means that the average value of the inductor voltage (V_L) is zero

$$(Vi - Vo)DT - Vo\delta T = 0$$

The output current delivered to the load (I_o) is constant, as we consider that the output capacitor is large enough to maintain a constant voltage across its terminals during a commutation cycle. This implies that the current flowing through the capacitor has a zero average value.

C. *Hard Switching*

Reduction of size and weight of converter systems require higher operating frequencies, which would reduce sizes of inductors and capacitors. However, stresses on devices are heavily influenced by the switching frequencies accompanied by their switching losses. It is obvious that switching-aid-networks do not mitigate the dissipation issues to a great extent. Turn-on snubbers though not discussed are rarely used. Even if used, it would not be able to prevent the energy stored in the junction capacitance to discharge into the transistor at each turn-on.

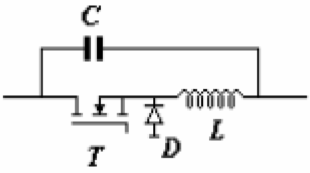

Fig.2 Hard switching

D. Soft Switching

Soft switching techniques use resonant techniques to switch ON at zero voltage and to switch OFF at zero current. There are negligible switching losses in the devices, though there is a significant rise in conduction losses. There is no transfer of dissipation to the resonant network which is non-dissipative.

IV. ZERO VOLTAGE SWITCHING

Zero Voltage Switching means that the power to the load (heater or cooler or other device) is switched on or off only when the output voltage is zero volts. Zero Voltage Switching can extend the life of a controller and of the load being controlled. Controllers with Zero Voltage Switching use triacs instead of mechanical relays, and, in fact, all of our temperature controllers which use a triac are inherently Zero Voltage Switching.

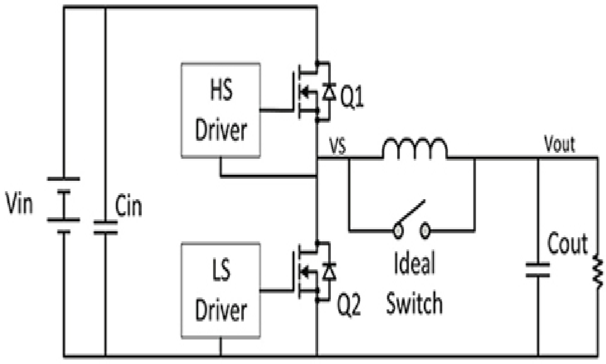

Fig.3 ZVS operation diagram

The ZVS buck converter operates in three main states. They are defined as Q1 on phase, Q2 on phase, and clamp phase. Q1 turns on at zero current and when the drain-to-source voltage is nearly zero. Current ramps up in the MOSFET and the output inductor to a peak current determined by the on-time of Q1, the voltage across the inductor, and the inductor value. During the Q1 on phase, energy is stored in the output inductor and charge is supplied to the output capacitor. During the Q1 on phase, the power dissipation in Q1 is dominated by MOSFET on-resistance and the switching loss is negligible.

Next, Q1 turns off rapidly followed by a very short body diode conduction time (adding negligible power dissipation). During the current commutation to the body diode, Q1 does experience turn-off losses in proportion to the peak inductor current. Next, Q2 turns on and the energy stored in the output inductor is delivered to the load and output capacitor. When the inductor current reaches zero, the synchronous MOSFET Q2 is held on long enough to store some energy in the output inductor from the output capacitor.

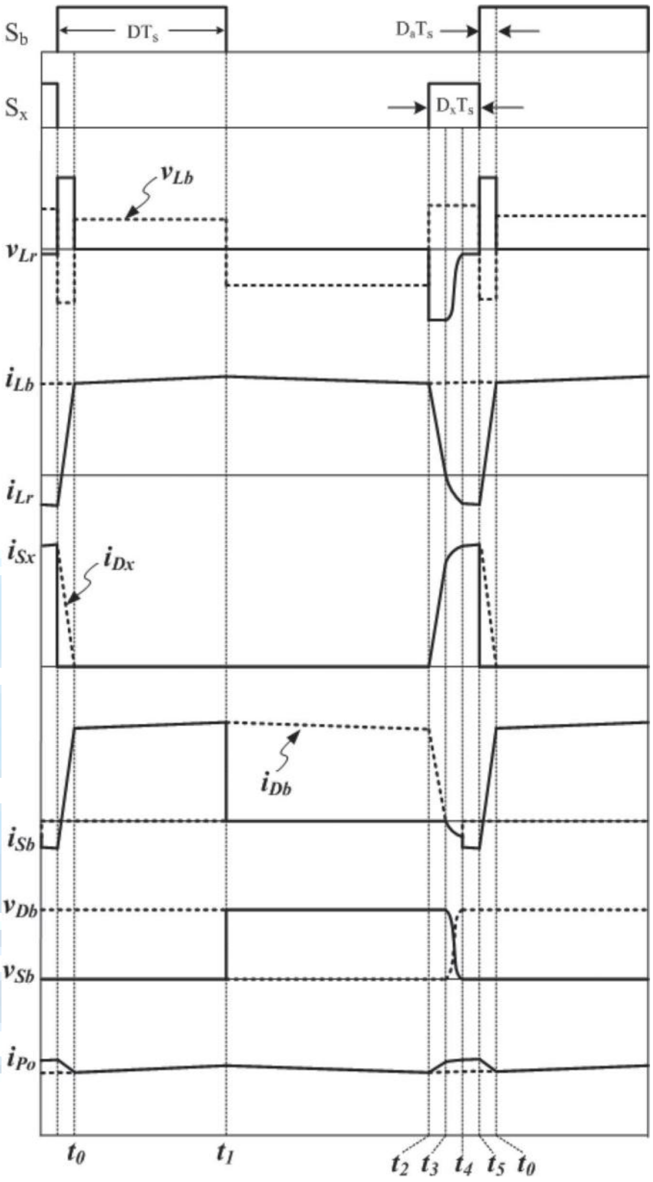

Fig. 4. Waveform for mode analysis

Once the controller has determined that there is enough energy stored in the inductor, the synchronous MOSFET turns off and the clamp switch turns on, clamping the VS node to VOUT. The clamp switch isolates the output inductor current from the output while circulating the stored energy as current in a nearly lossless manner. During the (very small) clamp-phase time the output is supplied by the output capacitor.

When the clamp phase ends, the clamp switch is opened. The energy stored in the output inductor resonates with the parallel combination of the Q1 and Q2 output capacitances, causing the VS node to ring towards V_{IN}. This ring discharges the output capacitance of Q1, diminishes the gate-to-drain (Miller) charge of Q1 and charges the output capacitance of Q2. This allows Q1 to turn on in a lossless manner when the VS node is nearly equal to V_{IN}.[3]

V. ZERO CURRENT SWITCHING

Reducing stress on the switching components is a major incentive for resonant operation and we need to understand ways through which that might be fulfilled. The simplest approach and the one to which most of this paper presents ZCS operation of converter switch must be such that involves the current flowing through the switch being induced to rise gradually just after the switch is turned-on. The switch current must also be induced to descend gradually just before the switch is turned-off. The ZCS turn-on feature of a converter switch can beamed certain by simply connecting an inductor in series as the current flowing through the other devices in the converter is gradually drawn back so that they can turn-off with ZCS

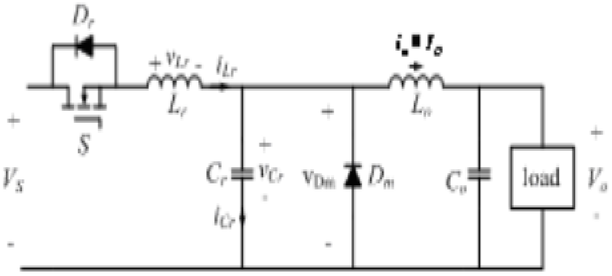

Fig.5 Zero current switching

VI. CONCLUSION

This paper presented a step down converter with an improved zero-current-switching (ZCS) PWM switch cell. The improved ZCS PWM switch cell provides zero-current-switching conditions for the main switch and the auxiliary switch without additional conduction loss of the main switch. The additional conduction losses for the soft switching are minimized, since the circulating current for the soft switching flows only through the auxiliary circuit and minimum number of switching devices are involved in the circulating current path. The diodes commutate softly and reverse recovery problems are alleviated.

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