ZERO CURRENT SWITCHING QUASI-RESONANT BUCK CONVERTERS

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Abstract: This paper reviews the basic topologies of zero current switching quasi-resonant buck DC-DC converters and describes their basic properties. Further, there is an analysis of half-wave and full-wave zero current switching quasi-resonant DC-DC converters.

Keywords: quasi-resonant buck DC-DC converter, zero current switching, zero voltage switching, ZCS QRC, ZVS QRC

1 INTRODUCTION

Switching converters are used today in almost every electrical or electronic device. Switching converters enable to reduce dimensions and weight of used transformers, coils and capacitors in conventional power sources and allow to reduce losses and thus increase efficiency, even with the possibility of electronic regulation of output quantities.

However, conventional hard-switched converters cause considerable electromagnetic interference due to the fast switching of semiconductor elements.

During the switching events, switching losses are on the semiconductor elements, which negatively affect the resulting efficiency of the converter. E.g. during the switching-on or switching-off process of the switching transistor in a buck-converter, a state occurs in which the supply voltage is on the semiconductor element and simultaneously through which the output current flows. The instantaneous value of the power losses on the switch $p_{\mathrm{SW}}(t)$ is then given by the relation 1.

$$p_{\mathrm{SW}}(t) = v_{\mathrm{DS}}(t) \cdot i_{\mathrm{D}}(t) \tag{1}$$

Resonant and quasi-resonant converters are removing these shortcomings. They switch the semiconductor elements either when zero voltage v_{DS} is on the switching element or no current i_{D} flows through it. Surrounding elements ensure that this condition is approximately fulfilled during the entire duration of the switching event.

Resonant and quasi-resonant converters can generally use various types of half controllable semiconductor elements or fully controllable elements as controllable switches. In this article I will limit myself to transistor switches, namely MOS-FET. However, the basic properties described will not differ significantly even when using some other semiconductor switching elements.

2 QUASI-RESONANT CONVERTERS (QRC)

The basic topologies of the quasi-resonant converters can be divided according to the switching method into zero current switching (ZCS) and zero voltage switching (ZVS).

2.1 Zero Voltage Switching (ZVS)

The principle is based on the fact that a capacitor is connected in parallel to the switching transistor. This ensures that when the switching event occurs at zero voltage, the voltage does not manage to increase too much during the short time of switch on or switch off events of the transistor so that the voltage can typically be considered to be zero during the entire duration of the switching event. [1] Basic topology of half-wave zero voltage switching quasi-resonant DC-DC converters is in the Fig. 1.

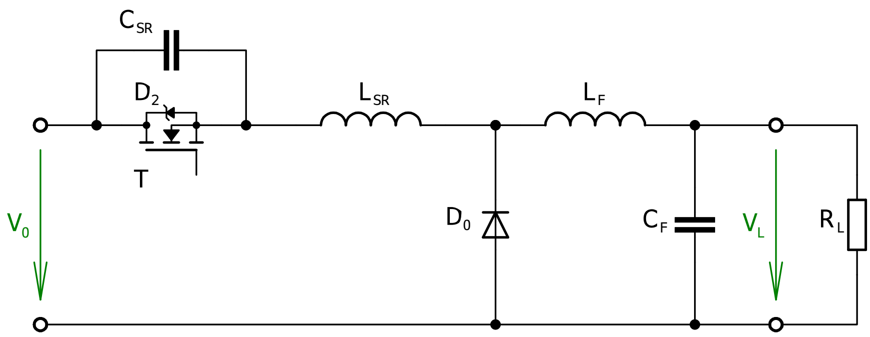

Figure 1: Basic topology of half-wave zero voltage switching quasi-resonant DC-DC converters

2.2 Zero Current Switching (ZCS)

Analogously, the principle is that an inductor is connected in series with the switching transistor. This ensures that when the switching event starts at zero current, the current does not manage to increase too much during the short time of switch on or switch off events of the transistor so that the current can typically be considered to be zero during the entire duration of the switching event. This type of converter is further divided into two types: half-wave ZCS QRC and full-wave ZCS QRC. [2]

2.2.1 Half-Wave ZCS QRC

Basic topology of half-wave zero current switching quasi-resonant DC-DC converters is in the Fig. 2. Important waveforms are in the Fig. 3.

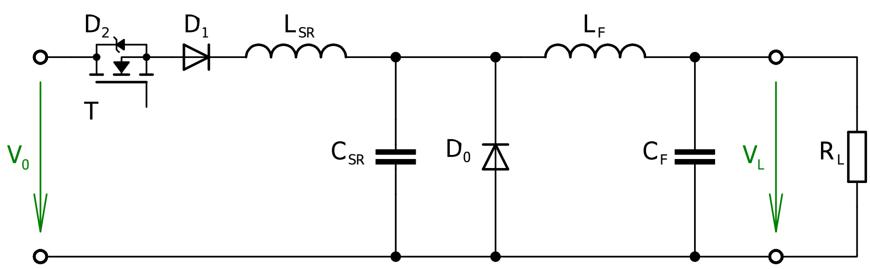

Figure 2: Basic topology of half-wave zero current switching quasi-resonant DC-DC converters

Transistor T is switched on when the capacitor C_{SR} is completely discharged and a free-wheeling diode D_0 is flowed by current I_{LF} (time t_1). Thus, the inductance L_{SR} is applied to the entire input voltage V_0. The current inductance I_{LSR} will start to grow linearly (until t_2). When I_{LSR} reaches I_{LF}, the free-wheeling diode D_0 closes and the capacitor C_{SR} starts charging.

This decreases the voltage at the inductance V_{LSR} and thus the steepness of the current increase by the inductance I_{LSR} begins to decrease. As soon as the voltage at the capacitor V_{CSR} reaches the supply voltage V_0, the current by the inductance I_{LSR} stops rising and then starts to drop (t_3). However, the capacitor C_{SR} is still charging, so the voltage on it increases (until t_4).

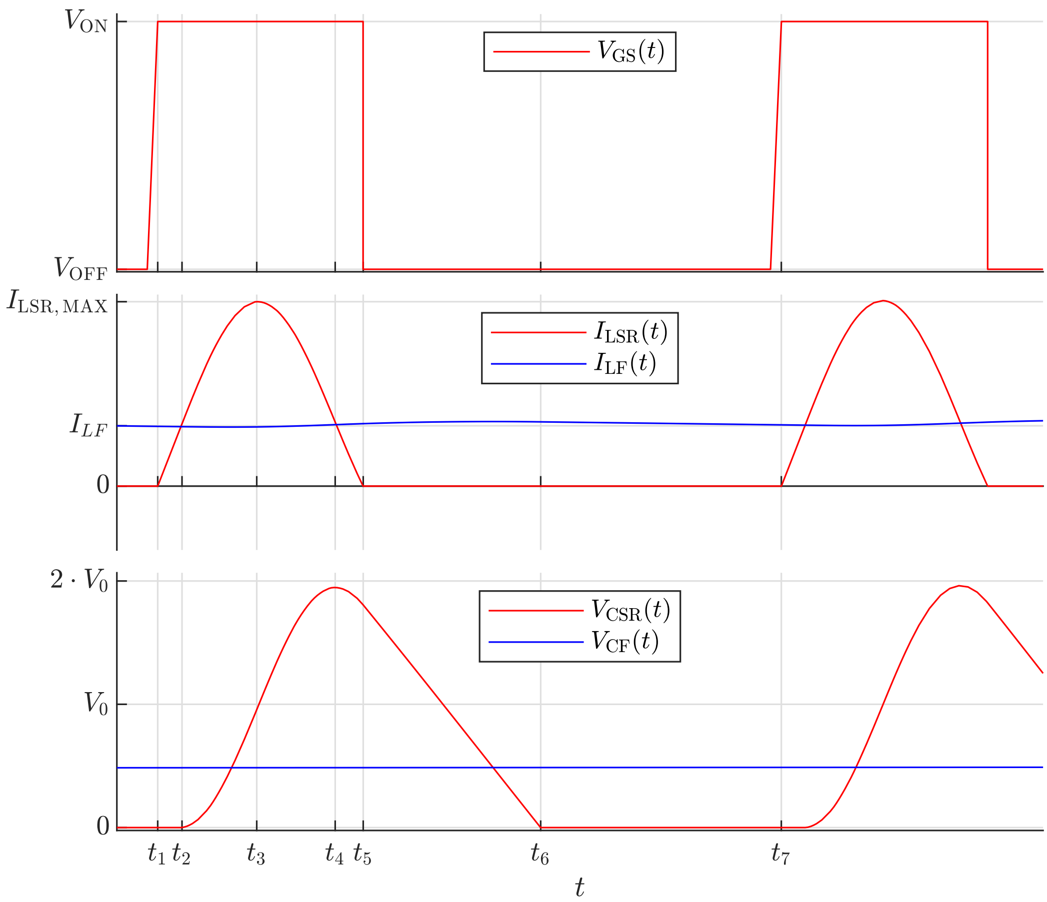

Figure 3: Simulation time courses of half-wave zero current switching quasi-resonant DC-DC converters

After the current I_{LSR} drops of inductance to zero, no current flows through it because the diode D_1 closes (t_5). Furthermore, the capacitor C_{SR} is discharged only by the current drawn I_{LF}. When it is completely discharged, the diode D_0 will open and the current I_{LF} will only flow through this diode (t_6).

2.2.2 Control of Half-Wave ZCS QRC

The inverter can be continuously controlled by changing the turn-off time. After the capacitor C_{SR} is discharged (t_6), the next period can be started immediately, thus achieving the maximum output voltage. In case the no-load, output voltage V_L will be equal to the input voltage V_0.

If the transistor T does not switch on immediately after the capacitor C_{SR} has been discharged, but the switch on is delayed, the mean value of the output voltage will drop. The LC filter smooths the pulsating voltage on the V_{CSR} capacitor so that the output voltage V_{CF} can be almost constant.

The basic condition of the function of this circuit is that an amplitude of a resonant current $I_{RES,MAX}$

will be higher than the current drawn by the load I_{LF}.

$$I_{\mathrm{RES,MAX}} = I_{\mathrm{LSR,MAX}} - I_{\mathrm{LF}} \tag{2}$$

$$I_{\mathrm{RES,MAX}} > I_{\mathrm{LF}} \tag{3}$$

$$I_{\mathrm{LSR,MAX}} > 2 \cdot I_{\mathrm{LF}} \tag{4}$$

If this condition were not met, the inductance current $I_{\mathrm{LSR}}(t)$ would not drop to zero and the transistor T would not be able to be switched off at zero current. [3]

2.2.3 Full-Wave ZCS QRC

Basic topology of full-wave zero current switching quasi-resonant DC-DC converters is in the Fig. 5. Important waveforms are in the Fig. 4.

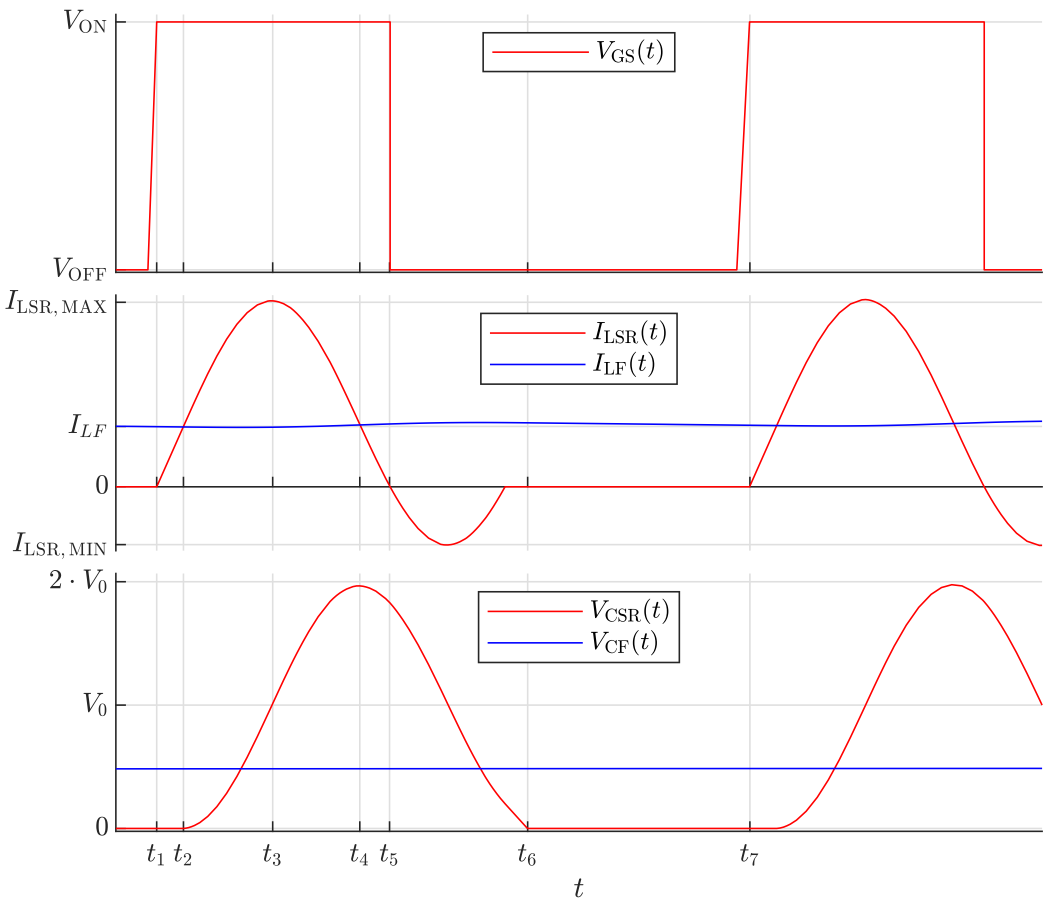

Figure 4: Simulation time courses of full-wave zero current switching quasi-resonant DC-DC converters

Until time t_5 this inverter behaves exactly the same way as the half-wave ZCS QRC described in the 2.2.1 section. Then, the current flows through the inductor I_{LSR} in the opposite direction – to the power supply via diode D_2. This will eliminate the losses caused by the diode D_1 compared to the previous solution.

Diode losses of D_2 are considerably smaller with I_{LF} compared to $I_{\mathrm{RES,MAX}}$, as the I_{LSR} current in the positive direction is significantly greater than the current I_{LSR} in the negative direction, as can be seen from the time course in the Fig. 4.

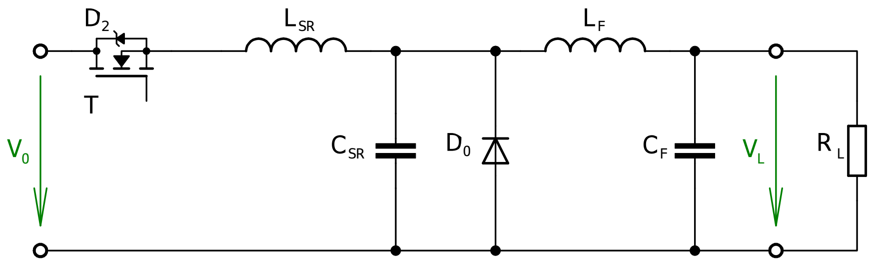

Figure 5: Basic topology of full-wave zero current switching quasi-resonant DC-DC converters

Another advantage of this converter can be the significantly lower dependence of the switching period on the current consumption I_{LF}. The disadvantage, however, is that part of the period returns part of the energy stored in the resonant circuit to the power supply, which unnecessarily increases line losses. [3]

3 CONCLUSION

Zero current switching quasi-resonant buck DC-DC converters combine the advantages of conventional converters in the form of relatively simple control and resonant inverters in the form of soft transistor switching, eliminating transistor switching losses and the absence of steep edges causing broadband interference.

The above-mentioned ZCS QRCs are very simple wiring with the minimum necessary components to ensure reliable operation. The only limitation for proper operation is not to exceed the maximum load current.

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