Quasi Resonant DC-DC Converters

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Abstract – **In present paper a review of quasi-resonant DC-DC converter is done. Such converters have lower commutation losses in comparison with the hard switching converters. The main circuit of mentioned converters, which have ZCS and ZVS (zero current switching and zero voltage switching) are examined. The equivalent circuits are presented, which makes possible the analysis of such type of converters.**

Keywords – **Quasi-resonant converters, soft-switching, DC-DC converters**

I. Introduction

In the work are examined quasi-resonant DC converter with so called "soft commutation" – zero current switching (ZCS) or zero voltage switching (ZVS). Such converters have decreased switching losses in comparison with converters with "hard switching". Different circuit version with and without transformer output are described, thus are shown their equivalent circuits, which helps the analysis and obtainment of waveforms of such converters.

Generally DC-DC converters operate in hard-switching mode of devices, which are switching-on and off with non-zero values of current or voltage, even worse with maximum values of current and voltage. With such commutation big losses are observed. The reduction of losses can be achieved with snubber groups or the soft switching method [1, 2, 3]. Typical for the method is the further addition to the power circuit of converter a resonant L_rC_r circuit and depending on the mode of connection, it may be serial or parallel. Thus we obtain ZVS when the connection is serial, while it is parallel we get ZCS.

II. ZVS DC-DC Converters

In Fig.1 are presented the basic circuits of DC-DC converters: Buck, Boost, Boos-Buck, Cuk and Sepic, as to them were added respectively serial resonant circuit for receiving ZVS mode.

From [1, 4, 7, 10, 11, 13, 14] is known that we can divide into 4 time intervals of operation of all ZVS quasi-resonant converters:

- **First stage** – energy accumulation in resonant inductance;
- **Second stage** – switch conductance;
- **Third stage** – charging the resonant capacitor;
- **Fourth stage** – resonant process.

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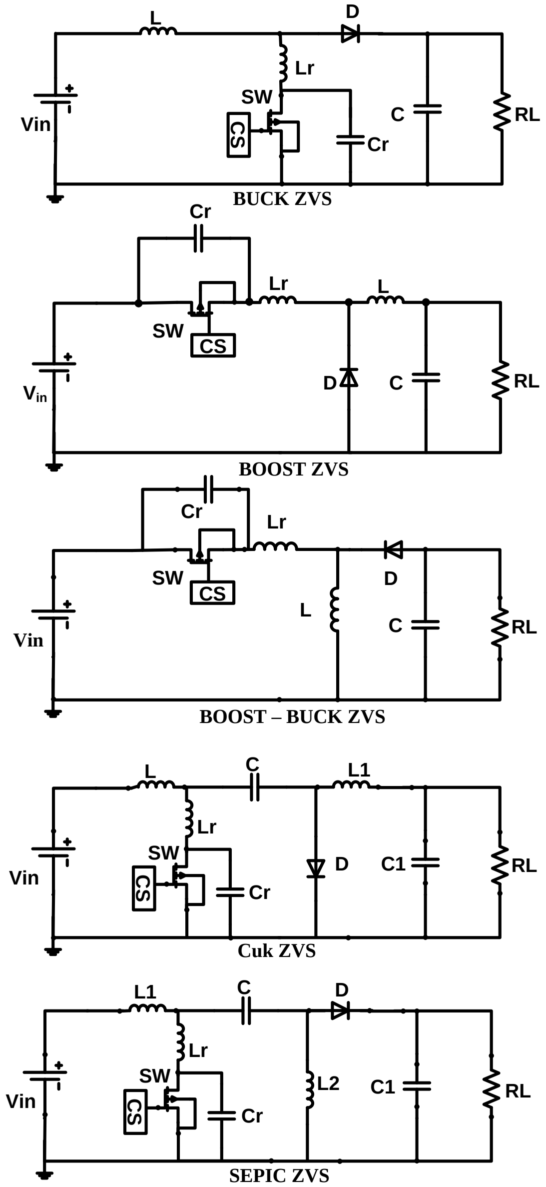

Fig. 1 ZVS DC-DC Converters

After some studies and simulations of DC-DC converters with ZVS and serial resonant circuit, we confirmed the a.m. four stages of operation. Thus we are going to examine in details the Buck DC-DC converter, shown in Fig.2a.

For the different stage of operation in Fig.2b-2e are presented the 4 equivalent circuit for each stage, while in Fig.3 are shown the waveforms, which illustrate its action.

First stage: from the moment 0 to t_1 – time interval during which we have energy accumulation in the inductance Lr, while switch and diode are ON. The equivalent circuit of that stage is shown in Fig.2b. During that interval for currents and voltages are valid the following equations: $V_S = 0$, $I_L = 0$, $I_C = 0$, $V_{LR} = V_I$. The stage ends with zero current through diode, e.g. $I_D(\omega_s t_1) = 0$.

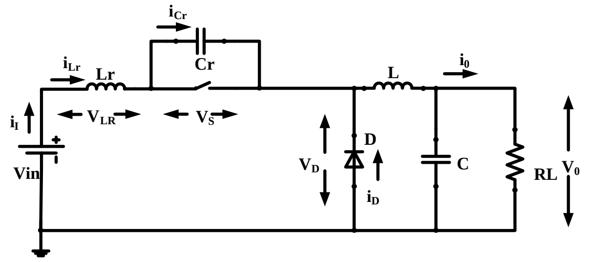

Fig.2a Buck ZVS DC-DC converter

Second stage: for the time interval $t_1 < t \leq t_2$, diode is OFF, e.g. there is no current through it. The equivalent circuit for this stage is shown in Fig.2c. During the stage are valid the following equations: $V_S = 0$, $I_{CR} = C_r dv_S / dt = 0$, $I_D = 0$, $i_s = i_{LR} = I_O$, $V_{LR} = Lr\, di_{Lr} / dt = 0$, and $V_D = V_I$. The stage ends with transistor's switching off $\omega_s t_2 = 2\pi D$.

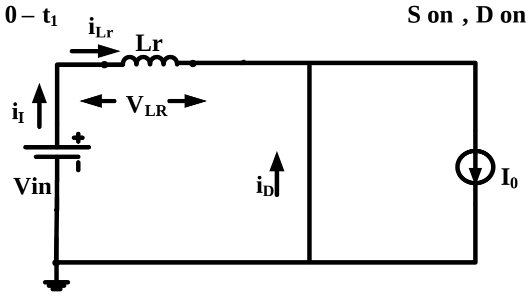

Fig.2b Energy accumulation in Lr

Third stage: for time interval $t_2 - t_3$. The switch and diode are OFF, while capacitor Cr is charging. The equivalent circuit is shown in Fig.2d. During the stage are valid the following equations: $i_S = 0$, $I_D = 0$, $I_{LR} = I_{CR} = I_O$, $V_{LR} = 0$. The stage ends when the voltage across diode reaches 0, e.g. $v_D(\omega_s t_3) = 0$.

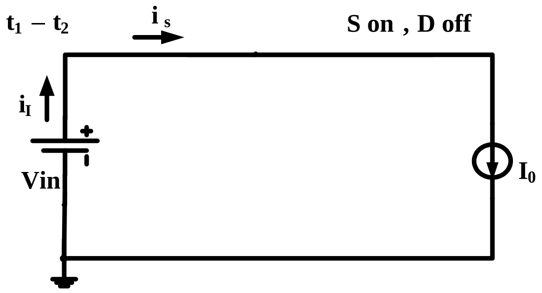

Fig.2c Switch conductance

Fourth stage: for time interval $t_3 - T$. Diode changes its state from OFF to ON. The equivalent circuit of the stage is shown in Fig.2e. During that stage for currents and voltages are valid the following equations: $i_S = 0$. In resonant circuit are running resonant processes with the next initial conditions: $I_{LR}(\omega_s t_3) = I_O$ and $v_{Cr}(\omega_s t_3) = V_S(\omega_s t_3) = V_I$.

From waveforms, shown in Fig.3 it is obvious that transistor is switching ON and OFF with ZVS, while diode is switching OFF with ZCS.

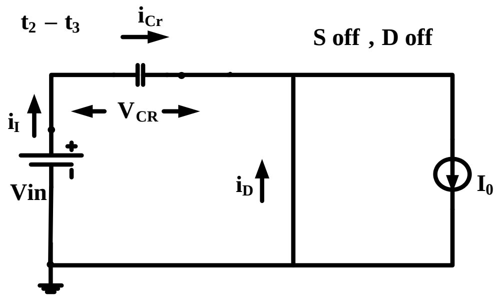

Fig.2d Charging the capacitor Cr

The additional resonant circuit hardly changes circuit's operation, but helps decreasing commutation losses in switch, because we have ZVS in switching ON and OFF.

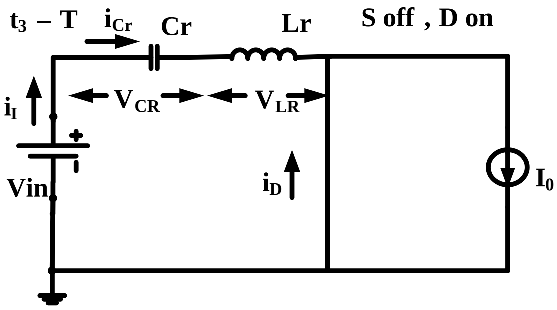

Fig.2e Serial resonant circuit

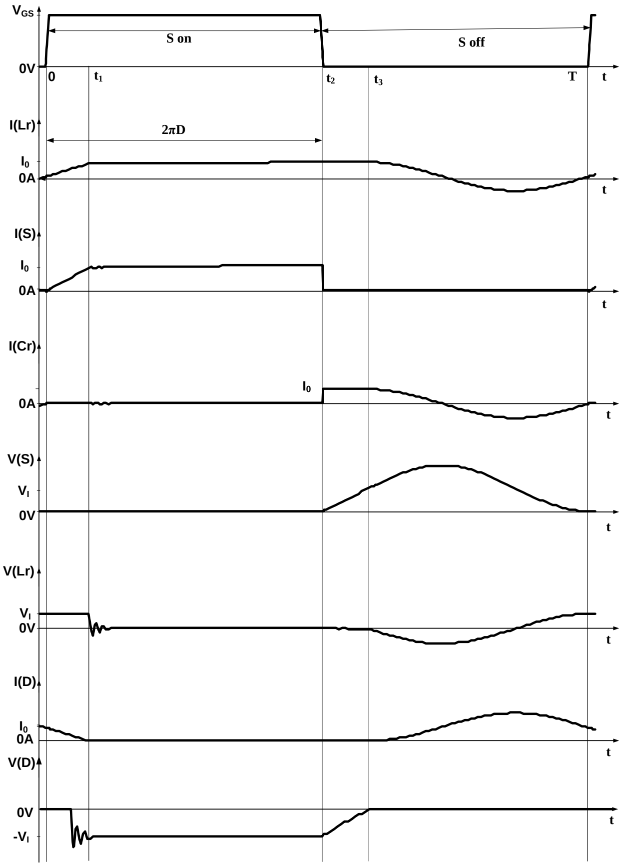

Fig.3 Waveforms of circuit's operation

The differences with classic circuits (with hard switching) are in the transistor's voltage, which is higher and depends on circuit's Q-factor. There is no difference between both type of circuits regarding the current.

III. ZCS DC-DC CONVERTERS

If we add in parallel a capacitor to serial connected switch and resonant inductance, we will obtain DC-DC converters with ZCS [1, 15, 16].

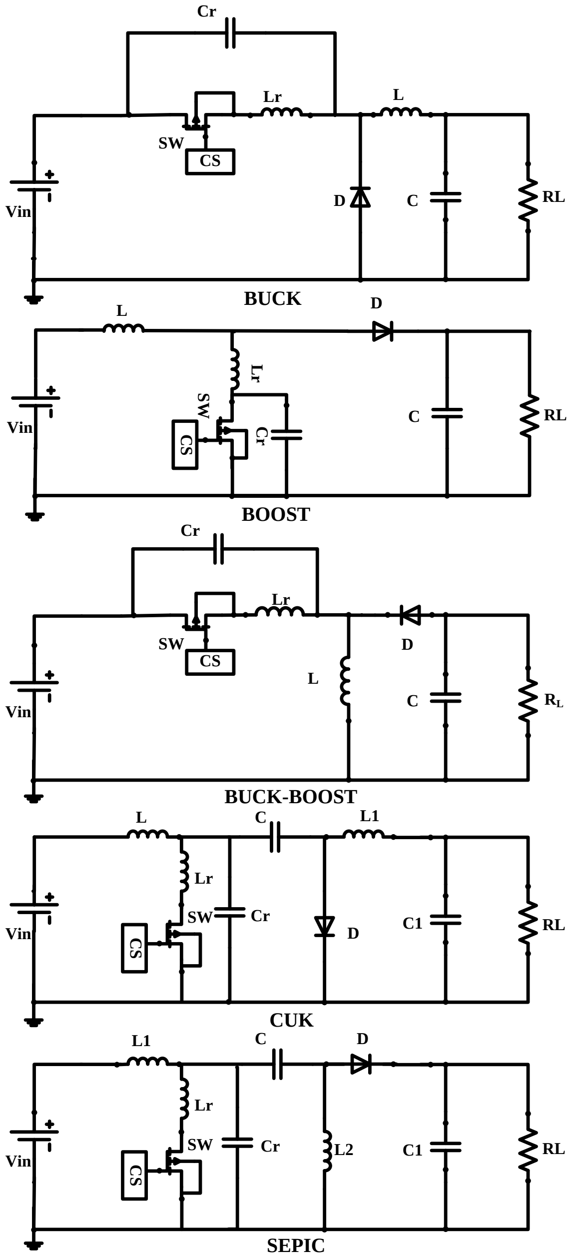

Fig.4 ZCS DC-DC converters

In Fig.4 are shown the basic circuits of DC-DC converters with ZCS – Buck, Boost, Boost-Buck, Cuk and Sepic.

Again, similarly to ZVS converters, we have 4 stages of operation [1, 3, 13]:

- **First stage**: during which capacitor is charging;
- **Second stage**: switch conductance;
- **Third stage**: energy accumulation in resonant circuit;
- **Fourth stage**: resonant process.

After some studies we found all 4 stages are usual for all circuits with ZCS DC-DC converters. The processes will be examined in details only for Boost DC-DC converter with ZCS. The circuit of the converter is shown in Fig.5a. The stages of operation are presented with their respective equivalent circuit in Fig.5b-5e.

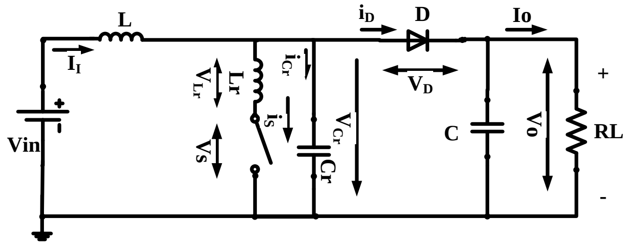

Fig.5a Boost ZCS DC-DC converter

First stage: time interval $0 - t_1$. During which the resonant capacitor Cr is charging. The equivalent circuit is shown in Fig.5b. Throughout that stage switch and diode are OFF, and for currents and voltages are valid the following equations: $i_S = 0$, $i_D = 0$, $v_{Lr} = 0$ and $i_{Cr} = I_I$. The stage ends when $v_D(\omega_S t_1) = 0$;

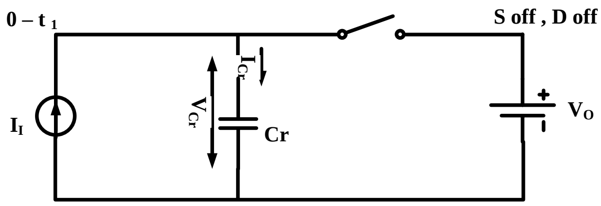

Fig.5b Capacitor Cr charging

Second stage: time interval $t_1 - t_2$. During which we have energy accumulation in resonant inductance Lr. Stage's equivalent circuit is shown in Fig.5c. For currents and voltages are valid the following equations: $i_S = 0$, $i_D = I_I$, $v_D = 0$, $v_{Lr} = 0$, $v_{Cr} = v_S = V_O$, $i_{Cr} = 0$ and $i_D = I_I$. Stage ends when Control Systems switches ON the switch and transistor starts conducting – the moment $\omega_S t_2 = 2\pi(1 - D)$;

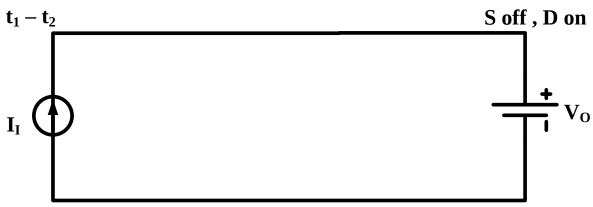

Fig.5c Energy accumulation in Lr

Third stage: time interval $t_2 - t_3$. During which the switch is ON. The equivalent circuit is shown in Fig.5d. For currents and voltages are valid the following equations: : $v_S = 0$, $v_D = 0$, $v_{Lr} = v_{Cr} = V_O$ and $i_{Cr} = 0$. Stage ends with diode's switch OFF, when $i_D(\omega_S t_3) = 0$;

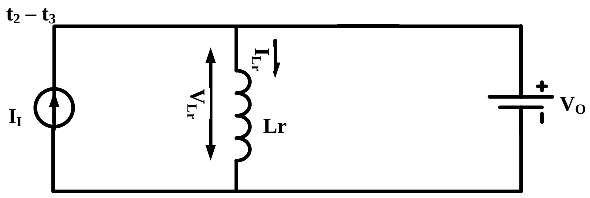

Fig.5d Switch conductance

Fourth stage: time interval $t_3 – T$. During which resonant process run. Equivalent circuit is shown in Fig.5e, while for currents and voltages are valid the following equations: $v_S = 0$ and $i_D = 0$, $v_{Lr} = 0$. Initial conditions for resonant process are respectively: $i_{Lr}(\omega_S t_3) = i_S(\omega_S t_3) = I_I$ and $v_{Lr}(\omega_S t_3) = V_O$.

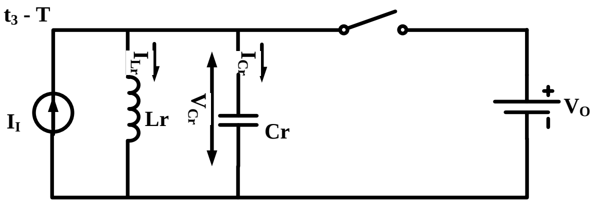

Fig.5e Parallel resonant circuit

Waveforms, which describe operation of circuit are shown in Fig.6. From there is obvious that transistors switches ON and OFF with ZCS, while diode switches OFF with ZVS. Also the additional resonant circuit barely changes mode of operation, but assists for diminishing commutation losses, because of ZCS.

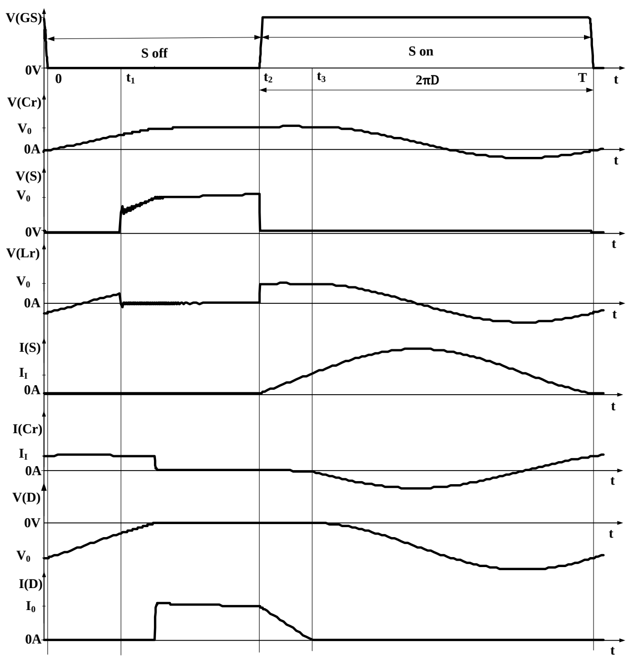

Fig.6 Waveforms of circuit's operation

IV. Conclusion

After the studies carried out we can make a conclusion that circuits with additional serial or parallel resonant circuit have lower commutation losses. This achievement is because of ZVS and ZCS. This let us increasing the frequency of operation and from there decreasing values of circuit's passive components (inductances, transformers) and size and weight of Power Devices as a whole. The main weakness is the higher voltages or currents over the semiconductor switches, which augments conductance losses.

Acknowledgement

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