QUASI-RESONANT CONVERTER

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Abstract: The quasi resonant converter, described in this article, evinces high efficiency, thanks to limitation of switching losses. Switch-on losses ale limited because of inductive character of the load. The switch-off losses are reduced by snubber capacitors, paralelly connected to power transistors. With charging and discharging of these capacitors, we achieve the zero voltage switching mode. This quasi-resonant converter is able to control output voltage in wide range.

Keywords: resonant converter, quasi-resonant converter, series resonant converter

1. INTRODUCTION

There are two main types of switching converters. The most expanded converters are hard-switching ones. These converters are easy to control, usually by pulse-width modulation, so we can control output voltage easily by changing width of switching pulses. This control allows us to drive output voltage from 0% to 100% continuously to supply, for example, variable load. The main disadvantage of hard-switching inverters, are switching losses. The converter switches, when the maximal current is in circuit. It means, that the switching losses are maximal. To reduce these losses, we can use snubber circuits to limit losses in closing or opening phenomenon of transistor. Limit both phenomena is very problematic. We can divide snubber circuits to loss and lossless. The lossless circuits are much more complicated than the others.

The second main type of converters, are soft-switching ones. Their main advantage is limitation of losses from the principle of working. They work in ZCS (zero current switching), see [1], [2], ZVS (zero voltage switching), see [3], [4], or combination of both. But there is a big disadvantage. The soft-switching converters are hard to control. If they work in nominal point, with nominal output voltage and nominal load, there are no switching losses. But if we need different output voltage, or supply variable load, we need to switch on the transistor in time, when the voltage on transistor isn´t zero (non ZVS) or switch off when the current isn´t equal to zero (non ZCS).

In this article, I will describe converter that is based on series resonant converter, but with possibility to control output voltage. So the result should have high efficiency, thanks to ZVS and ZCS, and should be controllable for wide range of load.

2. RESONANT CONVERTER

The resonant converter is the main type of soft switching converters.

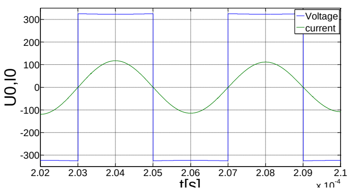


Figure 1: Zero current switching mode (voltage blue, current green)

As we can see on Figure 1, the transistors switch on and off exactly in instant, when the collector current of the transistor decreases to zero. That means that the switching losses don´t exist in this case.

2.1. SERIES RESONANT CONVERTER

In this converter, the resonant elements are connected in series. This connection can be used with advantage for compensating leakage inductance in primary winding of transformer. The basic connection is shown on picture below:

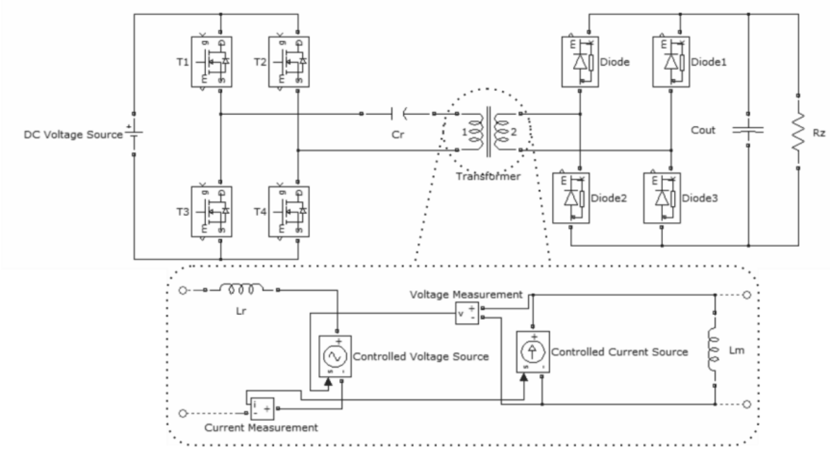


Figure 2: Basic connection of Full bridge series resonant converter with equivalent connection of transformer [5]

In this case, the resonant capacitor C_r is in series resonance with leakage inductance L_r of transformer and the resonant frequency is given by:

$$f_r = \frac{1}{2\pi\sqrt{L_r.C_r}} \quad (1)$$

where L_r is given by:

$$L_r = L_1.(1-k^2) \quad (2)$$

where L_1 is the primary inductance of transformer and k is coefficient of coupling between transformer windings.

2.2. POSSIBILITIES OF DRIVING RESONANT CONVERTER

The main disadvantage of resonant converter is impossibility to control output voltage. The reason is following: The ZCS regime is conditioned to work with the maximal duty cycle, i.e. $d = 0.5$. But, it is strongly in the contradiction with the controllability of the converter. But there are few solutions of changing output voltage.

The first possibility is to drive the converter, like hard-switching type, with pulse-width modulation (PWM).

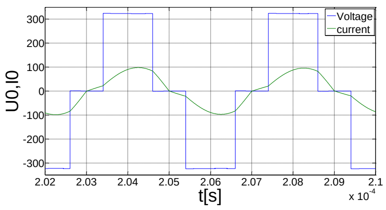


Figure 3: Resonant converter driven by PWM (voltage blue, current green)

In this case, the output voltage is controlled by changing duty cycle, but the transistors don´t switch on and off in ZCS => nonzero switching losses.

The second possibility is to change switching frequency up.

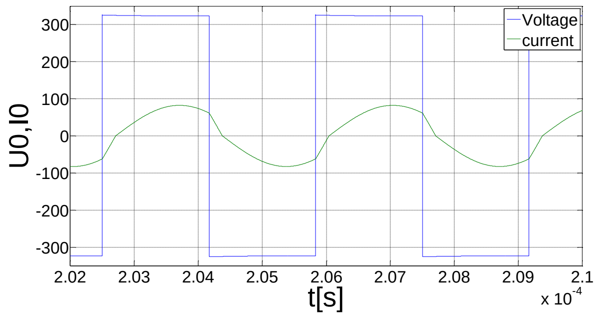


Figure 4: Switching with higher frequency, f_s = 300 kHz, f_r = 250 kHz, voltage blue, current green

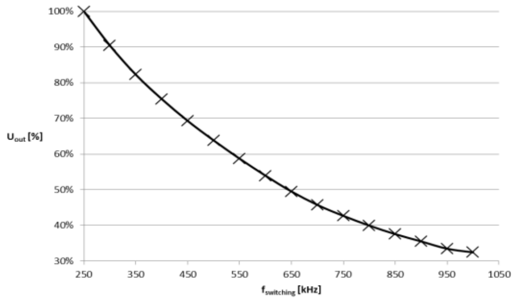


Figure 5: Dependence of output voltage on switching frequency (f_r = 250 kHz)

The Figure 5 shows that the output voltage can be controlled also by increasing switching frequency. To use this technique, the nominal work point is set to 250 kHz and if the output load needs, we can lower the output voltage simply by increasing the switching frequency. In nominal point, the switching losses are equal to zero.

3. SIMULATION OF RESONANT CONVERTER IN MATLAB/SIMULINK

For simulation of resonant converter, I used the environment Matlab/Simulink with additional library SimpowerSystems. This extra library allows us to simulate directly with electrical elements. There is no need to represent electrical elements with mathematical equations.

3.1. MODEL OF SERIES RESONANT CONVERTER

Because the extra SimPowerSystems library contains only unusable models of transformer, I used model of transformer from [5], which works perfectly.

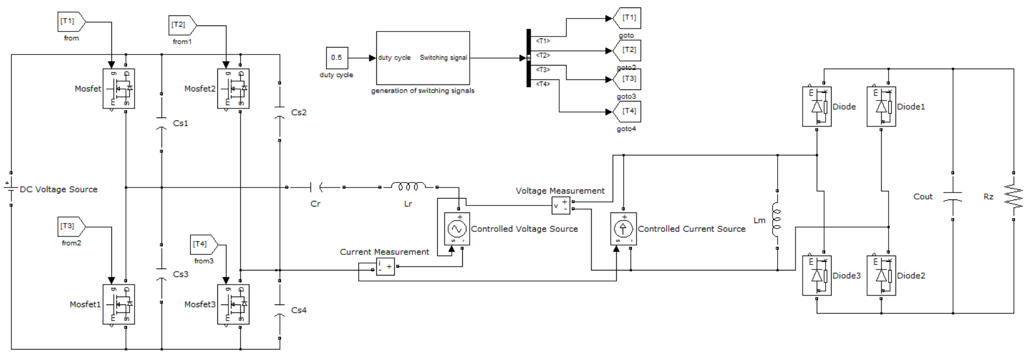


Figure 6: Model of series resonant converter

In the model in Figure 6, we can change duty cycle and also switching frequency. The blocks „Mosfet“ represent switching devices, specifically N-channel unipolar transistors with equivalent circuit of:

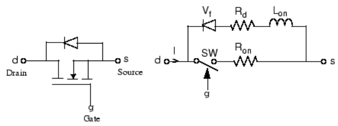
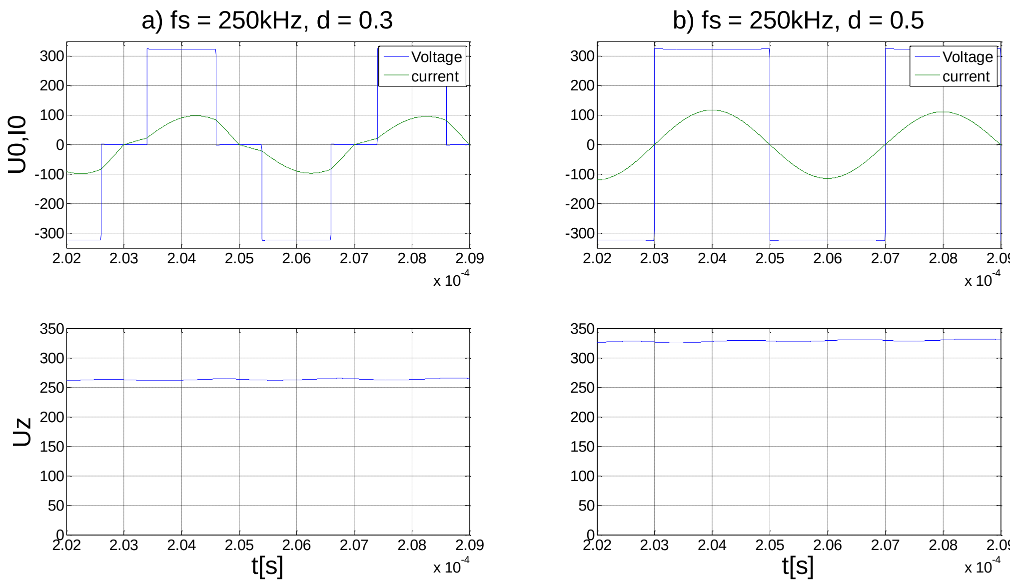
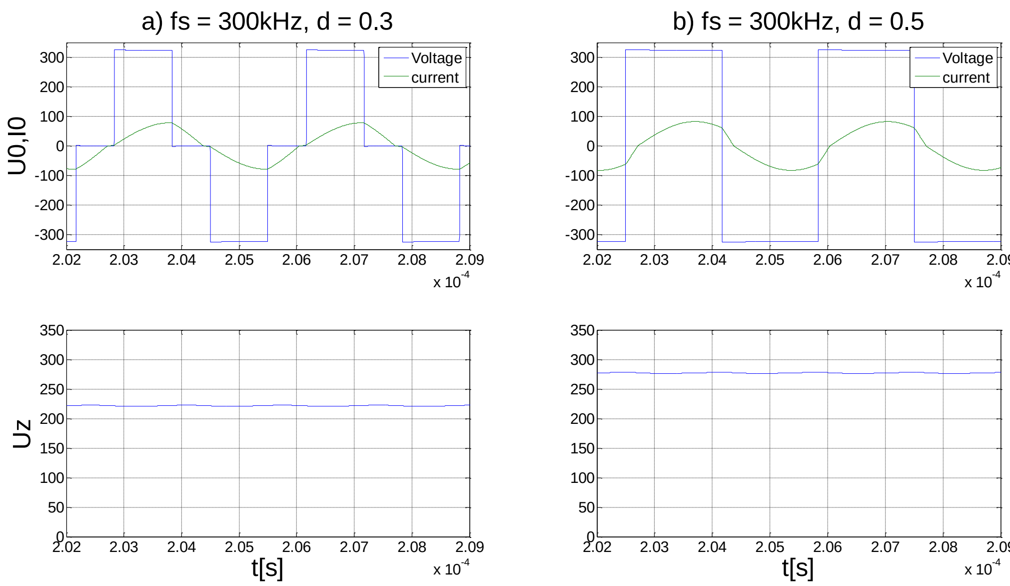


Figure 7 – equivalent connection of MOS-FET switch is Matlab/Simulink SimPowerSystems

The other blocks represent real elements, e.g. R_z represents load and $C_{s1\text{-}4}$ represents snubber capacitors.

3.2. RESULTS OF SIMULATION





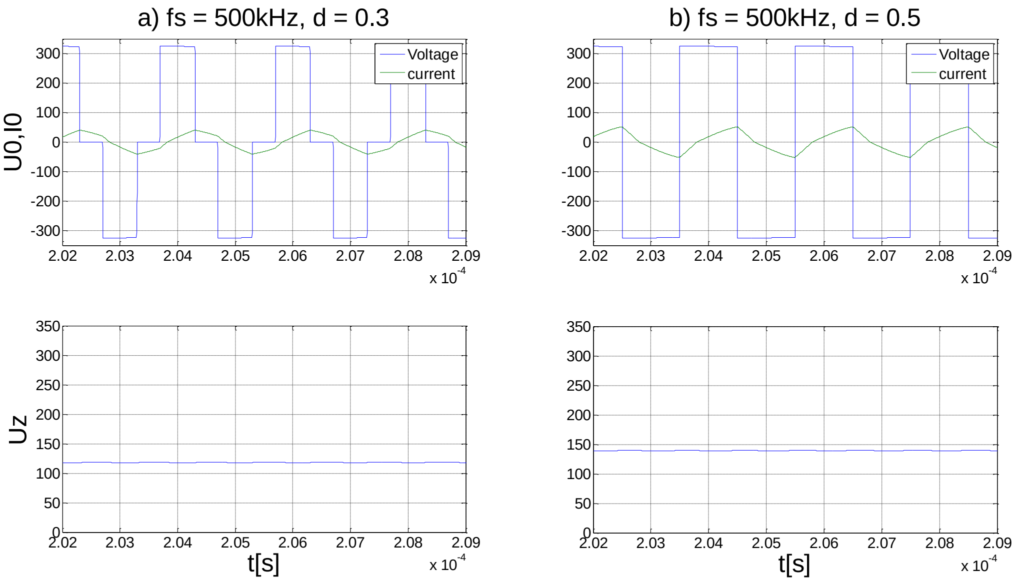


Figure 8: Results of simulation, f_r = 250 kHz; a) f_s = 250 kHz, d = 0.3; b) f_s = 250 kHz, d = 0.5; c) f_s = 300 kHz, d = 0.3; d) f_s = 300 kHz, d = 0.5; e) f_s = 500 kHz, d = 0.3; f) f_s = 500 kHz, d = 0.5;

As we can see on Figure 8, the output voltage U_z and current I_z are influenced by the duty cycle and switching frequency. With wider duty cycle, the output voltage rises and with higher switching frequency, the output voltage falls down.

4. CONCLUSION

This article describes two paths for controlling output voltage of series resonant converter. Both of these ways of control have advantages and disadvantages, but the best way seems to be combination of both. In theory and in simulation in Matlab, resonant converter, regulated by duty cycle and switching frequency, seems to work. This theoretical knowledge is now used to build real converter and verify simulations on real converter.

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