SWITCHABLE RESONANT CONVERTER TO ACHIEVE LOWER SWITCHING LOSSES

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Abstract: This work deals with the switching losses comparison in hard-switching converter and soft-switching series resonant converter controlled by two different PWM algorithms. The first algorithm uses basic pulse-width modulation and the second one uses modified PWM which is improved at the lower duty cycle regime as shown in the article. The proposed converter shows the ability to switch from resonant mode to hard switching to achieve the lowest switching losses in whole output voltage range.

Keywords: resonant converter; switching losses, series resonant converter; hard switching; soft switching; combined converter;

1. INTRODUCTION

There are two main types of switching converters. The most expanded converters are hard-switching ones, see Fig. 1. These converters are easy to control by pulse-width modulation (PWM). So we can control the output voltage easily by changing the duty-cycle of switching pulses. This control allows us to drive output voltage from 0% to 100% continuously. The big disadvantage of hard-switching inverters, are high switching losses. The reason lies in the fact, that transistors switch-on and switch-off high currents, see Fig. 2.

The second main type of converters, are soft-switching ones. Their main advantage is suppression of losses from the principle of working. They work in ZCS regime (zero current switching), see [1], [2], ZVS regime (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 with maximal output voltage (full duty cycle), there are no switching losses. But if we need to control output voltage, then the transistor must be switched 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, there are compared switching losses in hard-switching converter with losses in the series resonant converter loaded by few different types of load.

The proposed converter (Fig. 14) has the ability to change the working regime from hard switching to resonant and back. The assumed output characteristics are shown in Fig. 15.

2. HARD-SWITCHING CONVERTER

The hard-switching converter’s main disadvantage is switching losses. These losses grow with switching frequency, so it is difficult to work with high switching frequencies.

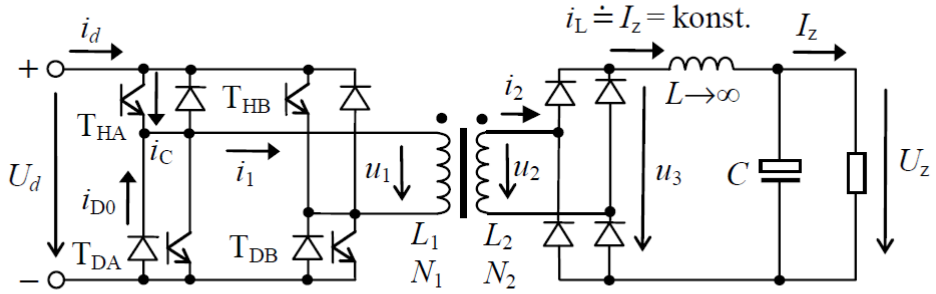

Fig. 1. Hard-switching converter, taken from [5]

3. SERIES RESONANT CONVERTER

When comparing with hard-switching converter, the series resonant converter (see Fig. 2) has following advantage: If it works with maximal output voltage, the switching losses are equal to zero. The reason is following: the transistor switches-on and switches-off in this time instant, in which the current is equal to zero (ZCS – zero current switching.

Thus, the problem arises when the output voltage must be controlled to low levels. In this case the converter can be driven by usual basic PWM as it is possible to see in Fig. 3.

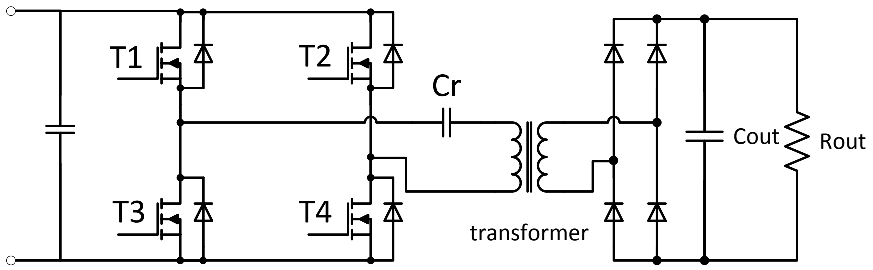

Fig. 2. Series resonant converter

This type of controlling is very good, when the converter works with high duty cycle. If the duty cycle is full, the switching losses are zero. But, if the required duty cycle is low or near zero, the switching losses rise because the transistor switches near the peak value of the sinusoidal current as it is shown in Fig. 3. (The switching loss energies are directly proportional to instantaneous value of the switched current.) This operating mode can be named as 1st algorithm.

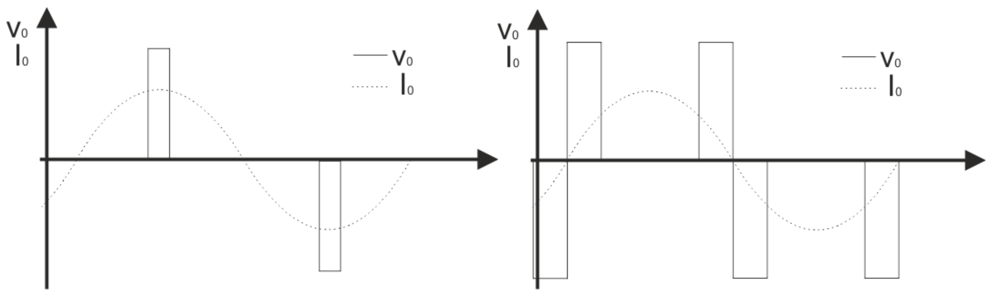

Fig. 3. Resonant converter driven with 1st algorithm at low duty cycle (left), Resonant converter driven with 2nd algorithm at low duty cycle (right)

This algorithm works very well with low duty cycle and is usable for low output voltage.

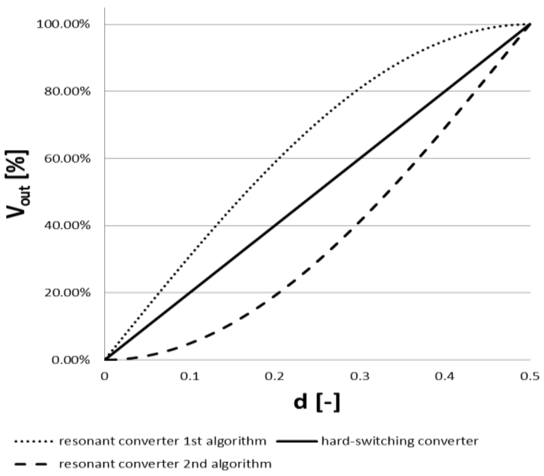

Fig. 4. The output voltage dependence on the duty cycle

The output voltages in Fig. 4 are given by equations:

$$V_{out.1_{st}\,a\lg} = V_d \cdot \sin(\pi \cdot d) \tag{1}$$

$$V_{out.2_{nd}\,a\lg} = V_d \cdot (1 - \cos(\pi \cdot d)) \tag{2}$$

$$V_{out.hard} = V_d \cdot (2 \cdot d) \tag{3}$$

On Fig. 4 the output voltage dependence on the duty cycle is shown. In case of hard-switching converter, the dependence is linear. In case of the resonant converter, the dependence is sinusoidal.

4. COMPARISON OF SWITCHING LOSSES

In this chapter, there will be shown the comparison of hard-switching converter with the series resonant converter working with load type – Pure resistor:

In this case, the load of converters is presented by resistor only, so the output current is directly proportional to output voltage by equation:

$$I_{out} = \frac{V_{out}}{R_{load}} \tag{4}$$

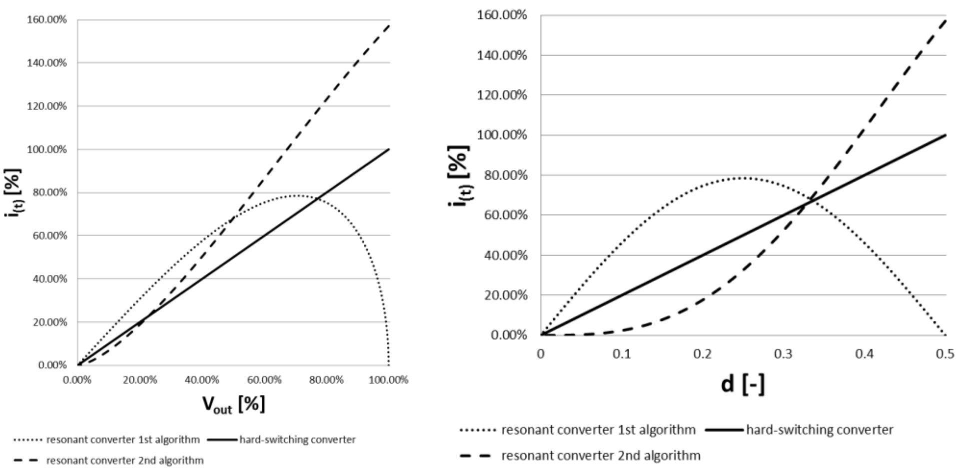

Fig. 5. The switching currents dependence on the output voltage and duty cycle

In Fig. 5, we can see the dependence of the switching currents on the output voltage and duty cycle. As we can see, the 2nd algorithm works well at low output voltage from 0% to 20% of maximal output voltage. The hard-switching converter is best in range from 20% to 80% of maximal output voltage. The resonant converter driven by 1st algorithm switches smallest currents in range from 80% to 100%.

5. PROPOSED CONVERTER

As we can see in Fig. 5, the way to achieve the lowest switching losses in whole output range is to combine the hard switching and resonant converter. The resonant capacitor and output inductor are bypassed by switches. These switches provide the ability to change the converter from resonant to hard switching.

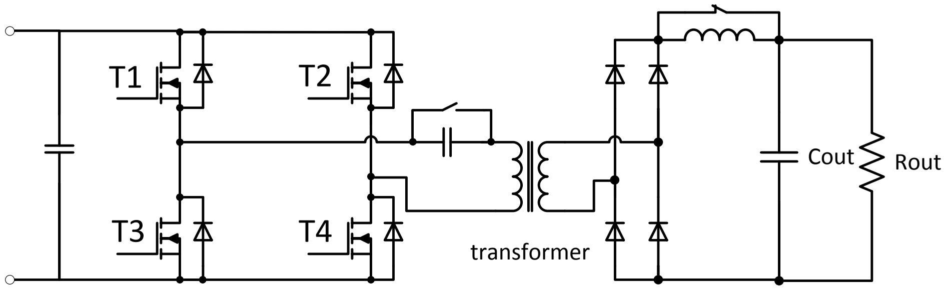

Fig. 6. Resonant to hard-switching switchable converter

The expected characteristics are shown in Fig. 7. The converter is driven by 2nd algorithm (Fig. 3) from 0% to 25%. If the higher output voltage is needed, the converter switches to hard switching mode to supply the load from 25% to 80% of output voltage. And when the load requires full output voltage, the converter switches back to resonant mode with 1st algorithm (Fig. 3) to achieve smaller switching losses.

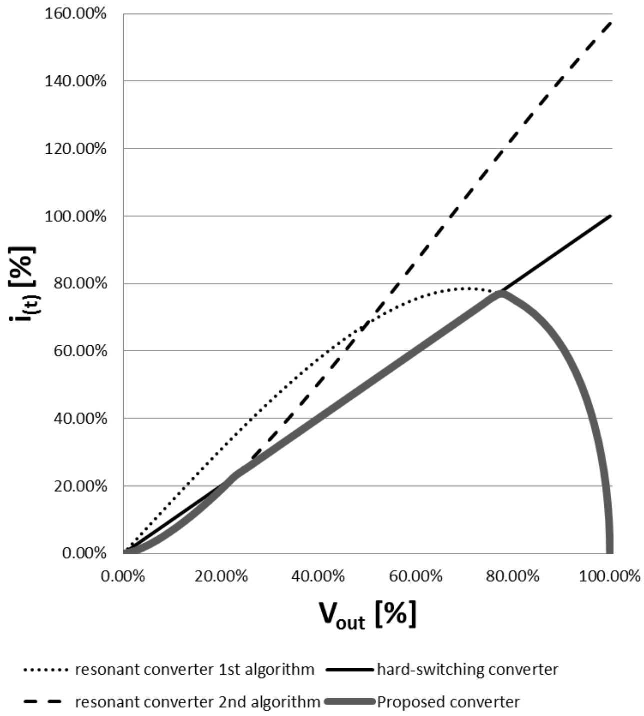

Fig. 7. Output characteristics of combination of resonant and hard switching converter with pure resistor load type

6. CONCLUSION

This article deals with switching losses comparison in hard-switching converter and soft-switching series resonant converter driven by two different manners. The results are shown in Fig.

The figures show, that the resonant converter is usable in the regime with very low duty cycle (2nd algorithm) or in the regime with the high duty cycle (1st algorithm). In middle range of output voltage (from 20% to 80%), the losses of the hard-switching converter are a little lower but comparable.

As we can see in Fig. 5, the way to achieve the lowest switching losses in whole output range is to combine the hard switching and resonant converter. The resonant capacitor and output inductor can be bypassed by switches to provide the ability to change the converter from resonant to hard switching.

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