NON-TRADITIONAL QUASI-RESONANT SNUBBER CIRCUIT FOR FLYBACK CONVERTER

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Abstract: This paper deals with the topic of simulation and practical applications of using a non-traditional, non-dissipative snubber circuit for a flyback converter. Simulation of the snubber was created in MATLAB Simulink. A quasi-resonant snubber circuit was tested on a DC/DC converter for a photovoltaic panel.

Keywords: Power electronics, quasi-resonant snubber, Simulink

1 INTRODUCTION

DC/DC and AC/DC converters are an integral part of everyday life. Converters for things such as motors are facing increased requirements for efficiency whilst maintaining the balance between power and size. The selection of converter topology is therefore critical with different requirements for transmitted power, control properties and overall system build difficulty. For galvanically isolated applications using a minimum number of switching elements (i.e. simple controllers) the flyback converter is a suitable topology. Unfortunately the standard design of a flyback converter with a dissipative snubber circuit can only be used for low power (~100W). When the non-dissipative circuit is used we can achieve much higher power capacities (>500W).

This article summarizes and compares the dissipative and non-dissipative snubber circuits for flyback topology. The article is divided into three parts - general theory, quasi-resonance snubber analysis and practical application with the quasi-resonance non-dissipative snubber circuit.

2 FLYBACK TOPOLOGY

The standard flyback topology is shown in Figure 1. The entire converter consists of only one transistor, a high-frequency transformer, one diode and one capacitor. The biggest disadvantage of this topology is the presence of the parasitic leakage inductance of the transformer. The leakage inductance causes a voltage overshoot on the transistor at the time when the transistor is turned off. This voltage overshoot can be limited by the snubber circuit connected to the primary winding of the transformer. The current flowing through the primary winding at the time when the transistor is switched on cannot immediately disappear when the transistor is switching off. Therefore, at the moment of switching off the transistor, the snubber circuit takes this current which gradually disappears in the snubber circuit. The behavior of the current depends on the mode of the flyback converter. In discontinuous mode the current will fall to zero, whereas in continuous current mode the current will drop to a defined value. The snubber circuit may be dissipative (contains a resistor) or non-dissipative (composed of coils and capacitors). The voltage overshoot on the transistor is limited to the defined value of the snubber circuit. It is therefore possible to select a transistor based on this voltage between drain and source instead of using a transistor with higher u_{DS} voltage.

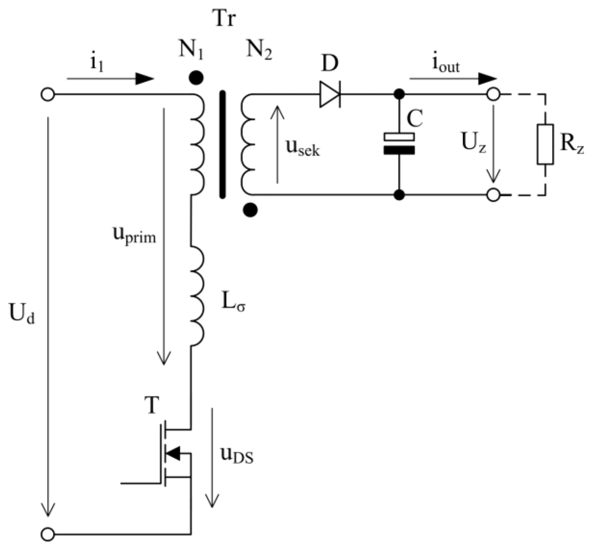

Figure 1: Flyback converter without snubber circuit.

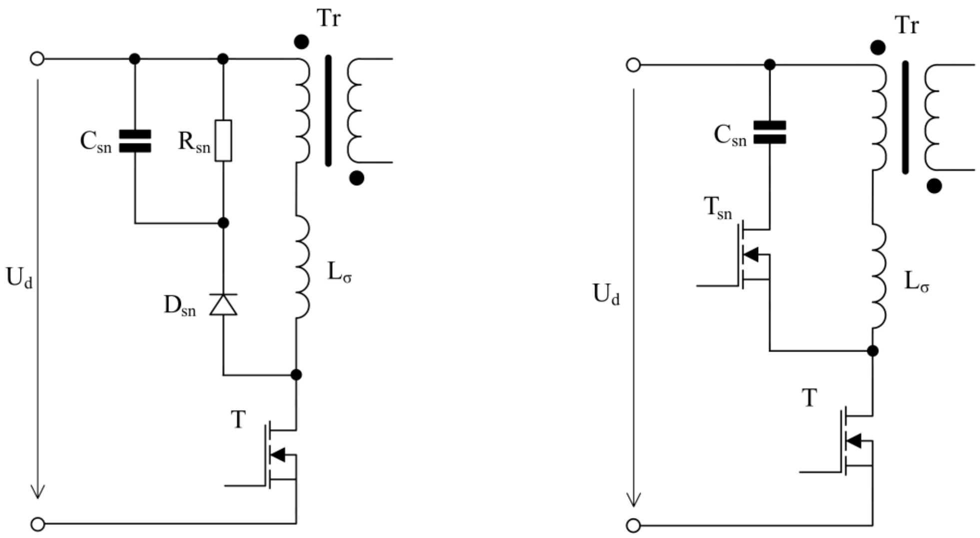

Figure 2: Flyback converter with a dissipative snubber circuit (on the left) and flyback converter with an active clamp (on the right) – without secondary side.

2.1 DISSIPATIVE SNUBBER CIRCUITS

Dissipative snubber circuits are the simplest snubber circuits which convert electrical energy into heat. These snubbers are known as *RCD* (resistor, capacitor, diode) - see Figure 2. The function of the snubber is as follows: When the transistor is switched off the current begins to flow through the open diode D_{sn}, resistor R_{sn} and also charges the capacitor C_{sn}. At the time of closing the diode D_{sn} the energy accumulated in the capacitor C_{sn} is gradually converted by the resistor R_{sn} to heat.

This method of limiting the voltage overshoot is not ideal because it reduces the efficiency of the converter and increases the heat dissipation generated by the converter, which may not be suitable for some applications. The advantage of this solution is simplicity and price. Maximum power is the most limiting factor of this topology as the demands on the snubber circuit are increased with increasing power.

2.2 NON-DISSIPATIVE SNUBBER CIRCUITS – ACTIVE CLAMP

Non-dissipative snubber circuits can be divided into two groups: passive and active. Passive snubbers consist of passive elements (*CLD*) and active snubbers consist of transistors or thyristors.

A passive non-dissipative snubber circuit will be mentioned in the next subchapter.

An example of an active clamp is shown in Figure 2. When the main transistor T is switched off the transistor T_{sn} is switched on and thus the capacitor C_{sn} and the primary winding of the transformer Tr are connected in parallel. The current charges the capacitor and at the appropriate time the capacitor energy is transferred to the secondary side of the transformer to the load.

Appropriate control of the transistor T_{sn} can achieve the state where the transistor T operates in *ZVS* (Zero Voltage Switching) mode. This mode increases the efficiency of the entire converter. Incorrect switching of the transistor T_{sn} can result in damage to the entire converter. More demanding control and extra switching elements increase the cost and may not be robust in some applications.

Making non-dissipative snubber circuits completely non-dissipative is not possible because the dissipation in these snubbers is caused by the parasitic properties of the selected components. For example, the resistance of the choke wire of inductors can be specified. If both types of snubber circuits are compared on the same flyback converter, the flyback converter with the non-dissipative snubber circuit will achieve higher efficiency and lower heat dissipation than the flyback converter with a dissipative snubber.

3 ANALYSIS OF QUASI-RESONANT SNUBBER CIRCUIT

The quasi-resonant snubber circuit (Figure 3) may be a suitable alternative to the active clamp circuit. The description of a quasi-resonant snubber is based on [1] and [2].

The snubber circuit function is as follows: The transistor T is closed and the Tr transformer is magnetized. When the transistor T is switched off the capacitor C_{sn} is charged to the voltage $-U_d$. After switching off the transistor T, the current i_1 cannot disappear therefore the diode D_{2sn} is opened and the current loop is closed via the C_{sn} capacitor. The voltage u_{Csn} on the capacitor C_{sn} increases due to the flow of current i_1 and thus the drain-source voltage u_{DS} of the transistor T increases. Voltage u_{DS} is given by the sum of the DC-link voltage U_d and the voltage u_{Csn}. After the disappearance of the primary current i_1 (the primary current is closed through the capacitor C_{sn} and the diode D_{2sn}), the voltage u_{DS} on transistor T immediately decreases to the sum of the voltage of the DC-link U_d and the conversion of the converted voltage from the secondary side of the transformer u_{sec}. Now can occur two states with respect to the reached voltage u_{Csn}. If the voltage has reached a higher value than the voltage given by the sum of the converted voltage from the secondary side u_{sec} and the voltage of the DC-link U_d, the diode D_{1sn} will be opened. At this point the voltage at the L_{sn} inductance is reduced from the u_{Csn} voltage difference and the sum of the u_{sec} and U_d volts appear on the L_{sn} inductance. The i_{Lsn} current starts to flow and the energy from the quasi-resonant circuit is returned to the DC-link. The voltage u_{Csn} of the C_{sn} capacitor gradually decreases to the sum given by the volts U_d and u_{sec}. At the moment of equilibrium of these voltages the current i_{Lsn} disappears and the diode D_{1sn} closes. If the u_{Csn} voltage does not exceed the sum of U_d and u_{sec} then this energy transfer will not occur at all. At the moment of switching on the transistor T, the capacitor C_{sn} is connected to the serial connection of the diode D_{1sn} and the inductance L_{sn}. The D_{1sn} diode opens and the u_{Csn} voltage is connected to the L_{sn} inductance. The energy accumulated in the C_{sn} capacitor gradually flows into the L_{sn} inductance. However, the current i_{Lsn} contributes to the stress of the closed transistor T during this energy transfer. When the capacitor voltage drops to $-U_d$, current i_{Lsn} cannot disappear immediately and therefore the D_{2sn} diode opens. The L_{sn} inductance is now connected in parallel to the DC-link voltage U_d and is demagnetized (current decreases with steepness $-U_d$ / L_{sn}). In the demagnetization of the inductance by the DC-link voltage, no additional current is applied to the transistor T. After the i_{Lsn} current disappears, the D_{1sn} and D_{2sn} diodes are closed and the quasi-resonant snubber is ready for the next cycle.

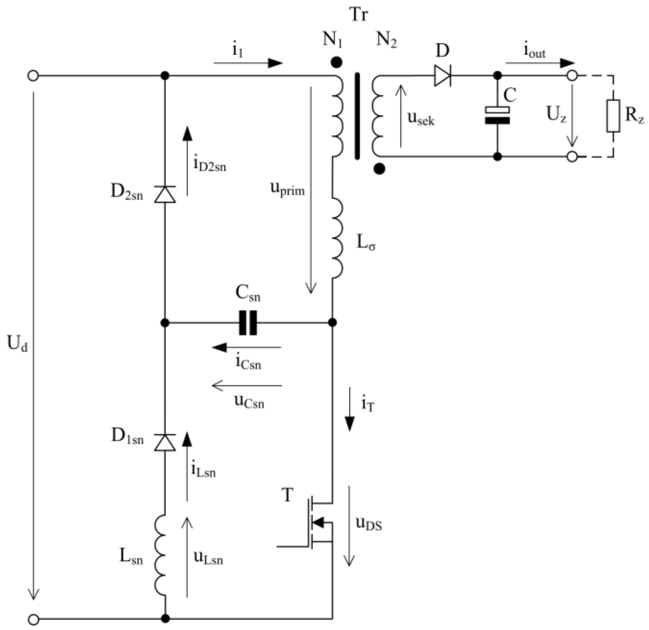

Figure 3: Flyback converter with a non-dissipative quasi-resonant circuit.

4 MODELLING OF QUASI-RESONANT SNUBBER CIRCUIT

The entire flyback converter was modeled in MATLAB Simulink using SimScape libraries. The model was not compiled from differential equations as standard. The SimScape library allows the problem to be solved as an electrical scheme. Only the transformer was modeled from derived diffractive equations valid for the gamma circuit, largely because of the variability of the variables.

Figure 4 below shows the results of simulating the time-varying voltage and current waveforms in the quasi-resonant snubber circuit. The waveforms correspond to the selected direction of variables as according to Figure 3.

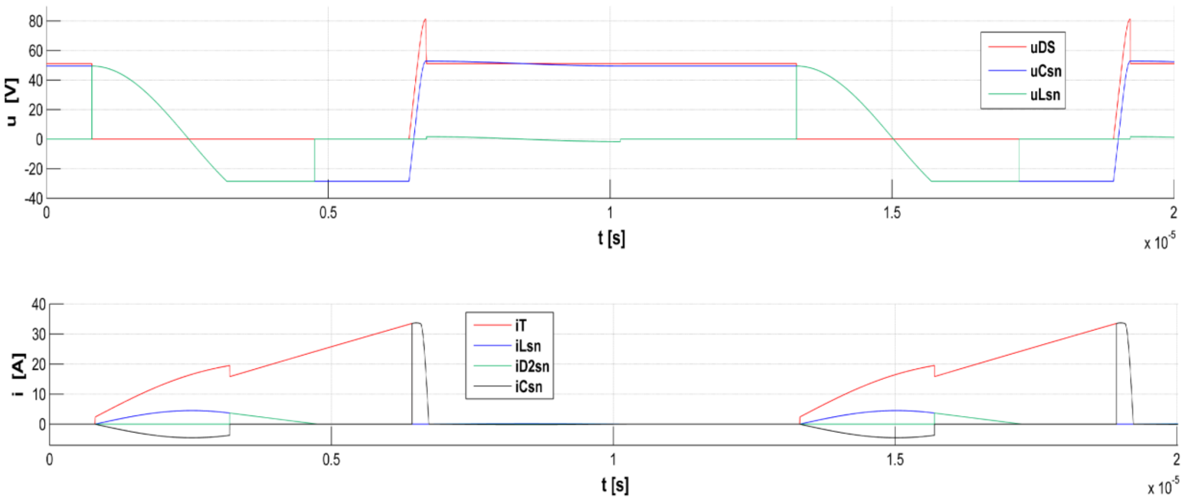

Figure 4: Voltage and current waveforms in a quasi-resonant snubber circuit.

5 PRACTICAL USING OF QUASI-RESONANT SNUBBER CIRCUIT

The flyback converter with a quasi-resonant snubber circuit was successfully applied and tested in the application of a DC/DC converter for a single photovoltaic panel. The input voltage of the converter is 24 – 30 V, the output voltage is 350 V and the output power is 250 W. The efficiency of the converter is approximately 94.5 % at the 28.5 V rated input voltage. The entire converter is fully digitally controlled by the ARM STM32F334 microcontroller. The control algorithm features Maximum Power Point Tracking (*MPPT*), Perturb & Observe and Incremental Conductance methods for increasing solar energy yield. The converter is designed to be able to communicate via CAN with other converters or similar peripherals.

Figure 5: Application of a quasi-resonant snubber circuit – DC/DC converter for one photovoltaic panel.

6 CONCLUSION

The aim of this article was to introduce different types of snubber circuits suitable for a flyback converter. Dissipative and non-dissipative types were described along with their selection criteria. The advantages and weaknesses of each type was explained. The largest part of the article was devoted to the quasi-resonant snubber circuit and included simulation results. Finally, an example application of the flyback converter with a quasi-resonant snubber circuit was described.

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