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Research Article

DESIGN AND ANALYSIS OF A FLYBACK CONVERTER WITH IMPROVED SNUBBER CELLS

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ABSTRACT

In today's industrial systems, especially at low power applications, since they have simple structure and easy control, flyback converters are preferred. Furthermore, with suitable for multiple output levels on one device, be able to respond to different power demands, simple installation, eligibility of cost requirements, isolation between the inputs and outputs of the circuit structure, compliance with default safety standards and such advantages have been preferred. Although they have these advantages, flybacks suffers from leakage inductances. They cause high voltage spikes and extra losses. In our circuit model based on flyback topology, contribute to work on the circuit by eliminating the losses as much as possible, for feeding devices that require different voltage values with a single power supply, and increase efficiency by reducing voltage stress on the semiconductors and such improvements have been made. On the basis of these improvements, primarily classical circuit modeling has been done, all necessary numerical and analog measurements were presented. After that emphasis is placed on the increase in circuit efficiency with subsequent loss prevention improvements. 5 Voltage - 1 Ampere and 12 Voltage - 1 Ampere values, which are used in two separate and isolated output voltage sources are obtained.
Keywords: Flyback converter, power supply, snubber circuits.

1. INTRODUCTION

The usage of the dc-dc converters has been increasing day by day. The welfare of societies and technological developments have made it necessary to use energy in a quality and efficient manner. Energy consumption has been increasing and energy has become a global problem. Furthermore, isolation is necessary for the electiral safety.

Pulse Width Modulated (PWM) DC-DC converters are widely used in industry because of fast dynamic response, easy control and simple structure. Non-isolated and isolated are the terms of the DC-DC conveters [1-19]. Buck, boost and buck-boost type converters are used for many applications in industry thanks to their simple control and structure. However, there are isolation problem between in these converters [2,15]. Flyback and forward converters are used at the systems which require isolation. Flyback conventers operation is similar to buck-boost converter and forward converters operation is similar to buck converters [3].

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At isolated converters, transformer design and the core selection are important at the applications. Magnetizing current is equal to primary winding current and it is high in flyback converter where it is low at forward converters since primary and seconder windings operate together [4-5]. However, there are three windings in forward converters. So, flyback converters are used at the industrial systems, since they have simple structure and easy control. However, flyback converters suffer from the leakage inductance and so extra losses. In [6-8, 17-19] flyback converters are used for soft switching. However, at these applications, the proposed snubber cell with flyback converter causes extra voltage stresses and losses, since there are no proper snubber selection for flyback converters. This causes external cooling system and external costs. It also causes low efficiency and flyback converters to be used at low power applications. At [13] and [14] passive snubber circuits are proposed. However, in these converter, they require more passive components and there are many resonance intervals which causes low Electro Magnetic Interference (EMI) and high losses.

There are two modes as Continuous Current Mode (CCM) and Discrete Current Mode (DCM) for resetting the magnetizing inductance current within a switching period [15,16]. At CCM operation, energy is transffred from input to output, all the switching period. So, they are used at high power applications. At DCM operation, there is an interval which there is no energy which is transfered from input to output and the current has been reached to zero. So, soft switching is achieved and also the reverse recovery losses of diode is eliminated and, the efficiency of the DCM operation is higher than CCM ones [11-15].Furhermore, with selecting suitable snubber cells improves the efficiency of the converters. There are two snubber structures for flyback converter. The primary snubber cell is connected to the primary windings via a fast diode and supress the switch voltage stresses. The other snubbers are called as light snubber cells which is connected parallel to the diodes. This snubber cell parameter selection is more important for the operation of the flyback converters.

In this study, analysis and design of a flyback converter with suitable snubber cells which does not include the disadvantages mentioned above are achieved. At this study, to verify the theoretical analysis, the detailed theoretical analysis was confirmed by an application circuit with two outputs of 5V-1A and 12V – 1A with input voltage of 310 V DC via 66 kHz and 138 kHz are achieved. The selecting twice for the switching frequency may cause external stresses and losses at the applications of the passive snubbers. So, they may require external soft switching cells. In this study, the snubber circuit operates perfectly under different frequencies without external soft switching cells. Accordingly, in our circuit, the snubber circuits at the seconder side of our transformer at an operating power such as 17W-18W, it is in an excess position dismantling can be done in mind. The primary and seconder snubber parameters are selected to not to cause external voltage stressses and losses. Because the switching equipment the voltage rise while turning off interval is subject to the current increase while turning on. By comparing this situation, the advantageous snubber values has to be preferred for the circuit efficiency.

2. THEROTICAL METHOD

The conventional flyback converter is given in Figure 1. This converter occurs from input DC voltage source, L_M magnetizing inductance, transformer TR, turn ratio n, Mosfet Q1, schottky diode D1, and output capacitor C. Furthermore, mosfet is selected since they are suitable for low power and high frequency applications. The proposed flyback converter operates under DCM.

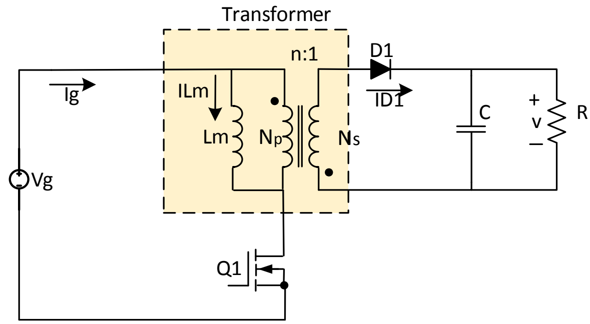


Figure 1. The conventional flyback converter

2.1. Operation Stages

In the designed flyback, three different intervals occur during one switching period T_s. At the beginning, the load is fed from only the output capacitor and magnetizing inductance has been resetted.

Stage 1 (t_0<t<t_1)

Mosfet control signal is applied to the gate terminal and the switch turns on. The magnetizing inductance current begin to increase via the input voltage V_g.

$$i_{Q1} = i_{LM} = \frac{V_g}{L_M} t \tag{1}$$

where L_M is the magnetizing inductance and i_{LM} magnetizing current. Also, the switch current is equal to this magnetizing current. This interval ends when the switch turns off.

Stage 2 (t_1<t<t_2)

At the beginning of this stage, $i_{Q1} = 0$ and $i_{D1}=I_{D1\_max}$. After turning off of the switch, D_1 turns on and this stage begins. At this stage, magnetizing energy is transferred to the output. For this interval,

$$i_{D1} = I_{D1\_max} - \frac{V}{L_s} t \tag{2}$$

$$I_{D1\_max} = I_{LM\_max} n \tag{3}$$

are valid. In these equations, L_S is the seconder windings of transformer, I_{D1_max} is the maximum current of the diode and n is the turn ratio of the transformer primary and seconder windings. This interval ends when the diode turns off with zero current switching. So, reverse recovery losses are eliminated.

Stage 3 (t_2<t<t_3)

This interval begins when the diode current reaches to zero. In this interval, magnetizing inductance energy is resetted. This stage ends when the control signal is applied to the switch of Q1.

2.1. Design Procedure

In genereal, while making a DC-DC converter design circuit determining the parameters that will provide the desired output values before the stages is required. For this requirement, the supply input and output voltages maximum, minimum values, line frequency from which the supply voltage is taken, operating frequency of the switching element; the power value to be taken from the output; exit and the efficiency value against which the input powers are compared, the control mode of the circuit and the operation mode (discontinuous - continuous); loss factor and ripple factor values should be determined and must be calculated. These design parameters, respectively, are presented in the following section is explained. Furhermore, this study, snubber circuit design is added.

2.1.1. Input Analysis

The input voltage waveform is given in Figure 2. At this figure t_C is the charging time of the input capacitor. V_{AC} is the line voltage RMS value.

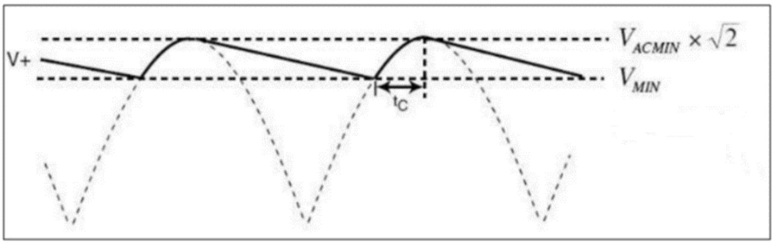


Figure 2. The input capacitor voltage waveform

In this converter, input rectifier capacitor can be calculated as follows. Firstly, the input power is calculated as given.

$$P_i = \frac{P_o}{\eta} \tag{4}$$

We assume that the line frequency is f_L, the input capacitor is defined as in the given equation.

$$C_{in} = \frac{P_i\left(\frac{1}{f_L}\right) - 2t_C}{\left(V_{AC\max}{}^2 - V_{AC\min}{}^2\right)} \tag{5}$$

2.1.2. Transformer Analysis

The inductance value can be defined with assuming the bound operation between DCM and CCM. This inductance value is the magnetizing or the primary winding value of the transformer. It can be calculated according to the maximum load condition as follows.

$$L_{M\_max} = \frac{\left(V_{AC\_min} D_{max}\right)^2}{2P_i f_s} \tag{6}$$

At this equation, D_{max} is the maximum duty cycle under the worst conditions, which can be defined by maximum load, minimum input voltage with bound current mode, f_s is the switching frequency. Once, f_s and P_i is selected L_M can be calculated easily. At the applications, the inductance values which is lower than this calculated value guarantees DCM operation.

The turn ratio is calculated based on the secondary winding and primary winding voltage values and Voltage-Second balance equations. Choosing the reflected to the primary winding voltage V_R value too high, will cause a high conversion rate. So it will cause more voltage stresses on the mosfet and less voltage stress on the output diode. Choosing too low will result in a low conversion rate, which will lead to the opposite situation. So, the turns ratio n can be calculated as follows.

$$n = \frac{V_R}{V_o} \tag{7}$$

In here, if we accept the diode is non-ideal, we have to use V_R+V_{diode} instead of V_R. For the leakage inductance, the air gap size is more important. So, there are some formulas to define the airgap, assuming the the core A_l is 4700nH/n^2.

$$\Phi = BxA_e \tag{8}$$

Where A_e is the croos-sectional area of the core, and A_e value is 18 mm^2 for E20 type cores for out proposed converter. So, primary winding number of turns are calculated as in the following formula.

$$N_{P\_min} = \frac{L_m I_{LM\_max}}{BA_e} \tag{9}$$

Also the leakage inductance is defined as follows, where ℓ_g is the length of the air gap.

$$L_{lk} = \mu_o A_e \frac{N_p^{\ 2}}{L_p \ell_g} \tag{10}$$

2.1.4. Snubber Analysis

Snubber components are calculated according to the resonances and ripples on the semiconductor. The primary snubber is selected according to the energy of the leakage inductance. If the leakage inductance is selected suitable, the primary snubber parameter selection is easy and the power loss of the snubber is decreased. This primary snubber voltage is selected according to the engineer experience higher 50 V from V_R. So, the resistor can be calculated as follows.

$$P_{loos\_Rs} = \frac{(V_R + 50)^2}{R_S} \tag{11}$$

The other snubber is called as light snubber and it is connected parallel to semiconductors. It is calculated according to the resonance which occurs after the semiconductors turns off. At the industrial systems they are selected according to the experiences, however they cause external losses and voltage spikes. So, the calculated snubber values achieve high efficiency and low cost. They can be calculated as follows according to the resonance frequency ω_r. C_{s1} and R_{S1} are the snubber parameters.

$$\omega_r = \frac{1}{\sqrt{L_{lk} C_{s1}}} \tag{12}$$

$$R_{s1} = X_{Llk} = \omega_r L_{lk} \tag{13}$$

$$X_{Cs1} = \frac{R_{s1}}{5} = \frac{1}{\omega_r C_{s1}} \tag{14}$$

Once the leakage inductance is calculated the snubber parameters can be calculated easily.

2.1.4. Output Analysis

Expressed as follows, the ripple of the voltage at the output V_0, the D_{MAX} maximum duty cycle value and f_s is the value of the switching frequency. Also circuit the ripple amount of the current on this capacitance used at its output also is importance. It is preferred that this capacitor also has low ESR. On capacitor with ESR prevents additional filter.

$$C_o = \frac{D_{MAX} P_o}{f_s \Delta V_o V_o} \quad (15)$$

3. EXPERIMENTAL RESULTS

According to the aforementioned design procedure, the parameters of the converter can be defined as in Table I. At this converter, TOPS249witch is used for the application.

Table 1. Parameters of the implementation circuit

Parameter	**Symbol**	**Values**	**Model**
Input Voltage	V_{AC}	85 V-265 V	-
Output Voltage	V_o	12 V(1A) and 5V (1A)	-
Output Power	P_o	17 W	-
Switching Frequency	f_s	66 kHz and 133 kHz	-
Filter Capacitor	C_i	47 µF	Elektrolytic
Output Capacitor	C_o	470 µF	Elektrolytic
Primer Inductance	L_p	3500 µH	
Leakage Inductance	L_{lk}	3,5 uH	E20 core Np=127 Ns1=13 Ns2=6
Seconder Inductance	L_s	400 µH 100 µH	

The simulation circuit scheme is given in Figure 3.

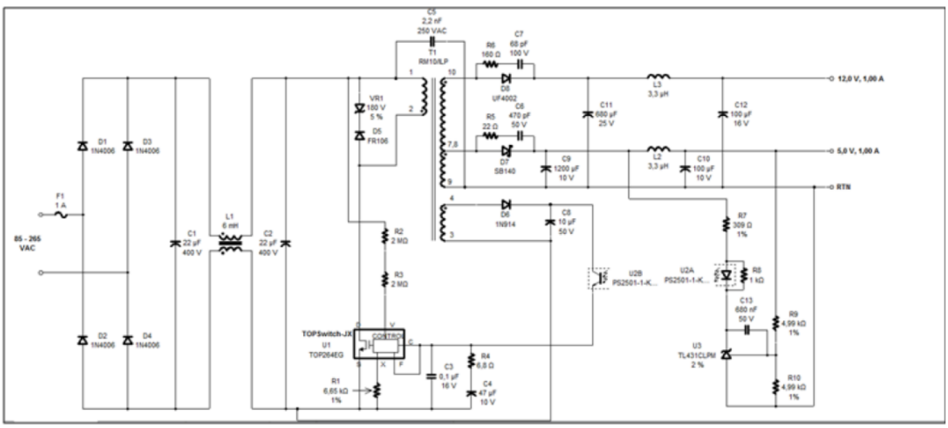


Figure 3. The simulation circuit scheme of the proposed flyback

The prototype of the proposed converter is given in Figure 4. The circuit size is minimum and snubber cell does not cause exceeding the volume.

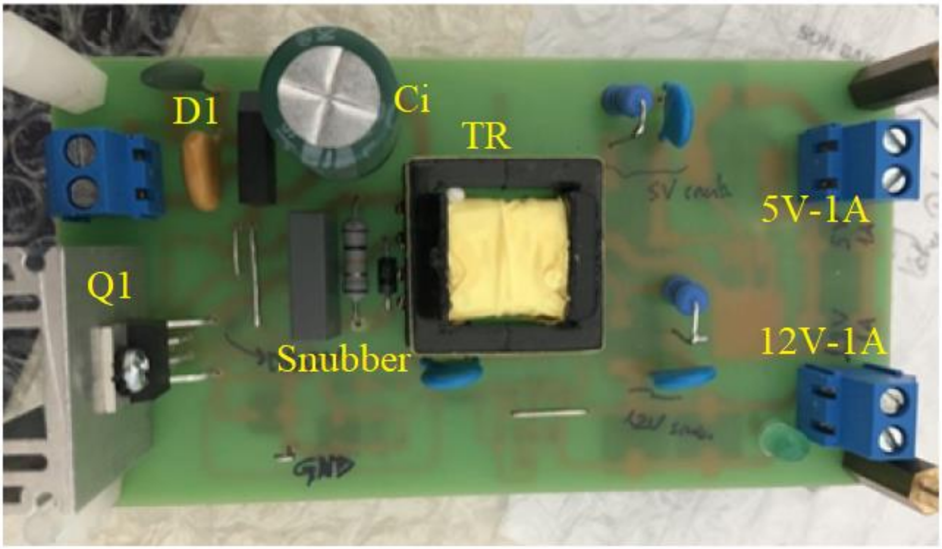


Figure 4. The prototype of the proposed flyback

Firstly, the voltage waveforms is taken as in Figure 5. The voltage stresses of the switch is reduced with the choosing optimum snubber cell 2W 10Ω with 2,2 nF for diodes and 100nF 2 W10 k Ω for primary winding according to snubber design procedure.

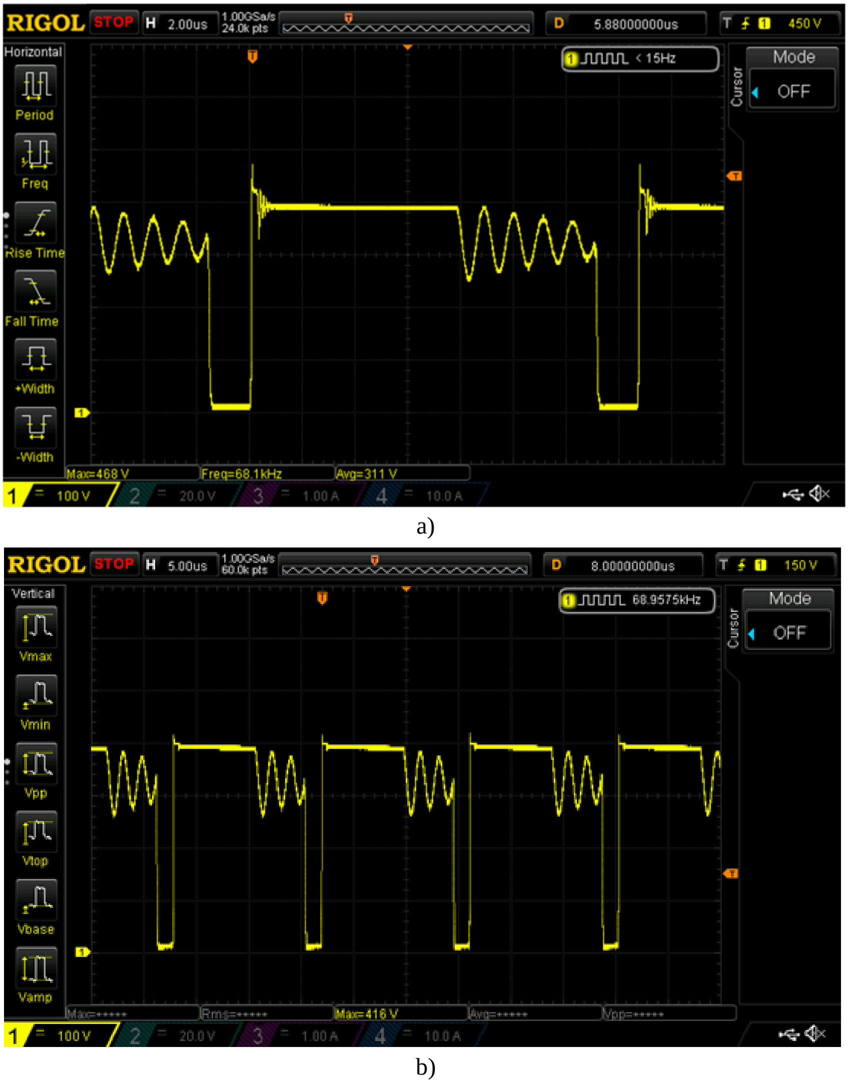
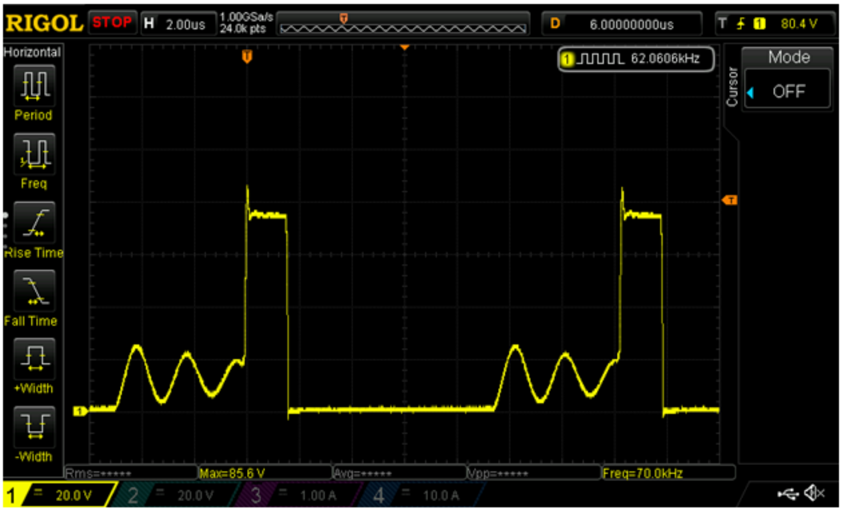
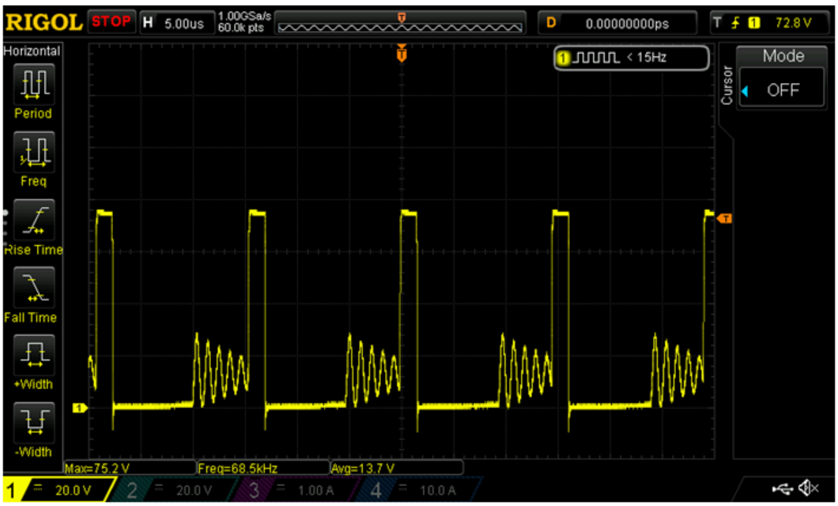


Figure 5. The voltage waveform of the switch a) without snubber, b) with snubber(150V/div)

The voltage waveforms of the dioede is taken as in Figure 6. It can be clearly seen that the voltage stresses of the diode is reduced from 80,4 V to 72,8 V with the choosing optimum snubber cell.



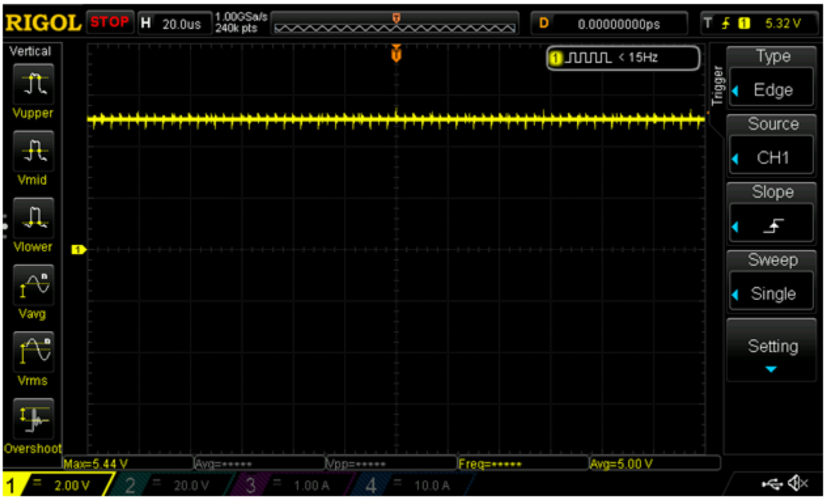
a)



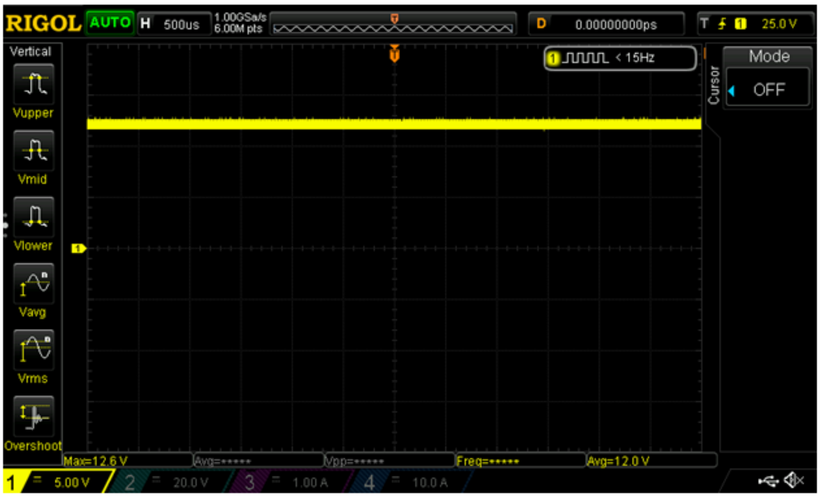
b)

Figure 6. The voltage waveform of the diode a) without snubber, b) with snubber(150V/div)

The voltage waveforms of the output voltages are given in Figure 7. The output voltages are tight regulated thanks to TOPswitch 247 and feedback control scheme.



a)



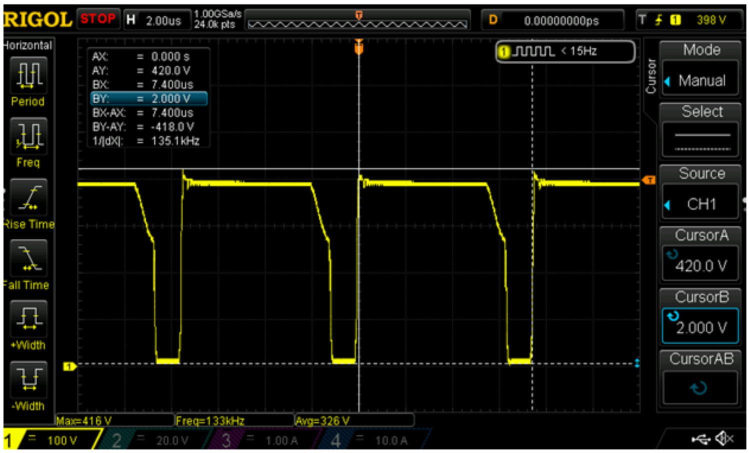
b)

Figure 7. The voltage waveform of the outputs a) 5V b) 12 V

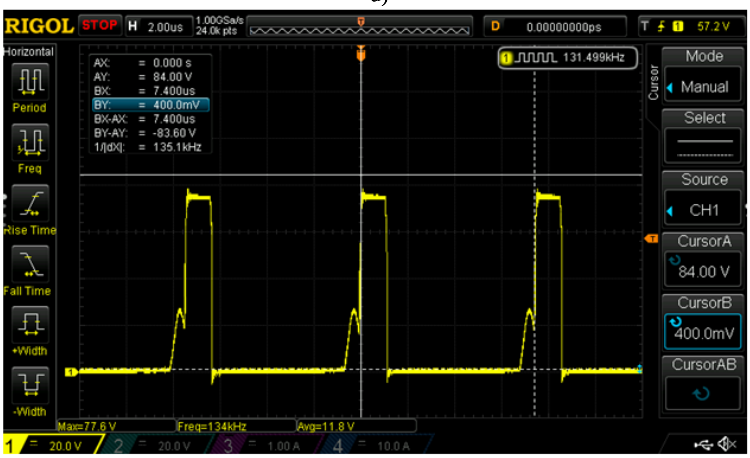
The voltage waveforms of the switch and diode voltages for 138 kHz are given in Figure 8. There are no external voltage stresses and we can say that proposed snubber cell is suitable for wide frequency ranges which may cause external losses.

4. CONCLUSIONS

In this study, analysis and design of a flyback converter with suitable snubber cells are achieved. At this study, to verify the theoretical analysis, the detailed theoretical analysis was confirmed by an application circuit with two ouputs of 5V-1A and 12V – 1A with input voltage of 310 V DC via 66 kHz and 138 kHz are achieved. The selecting twice for the switching frequency may cause external stresses and losses at the applications of the passive snubbers. So, they may require external soft switching cells. In this study, the snubber circuit operates perfectly under different frequencies without external soft switching cells. The theoretical analysis and design procedure was given and they are verified eith the prototype for 85 V- 265 V RMS input voltage values. Accordingly, in our circuit, the snubber circuits at the seconder side of our transformer at an operating power such as 17-18 W, it is in an excess position dismantling can be done in mind. The primary and seconder snubber parameters are selected to not to cause external voltage stressses and losses. The efficiency is measured %77 thanks to minimum power losses on the proposed snubber. Furhermore, the voltage stresses of the switch and the diode is suppressed.



a)



b)

Figure 8. The voltage waveform of a) the switch and b) the diode

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