Abstract-- This paper presents a novel integrated nondissipative snubber for flyback converter. The overall efficiency of proposed circuit is higher than that using conventional nondissipative snubber. By the use of a multi-winding transformer, the novel nondissipative snubber integrates the snubber inductor with flyback transformer in a magnetic core. The additional magnetic core, using in conventional nondissipative snubber, is not need for the proposed circuit.

To verify the performance of proposed topology, an experimental prototype is built to demonstrate the performance of the proposed integrated nondissipative snubber. The experimental results show the advantages of the proposed circuit.

I. INTRODUCTION

A turn off snubber is frequently used in switching power applications to limit the rate of rise voltage across the switching device at turn off. In this chapter, the conventional dissipative snubber and nondissipative snubber circuits are reviewed. It involves conventional RCD [1], regeneration RCD [2], TVS [3]-[4] passive and active nondissipative snubber. A novel nondissipative snubber integrates with flyback converter is proposed. The mathematics analysis of proposed circuit is derived along with five operating states. The simulation and the experimental results have shown the advantage of the proposed circuit. Comparison among these snubber circuits is present.

Usually, a snubber capacitor is used in turn off snubber circuit, the power in the snubber circuit to be dissipated or transferred. This dissipated or transferred power can be expressed as

$$P_c = \frac{1}{2} CV_s^2 f_s$$  \hspace{1cm} (1)

Where $V_s$ is the DC bus voltage and $f_s$ is the switching frequency. To obtain a smaller volume and achieve fast regulation, the switching frequency of modern power supplies is normally higher than 50 kHz. Therefore the $P_c$ is increased and the overall efficiency is decreased. Fig. 1 shows the conventional snubber circuits. In Fig. 1(a), an RCD snubber is paralleled with the power switch. The power storage in the capacitor $C_s$ during turn-off period must be dissipated by the resistor $R_s$ while $S$ is turned on. The disadvantage is increasing the turn-on current of switch. The improved scheme is shown in Fig. 1(b). It can be observed that the capacitor energy is discharged by the parallel resistor directly, and it will not cause additional current on the power switch while the switch is turned on. For flyback converter, a transient voltage suppressor (TVS) shown in Fig. 1(c) is widely employed in low power applications. $D_1$ and $D_2$ are used to reduce the leading-edge voltage spike and ringing caused by transformer leakage inductance to a safe value. However, these dissipative snubbers can not meet the high efficiency desired for modern power supply.

II. REGENERATIVE AND NONDISSIPATIVE SNUBBERS

To improve the overall efficiency of power converter, several regenerative and nondissipative snubber circuits were proposed. They are reviewed as follows:

(A). RCD regenerative snubber

Fig. 2(a) shows a RCD regenerative snubber with additional ferrite transformer without active device. This method can be passively recovered more than 70% of $P_c$ into the DC bus. However, it still dissipates part of $P_c$ on the snubber resistor $R_s$.

(B). Active clamp snubber

An alternated scheme of regenerative snubber shown as Fig. 2(b) is active clamp snubber [5]-[9]. The incorporation of the active clamp circuit into basic flyback topology not only regenerates the energy stored in snubber capacitor; it can also achieve zero voltage switching (ZVS) for the power switches [10]-[11]. Of cause, the additional active switch and complicated controller are needed in this topology.

(C). Passive nondissipative snubber

A simple and cost advantageous regenerative snubber for flyback converter shown in Fig. 3 is a passive nondissipative snubber [12]-[16]. The nondissipative snubber can decrease substantially the turn off switching loss and regenerated the energy stored in snubber capacitor to DC bus or in the magnetizing inductor $L_m$ of the flyback transformer.
III. PROPOSED INTEGRATED NONDISSIPATIVE SNUBBER

![Diagram of proposed integrated nondissipative snubber with flyback converter.](image)

From the concept of multiple-winding transformer, a novel nondissipative snubber by multiple-winding transformer is proposed. Multiple-winding transformer or couple inductors are employed wildly such as magnetizing energy reset, multiple output power supply [17], reduction the cross-regulation of output voltage[18] and ripple suppression [19]-[22].

In this paper, a novel nondissipative snubber integrated the snubber circuit with the flyback circuit by the addition of a third winding in the transformer. It can be observed in Fig. 4, the energy stored in snubber capacitor will recovery to DC bus and the magnetizing inductor \( L_m \) of the flyback transformer. The mathematics analysis and the results of simulation and experiment are presented in next section.

**Analysis of proposed integrated nondissipative snubber**

There are five operating states in the steady state of the proposed integrated nondissipative with a flyback converter. Table 1 lists the device conduction mode of the proposed circuit. The duration of the operating states is present in Fig. 5, showing circuit waveforms over one switching period. The operations of proposed circuit can be observed and analyzed. Table 2 lists the symbols of the parameters of proposed circuit. Each operating state is as analyzed as follows:

<table>
<thead>
<tr>
<th>Table 1. Device conduction mode.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>State</strong></td>
</tr>
<tr>
<td><strong>S</strong></td>
</tr>
<tr>
<td><strong>D_1</strong></td>
</tr>
<tr>
<td><strong>D_2</strong></td>
</tr>
<tr>
<td><strong>D_3</strong></td>
</tr>
</tbody>
</table>

![Diagram of proposed circuit.](image)

(A). State 1 \((t_0-t_1)\)

As shown in Fig. 5 and Fig. 6(a), \( S \) and \( D_2 \) are turned on in this operating state, the voltage of capacitor \( v_{CR} \) is discharged to the magnetizing inductor \( L_m \) and DC bus through the third winding \( n_3 \). From Fig. 6(a), the capacitor can be expressed as:

\[
v_{CR} + L_2 C_r \frac{d^2 V_{CR}}{dt^2} = k_3 V_i
\]

where

\[
k_3 = \frac{L_{m3} n_3 V_i}{L_{m31} + n_3^2 L_{131}}
\]

\[
L_p = L_{31} + \frac{V_{CR}^2}{n_3^2 L_{131}}
\]

\[
d_{i_1}/dt = \frac{V_{CR} - L_{31} \frac{di}{dt}}{L_{31}}
\]

\[
d_{i_2}/dt = \frac{V_{CR} - L_{31} \frac{di}{dt}}{L_{31}}
\]

**Table 2. The symbols of the proposed circuit.**

- \( L_m \): magnetizing inductance on primary side
- \( L_2 \): the equivalent inductance on secondary side
- \( L_3 \): the equivalent inductance on the third winding
- \( L_{m31} \): mutual inductance between third and primary side converted to third side.
- \( L_{o32} \): mutual inductance between third and secondary side converted to third side.
- \( L_{o33} \): leakage inductance between primary and secondary side converted to primary side.
- \( L_{o32} \): leakage inductance between third and primary side converted to third side.
- \( L_{o32} \): leakage inductance between third and secondary side converted to third side.
- \( n_{12} \): turns ratio of \( n_1 \)/\( n_2 \)
- \( n_{31} \): turns ratio of \( n_3 \)/\( n_1 \)

\[v_{CR} = \frac{V_{CR} - L_{31} \frac{di}{dt}}{L_{31}} \]

\[
d_{i_1}/dt = \frac{V_{CR} - L_{31} \frac{di}{dt}}{L_{31}}
\]

\[
d_{i_2}/dt = \frac{V_{CR} - L_{31} \frac{di}{dt}}{L_{31}}
\]
The circuit waveforms of the proposed nondissipative snubber integrated in flyback converter.

\[ i_2 = 0, \quad i_3 = -i_{Cr} \]  \quad (9)

\[ v_{Co} = \frac{1}{R_o C_o} \frac{dv_{Co}}{dt} \]  \quad (10)

(B). State 2 \((t_1-t_2)\)

This operating state is the same as the turn on state of a typical flyback circuit. Thus, only the switch S is turned on in this state. The magnetizing inductor \(L_m\) is charged by the DC bus, and the input current can be expressed as follows:

\[ i_1 = i_1 = \frac{v_i}{(L_{Q12} + L_m)} (t-t_1) + i_1(t_1) \]  \quad (11)

\[ i_2 = 0, \quad i_3 = 0 \]  \quad (12)

(C). State 3 \((t_2-t_3)\)

In this state, the switch S is turned off firstly, a part of the energy stored in leakage inductor \(L_{L2}\) is absorbed by the capacitor \(C\). Thus the switch voltage slope and overshoot are reduced, and resulting in lower turn-off loss. Then, the diode \(D_3\) is conducted to charge the output capacitor. In this state, the relative circuit parameters can be expressed as follows:

\[ v_{Cr} + (L_{Q12} + L_m) C_r \frac{d^2 v_{Cr}}{dt^2} = 0 \]  \quad (13)

\[ i_1 = 0 \]  \quad (14)

\[ i_1 = i_{Cr} = C_r \frac{dv_{Cr}}{dt} \]  \quad (15)

\[ i_2 = n_{L2}(i_d(t_2) - i_d(t)) \]  \quad (16)

\[ v_{Co} = \frac{1}{R_o C_o} \frac{dv_{Co}}{dt} \]  \quad (17)

\[ i_1 = 0, \quad i_2 = 0, \quad i_{Cr} = 0, \quad i_3 = 0 \]  \quad (18)

(D) State 4 \((t_3-t_4)\)

The energy stored in magnetizing inductor \(L_m\) is discharged through the secondary side, the capacitor \(C_o\) and the load \(R_o\) absorb the energy from \(L_m\). It results in

\[ i_2 \approx -\frac{V_o}{L_2} + i_3(t_3) \]  \quad (19)
while the energy in \( L_r \) is decreasing to zero, \( D_1 \) is turned on and \( D_2 \) is conducted.

\( E \) State 5 \((t_5-t_6)\)

The capacitor voltage \( v_c \) is discharged through \( D_3 \), winding \( n_3 \) and winding \( n_1 \) to the DC bus. The equations can derived as follows:

\[
i_c = C_r \frac{d v_c}{d t}
\]

(21)

\[
\frac{d i_c}{d t} = C_r \frac{d^2 v_c}{d t^2}
\]

(22)

\[
v_i = L_{12} \frac{d i_c}{d t} + n_{12} v_o + v_c + L_{32} \frac{d i_c}{d t} + n_{32} v_o = (n_{12} + n_{32}) v_o + v_c
\]

(23)

\[
v_i = L_{12} C_r \frac{d^2 v_c}{d t^2} + n_{12} v_o + v_c + L_{32} C_r \frac{d^2 v_c}{d t^2} + n_{32} v_o
\]

(24)

\[
v_i = (L_{12} C_r + L_{32} C_r) \frac{d^2 v_c}{d t^2} + (n_{12} + n_{32}) v_o + v_c
\]

(25)

\[
\frac{d^2 v_c}{d t^2} + \frac{v_c}{L_{12} C_r + L_{32} C_r} = \frac{v_i - (n_{12} + n_{32}) v_o}{L_{12} C_r + L_{32} C_r}
\]

(26)

It can be observed in Fig. 6(e), the capacitor energy regenerated to DC bus and flyback transformer has not through the diode \( D_1 \). Thus, more power loss of proposed nondissipative snubber is reduced than that in conventional nondissipative snubber.

IV. SIMULATION AND EXPERIMENTAL RESULTS

The IsSpice circuit simulation program was used to evaluated performance of the proposed circuit evaluation. In addition, an experimental prototype has built to show the performance of the proposed integrated nondissipative snubber. The specifications and parameters for simulation and experimental prototype are listed in Table 3.

Table 3 The specifications and parameters of prototype with proposed topology.

<table>
<thead>
<tr>
<th>( V_r )</th>
<th>( V_o )</th>
<th>( n_1 )</th>
<th>( n_2 )</th>
<th>( L_r )</th>
<th>( L_c )</th>
<th>( C_r )</th>
<th>( C_o )</th>
<th>( R_o )</th>
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<tbody>
<tr>
<td>150</td>
<td>15</td>
<td>60</td>
<td>10</td>
<td>340</td>
<td>50</td>
<td>4.7</td>
<td>220</td>
<td>3.75</td>
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</table>

Table 4 The specifications and parameters of prototype with conventional nondissipative snubber.

<table>
<thead>
<tr>
<th>( V_r )</th>
<th>( V_o )</th>
<th>( n_1 )</th>
<th>( n_2 )</th>
<th>( L_r )</th>
<th>( C_r )</th>
<th>( C_o )</th>
<th>( R_o )</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>15</td>
<td>60</td>
<td>10</td>
<td>340</td>
<td>2.2</td>
<td>220</td>
<td>6.8k</td>
</tr>
</tbody>
</table>

Table 5 The specifications and parameters of prototype with RCD snubber.

<table>
<thead>
<tr>
<th>( V_r )</th>
<th>( V_o )</th>
<th>( n_1 )</th>
<th>( n_2 )</th>
<th>( L_r )</th>
<th>( L_{rs} )</th>
<th>( L_{so} )</th>
<th>( C_r )</th>
<th>( C_o )</th>
<th>( R_o )</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>15</td>
<td>60</td>
<td>10</td>
<td>340</td>
<td>10</td>
<td>10</td>
<td>9.4</td>
<td>220</td>
<td>3.75</td>
</tr>
</tbody>
</table>

V. CONCLUSION

In this paper, a novel integrated nondissipative snubber is presented to improve the efficiency of flyback converter. The analysis of proposed topology is presented. To verify the performance of proposed topology, an experimental prototype has built to show the performance of the proposed integrated nondissipative snubber. The simulation and the experimental results have shown the advantage of the
proposed circuit.

Fig. 7  The voltage and current of the snubber capacitor. (a) Simulation results (b) Experimental results. (100V/div.; 2A/div.; 5µs/div.)

Fig. 8  The switch voltage $v_{ds}$ and current $i_{ds}$. (100V/div.; 2A/div.; 5µs/div.) (a) Simulation results. (b) Experimental results.

Fig. 9  The switch voltage $v_c$ and input current $i_c$. (100V/div.; 2A/div.; 5µs/div.) (a) Simulation results. (b) Experimental results.

Fig. 10 The capacitor voltage $v_{Cr}$ and current $i_{Cr}$ with conventional non-dissipative snubber. (100V/div.; 2A/div.; 5µs/div.)

Fig. 11 The voltage $v_{ds}$ and current $i_{ds}$ with conventional non-dissipative snubber. (100V/div.; 2A/div.; 5µs/div.)
Fig. 12 The voltage $v_{ds}$ and current $v_{Cs}$ with conventional RCD snubber. (100V/div.; 5µs/div.)

Fig. 13 The experimental efficiency measured in the prototype with (a) proposed integrated non-dissipative snubber, (b) conventional RCD snubber and (c) conventional non-dissipative snubber.

References


