**Abstract**—This brief introduces a method of improving the power conversion efficiency of a dc-dc boost converter with a passive snubber circuit. This method uses a passive snubber circuit which consists of two inductors, a capacitor, and a diode, to reduce switching loss. The use of passive soft-switching methods has been emphasized as better alternative to active methods mainly because they do not require extra switches or additional control circuitry. They are less expensive, have higher reliability, and have been reported to achieve higher performance. In this paper, a new high-efficiency dc-dc boost converter with a passive snubber circuit is proposed. Passive soft-switching methods have been used to reduce these switching losses.

**Index Terms**—Direct-current–direct-current (dc–dc) power conversion, light-emitting-diode (LED) displays, snubbers.

I. INTRODUCTION

A dc-dc boost converter is a step-up converter. It has several advantages over other step-up dc–dc converters. It has a simple structure that consists of a few components; therefore, it can easily be designed and implemented using a small inexpensive circuit. Various soft-switched boost converters with a passive snubber circuit have been proposed. The proposed boost converter utilizes a soft switching method using an auxiliary circuit with a resonant inductor and capacitor, auxiliary switch, and diodes. Therefore, the proposed soft-switching boost converter reduces switching losses more than the conventional hard switching converter. Passive snubber circuits can achieve soft switching and reduce the reverse recovery current of a rectifier diode by using only passive components such as inductors, capacitors, and diodes without auxiliary switches. Compared with active snubber circuits, passive snubber circuits are generally simpler to design and have fewer components; therefore, they are less expensive, more reliable, and smaller. In this project, a new high-efficiency dc–dc boost converter with a passive snubber circuit is proposed. Passive soft-switching methods have been used to reduce these switching losses. Recently, passive soft-switching has received renewed inspection as a better alternative than the active methods.

![Fig. 1. Circuit diagram of the proposed boost converter. Its components are described in the text.](image)

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A. Circuit Description

Mode 1 ([t₀ − t₁]): At this mode, Q is turned on and the current iₘ has reached zero. Thus, Q₀ is turned off during this mode without any reverse recovery process. i₉ begins to decrease iₘ early because V₉ applied across Lₛ₁ is constant, but...
The current $i_q$ begins to increase at the same rate because $I_q + i_d = I_{in}$, which is constant. Currents $i_d$ and $i_q$ are given by

$$i_d(t) = I_{in} - \frac{V_o}{L_{sl}}(t - t_0)$$

$$i_q(t) = \frac{V_o}{L_{sl}}(t - t_0)$$

Thus, $Q$ is turned on at $i = t_0$ under ZCS. $i_d$ reaches 0 and $i_q$ reaches $I_{in}$ at $t = t_0 + \frac{\ln L_{sl}}{V_o} = t_1$.

During this mode, $C_s$ is discharged through $L_{s2}$ to the load by $i_{s2}$ and thus $V_{o}$ decreases from $V_{o}(t_0)$ to $V_o$.

**Mode 2 [t_1 − t_2]:** In this mode, $Q$ remains on, $S_{on}$, $D_3$ remains off, and $D$ is turned off without any reverse recovery process because has reached zero at $t_1$; thus $I_q(t) = I_{in}$. At $t_2$, $i_{s2}$ reaches $i_{s2}(t_2)$ and $V_{o}$ reaches $V_{o}(t_2)$.

**Mode 3 [t_2 − t_3]:** At $t_2$, $Q$ is turned off and $D_3$ is turned on. $D$ remains off. Thus, $i_{s2}$ flows through $D_3$. $i_{D3}(= I_{in})$ is divided into $i_{s2}$ and $i_{C_s}$, which results in $V_{o}$ increase slowly because $C_s$ is charged by $i_{C_s}$. Because the forward voltage of $D_3$ and the voltage across $L_{sl}$ are negligibly small, $V_{o} = V_{o}$ and $V_{o} = V_{o} - V_{o}$. Thus, $V_{o}$ increases slowly, and $V_{o}$ decreases slowly at the same rate.

Where

$$\omega_1 = \frac{1}{\sqrt{L_{s2} C_s}}$$

$$Z_s = \sqrt{\frac{L_{s2}}{C_s}}$$

At $t_2$, $V_{o}$ increases to $V_0$. Thus, $V_{o}$ decreases to 0 and $D$ starts conducting. Currents $i_{s2}$ reaches $i_{s2}(t_3)$ and $i_{C_s}$ reaches $i_{C_s}(t_3)$. The duration of this mode is

$$\Delta t_3 = t_3 - t_2 = 1 - \frac{1}{\omega_1 \tan^{-1} \left( \frac{V_0 - V_{o}(t_2)}{\ln I_{in} - i_{s2}(t_2)} \right)}$$

**Mode 4 [t_3 − t_4]:** In this mode, $Q$ remains off and $D_3$ remains on, $D$ is turned on, and $D_3$ is turned off. $i_{s2}$ flows through $D$ and $D_3$, and $i_{s2}$ is divided into $i_{s2}$ and $i_{C_s}$. Then $i_{s2}$ flows through $L_{s2}$ in $V_{o}$ and $i_{C_s}$ charges $C_s$. $V_{o}(= V_{o})$ is increased slowly from $V_{o}$ by the resonant current $i_{C_s}$. $i_{s2}$ and $i_{C_s}$ are given by

$$V_{o}(t) = Z_s i_{s2}(t_3) \sin \omega_1 (t - t_2) + V_0$$

$$i_{C_s}(t) = i_{C_s}(t_3) \cos \omega_1 (t - t_2)$$

Where

$$\omega_2 = \frac{1}{\sqrt{L_{s2} C_s}}$$

$$Z_s = \sqrt{\frac{L_{s2} i_{s2}}{(C_s + i_{s2}) C_s}}$$

By setting the duration $\Delta t_4$ of this mode as

$$\Delta t_4 = t_4 - t_3 = \frac{\pi}{2 \omega_2}$$

### III. DESIGN CONSIDERATIONS

In the proposed boost converter, the ZCS turn-on of $Q$ is achieved by controlling the turn-off $d_1/d_0$ of $D$ using $L_{s2}$ and by eliminating reverse recovery current of $D_3$. $L_{s2}$, $L_{sl}$, and $C_s$ are the main components that should be designed to achieve optimal performance of the proposed boost converter. To control the turn-off $d_1/d_0$ of $D$, $L_{sl}$ should be determined according to

$$L_{sl} > \frac{V_o}{I_{in}} \equiv Ls1_{min}$$

Where the switch current rise time $t_s$ is dictated by $Q$ and its gate drive circuit. $L_{sl}$ should be larger than $L_{sl_{min}}$ to guarantee ZCS turn-on of $Q$. In practice, as $L_{sl}$ increases, the switching loss decreases but the inductor loss increases. Thus, $L_{sl}$ should be determined experimentally so that the sum of the switching loss and the inductor loss has the minimum value. To eliminate the reverse-recovery-current of $D_3$, the current $i_{D3}$ should reach zero at $t_4$. Thus, the following equations should be satisfied.

$$\Delta t_3 = (1 - D_r) T_s - \frac{1}{\omega_2} \tan^{-1} \left( \frac{Z_s}{Z_s \tan \omega_2 \Delta t_3} \right)$$

$$\Delta t_3 = \frac{1}{\omega_2} \tan^{-1} \left( \frac{Z_s}{Z_s \tan \omega_2 \Delta t_3} \right)$$

If $i_{D3} > 0$ at $t_4$, switching losses occur at the instant of switch turn-on due to the high turn-off $d_1/d_0$ and reverse recovery current of $D_3$; and if $i_{D3}$ reaches 0 at $t_4$, the parasitic oscillation of $Q$ occurs due to the resonance of $L_{sl}$ and the internal capacitance of $Q$ during $t_4 - t_4$, causing extra power losses. But, these losses are smaller than the reverse recovery-related loss of the boost diode in the conventional boost converter in the proposed boost converter, it is required that the input energy and the energy stored in $C_s$ is transferred to the output load during overall operating modes. Thus, $i_{s2}$ that has the minimum value at $t_3$ (in Mode3) should be

$$i_{s2}(t_3) = I_{in} \left( 1 - \cos \omega_1 \Delta t_3 - \frac{\sin \omega_1 \Delta t_3}{\tan \omega_1 (\Delta t_3 + \Delta t_3)} \right) > 0$$

Otherwise, the energy stored in $C_s$ is transferred to $C_s$ while $i_{s2} < 0$.

The voltage stress of the diodes $D$ and $D_3$ are determined by $V_{o}$, and the voltage stress of $Q$ is determined by $V_{o}$ given in (mode 3). $V_{o, max}$ can be presented as

$$V_{o, max} = Z_s I_{in} \left( \cos \omega_1 \Delta t_3 - \frac{\sin \omega_1 \Delta t_3}{\tan \omega_1 (\Delta t_3 + \Delta t_3)} \right)$$

Due to the resonant peak generated by $L_{sl1}, L_{s2}$ and $C_s$, the Voltage stress ($= V_{o, max}$) of $Q$ in the proposed boost converter is higher than that ($= V_{o}, V_{o}$) in the conventional boost converter.

The current stress of $Q, D$ and $D_3$ are determined by $I_{in}$ and the current stress of $Q$ in the proposed boost converter is...
lower than that in the conventional boost converter because the reverse-recovery-current spikes of $D_1$ and $D_3$ are eliminated in the proposed boost converter.

IV. EXPERIMENTAL RESULTS

The the dc-dc boost converter with passive snubber circuit was designed using the following specifications given below.

<table>
<thead>
<tr>
<th>Input Voltage ($V_i$)</th>
<th>24 VDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage ($V_o$)</td>
<td>46 VDC</td>
</tr>
<tr>
<td>Switching Frequency $f_s$</td>
<td>10kHz</td>
</tr>
<tr>
<td>Inductance $L$</td>
<td>5µH</td>
</tr>
<tr>
<td>Capacitance $C$</td>
<td>10µF</td>
</tr>
<tr>
<td>Resistance $R_S$</td>
<td>25Ω</td>
</tr>
<tr>
<td>Inductance $L_S$</td>
<td>0.6µH</td>
</tr>
</tbody>
</table>

The complete schematic of the experimental setup of the dc-dc boost converter with passive snubber circuit for closed loop circuit is shown in Fig. 5. The boost converters were designed to produce the constant dc output $V_O = 46$ V for an input voltage $V_{IN}$ range of 24 V. They were operated at a switching frequency of 10 kHz. A dc voltage feedback control was used to ensure the stability of the converters. The circuits were built using the following components: $L = 0.6\mu H$; $C = 250\mu F$. The values of $L_{S1}$, $L_{S2}$, and $C_S$ for the passive snubber circuit $V_{Q,max}$ value for the entire output power range. For the LED-BLU experiment $L_{S2} = 10\mu H$, and $C_S = 10\mu F$ which resulted in $V_{Q,max} < 46$ V for $80 \leq P_o \leq 82$ W. The current and voltage waveforms of switch $Q$ were measured at $V_{IN} = 24$ V, $V_o = 46$ V, and $P_o = 82$ W.

The maximum voltage across the powerMOSFET switches is measured to be $V_f = 24$ V as shown at selected values of output power. To reduce electromagnetic interference noise generated at the instant of turn-off switching, simple resistance capacitance snubber circuits composed of a resistor and a capacitor were connected in parallel to the boost switches and diodes of the passive snubber circuit. The passive snubber circuit is clearly avoided in the proposed converter, and hence, a MOSFET with a lower voltage rating can be safely used.

V. CONCLUSION AND FUTURE WORK

This brief has proposed a new high-efficiency dc–dc boost converter with passive snubber circuit to reduced transistor voltage spikes. The steady-state analysis of the proposed converter has been presented by taking the voltage and current spikes into account. The passive snubber circuit consists of two inductors, a capacitor, and a diode; it reduces the reverse-recovery-related losses of the diodes and provides ZCS turn-on for the boost switch. The proposed boost converter ensured the reliable operation and high-power efficiency under the ±10% variation of the input voltage and ±20% variation of passive-snubber component values.
Compared with the conventional boost converter, the current stress and thermal stress of the boost switch and the diode were decreased, whereas the voltage stress of the boost switch and the diode was increased. The analysis and experimental results provide a basic understanding of the converter behaviour. The proposed passive snubber circuit is a simple topology and can be of high practical value for various industrial applications such as large scale liquid crystal display televisions, light emitting diode (LED) backlight units (BLUs) are gradually replacing cold cathode fluorescent lamp and external electrode fluorescent lamp BLUs.

REFERENCES