A NOVEL SOFT SWITCHED BOOST CONVERTER USING A SINGLE SWITCH

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Abstract-This paper proposes an alternate soft switching scheme for conventional boost converters using lower source voltages. The proposed circuit is simple, uses a single switch and minimum components, and offers load independent operation. The only switch used in the converter is turned on with zero current and turned off at zero voltage. Modewise analysis of the circuit and extensive simulation in PSPICE under wide range of loading conditions have been carried out. The simulation results are found to be in agreement with the analytical expressions.

1. INTRODUCTION

In the last two decades switched mode power supplies have come of age and the recent research has been focussed on soft switching techniques. Soft switching considerably reduces turn on and turn off switching losses which become a major factor to reckon with at higher frequencies and hence makes operation at higher frequencies feasible. A number of circuits [1], [3] and [5] use an additional switch to accomplish the function of soft switching the main device. The circuits proposed in [2] and [4] use a single switch but the device count is high. The circuit of [4] accomplishes reduced voltage and current stresses and the coupling between main and auxiliary circuit inductors significantly attenuates the duty cycle limitations. The circuit proposed in [6] uses a single switch, is simple but has a high device count. This paper offers an alternate scheme for soft switching of the conventional boost converter. The circuit proposed in this paper consists of a simple auxiliary circuit for achieving zero voltage turn off and zero current turn on of the main switch with minimum number of devices or components and does not use an additional switch or coupled inductors.

2. PRINCIPLES OF OPERATION

The proposed circuit is shown in fig. 1. The switch S1, L1, D1 and C2 are the main boost converter components, while R represents the resistive load on the converter. Inductor L2, L3, D1, D2, and C1 form the auxiliary circuit for accomplishing the soft switching of S1. Inductors L2 and L3 are much smaller than L1 and C1 is much smaller than C2. The duration of modes 1, 2, 5 and 6 being quite small iL1 and Vout are assumed constant at I1, and V1 for modes 1 and 2, and I2 and V2 for modes 5 and 6 respectively. The modewise analysis of the circuit is as follows.

Mode 1(t0 - t1): This mode begins with the turn on of S1 at zero current at t0. The equivalent circuit for this mode is shown in fig. 2. The initial conditions on L2, L3 are zero. C1 is previously charged to a value Vc1(t0). The current iL1(t) gradually rises and it becomes equal to I1 + iL3(t) at t1 when D2 stops conducting and this mode comes to an end. The expressions for iL1(t), iL3(t) and Vc1(t) are

\[ i_{L1}(t) = \frac{V_1}{L_2} t \]  
\[ V_{c1}(t) = [V_1 - V_{c1}(t_0)] \left[ 1 - \cos \omega_1 t \right] + V_{c1}(t_0) \]  
\[ i_{L3}(t) = \left[ V_{c1}(t_0) - V_1 \right] \frac{\sin \omega_1 t}{\omega_1 L_3} \]
where \( \omega_1 = \frac{1}{\sqrt{L_2C_1}} \)

**Mode 2 \( t_1 \rightarrow t_2 \):** The equivalent circuit for this mode is shown in fig. 3. The initial conditions on \( L_1, L_2 \) and \( C_1 \) are, \( i_{L_1}(t_1) \) and \( i_{L_2}(t_1)+I_1 \) and \( V_{e_1}(t_1) \) respectively, attained at the end of mode 1. In this mode \( C_1 \) completely discharges and its reverse charging is arrested by \( D_1 \). This mode comes to an end when \( V_{e_1} \) reaches zero at \( t_2 \). The expressions for \( i_{L_2}, i_{L_3} \) and \( V_{e_1} \) are as follows.

\[
V_{e_1}(t) = \frac{V_{c_1}(t_1)}{1 - \cos \omega t} + i_{L_1}(t_1) \cos \omega t + I_1 \]  

(4)

where \( \omega = \frac{1}{\sqrt{L_2C_1}} \)

**Mode 3 \( t_2 \rightarrow t_3 \):** The equivalent circuit for this mode is shown in fig. 4. The initial conditions on \( i_{L_2}, i_{L_3} \) and \( V_{e_1} \) for this mode are \( i_{L_2}(t_2), i_{L_3}(t_2) \) and zero. This mode comes to an end at \( t_1 \) when \( i_{L_3} \) reaches zero at \( t_1 \). The expression for \( i_{L_2} \) for this mode is

\[
i_{L_2}(t) = \frac{V_{c_1}(t_1)}{\omega_2 (L_2 + L_3)} \sin \omega_2 t + i_{L_2}(t_1) \cos \omega_2 t + I_1 \]  

(5)

**Mode 4 \( t_3 \rightarrow t_4 \):** The equivalent circuit for this mode is shown in fig. 5. \( i_{L_3}(t) \) attains a value of \( I_2 \) and \( V_{e_1}(t) \) attains a value of \( V_2 \) at the end of this mode. This mode comes to an end when \( S_1 \) is turned off at zero voltage at \( t_4 \). In this mode current build-up in \( L_1 \) and \( L_2 \), and \( V_{e_1} \) are governed by the equations:

\[
i_{L_2}(t) = i_{L_3}(t) = \frac{V_{S}}{L_2 + L_3} \]  

(8)

\[
V_{e_1}(t) = \frac{V}{\frac{1}{C_1}} \]  

(9)

**Mode 5 \( t_4 \rightarrow t_5 \):** This mode begins with the turn off of \( S_1 \) at zero voltage at \( t_4 \). The equivalent circuit for this mode is shown in fig. 6. The initial condition on \( i_{L_3} \) for this mode is \( I_1 \). The expressions for \( i_{L_2}, i_{L_3} \) and \( V_{e_1} \) for this mode are as follows.

\[
i_{L_2}(t) = \frac{L_2}{L_2 + L_3} \sin \omega_1 t - \frac{V_{c_1}}{L_2 + L_3} \sin \omega_1 t + I_2 \]  

(11)

\[
i_{L_3}(t) = \frac{L_2}{L_2 + L_3} \left[ -V_{c_1} \sin \omega_1 t + I_2 \right] + I_2 \]  

(12)

where \( \omega_1 = \frac{1}{\sqrt{L_2L_3C_1}} \) This mode ends when \( i_{L_2} \) reaches zero at \( t_5 \).

**Mode 6 \( t_5 \rightarrow t_6 \):** The equivalent circuit for this mode is shown in fig. 7. In this mode \( i_{L_3} \) reduces to zero. This mode comes to an end at \( t_6 \) when \( i_{L_3} \) becomes zero. The expression for \( i_{L_3} \) and \( V_{e_1} \) for this mode are

\[
i_{L_3}(t) = \frac{V_{c_1}}{L_2} \sin \omega_1 t + i_{L_3}(t_5) \cos \omega_1 t \]  

(13)

\[
V_{c_1}(t) = \frac{V_{c_1}(t_5) - V_2}{L_2} \sin \omega_1 t + i_{L_3}(t_5) \cos \omega_1 t \]  

(14)

This mode comes to an end when \( i_{L_3} \) becomes zero at \( t_6 \).

**Mode 7 \( t_6 \rightarrow t_7 \):** The equivalent circuit for this mode is shown in fig. 8. In this mode \( i_{L_2}, i_{L_3} \) are zero. This mode comes to an end at \( t_7 \) when \( S_1 \) is turned on at zero current.

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*Note: The above text is a transcription of the mathematical expressions and equations found in the original document.*
This is the normal mode of the boost converter. The inductor current $i_{LI}$ reaches $I_1$ and $V_{out}$ reaches $V_1$ at the end of this mode. The expressions for $V_{out}$ and $i_{LI}$ in this mode are

$$V_{out}(t) = e^{-\alpha t} [A \sin \omega_4 t + B \sin \omega_4 t] + V_S$$

$$i_{LI}(t) = \frac{V_{out}(t)}{R} e^{-\alpha t}$$

$$[(-BC_2 \dot{\alpha} + AC_2 \dot{\alpha}) \cos \omega_4 t$$

$$-(AC_2 \dot{\alpha} + BC_2 \dot{\alpha}) \sin \omega_4 t]$$  \hspace{1cm} (15)

where $\alpha = \frac{1}{2RC_2}$, $\omega_4 = \frac{1}{\sqrt{L_1C_2}}$

$$A = \frac{I_2}{\omega_4 C_2} - \frac{V_2}{R \omega_4 C_2} + \frac{\alpha(V_2 - V_S)}{\omega_4}$$

$$B = V_2 - V_S$$

$$i_{LI}(t) = \frac{V_{out}(t)}{R} e^{-\alpha t}$$

$$[(-BC_2 \dot{\alpha} + AC_2 \dot{\alpha}) \cos \omega_4 t$$

$$-(AC_2 \dot{\alpha} + BC_2 \dot{\alpha}) \sin \omega_4 t]$$  \hspace{1cm} (16)

3. SIMULATION RESULTS

The circuit shown in fig. 1 is simulated in PSpice with $V_s = 10V$, $L_1=1\text{mH}$, $C_1=10\text{nF}$, $L_2=L_3=10\text{uH}$, $C_2=10\text{uF}$ and $R$ ranging from 10 ohms to 2000 ohms. The simulation results are shown in figs. 9 and 10 for frequency=25KHz, $R=50$ohms and duty cycle=75% and 50%. The simulation results agree with analytical results.

4. CONCLUSION

This paper proposes an alternate scheme for soft switching boost converters using low source voltages. It uses a simple circuit with a single switch in the converter and uses minimum number of components. The only switch used in the converter is turned on with zero current and turned off at zero voltage. The analytical expressions for circuit variables in each mode are found to be in agreement with the simulation results.

REFERENCES


Waveforms for R=50 ohms and duty cycle=75%

Fig. 9

Waveforms for R=50 ohms and duty cycle=50%

Fig. 10