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 volatge 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 S_1, L_1 D_3 and C_2 are the main boost converter components, while R represents the resistive load on the converter. Inductor L_2, L_3, D_1, D_2, and C_1 form the auxiliary circuit for accomplishing the soft switching of S_1. Inductors L_2 and L_3 are much smaller than L_1 and C_1 is much smaller than C_2. The duration of modes 1,2,5 and 6 being quite small i_{L1} and Vout are assumed constant at I_1 and V_1 for modes 1 and 2, and I_2 and V_2 for modes 5 and 6 respectively. The modewise analysis of the circuit is as follows.

Mode 1(t_0 - t_1): This mode begins with the turn on of S_1 at zero current at t_0. The equivalent circuit for this mode is shown in fig. 2. The initial conditions on L_2, L_3 are zero. C_1 is previously charged to a value $V_{c1}(t_0)$. The current $i_{L2}(t)$ gradually rises and it becomes equal to $I_1+i_{L3}(t)$ at t_1 when D_3 stops conducting and this mode comes to an end. The expressions for $i_{L2}(t)$, $i_{L3}(t)$ and $V_{c1}(t)$ are

$$i_{L2}(t) = \frac{V_1}{L_2}t \tag{1}$$

$$V_{C1}(t) = [V_1 - V_{C1}(t_0)].[1-\cos\omega_1 t] + V_{C1}(t_0) \tag{2}$$

$$i_{L3}(t) = [V_{c1}(t_0) - V_1]\frac{\sin\omega_1 t}{\omega_1 L_3} \tag{3}$$

where $\omega_1 = \frac{1}{\sqrt{L_3 C_1}}$

Mode 2(t_1-t_2): The equivalent circuit for this mode is shown in fig. 3. The initial conditions on L_3, L_2 and C_1 are, $i_{L3}(t_1)$ and $i_{L2}(t_1)+I_1$ and $V_{c1}(t_1)$ 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_{c1} reaches zero at t_2. The expressions for i_{L2}, i_{L3} and V_{c1} are as follows.

$$V_{C1}(t) = -V_{C1}(t_1)(1-\cos\omega_2 t) - \frac{i_{L3}(t_1)}{\omega_2 C_1}\sin\omega_2 t - V_{C1}(t_1) \quad (4)$$

$$i_{L3}(t) = \frac{V_{C1}(t_1)}{\omega_2(L_2+L_3)}\sin\omega_2 t + i_{L3}(t_1)\cos\omega_2 t \quad (5)$$

$$i_{L2}(t) = \frac{V_{C1}(t_1)}{\omega_2(L_2+L_3)}\sin\omega_2 t + i_{L3}(t_1)\cos\omega_2 t + I_1 \quad (6)$$

where $\omega_2 = \frac{1}{\sqrt{(L_2+L_3)C_1}}$

Mode 3(t_2 - t_3): The equivalent circuit for this mode is shown in fig. 4. The initial conditions on i_{L2}, i_{L3} and V_{c1} for this mode are $i_{L2}(t_2)$, $i_{L3}(t_2)$ and zero. This mode comes to an end at t_3 when i_{L3} reaches zero at t_3. Reversal of i_{L2} is arrested by D_2. The expression for i_{L3} for this mode is

$$i_{L3}(t) = \frac{-VsL_2}{[L_1L_2 + L_2L_3 + L_3L_1)}t + i_{L3}(t_2) \quad (7)$$

Mode 4 (t_3 - t_4) : The equivalent circuit for this mode is shown in fig. 5. $i_{L1}(t)$ attains a value of I_2 and $V_{out}(t)$ 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 Vout are governed by the equations.

$$i_{L1}(t) = i_{L2}(t) = \frac{Vs}{(L_1+L_2)}t + I_1 \quad (8)$$

$$Vout(t) = V_1 e^{-\frac{t}{RC_2}} \quad (9)$$

Mode 5 (t_4- 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_{L2} for this mode is I_2.The expressions for i_{L2}, i_{L3} and V_{c1} for this mode are as follows

$$V_{c1}(t) = V_2(1-\cos\omega_3 t) + \frac{I_2}{\omega_3 C_1}\sin\omega_3 t \quad (10)$$

$$I_{L2}(t) = \frac{L_2}{L_2+L_3}[V_2C_1\omega_3\sin\omega_3 t - I_2(1-\cos\omega_3 t)] + I_2 \quad (11)$$

$$I_{L3}(t) = \frac{L_2}{L_2+L_3}[-V_2C_1\omega_3\sin\omega_3 t + I_2(1-\cos\omega_3 t)] \quad (12)$$

where $\omega_3 = \frac{1}{\sqrt{\frac{L_2L_3}{(L_2+L_3)}C_1}}$ This mode ends when i_{L2} reaches zero at t_5.

Mode 6 (t_5 - t_6): The equivalent circuit for this mode is shown in fig. 7. In this mode i_{L3} reduces to zero. This mode comes to an end at t_6 when i_{L3}becomes zero. The expression for i_{L3} and V_{c1} for this mode are.

$$i_{L3}(t) = \frac{V_{C1}(t_5) - V_2}{L_3\omega_1}\sin\omega_1 t + i_{L3}(t_5)\cos\omega_1 t \quad (13)$$

$$V_{C1}(t) = [V_{C1}(t_5) - V_2][\cos\omega_1 t - 1] - \frac{i_{L3}(t_5)}{\omega_1 C_1}\sin\omega_1 t \quad (14)$$

This mode comes to an end when i_{L3} becomes zero at t_6

Mode 7 (t_6 - t_7): The equivalent circuit for this mode is shown in fig. 8. In this mode i_{L2}, i_{L3} are zero. This mode comes to an end at t_7 when S_1 is turned on at zero current.

This is the normal mode of the boost converter. The inductor current i_{L1} reaches I_1 and V_{out} reaches V_1 at the end of this mode. The expressions for Vout and iL1 in this mode are

$$Vout(t) = e^{-\alpha t}\,[A\sin\omega_4 t + B\sin\omega_4 t] + Vs \qquad (15)$$

$$i_{L1}(t) = \frac{Vout(t)}{R} + e^{-\alpha t}\,[(-BC_2\alpha + AC_2\omega_4)\cos\omega_4 t - (AC_2\alpha + BC_2\omega_4)\sin\omega_4 t] \qquad (16)$$

where $\alpha = \frac{1}{2RC_2}$, $\omega_4 = \frac{1}{\sqrt{L_1 C_2}}$,

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

$B = V_2 - Vs$

3. SIMULATION RESULTS

The circuit shown in fig. 1 is simulated in PSPICE with Vs = 10V, L_1=1mh, C_1=10nf, L_2=L_3=10uH, C_2=10uF and R ranging from 10 ohms to 2000 ohms. The simulation results are shown in figs. 9 and 10 for frequency=25Kz, R=50hms 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.

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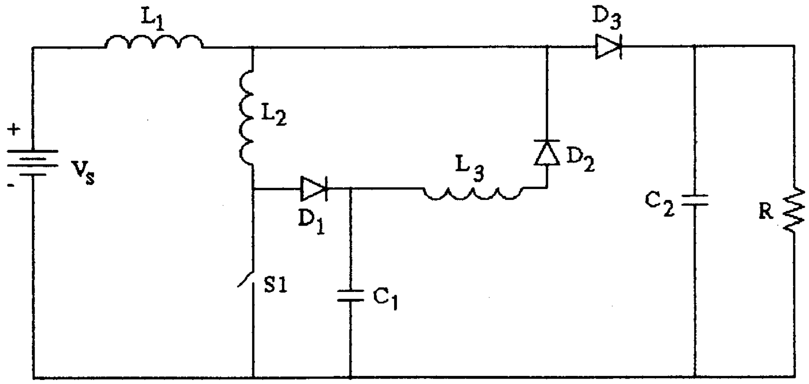


Fig. 1

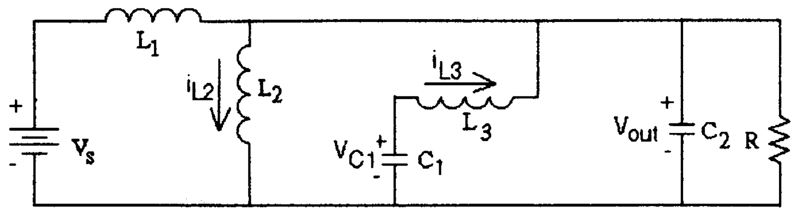


Fig. 2

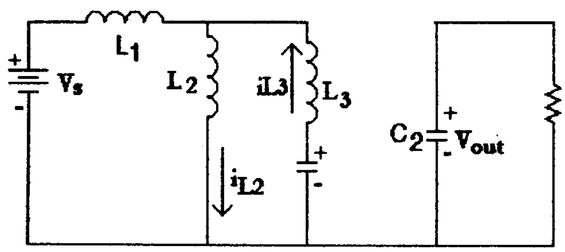
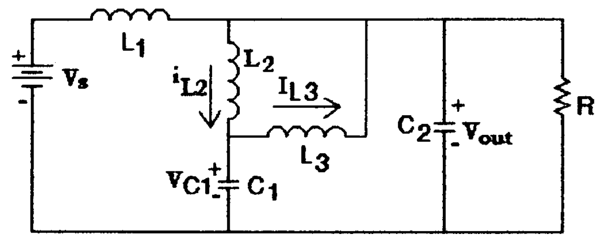


Fig. 3



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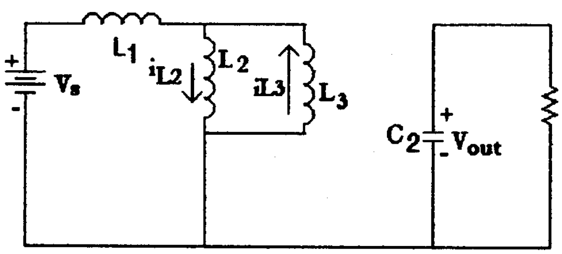


Fig. 4

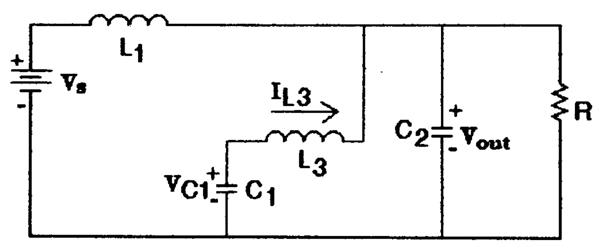


Fig. 7

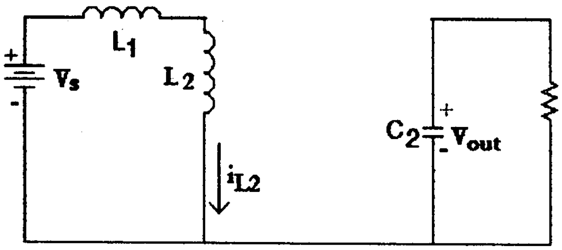


Fig. 5

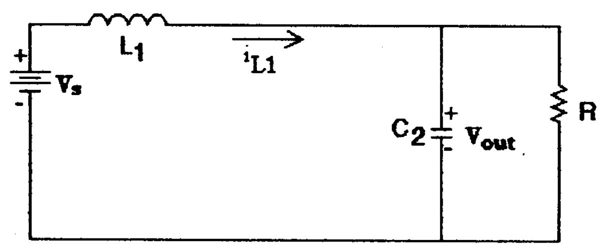
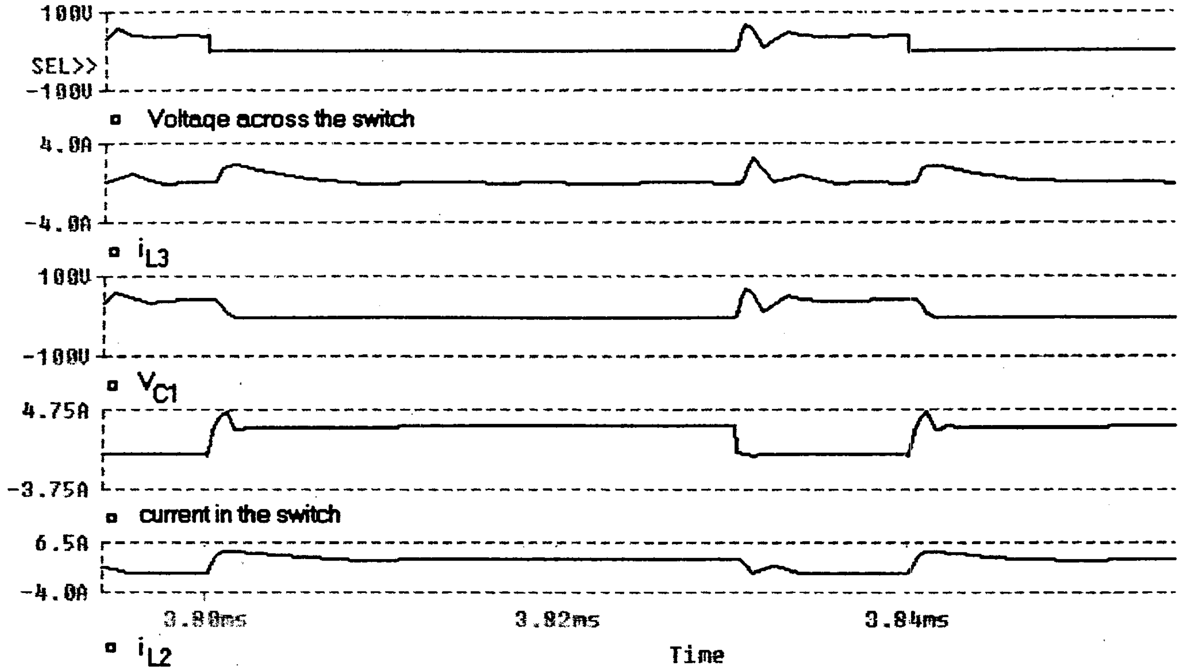
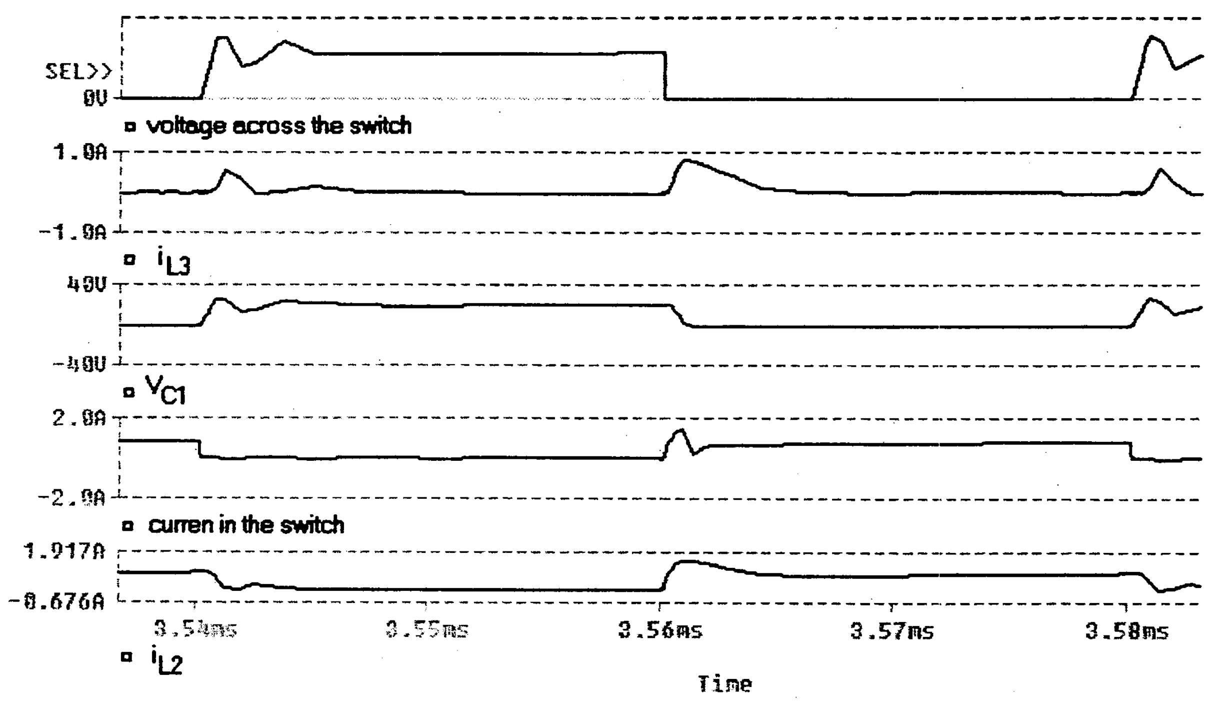


Fig. 8



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

Fig. 9



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

Fig. 10