Design and Development of Zero-Voltage Transition Low Ripple Current Fifth Order Boost Converter

Mahesh, Nagabhushan Patil
M.Tech Power Electronics, Associate Professor Dept. of EEE
Poojya Doddappa Appa College of Engineering

Abstract : This paper introduces a design and developmental method for dc-dc low ripple current fifth-order boost converter with constant output voltage. The boost dc-dc converters are used in applications where the required output voltage is higher than the given voltage. The fifth-order boost converter gives higher output voltage at lower duty ratios with lower ripple. The zero-voltage transition cell is also added in the circuit to achieve the zero-voltage transition to reduce switching losses for nearly all switching devices. In order to verify the soft switching performance of this converter simulation is carried out in TINA and converter operation is seen for a 12 to 36 V, 25 W prototype in simulation.

***Index Terms* - Fifth-order boost converter, Point of load converter, Soft-switching, Zero-voltage transition. TINA simulation software..**

I. INTRODUCTION

Converter are the devices used for change the nature of an electric current or signal, they are classified as Cycloconverter (AC-AC), Rectifier (AC-DC), chopper (DC-DC) and inverter (DC-AC).

DC-DC converters is an electronic circuit that converts a source of direct current (DC) from one voltage level to another. The proposed converter is DC-DC boost converter where the output voltage is more as compared to source voltage. The conventional boost converter undergoes several disadvantages such as requires higher duty ratio for realizing required voltage gain, efficiency also reduced the switching devices also undergo voltage and current stresses to eliminate some of these limitation higher boost pulse width modulated(PWM) converters are used due to their high power density, fast transient response and simple control.

For improvement in efficiency of these converters soft switching schemes are adopted zero-voltage-switching (ZVS) during turn-on and zero current switching (ZCS) during turn-off. In recent years, a number of zero voltage switching and zero current switching PWM converters proposed by adding resonant active snubbers to the conventional PWM converter to combine the desirable features of both resonant and normal PWM techniques [1][2]. In some proposed topology they combine both the features ZVS and ZCS but need more auxiliary component to achieve the operation [3].

To realize improved efficiency at full load condition many soft switching schemes are adopted as they remove unwanted switch transition losses that present in the hard switched DC-DC converters. Some of the zero-voltage-switched (ZVS) quasi resonant converter (QRC) achieves the soft switching of main switch with ZVS and the diode with zero current switched (ZCS) but both the main switch and diode undergo voltage stress due to the resonance operation [5].

The referred literature papers focuses on the soft switching schemes but does not adequately cover the soft switching schemes for the fifth order boost converter. Therefore, the aim of work is to improve the efficiency of fifth order boost converter by using zero voltage transition (ZVT) technique to obtain soft switching. Here the soft switching carried by adding the ZVT cell in fifth order boost converter which includes auxiliary switch, diode and resonant inductor and capacitor.

II. STEADY STATE ANALYSIS OF SOFT SWITCHING LOW CURRENT RIPPLE FIFTH ORDER BOOST CONVERTER

Proposed converter exhibits seven operating modes in one switching cycle of operation the on/off status of the various devices indicated in the table I. corresponding equivalent circuit can easily be analyzed. For successful ZVT the time delay between the auxiliary switch turn-on and the main switch turn-on should be greater than the minimum time delay (T_{Dmin}, given by the addition of mode-1 timing and mode-2 timing) and the switch on time of the auxiliary switch should be greater than T_{Dmin}. Also the turn-on of the main switch should take place simultaneously as the turn-OFF of auxiliary switch or before it.

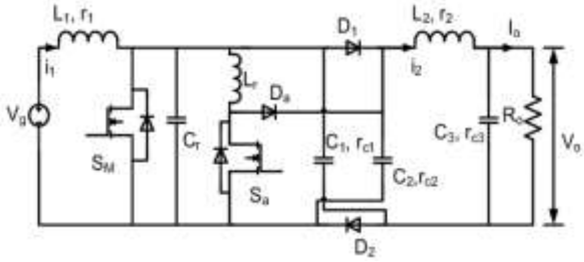

Fig 1: Circuit diagram of the soft-switching low current ripple fifth-order boost converter.

Mode I: (t0 < t < t1)

During this mode the auxiliary switch turned on and main switch made as off, initially resonant inductor current rises also main diodes get forward bias and conducts the current fed to capacitor cr, c1,c2,c3 and load the diode D1 and D2 turned off this is the indication of end of mode 1.

$$\text{Initial conditions: } VCr(t0) = V_o';\ I\,Lr = 0;$$

$$V_o' = Vg / (1 - D);\ \text{and } VCr(t) = V_o';$$

For the resonant inductor applying KVL

$$V_o' = Lr\ di_{lr/dt},\ I\,Lr(t) = V_o'/Lr(t - t0)$$

$$(t1 - t0) = Lr\,(Ig + Io)/ V_o'$$ This gives the time duration for mode 1.

Mode II: (t1 < t <t2)

During this mode expect auxiliary switch all the switching devices are off this mode end when the resonant inductor charges to its peak value, output is fed by output capacitor this mode ends for very short period.

$$\text{Initial conditions: } VCr(t1) = V_o';\ I\,Lr = Ig + Io$$

$$\text{Applying KCL: } Cr\ d(VCr)/dt = Ig + Io - I\,Lr$$

$$\text{Applying KVL: } Lr\ d(I\,Lr)/dt = VCr$$

Combining the two equations, we get

$$d/dt(dilr/dt) + (I\,Lr(t) / Lr\,Cr) - (Ig + Io) / Lr*Cr = 0$$

Solving the above differential equations with initial conditions

$$I\,Lr(t) = Ig + Io + (Vo'/Zr)*\sin(wr(t - t1))$$

$$wr = 1/\mathrm{sqrt}(Lr*Cr)\ ;\ Zr = \mathrm{sqrt}(Lr/ Cr)\ \text{also } VCr(t) = V_o'*\cos(wr(t - t1));$$

$$(t2 - t1) = pi / 2*wr = (pi/2)*\mathrm{sqrt}(Lr*Cr)$$ This gives the time duration for mode 2.

Table I. States of switching devices in different modes

Mode	Time duration	Main switch	Aux. switch	Main diode	Aux. diode
I	T0<t<T1	OFF	ON	ON	OFF
II	T1 t <T2	OFF	ON	OFF	OFF
III	T2<t<T3	OFF, DSM ON	ON	OFF	OFF
IV	T3<t<T4	ON	OFF	OFF	ON
V	T4<t<T5	ON	OFF	OFF	OFF
VI	T5<t<T6	OFF	OFF	OFF	OFF
VII	T6<t<T0	OFF	OFF	ON	OFF

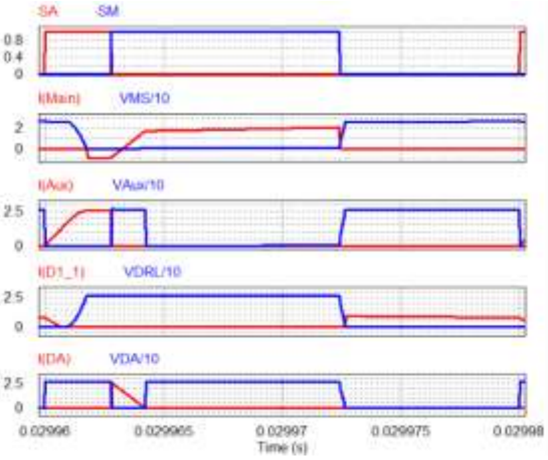

Fig. 2. Steady-state waveforms.

Mode III: (t2 < t < t3)
This mode is similar to mode 2 operation but the negative current flow through diode across main switch, this mode ends as soon as auxiliary switch turn-off.

Mode IV: (t3 < t < t4)
During this mode the main switch is on and auxiliary diode is on auxiliary switch and main diodes are off the stored inductor energy of the auxiliary inductor flows through auxiliary diode fed to capacitor and load when current reaches zero of the auxiliary inductor this mode get end.

Mode V: (t4 < t < t5)
In this mode no change in the resonant tank element as they are disconnected from the circuit. This mode is identical to switch on condition of conventional boost converter. This mode ends when Sm is turned off.

Mode VI: (t5 < t < t6)
This mode ends for very short time interval where all the switches are off soon after this the main diodes get on this is the end of this mode.

Mode VII: (t6 < t < t7)
This mode is similar to freewheeling stage of the conventional boost converter at t=ts this mode ends when Sa turned on new cycle begins.

III. DESIGN PARAMETERS SOFT-SWITCHING ZVT-FIFTH-ORDER BOOST CONVERTER

The power stage components of the soft switching ZVT are designed as per the input parameters given in Table II.

Table II. Converter Parameters

Input Parameter	Value
V_g	12 V
V_o	36 V
P_o	25 W
R_o	50 ohm
D	0.48
D_{aux}	0.14
F_s	50 kHz
Fns	0.172

By using power balance and volt-second balance on the inductors the average current through the inductors can be easily found out to be as follows:

$$I_{L1} = Vo(1+D)/Ro(1-D); \quad I_{L2} = Vo/Ro$$

also, the capacitor voltages are as follows:

$$VC1 = VC2 = Vo/(1-D)$$

Using these equations, the design equations for the power stage elements can be found as follows:

$$L1 = Vg\,D/\Delta i_{L1}\,; \qquad L2 = Vg(1-D)T/\Delta i_{L2}\,;$$
$$C1 = i_{L1}\,DT/\Delta V_{C1}\,; \qquad C2 = i_{L2}/\Delta V_{C2}\,;$$

$$C3 = Vo\,D/\Delta V_{C3}8fs(1+D)L2;$$

In order to design the resonant circuit elements, i.e., resonant inductor (Lr) and resonant capacitor (Cr), the auxiliary switch duty ratio was fixed to the desired value and then the inductor and capacitor values were plotted with the variation of Q (Normalized load). This plot is shown in figure 3. The plot also species the range of values of the Lr, Cr for which the ZVT condition is satisfied. From the range satisfying the ZVT condition the Lr, Cr values were selected to obtain the desired Fns.

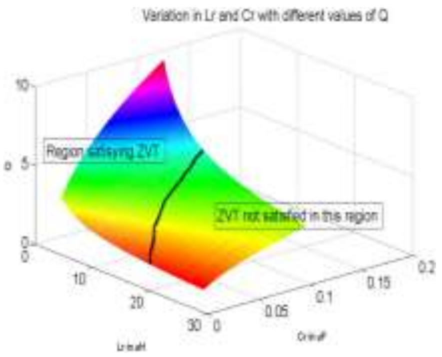

Fig.3. Plot of L_r and C_r variation with Q.

The converter parameter values are designed for the 50khz sampling frequency L1=500 µH, L2=100 µH, Lr=25 µH, Cr=10 nF, C1=100 µF, C2=100 µF, C3=100 µF, R= 50Ω.

IV. GATING SEQUENCE FOR SUCCESSFUL ZVT

For successful ZVT the time delay between the auxiliary switch turn-on and the main switch turn-on should be greater than the minimum time delay (TDmin, given by the addition of mode-1 timing and mode-2 timing) and the switch on time of the auxiliary switch should be greater than TDmin. Also the turn-on of the main switch should take place simultaneously as the turn-OFF of auxiliary switch or before it.

TDmin can be seen in the steady state waveform when inductor current reaches to the peak value and I main current is going negative value otherwise mode I timing and mode II timing is given in the modes of operation.

V. STEADY-STATE WAVEFORM VS SIMULATION RESULTS COMPARISION USING TINA SIMULATION SOFTWARE.

The simulation prototype is carried in Tina software for 12 to 36 V, 25 W, made comparison with the steady state waveforms and found zero voltage transition for main switch, auxiliary switch and auxiliary diode.

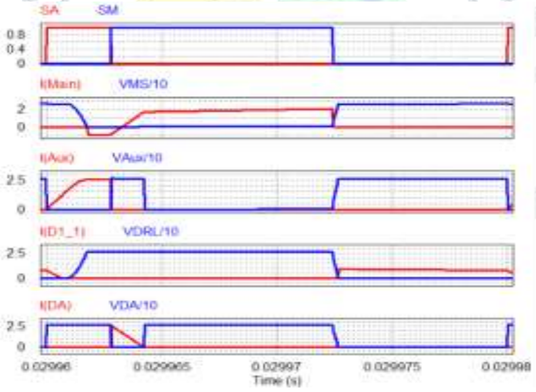

Fig. 4. Steady-state waveforms.

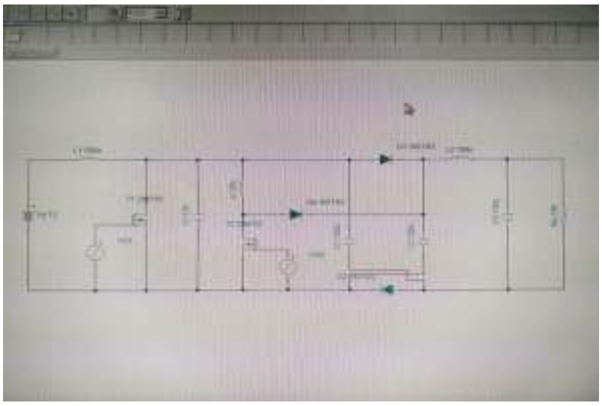

fig5: circuit diagram of ZVT zero voltage transition using TINA simulink

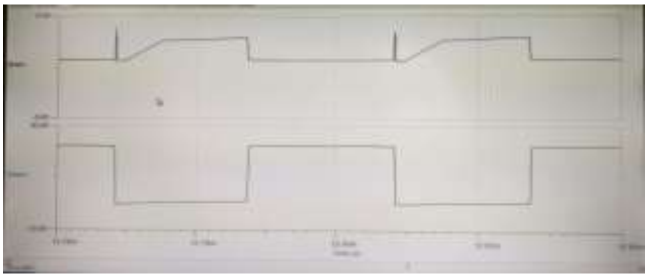

fig6: current (I main) and voltage (V main) waveform of main switch

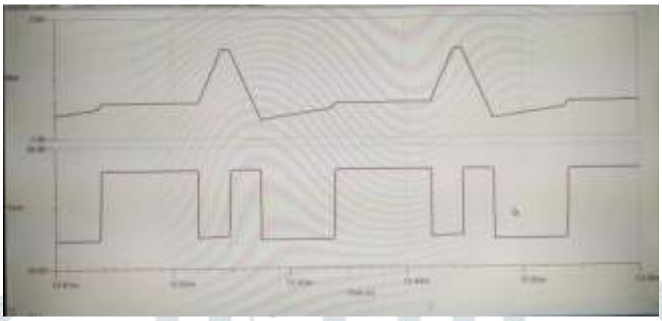

fig7: current (I aux) and voltage (V aux) waveform of auxiliary switch

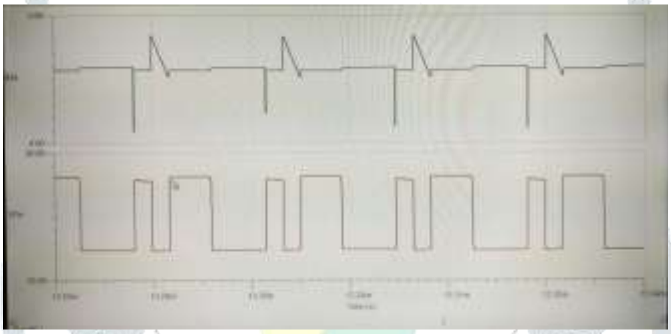

fig8: current(IDa) and voltage (VDa) waveform of auxiliary diode

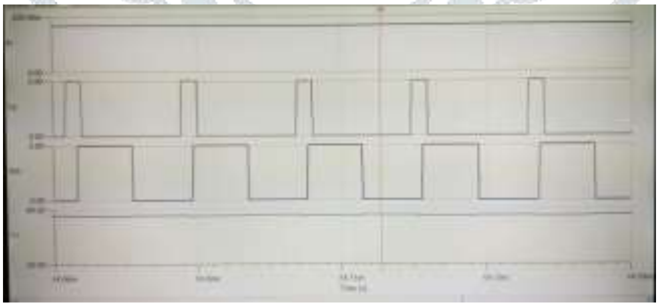

fig7: main switch and auxillary switch getting sequence also output current (Io) and voltage (Vo) waveform.

VI. CONCLUSION

In this paper the soft switching scheme for low current ripple fifth order boost converter is performed and observed that zero voltage switching nearly for all switching devices is possible using ZVT cell. There is improvement in efficiency as compared to identical hard switched converter for same power and voltage levels.

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