Design and Simulation of a soft switching scheme for a dc-dc Boost Converter with pi controller

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Abstract

This paper presents the design of simple but powerful soft switching scheme for a DC-DC Boost Converter with a closed loop control. A new novel soft switching scheme is proposed with a single switch and minimum components which offers load independent operations. The only switch used in this converter is switched ON at zero current and switched OFF at zero voltage .The proposed Controller is used to improve the dynamic performance of DC-DC converter by achieving a robust output voltage against load disturbances. The duty cycle of the Boost converter is controlled by PI Controller. A 50W/50KHz soft switched PWM Boost converter is simulated and analyzed. The results are simulated using PSIM.

Keywords: Boost converter, Zero voltage switching, Zero current transition, Pulse Width Modulation, PI controller.

1. INTRODUCTION

Switched-mode Power Supply Units in domestic products such as personal computers often have universal inputs, meaning that they can accept power from most mains supplies throughout the world, with rated frequencies from 50 Hz to 60 Hz and voltages from 10 V to 240V. PWM based switched mode power supplies are used in telecommunication, aerospace application etc. The switches used in these types of power supplies are subjected to high switching stresses and high switching power loss that increases linearly with the switching frequency of the PWM. Hence the converters in the SMPS are also experience high switching losses, reduced reliability, electromagnetic interference and acoustic noise. Another significant drawback of the switch mode operation is the EMI produced due to large di/dt and dv/dt caused by a switch-mode operation. These shortcomings of switch-mode converters are overcome by increasing the switching frequency in order to reduce the converter size and weight and hence to increase the power density. Therefore, to realize high switching frequency in a converter changes its status (from on to off), when the voltage across it and/or the current through it is zero at the switching instant.[3]. DC-DC converters are nonlinear systems due to their inherent switching operation. To assure a constant output voltage, a classical linear design of a control is frequently used. The regulation is normally achieved by the pulse width modulation (PWM) at a fixed frequency. The switching device is a power MOSFET. The PWM linear control techniques are widely used [8].A number of circuits [l], [2] 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 accomplishes reduced voltage and current stresses and the coupling between main and auxiliary circuit inductors significantly attenuate the duty cycle limitations [4].

The PI controller is proposed is to improve the performance of the soft switched boost converters. The duty cycle of the boost converter is controlled by PI controller. The conventional PI controllers for such converters are designed under the worst case condition of maximum load and minimum line condition. As power electronic converters are nonlinear, and also are prone to variations in its operating states over a wide range, the conventional PI controllers are to be designed to provide optimal performance as the operating point changes. To provide optimal performance at all operating conditions of the system PI controller is developed to control the duty cycle of the boost converter. PI controller is designed based on an average state space model of the classical boost DC-DC converter. Simulation of boost converter subjected to load changes is performed to demonstrate the effectiveness of the proposed controller.[9][12]

A converter topology with single switch and switching strategies discussed in this paper, which make the switch on at zero current and off at zero voltage at the given switching time. This topology applied to a dc-dc boost converter. In this paper design and simulation of linear PI controller for a soft switched dc-dc converter is discussed. The results were taken for different load disturbances.

Design and Analysis of the Proposed Converter

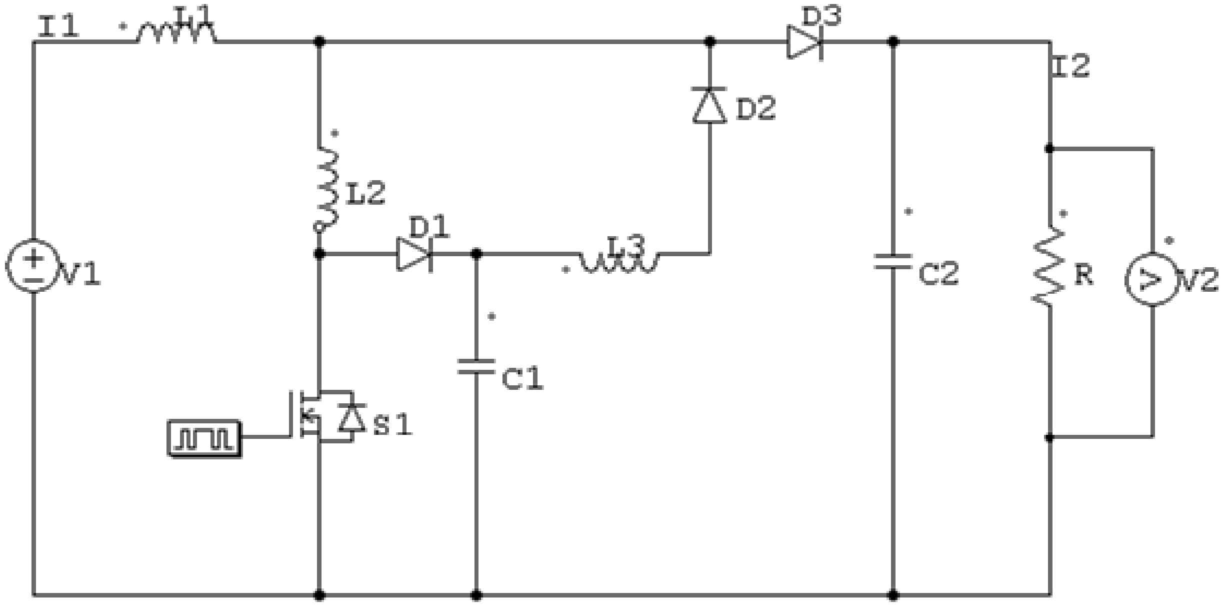

FIGURE 1: Proposed Soft switched dc-dc boost converter

The circuit diagram of the proposed converter with soft switching scheme is shown in fig.1, the switch S_1, L_1, D3 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. There are seven modes of operation. The duration of modes 1, 2, 5 and 6 being quite small i_{L1} and V_{out} 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.[10]

MODE 1: This mode begins with the turn on of S_1, at zero current at t_0.The expressions are,

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

$$v_{C_1}(t) = [V_1 - V_{C_1}(t_0)][1 - \cos \omega_1 t] + V_{C_1}(t_0) \tag{2}$$

$$i_{L_3}(t) = [V_{C_1}(t_0) - V_1] \frac{\sin \omega_1 t}{\omega_1 L_3} \tag{3}$$

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

When D_3 stops conducting and this mode comes to an end.

MODE 2: The initial conditions on L_3, L_2 and C_1 are, $i_{L_3}(t_1)$, $i_{L_2}(t_1) + I_1$ and V_{C_1} respectively, attained at the end of

Mode 1.The expressions are,

$$V_{C_1}(t) = -V_{C_1}(t_1)[1 - \cos \omega_2 t] + \frac{i_{L_3}(t_1)}{\omega_2 C_1} \sin \omega_2 t - V_{C_1}(t_0) \tag{4}$$

$$i_{L_3}(t) = \frac{V_{C_1}(t_1)}{\omega_2 (L_2 + L_3)} \sin \omega_2 t + i_{L_3}(t_1) \cos \omega_2 t \tag{5}$$

$$i_{L_2}(t) = \frac{V_{C_1}(t_1)}{\omega_2 (L_2 + L_3)} \sin \omega_2 t + i_{L_3}(t_1) \cos \omega_2 t + I_1 \tag{6}$$

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

This mode comes to an end when V_{C_1} reaches zero at t_2.

MODE 3: The initial conditions on i_{L_2}, i_{L_3} and V_{C_1} for this mode $i_{L_2}(t_2), i_{L_3}(t_2)$ are zero The expression for i_{L_3} is,

$$i_{L_3}(t) = -\frac{V_S L_2}{L_1 L_2 + L_2 L_3 + L_3 L_1} t + I_{L_3}(t_2) \tag{7}$$

This mode comes to an end at t_3 when i_{L_3} reaches zero at t_3.

MODE 4: In this mode current buildup in L_1 and L_2, and Vout(t) are governed by the equations as follows.

$$i_{L_1}(t) = i_{L_2}(t) = \frac{V_S}{L_1 + L_2} t + I_1 \tag{8}$$

$$V_{out}(t) = V_1 e^{\frac{1}{RC_2}} \tag{9}$$

This mode comes to an end when S_1 is turned off at zero voltage at t_4.

MODE 5: This mode begins with the turn off of S_1 at zero voltage at t_4.The expressions are,

$$V_{C_1}(t) = V_2(1 - \cos \omega_3 t) + \frac{I_2}{\omega_2 C_1} \sin \omega_3 t \tag{10}$$

$$I_{L_2}(t) = \frac{L_2}{(L_2 + L_3)} [V_2 C_1 \sin \omega_3 t - I_2(1 - \cos \omega_3 t)] + I_2 \tag{11}$$

$$I_{L_3}(t) = \frac{L_2}{(L_2 + L_3)} [-V_2 C_1 \omega_3 \sin \omega_3 t + I_2(1 - \cos \omega_3 t)] \tag{12}$$

Where $\omega_3 = \dfrac{1}{\sqrt{\dfrac{L_2 L_3}{L_2 + L_3} C_1}}$

This mode ends when i_{L_2} reaches zero at t_6.

MODE 6: 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_{C_1} for these mode is.

$$i_{L_3} = \frac{V_{C_1}(t_5) - V_2}{L_3 \omega_1} \sin \omega_1 t + i_{L_3}(t_5) \cos \omega_1 t \tag{13}$$

$$V_{C_1}(t) = [V_{C_1}(t_5) - V_2][\cos \omega_1 t - 1] \frac{i_{L_3}(t_5)}{\omega_1 C_1} \sin \omega_1 t \tag{14}$$

MODE 7: 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 expressions are,

$$V_{out}(t) = e^{-\alpha t}[A \sin \omega_4 t + B \sin \omega_4 t] + V_S \tag{15}$$

$$i_{L_1}(t) = \frac{V_{out}(t)}{R} + e^{-\alpha t}[(-BC_2 + AC_2 \omega_4 t)\cos \omega_4 t - (AC_2 + BC_2 \omega_4)\sin \omega_4 t] \tag{16}$$

Where $\alpha = \dfrac{1}{2RC_2}$, $\omega_4 = \dfrac{1}{\sqrt{L_1 C_2}}$

$$A = \frac{I_2}{\omega_4 C_2} - \frac{V_2}{R \omega_4 C_2} + \frac{\alpha(V_2 - V_5)}{\omega_4}$$

$$B = V_2 - V_S$$

Design of PI controller

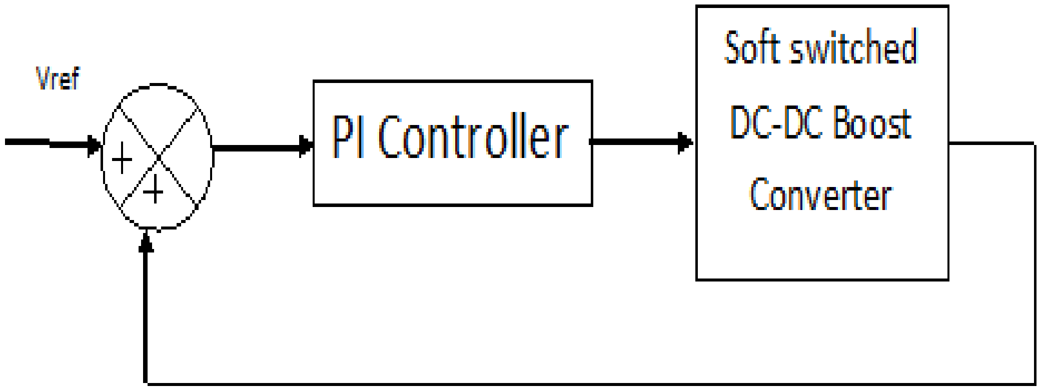

FIGURE 2: Block diagram of the Soft switched dc-dc boost converter with PI controller.

PI control is a traditional linear control method used in industrial applications. The linear PI controller controllers are usually designed for dc-dc converters using standard frequency response techniques and based on the small signal model of the converter. A Bode plot is used in the design to obtain the desired loop gain, crossover frequency and phase margin. The stability of the system is guaranteed by an adequate phase margin. However, linear PID and PI controllers can only be designed for one nominal operating point. A boost converter's small signal model changes when the operating point varies. The poles and a right-half plane zero, as well as the magnitude of the frequency response, are all dependent on the duty cycle. Therefore, it is difficult for the PID controller to respond well to changes in operating point. The PI controller is designed for the boost converter for operation during a start up transient and steady state respectively.

Fig. 2.shows the closed loop of the soft switched dc-dc boost converter with PI controller. The load current of the proposed converter is given to the PI controller. The time constant of the controller is designed according to the small signal transfer function of the boost converter which is given below. Then the output of the PI controller changes the pulse width of the square wave which changes the firing angle of the MOSFET switch, so the output of the converter is controlled for different load disturbances.

The small signal model of the boost converter is designed based on the average state space averaging techniques, the small signal transfer function of a boost converter is

$$\frac{Vo(s)}{D(s)}=\frac{Vs}{(1-D)^2}\frac{\left(1-s\frac{L}{R(1-D)^2}\right)}{1+s\frac{L}{R(1-D)^2}+s^2\frac{LC}{(1-D)^2}}$$

Simulation Results

For simulation purposes, a boost converter with the following specifications is used. The other parameters of the converter are L_1 =1mH, L_2=10µH, L_3= 10µH, C_1 =1µF, C2=,10pF, R=50Ω, MOSFET ('S') 'ON' resistance = 0.27 Q, and diode forward voltage drop = 1.5 V.

Input voltage	Output voltage	Rated output power	Switching frequency	Resistance
100 V	150V	50W	50Khz	50 ohms

TABLE 1: Simulation parameters

The current (fig.5) and voltage (fig.6) across the switch and the regulated output (fig.4 and fig.7),for the constant input fig.3 is studied and plotted using the PSIM. The switching behavior and performance of the proposed soft switched dc-dc boost converter for open loop and closed loop (PI controller is the feedback controller) were studied and plotted. The advantage of soft switched boost converter is that ZVS and ZCS are incorporated in the circuit.

The parameters are given as per the table1.

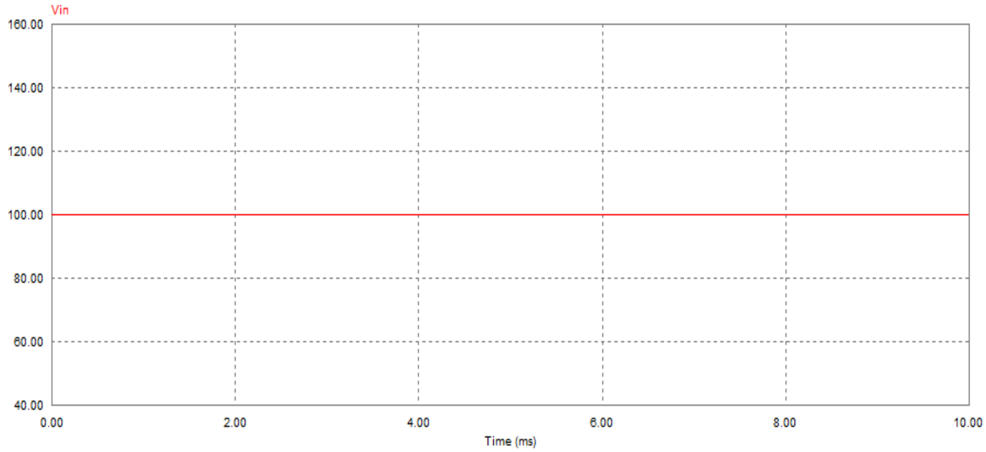

FIGURE 3: Input voltage waveform of the Soft switched dc-dc boost converter **Vin =100v**

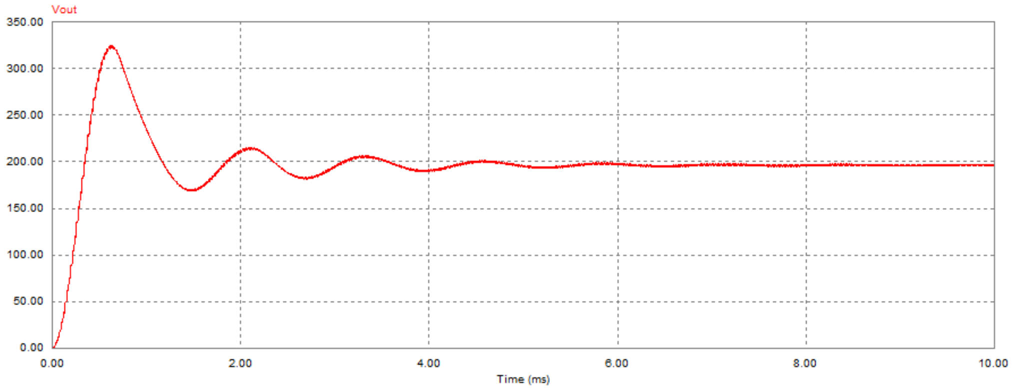

FIGURE 4: Output voltage waveform of the Soft switched dc-dc boost converter without PI controller Vout=200v

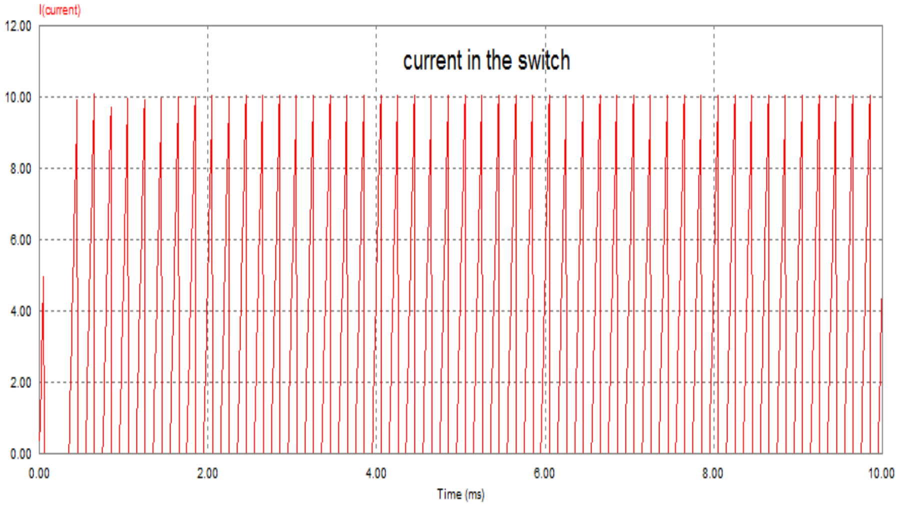

FIGURE 5: Zero current waveform of the Soft switched dc-dc boost converter.

Fig.5 and 6 shows the current and voltage waveform across the switch.Fig.4 and 7 shows the regulated output, for the constant input which is shown in fig.1.The switching behavior and performance of the proposed soft switched dc-dc boost converter for open loop and closed loop (PI controller is the feedback controller) were studied and plotted. The advantage of soft switched boost converter is that ZVS and ZCS are incorporated in the circuit. The circuit is simulated using PSIM.

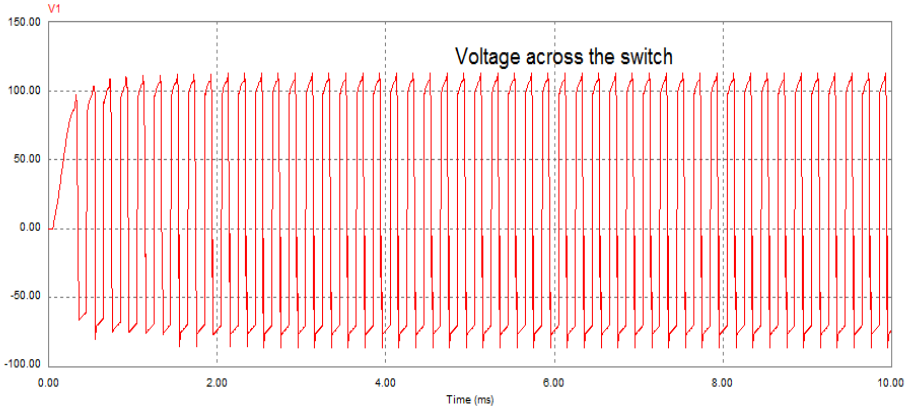

FIGURE 6: Zero Voltage waveform of the Soft switched dc-dc boost converter

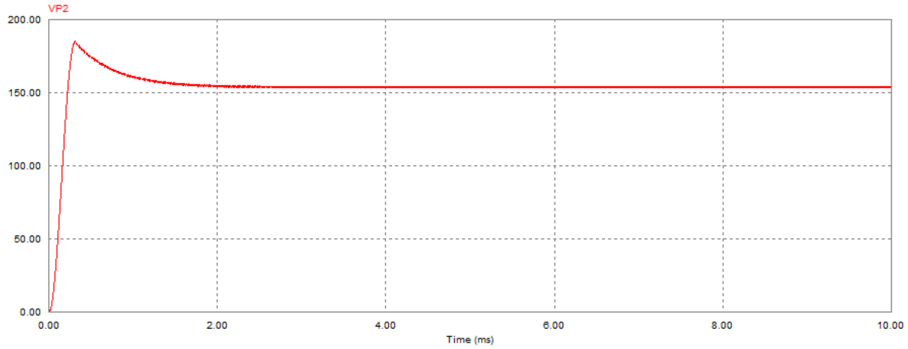

FIGURE 7: Output Voltage waveform of the proposed converter with PI controller V_{out}=150V

3. COMPARATIVE EVALUATION

Many researchers [13][14] explained soft switched dc –dc boost converter with two switches which gives high switching losses, in that one switch act as soft switching and the other as hard switching. The comparative evaluation of our results with the other research work shows that the total harmonic distortion is reduced as much as possible. Fig.8 clearly shows that the total harmonic distortion of soft switched dc-dc converter with two switches have fundamental and other odd harmonics.

Fig.9 shows that the total harmonic distortion of our proposed soft switched dc-dc converter with a single switch. It is clearly seen from the fig.9, except fundamental harmonics, higher order harmonics are eliminated, which gives the improved results over the other research works. In future we will eliminate the fundamental harmonics by using a suitable filter design techniques.

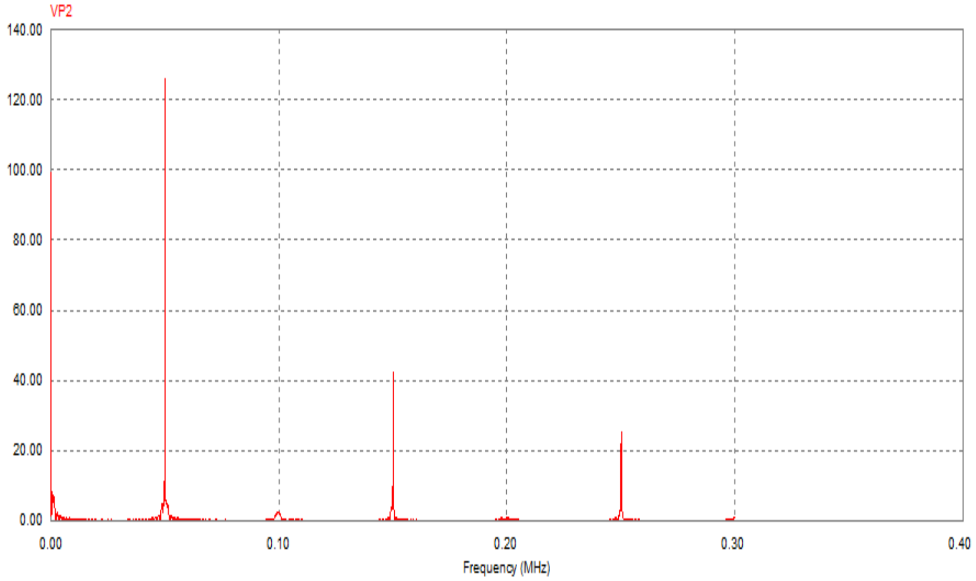

FIGURE 8: Total Harmonic Distortion of soft switched dc-dc boost converter with two switches.

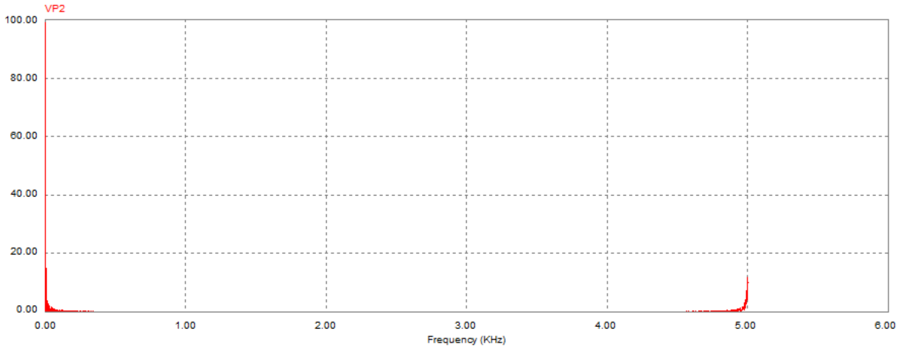

FIGURE 9: Total Harmonic Distortion of proposed soft switched dc-dc boost converter with single Switch

4.CONCLUSION & FUTURE WORK

Thus a new novel soft switching scheme is designed and simulated with a feedback control. PI controller is used for feedback control. We simulated the soft switching technique and achieved the low stress and less switching loss in the converter. The linear PI controller was designed based on frequency response of the boost converter using frequency response technique. The simulated results shows that the only switch used in this converter is switched ON at zero current and switched OFF at zero voltage. The output voltage is boosted and it is constant. It reaches the steady state vale within several micro seconds.

In future we can change the load from resistive to Inductive load or motor load. This soft switching circuit can be implemented to control different special machines like switched reluctance motor, Brushless DC motor etc. We can also change the controller to intelligent controllers like Neural network controller, fuzzy logic controller and Neuro-Fuzzy logic controller.

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