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Investigation and Analysis of Switching Performance of Boost Converter

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Abstract-- **This paper deals with the simulation and implementation of boost Converter with the interleaved approach, this topology not only decreases the current stress of the main circuit device but also reduces the ripple of the input current and output voltage. Moreover, by establishing the common soft-switching module, the soft-switching interleaved converter can greatly reduce the size and cost. The main switches can achieve the characteristics of ZVS and ZCS simultaneously to reduce the switching loss and improve the efficiency with a wide range of load. This topology has two operational conditions depending on the situation of the duty cycle.**

Index Terms-- Power Factor Correction, diode, rectifier, boost converter, step up chopper.

I. INTRODUCTION

Electromagnetic pollution of the power line introduced by power electronic systems include harmonic distortion due to nonlinear loads, typically, rectifiers [1]. So, various types of single phase converter circuits to improve the ac current waveform have been developed and used [2, 3]. This converter is constructed by a boost chopper circuit with a switching device in the dc side of the diode bridge rectifier circuit. Good characteristics such as a sinusoidal current waveform in phase with the ac line voltage and the constant dc voltage can be obtained from the PFC converter [4].

The concept of inductor design is presented and soft switching techniques in PWM converters. In the literature mentioned above, the hardware implementation of boost converter using Atmel microcontroller is not available. In this paper, the hardware details of embedded microcontroller based boost converter are presented [5].

II. SWITCHING PERFORMANCE OF BOOST CONVERTER

The non-ideal character of the input current drawn by the rectifiers creates a number of problems for the power distribution network and for other electrical systems in the vicinity of the rectifier including the phase displacement of the current and voltage fundamentals requires that the source and distribution equipment handle reactive power increasing their volt-ampere ratings, High input current harmonics and low input power factor, Lower rectifier efficiency because of the large rms values of the input current and the high reactive components size.

For the single boost converter can use the zero-voltage switching (ZVS) and/or zero-current switching (ZCS) to reduce the switching loss of the high-frequency switching. However, they are considered for the single topology. Many soft-switching techniques are then introduced to the interleaved boost converters. The interleaved boost converters with ZCS or ZVS are proposed. These topologies have higher efficiency than the conventional boost converter because the proposed circuits have decreased the switching losses of the main switches with ZCS or ZVS. Nevertheless, these circuits can just achieve the junction of ZVS or ZCS singly or need more auxiliary circuits to reach the soft switching. In the soft-switching circuit for the interleaved boost converter is proposed. However, its main switches are zero-current turn-ON and zero-voltage turn-OFF and the converter works in the discontinuous mode. The maximum duty cycle of the converter is also limited.

It does not reduce the switching losses of the interleaved boost converter by the soft-switching techniques, but it decreases the voltage stresses of the switches by the double voltage technique with the help of the double-voltage capacitor.

The thyristor converter with different firing angles will give less output power, more harmonics and less power factor as compared with Diode rectifier. Hence, the diode rectifier is used as a dc input source to the Boost converter as shown in Fig. 1. The voltage impressed across the inductor during on-period is V_d. During this period, the current rises linearly from a minimum level I_1 to a maximum level l_2. Therefore the voltage across inductor is,

$$V_L = V_d \tag{1}$$

Also,

$$V_L = L\,(I_2 - I_1) / T_{on} = L\,(\Delta I) / T_{on} \tag{2}$$

From (1) and (2),

$$T_{on} = L\,(\Delta I) / V_d \tag{3}$$

The voltage impressed across the inductor during off period is $(V_o - V_d)$ and the current drops linearly from the maximum level I_2 to the minimum level I_1. Therefore the voltage across the inductor is,

$$V_L = (V_o - V_d) \tag{4}$$

Also,

$$V_L = L\,(I_2 - I_1) / T_{off} = L\,(\Delta I) / T_{off} \tag{5}$$

From (4) and (5).

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$T_{off}=L\,(\Delta I) / (V_o - V_d)$ (6)

From (3),

$L(\Delta I)=T_{on} * V_d$ (7)

From (6)

$L(\Delta I)=T_{off} * (V_o - V_d)$ (8)

From (7) and (8)

$T_{on} * V_d = T_{off} * (V_o - V_d)$

$V_o=V_d / (1 - \alpha)$ (9)

Where α = delay angle of the boost converter. As firing angle increase from 0 to 1, the output voltage ideally increases from V_d to infinity. Hence, the output voltage is boosted.

The output voltage is greater than the input voltage. Boost converter is also called as step-up converter. A large inductor L in series with the source voltage is essential. When the switch is on, the input current flows through the inductor and switch and the inductor stores the energy during this period. When the switch is off, the inductor current cannot die down instantaneously; this current is forced to flow through the diode and the load during this off period. As the current tends to decrease, polarity of the emf induced in L is reversed. As a result, a voltage across the load is the sum of supply voltage and inductor voltage and it is greater than the supply voltage.

III. COMPOUND ACTIVE CLAMPING BOOST CONVERTER

The compound active-clamping boost converter circuit is shown in Fig.1.

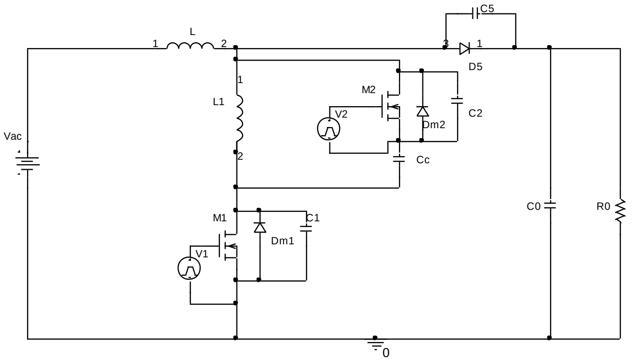

Fig.1. Compound Active Clamping Boost Converter

The compound active-clamping boost converter circuit consists of a input filter inductor L, resonant inductorL_1, main switch M_1, auxiliary switch M_2, clamping capacitor C_c, boost diode D_5 and output capacitor C_c. The auxiliary switch is always turned ON under zero voltage condition while the main switch can achieve zero voltage switching under certain condition. The off-state voltage across the main switch, the boost diode D_5, and auxiliary switch M_2 are clamped. There exists a parasitic resonance between junction capacitance of boost diode and resonant inductor. When M_1 is on, leading to high voltage stress on boost diode. To eliminate the parasitic ringing, the active clamping branch composed of a clamping capacitor and an active switch is placed in parallel with resonant inductor. The main switch, the auxiliary switch, the clamping capacitor, the boost diode and the output capacitor form a voltage loop. At any time, during operation, there are two switching devices are conducting among the main switch the diode and the auxiliary switch, so the voltage across the switch device that is off is clamped. The output filter capacitor C_0 is represented by a constant voltage source and the value of Cc is large enough so that the voltage ripple across it is small, thus can be seen as a voltage source. The resonant frequency of C_c and L_1 is much lower than the operation frequency of the converter. In this converter, the operating stages are almost same in the positive half line cycle and negative half line cycle. Thus, here only one switching cycle in the positive part of power line input is explained. The average output voltage V_0 greater than input voltage V_S can be obtained by a chopper called step up chopper. In the Fig.2 illustrates the step up chopper.

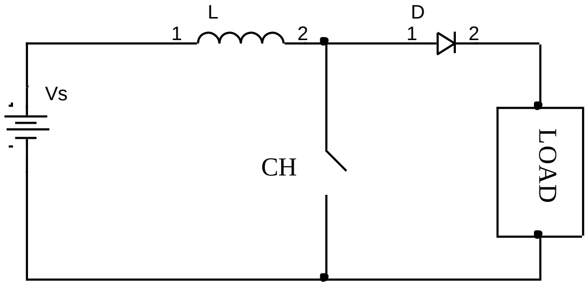

Fig.2. Step up chopper

In this chopper, a large inductor L in series with the source voltage V_S is essential. When the chopper CH is on, the inductor stores energy during the period of t_{on} When the CH is off, as the inductor cannot die down instantaneously, this current is forced to flow through the diode and load for a time t_{off}. As the current tends to decrease, polarity of the emf induced in L is reversed .As a result, voltage across the load given by $V_O = V_S + L\,(di/dt)$, exceeds the source voltage. In this manner, the circuit acts as a step up chopper and the energy stored in L is released to the load.

When CH is on, the current through the inductor would increase from I_1 to I_2.When the CH is off, the current would fall from I_2 to I_1. Assuming linear variation of output current, the energy input to inductor from source during the period t_{on} is,

Win = (voltage across L)(average current through L) t_{on}

$=V_S\,(I_1+I_2)/2\ t_{on}$ (10)

During the time t_{off} , when chopper is off, the energy released by inductor to the load is

Woff = (voltage across L)(average current through L) t_{off}

Woff = $(V_0\text{-}V_S)\,(I_1+I_2)/2\ \ t_{off}$ (11)

Considering the system to be lossless these two energies given by equations (10) and (11) will be equal.

$V_S\,(I_1+I_2)/2\ t_{on} = (V_0\text{-}V_S)(I_1+I_2)\ t_{off}$

$V_0 = V_S\ T\ /(T\text{-}t_{on})$

$V_0 = V_S/(1\text{-}\ \alpha)$ (12)

It is seen from the equation (12) that average voltage across the load can be stepped up by varying the duty cycle (α). If chopper of Fig.2 is always off, α =0 and V_0=V_S. If this chopper is always on, α=1 and V_0 is equal to infinity. In practice, chopper is turned on and off so that α is variable and the required output voltage is obtained. The principle of step up chopper can be employed for regenerative braking of dc motors. Then, V_S represents the motor armature voltage and V_0 the dc source, the power can be feedback to the dc source if $V_S/(1\text{-}\alpha\ )$ is more than V_0. In this manner, regenerative braking of dc motor occurs. Even at decreasing motor speeds, regenerative braking can be made to take place provided duty cycle α is so adjusted so that $V_S/(1-\alpha)$ exceeds the fixed source voltage V_S.

The average value of the source current can be obtained from

$P_i = P_0$

i.e. $V_i I_i = V_0^2/R$

$I_i = (V_0^2/V_i) /(1/R)$

$I_0 = I_1 (toff / T)$

$I_0 = I_i (1-\alpha)$

The input power and output power are given in equations (13) and (14)

$P_i = V_i * I_i$ (13)

$P_0 = V_0^2 / R$ (14)

Neglecting the losses, the output power must be the same as the power supplied by the source.

$V_i * Ii = V_0^2/R = V_i^2/(1-\alpha)^2 R$

$I_i = V_i / (1-\alpha)^2 R$

$I_L = (I_{max} + I_{min}) / 2$

$(I_{max} + I_{min}) / 2 = I_i$

$I_{max} + I_{min} = 2 I_i$ (15)

The voltage across the inductor is

$V_L = V_i = L\, di/dt$

$di/dt = V_i /L$

With the switch closed (t_{on}),

$Ii = V_i /L * t_{on}$

$Imax - Imin = V_i /L * t_{on}$ (16)

Adding the equations (15) and (16)

$2 * I_{max} = 2 Ii + V_i /L * t_{on}$

$Imax = Ii + V_i /2L * t_{on}$

$= V_i / (1-\alpha)^2 R + V_i /2L * t_{on}$

Imax is given in the equation (17).

$Imax = V_i [1/ (1-\alpha)^2 R + t_{on} /2L]$ (17)

Similarly Imin is given in the equation (18)

$Imin = V_i [1/ (1-\alpha)^2 R - t_{on} /2L]$ (18)

The peak-to-peak ripple in the input current is given by

$Ip\text{-}p = Imax - Imin = V_i * t_{on} /L$

For continuous current conditions, the minimum value of current required is equal to zero. Equating (18) to zero,

$Imin = V_i [1/ (1-\alpha)^2 R - t_{on} /2L] = 0$

$1/ R (1-\alpha)^2 = t_{on} /2L$

The value of the inductance is given in equation (19).

$L = [R * ton (1-\alpha)^2] / 2$ (19)

The description of the compound active clamping boost PFC converter, its modes of operation and the analysis of step up chopper are analyzed.

IV. SIMULATION RESULTS

The simulation circuit diagram of the compound active clamping boost converter with R load and RL load are shown in Fig.3 and Fig.4. The gate pulses for the switches are shown in Fig.4. The Fig.5 and Fig.6 show the voltage across the switches M_1 and M_2.The Drain Source voltage (V_{DS}) and Gate Source voltage (V_{GS}) for the MOSFET M1 is shown in Fig.7. The current through inductor L1 is shown in Fig.8. The voltage across the R and RL loads are shown in Fig.9 and Fig.10.

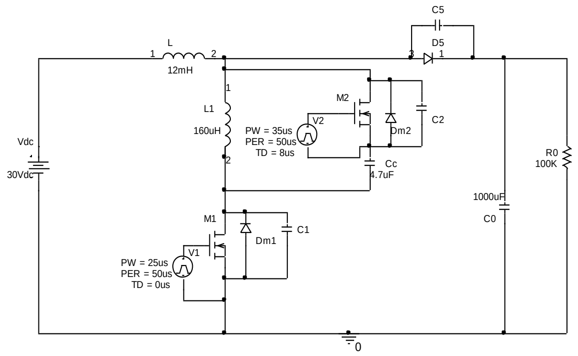

Fig.3.Simulated Circuit Diagram Of Compound Active Clamping Boost Converter (With R Load)

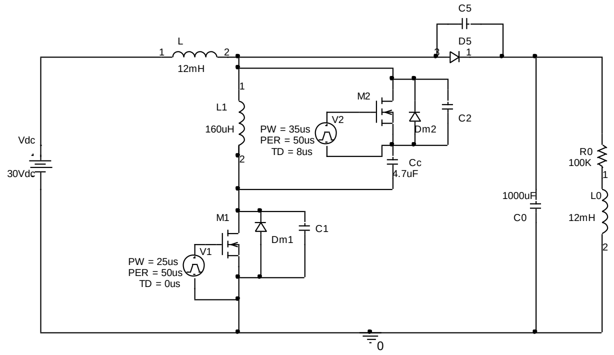

Fig.4. Simulated Circuit Diagram of Compound Active Clamping Boost Converter (With RL Load)

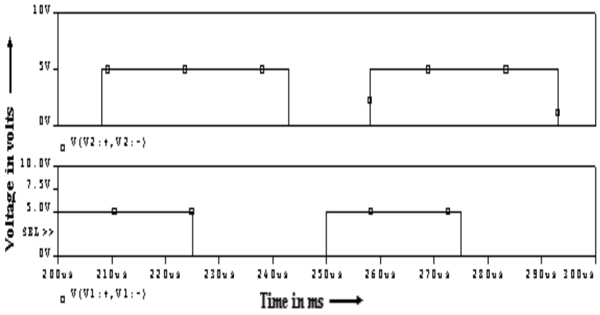

Fig.4. Gate Pulses For Switches M1 And M2

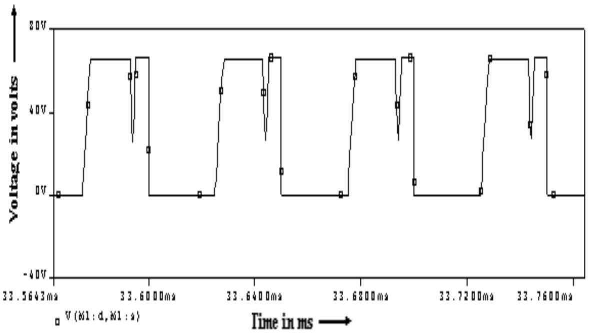

Fig.5. Voltage across M1

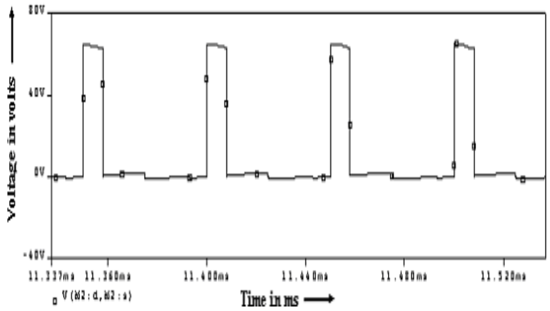

Fig.6 Voltage across M2

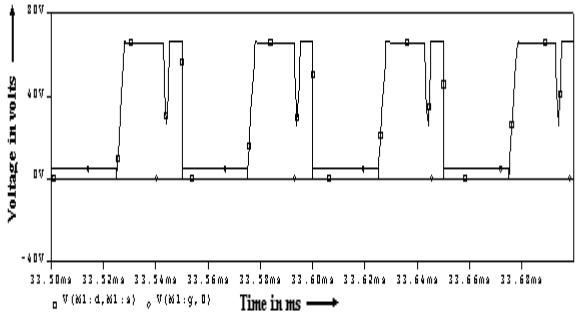

Fig.7.V_{DS} and V_{GS} of MOSFET M1

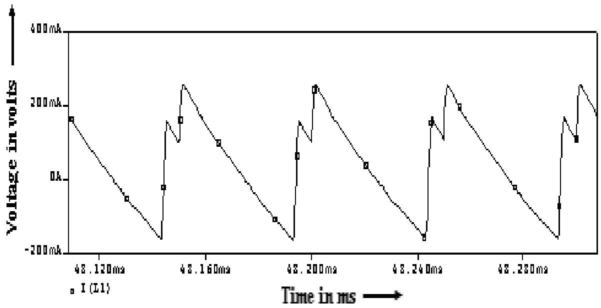

Fig.8.Current through Inductor L1

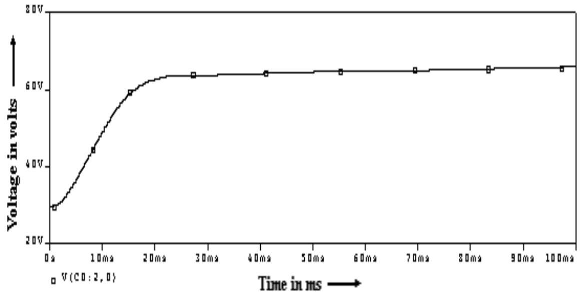

Fig.9. Voltage across R Load

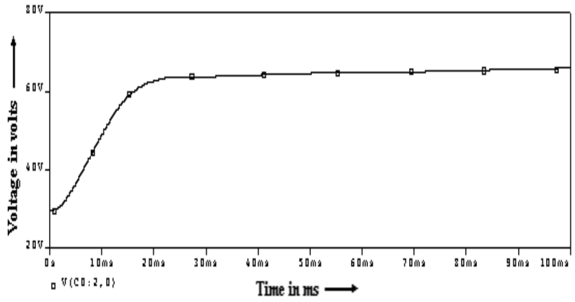

Fig.10.Voltage across RL Load

From the Fig.7, it can be seen that the gate pulse is given when the voltage across the MOSFET M1 is zero. Thus the ZVS condition is achieved. This simulation results presence the compound active clamping boost converter including the gate pulses applied to the switches is as shown in the Fig.11.

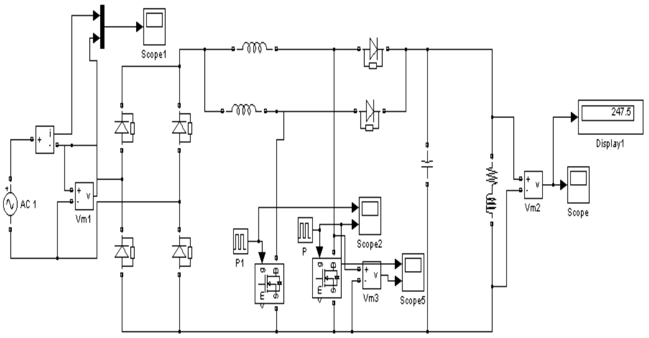

Fig.11. Circuit diagram

This simulation will be used to validate the newly designed switching circuit. Dynamic analysis includes analyzing the current linear regulator circuit. The analysis will include measuring the output voltage, current, and a thermal measurement of the amount of heat that is generated. After the switching regulator circuit replaces the linear regulator circuit, the same analysis will be done. This analysis should have the correct output voltage and current. Further, the heat that is generated should be significantly less than the linear model. The circuit should be cool to the touch, so that a thermal management solution is not needed. The waveforms of input voltage and current is as shown in the Fig.11(a).

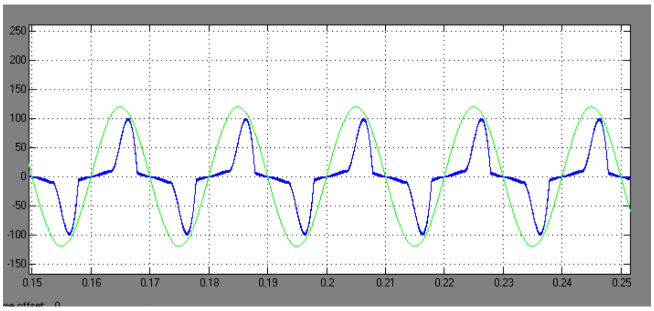

Fig.11 (a) Input voltage and current

The simulation software will display output voltage and current. Since this is a simulation tool, the measurements are based on ideal conditions, which may not be replicated in the real world. The various results of triggering pulses, voltage and current waveform is as shown in the Fig.11(b),Fig.11(c) and Fig.11(d) respectively.

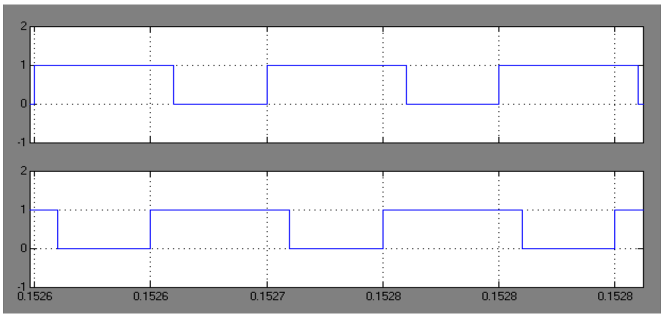

Fig.11. (b) Triggering pulses

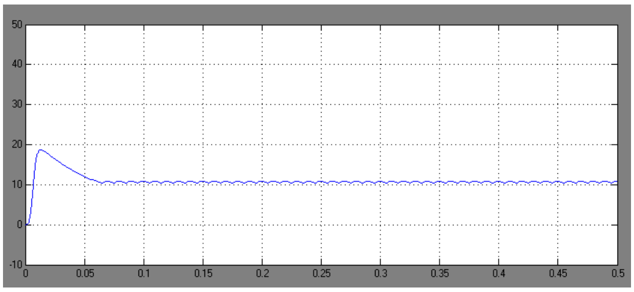

Fig.11. (c) Output current

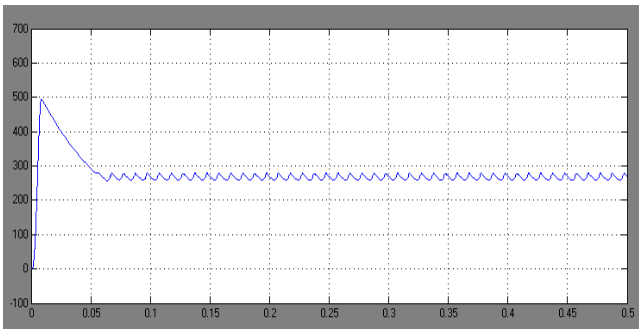

Fig.11 (d) Output voltage

The purpose of this subcomponent is to take the input DC voltage (either from a DC source e.g. power supply or battery, or from the rectifier output) and convert the output to a consistent 45Vdc. As the design considers that the input voltage may vary somewhere between 40V and 50V, the circuit must be able to both step-up and step-down the voltage as necessary. This need implies the usage of a buck-boost converter, which was originally proposed. The circuit diagram for dc motor load is as shown in the Fig.12.

This has been changed since the design review into a fly back converter, which operates equivalently save for several differences. The buck-boost converter inverts the output (in this case taking the positive input to a -45V output), which was not desired. The fly back converter can both invert the output or keep the sign unchanged, the output determined by the polarity on the secondary winding. Also, the fly back converter uses a coupled inductor in the design, which also provides electrical isolation to the output, which while not necessary may be beneficial in applications.

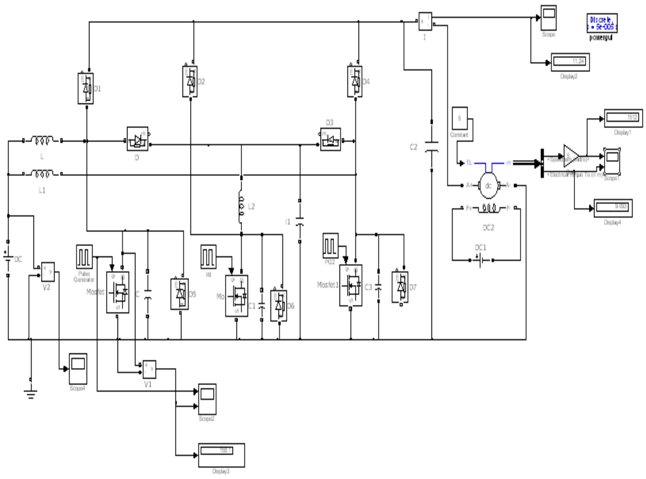

Fig.12.Circuit diagram for dc motor load

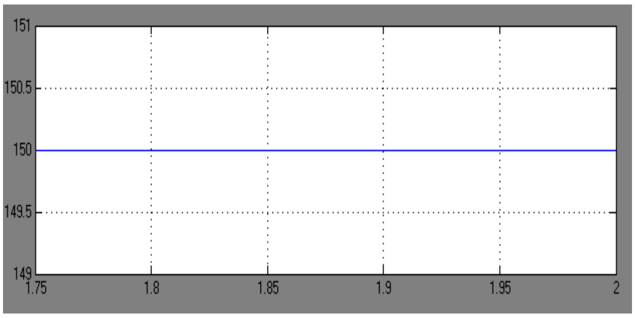

Fig.12 (a) Input voltage

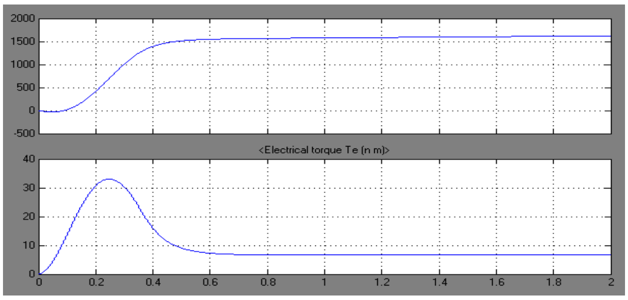

Fig.12 (b), (c) DC Motor speed and torque output

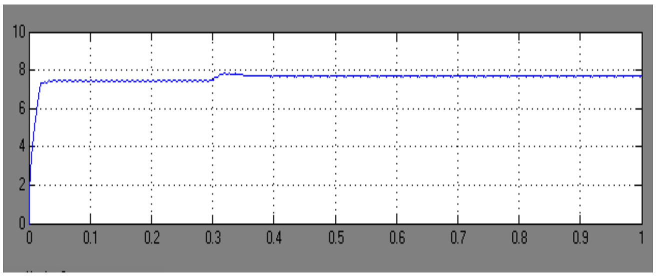

Fig.13(c) Output current

VI. CONCLUSION

The operation of compound active clamping boost PFC converter, the mathematical analysis of the step-up chopper and the simulation results of the circuit are presented. A novel interleaved boost converter with both zero-voltage switching and zero-current-switching functions is proposed in this paper the main switches can achieve both ZVS and ZCS. Thus we designed a interleaved booster with reduces switching loses and ripples of input current and output voltage. The voltage stress of all switches is equal to the output voltage. It has the smaller current stress of elements

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BIOGRAPHY

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