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BIDIRECTIONAL DC TO DC CONVERTER BASED DRIVE

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***Abstract* - This work deals with simulation of Bidirectional DC to DC converter fed PMDC motor drive. This converter can operate with steep conversion ratio, a soft-switching, a continuous inductor current, and fixed switching frequency and low switch stresses. Drive output taken for various input voltages during boost and buck mode of operation.**

Keywords – DC-DC power conversion, energy conversion, power electronics, Switched Mode Power Supplies and Permanent magnet DC motor.

I. INTRODUCTION

In recent years, HEV (Hybrid Electric Vehicles) has attracted more and more attentions of many countries vehicle industry. Automobiles powered by internal combustion engines represent a huge infrastructure investment, and about one third oil consumption. So the transition to an all-electric mobile fleet appears to be very attractive and desirable, but has been limited by several key technology and business issues. So the transition of researching on Hybrid Vehicles appears to be desirable [1].

Hybrid Vehicles have several advantages over conventional cars and there are some models available in the market. From the point of view of the power electronics field, in the power chain there are two circuits that have to be developed (shown in fig. 1).

The inverter to drive the motor and the DC/DC converter placed between the battery and the high voltage bus. This DC/DC converter should be bi-directional since the energy can flow from the battery to the DC link or in the opposite direction. This can integrate with the existing gasoline and electricity infrastructure is through the use of plug-in HEV (in fig. 1). By providing sufficient energy storage for a 40 mile range, by using the existing electricity infrastructure to recharge the battery at night, and by maintaining gasoline powered operation when sufficient charge is not available, one is able to realize most of the benefits at a societal level. In Fig.1 we can see the whole circuit, but the most important part is the bi-directional DC/DC converter, and its operation principle is controlled by current I_1 and I_2 (see fig. 2), and used between the direct voltage source V_1 and V_2. Both I_1 and I_2 are respectively the average current of V_1 and V_2. We use them to control the energy transfer direction. According to the need in practice, the direction of energy transfer is changed by bi-directional DC/DC converter, in other words, the energy can transfer from V_1 to V_2 (when I_1 is negative and I_2 is positive) or in the opposite direction. In hybrid electric vehicle, the voltage of energy storage devices, such as battery or super capacitor, varies with the change in load. So we have to utilize the bi-directional converter to optimize the drive characteristic of motor, and recycle the energy when the motor is braking, thereby increase the efficiency of the energy utilization. Furthermore, in order to make complete the instantaneous power output of battery, we utilize bi-directional converter to work with super capacitor to increase instantaneous power output, and improve the acceleration and deceleration of hybrid vehicle.

Hybrid Electric Vehicle (HEV) uses an electric energy source (battery, ultra-capacitor) to assist the propulsion of the vehicle in addition to the primary energy source (Internal Combustion Engine (ICE), fuel cell), and to absorb the kinetic energy during braking. With the ever increasing gas price, the need for zero

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emission vehicles and much more matured electric drive technologies available, HEV becomes more attractive and possible for commercialization [2].

Non isolated Buck-Boost Cascade Bidirectional DC-DC Converter Topology for EVs application is discussed in [3]. A four-quadrant bi-directional drive system based on non isolated bidirectional converter with reduced number of switches is given in [4]. Bidirectional DC – DC converter application in HEV with reduced switches and ZVS is discussed in [5]. A noval PWM ZVS bidirectional DC/DC converter with coupled inductor is given in [6].

For the traction drive inverter in ICE HEVs, isolation is usually not required [7]. There are two basic configurations for this inverter: one is a traditional PWM inverter powered by a battery as shown in Fig1, the other is a bidirectional DC - DC converter as shown in Fig.2.

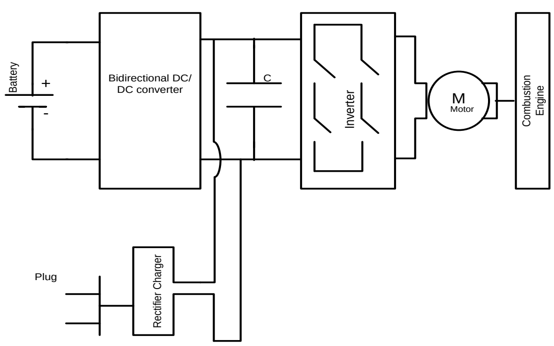

Figure.1 Block diagram of drive system of a hybrid vehicle

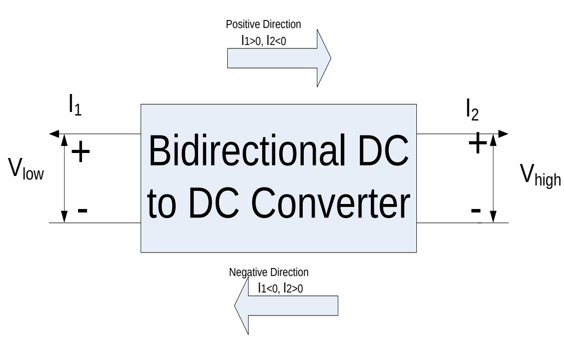

Figure.2. A Block diagram of bidirectional DC- DC converter

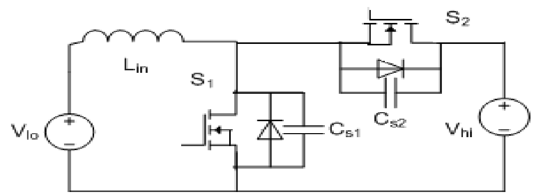

Figure. 2(a) Basic Bidirectional DC to DC converter

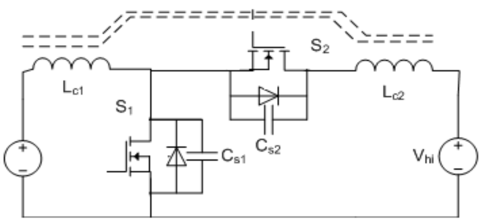

Figure.2 (b). Coupled Inductor PWM DC to DC Converter

II. BI-DIRECTIONAL CONVERTER OPERATION

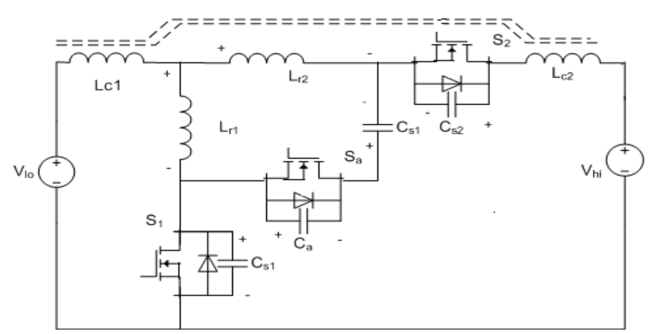

Figure.3 Coupled Inductor PWM ZVS DC to DC Converter with single auxiliary

A. Operation in Boost Mode

Fig.3 shows the coupled inductor PWM ZVS DC – DC converter. During boost mode of operation switch S_1 act as main switch and switch S_2 acts as body diode. The equivalent circuit diagram for each mode of operation in a single switching cycle shown in

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Fig.4 and ideal waveform for buck mode is shown in Fig.6.

Mode 0 ($t < t_0$): At $t=t_0$,the switch S_1 is on, the current through L_{C1} is raises and at the same time L_{C2} get energized because both the inductor shares the same core and current flows through it due to excess flux added to core. Now the converter works as standard coupled inductor PWM boost converter. There is no current flowing into the high voltage source V_{hi} during this mode

Mode 1 ($t_0 < t < t_1$): At $t = t_1$, Switch S_1 is turned off by ZVS and excess voltage is diverted to capacitor across S_1, C_{s1}.The current through inductor is used to charges the C_{s1}.

Mode 2 ($t_1 < t < t_2$): during this mode current through L_{r1} is diverted to L_{r2} at the same time D_a become forward biased, then in turn charges the capacitor C_r . At the end of this mode the current in L_{r1} is completely diverted to L_{r2} and no current flows through L_{r1}, D_a, C_r and L_{r2} makes the C_{s2} to discharge. The equations are

$$V_{Cr}(t) = I_{in,lo} Z_1 \sin w_1 (t-t_1) \quad (1)$$

$$i_{Lr1}(t) = I_{in,lo} \cos w_1(t-t_1) \quad (2)$$

$$i_{Lr2}(t) = I_{in,lo}[l - \cos w_1 (t-t_1)] \quad (3)$$

Where V_{Cr} is the voltage across the auxiliary circuit capacitor C_r, and

$$Z_1 = \sqrt{\frac{L_{r1}+L_{r2}}{C_r}} \quad (4)$$

$$\omega_1 = \sqrt{\frac{1}{(L_{r1}+L_{r2})\,C_r}} \quad (5)$$

and $I_{in,lo}$ is the input current from the low side source. The initial values of V_{Cr} and i_{Cr} (the voltage across auxiliary circuit capacitor Cr and the current through it) at the beginning of Mode 1 are $V_{Cr}(t_1) = 0$ and $i_{Cr}(t_1) = I_{inlo}$. At the end of this mode, V_{Cr} reaches a maximum value of

$$V_{Cr,max} \approx I_{in,lo} Z_1 \quad (6)$$

Mode 3 ($t_2 < t < t_3$): At $t = t_2$, during this mode capacitor C_{s2} is fully discharged and diode D_2 begins conduction, now converter operator standard coupled inductor boost converter and energy transfer from low voltage side to high voltage side through magnetic coupling between L_{c1}, L_{c2}.The current through L_{c1} is decreased due to negative voltage applied across it.

Mode 4 ($t_3 < t < t_4$): at $t= t_3$ switch S_a is turned ON, the capacitor C_r get discharged through the path C_r-L_{r1}-L_{r2} so that energy is stored in L_{r1} and L_{r2}, because of this S_a is turned on at ZCS.

$$i_{Lr1}(t) = -(V_{Cr}(t_3)/Z_a) \sin w_a (t-t_3) \quad (7)$$

$$V_{Cr}(t) = V_{Cr}(t_3) \cos w_a (t-t_3) \quad (8)$$

$$V_{S1}(t) = (V_{lo}/l-D_l) + V_{Cr,\,max} \cos w_a (t-t_3) \quad (9)$$

Where

$$\omega_a = \sqrt{\frac{1}{(L_{r1}+L_{r2})C_r}} \quad (10)$$

$$Z_a = \sqrt{\frac{L_{r1}+L_{r2}}{C_r}} \quad (11)$$

The initial conditions for eqns. (6)-(8) are $i_{L1}(t_3) = 0$, $i_{Cr}(t_3) = 0$, and

$$V_{Cr}(t_3) = I_{in,lo} Z_1 \quad (12)$$

$$V_{S1}(t_3) = (V_{lo}/l-D_1) + V_{Cr}(t_3) \quad (13)$$

Mode 5 ($t_4 < t < t_5$): in this mode switch S_a is turned OFF L_{r1}, L_{r2} starts resonating C_{s1}, C_{sa} and thus C_{s1} is discharged and charges the C_{sa}. At the end of this mode C_{s1} is completely discharged and C_{sa} is charged fully and excess current is flows through L_{r1} to the L_{C1}

$$i_{Lr1}(t) = (-Vcr(t_3)/Z_a) \cos w_a (t-t_4) \quad (14)$$

$$V_{S1}(t) = V_{S1}(t_4) - (V_{Cr}(0)/Z_a) Z_{S1} \sin w_{S1} (t-t_4) \quad (15)$$

Where

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$$\omega_{S1} = \sqrt{\frac{1}{(L_{r1}+L_{r2})(C_{S1}\|C_{Sa})}} \quad (16)$$

$$Z_{S1} = \sqrt{\frac{L_{r1}+L_{r2}}{(C_{S1}\|C_{Sa})}} \quad (17)$$

Where initial conditions $i_{Lr1}(t) = 0$,

$i_{Lr1}(t) = (-V_{Cr}(t_4)/Z_a)$ (18)

$V_{S1}(t) = V_{S1}(0) = V_{lo}/(1\text{-}D_1)$ (19)

Mode 6 ($t_5 < t < t_6$): At $t = t_5$, in his mode diode D1 conducts because of ring current, due to this voltage across the switch is zero (short circuited), thus switch s1 is turned ON at ZVS condition.

Mode 7 ($t_6 < t < t_7$): Again S_1 is ON and current through the L_{r1} is reversed. This mode continues until current is completely transferred to the S_1. Now converter operates in mode 0.

$t_{c1} = [(L_{r1} + L_{r2})\, I_{in,lo}] / [(V_{in,lo} + (V_{hi} / n))]$ (20)

Where t_{C1} is the time in which the current in the inductor L_{r2} is completely transferred to L_{r1}.

B. Operation in Buck Mode

From Fig.4, during buck mode of operation, switch S_2 act as main switch and S1 act as freewheeling diode. The equivalent circuit diagram for each mode of operation in a single switching cycle shown in Fig.6 and ideal waveform for buck mode is shown in Fig.8.

Mode 0 ($t < t_0$): before time t_0 the converter operates as standard coupled buck converter. Switch S_1 is on and current through the L_{c2} rises. L_{c1} gets energized through L_{r2}.

Mode 1 ($t_0 < t < t_1$): Here S_2 is turned OFF and the voltage is limited by capacitor C_{s2}, C_{s1} is charged through the L_{r2} and then current flows through the D_a, C_r, input current is diverted to L_{r1} and C_{s1} and C_{s1} get discharges.

$V_{Cr}(t) = I_{o,lo}\, Z_2 \sin w_1 (t\text{-}t_1)$ (21)

Where V_{Cr} is the voltage across the auxiliary circuit capacitor C_r, $I_{in,lo}$ is the input current flowing to the low-side voltage source, and

$$Z_2 = \sqrt{\frac{L_{r2}}{C_r}} \quad (22)$$

$$\omega_1 = \sqrt{\frac{1}{L_{r2}C_r}} \quad (23)$$

The initial value of V_{Cr} at the beginning of Mode 1 is $V_{Cr}(t_1) = 0$, and $i_{Cr}(t_1) = I_{in,lo}$.

Mode 2 ($t_1 < t < t_2$): At $t=t_1$ C_{s1} is completely discharged and diode D_1 starts conduction. The capacitor C_{s2} is fully charged and no current exist in L_{r1}-D_a-C_r path.

Mode 3 ($t_2 < t < t_3$): At $t=t_2$ the converter operates as a standard buck converter so that energy transferred from high voltage side to low voltage side due to magnetic coupling and current through the Lc2 is decreased due to negative voltage is impressed across it.

Mode 4 ($t_3 < t < t_4$): before switch S_2 is ON, the switch S_a is ON at ZCS .Capacitor C_r get discharged through L_{r1} and L_{r2} and current through the coupled inductor is decreases.

$i_{Lr2}(t) = (-V_{Cr}(t_3)/Z_a)\, \mathrm{Sin} w_a(t\text{-}t_3)$ (24)

$V_{Cr}(t) = V_{Cr}(t_3) \cos w_a (t\text{-}t_a)$ (25)

$i_{Lr2} = (-V_{Cr}(t_3)/Z_a) \cos w_a (t\text{-}t_4)$ (27)

$V_{s2}(t) = V_{s2}\text{-}(V_{Cr}(t_3)/Z_a) Z_{s2} \sin w_{s2}(t\text{-}t_4)$ (28)

$$\omega_{S1} = \sqrt{\frac{1}{(L_{r1}+L_{r2})(C_{S1}\|C_{Sa})}} \quad (29)$$

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$$Z_{S1} = \sqrt{\frac{L_{r1} + L_{r2}}{(C_{S1} \| C_{Sa})}} \quad (30)$$

The initial conditions for eqns. (23)-(24) are $i_{L1}(t3) = 0$, $i_{Cr}(t3) = 0$, And

$$V_{Cr}(t_3) = i_{in,io} Z_1 \quad (26)$$

Mode 5 ($t_4 < t < t_5$): In this mode the switch S_a is turned OFF. The current in L_{r1} and L_{r2} is used to discharges C_{s2} and charges up C_{sa}.

The initial conditions of eqns. (25)-(26) are

$$i_{Lr2}\ (t) = (-V_{Cr}\ (t_3)/Z_a) \quad (31)$$

$$V_{s2}\ (t) = V_{s2}\ (0) = V_{hi} + (nV_{lo}/1\text{-}D) \quad (32)$$

Mode 6 ($t_5 < t < t_6$): At $t = t_5$, the capacitor Cs2 is completely discharged and the body diode D_2 conducts so that across the switch S_2 is short circuited so that switch S_2 is turned ON at ZVS.

Mode 7 ($t_6 < t < t_7$): The current through the L_{r2} is reversed and current starts to flows from L_{r1} to S_2.This mode continues until current is completely transferred to S_2, now converter operation is simillar to mode 0. Where t_{c2} is the time in which the current in inductor L_{r1} is completely transferred to L_{r2}. By symmetry $t_{c1}=t_{c2}$

$$t_{c2\,=}\ [(L_{r1} + L_{r2})\ I_{in,\ lo]}\ /\ [(V_{in,\ lo} + (V_{hi}\ /\ n))] \quad (33)$$

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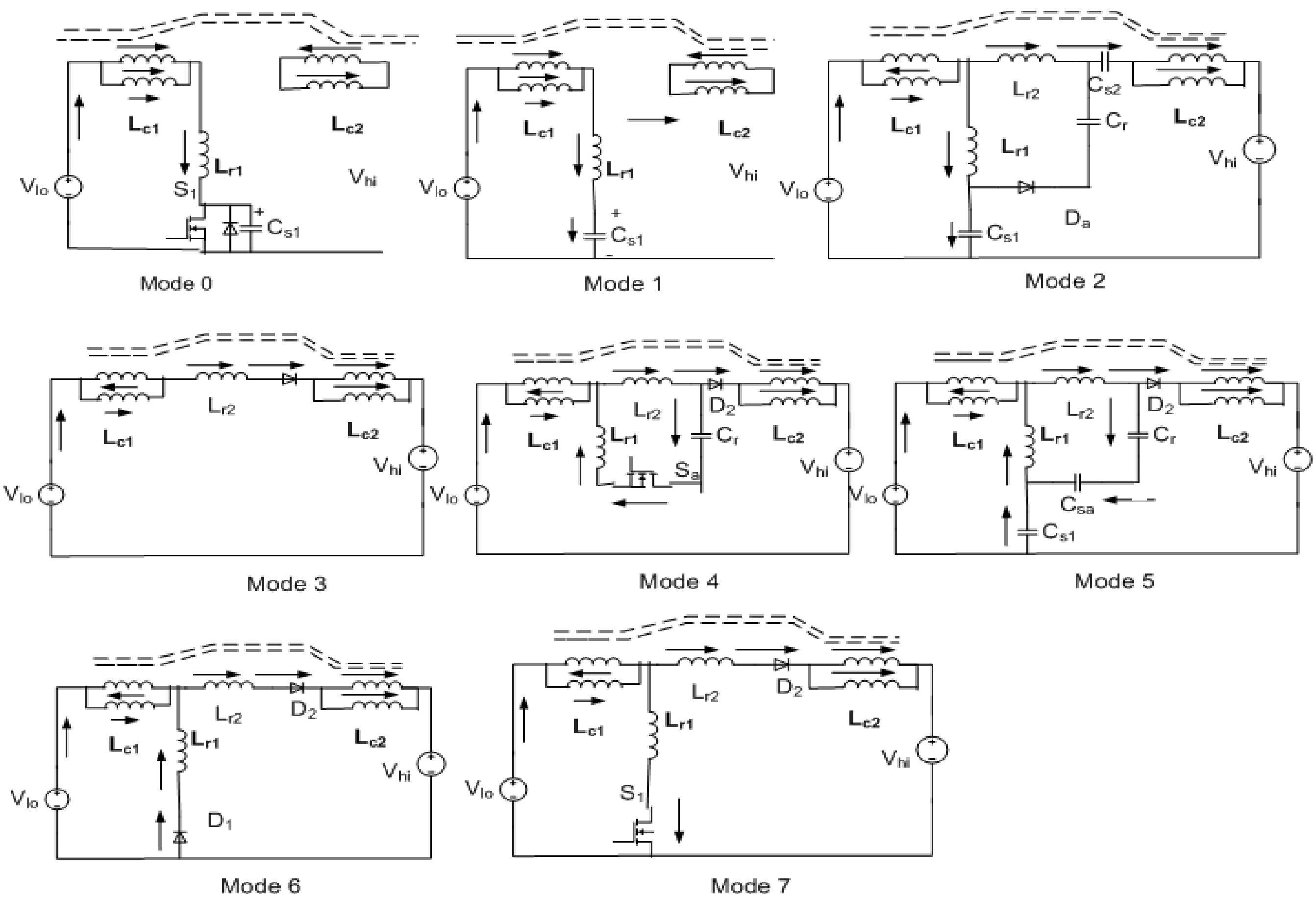

Figure. 5 Equivalent Circuits of Boost Mode operation

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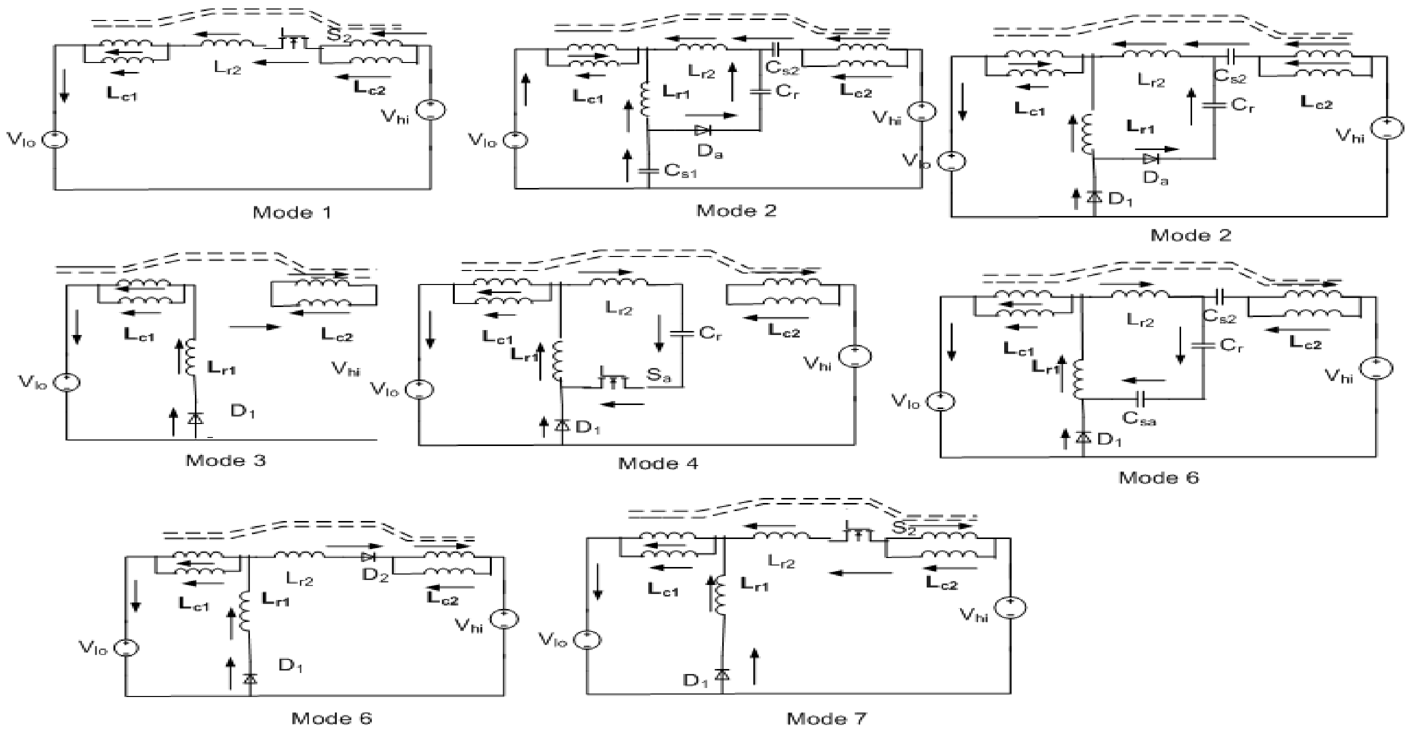

Figure. 5 Equivalent Circuits of Buck Mode operation

IV. SIMULATION RESULTS

The simulation is done using MATLAB and results are presented here for boost and buck mode.

Fig.6 (a) shows the simulation circuit for boost mode with motor load. Fig.6 (b) shows the gate pulses for boost switch S_1 and auxiliary switch S_a. Fig. 6(c) shows the input voltage and Fig 6(d) shows the armature speed output waveform. Fig.6 (e) shows output torque waveform of input voltage of 100 V. Fig. 6(f) shows output torque waveform of input voltage of 125 V. Fig 6(g) Shows output torque waveform of input voltage of 150 V.

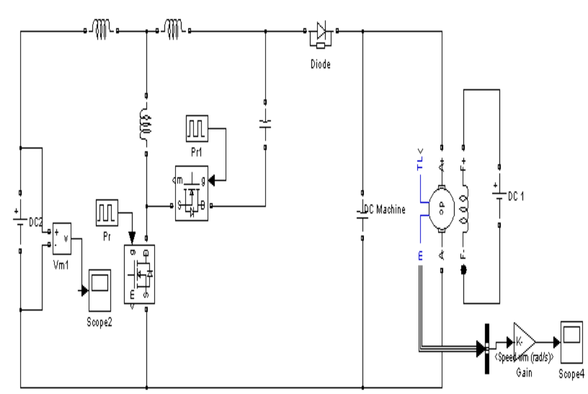

Figure.6 (a) Simulation circuit for boost mode

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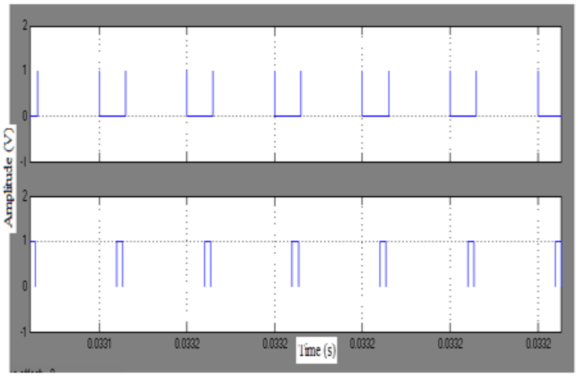

Figure.6 (b) Switching pulses for S_1 and S_a

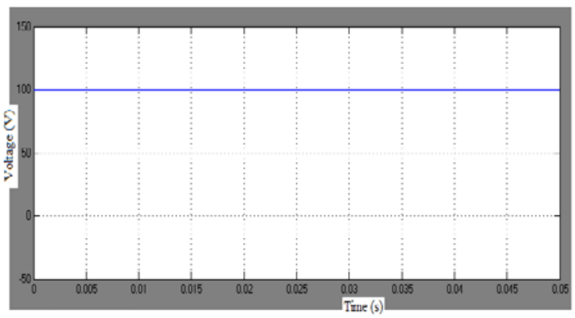

Figure. 6 (c) Dc input voltage

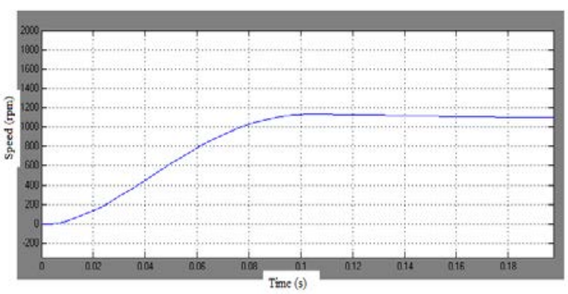

Figure 7(d)Armature speed output waveform

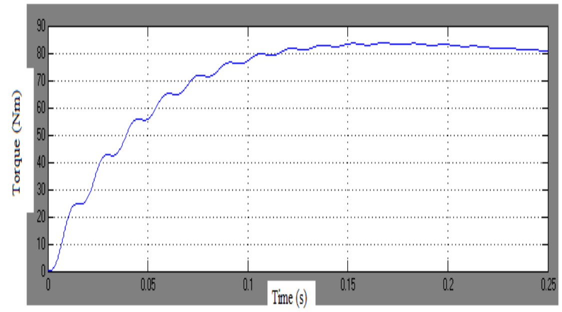

Figure. 7(e) Output torque waveform for input voltage of 100 V

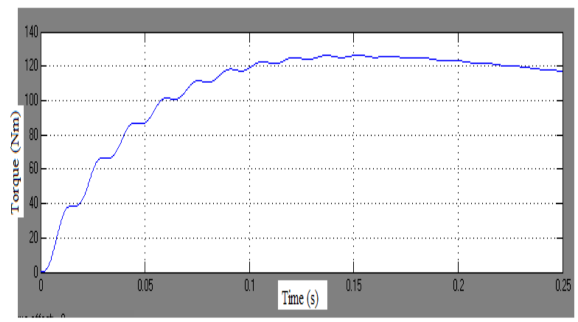

Figure. 6 (f) Output torque waveform for input voltage of 125 V

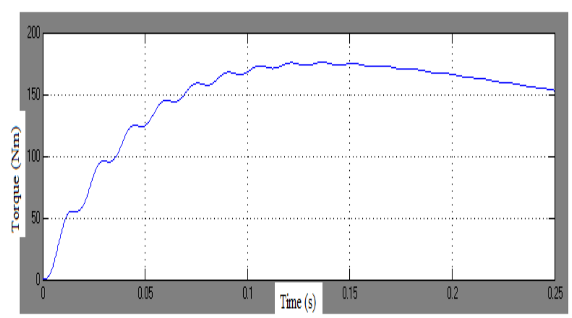

Figure. 6 (g) Output torque waveform for input voltage of 150 V

Fig. 6 (h) shows the simulation circuit for buck mode with motor load. Fig. 6(i) shows output torque waveform of input voltage of 200 V. Fig. 6(j) shows the armature speed output waveform for 200 V input voltage. Fig.6(k) shows output torque waveform of input voltage of 150 V. Fig. 7(l) shows output torque waveform of input voltage of 150 V. Fig. 6 (m) Shows output torque waveform of input voltage of 100 V. and Fig. 7(n) shows output torque waveform of input voltage of 100 V.

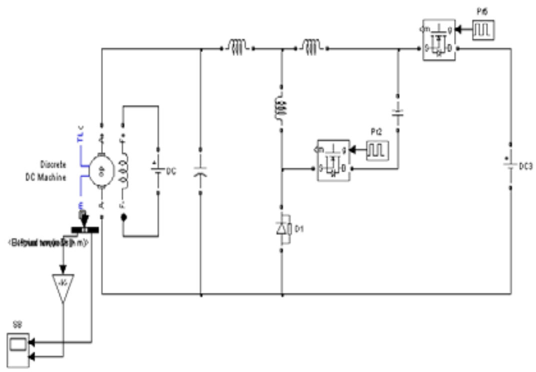

Figure. 6(h) Simulation circuit for buck mode

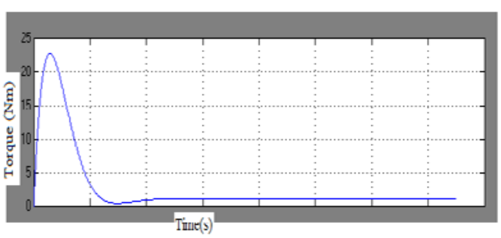

Figure. 7(i) Output torque waveform for input voltage of 200 V

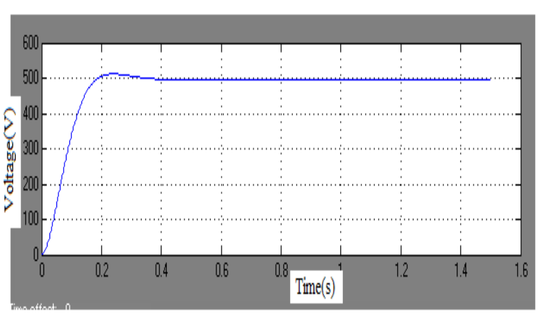

Figure. 6(j) Armature speed output waveform for input voltage of 200 V

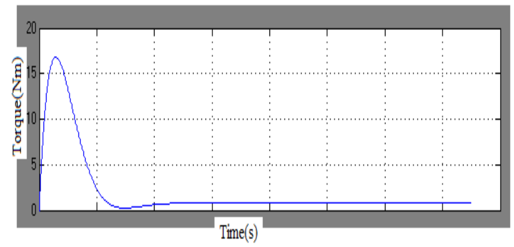

Figure. 6 (k) Output torque waveform for input voltage of 150 V

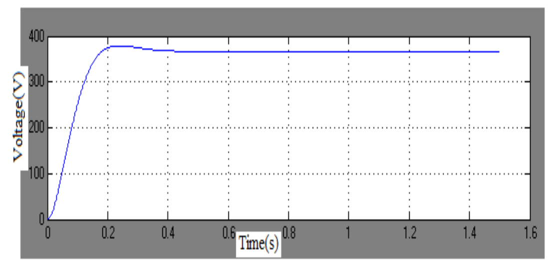

Figure. 6 (l) Armature speed output waveform for input voltage of 150 V

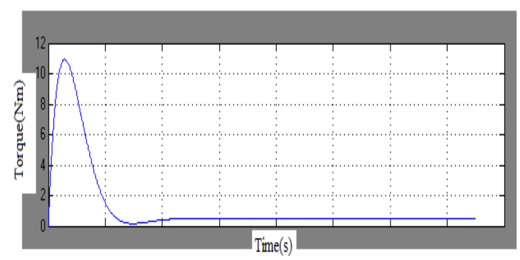

Figure. 6 (m) Output torque waveform for input voltage of 100 V

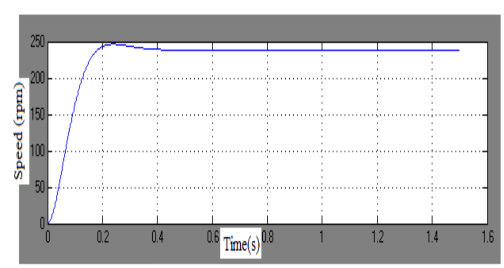

Figure. 7 (n) Armature speed output waveform for input voltage of 100 V

V. CONCLUSION

The Bidirectional DC-DC converter fed PMDC motor is modelled and simulated using MATLAB simulink. The results are presented for boost mode and buck mode. This converter can operate with steep conversion ratio, a soft-switching, a continuous inductor current, and fixed switching frequency and low switch stresses. Drive is simulated for various value of input voltages during boost and buck mode of operation.

REFERENCES

1. Yu Du, Xiaohu Zhou, Sanzhong Bai, Srdjan Lukic and Alex Huang, "Review of Non-isolated Bi-directional DC-DC Converters for Plug-in Hybrid Electric Vehicle Charge Station Application at Municipal Parking Decks", IEEE 2010
2. Mehran Ahmadi , Eduardo Galvan , Ehsan Adib , Hosein Farzanehfard, "New Fully Soft Switched Bi-directional Converter for Hybrid Electric Vehicles: Analysis and Control " , IEEE 2010
3. Hua Bai, and Chris Mi, "The Impact of Bidirectional DC-DC Converter on the Inverter Operation and Battery Current in Hybrid Electric Vehicles", IEEE 2011
4. Xiao Li, Wenping Zhang, Haijin Li, Ren Xie, Dehong Xu, "Design and Control of Bi-directional DC/DC converter for 30kW fuel cell power system", IEEE 2011
5. Pritam Das, Biran Laan, Sayeed Ahmad mousavi and Gerry Moschopoulos, " A Nonisolated Bidirectional ZVS – PWM Active Clamped DC-DC Converter",IEEE TPEL 2009, vol. 24.
6. Pritam Das, Ahamd Mousavi and Gerry Moschopoulos," Analysis and Design of a Non isolated Bidirectional ZVS – PWM DC – DC Converter with Coupled Inductors", IEEE TPEL 2009.
7. F. Caricchi, F. Crescimbini, G. Noia, D. Pirolo, "Experimental Study Of A Bidirectional Dc-Dc Converter For The DC Link Voltage Control And The Regenerative Braking In PM Drives Devoted To Electrical Vehicles", IEEE 1994
8. M. H. Rhasad, "Power Electronics handbook", 2010 .

About Author

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