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Bidirectional Dc to DC Converter with Ann Controller for Hybrid Electric Vehicle

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Abstract--A bidirectional chopper (BDC) is the one which can interface main source (HVS), auxiliary source (LVS) and a DC-Bus voltage at different levels which is implemented in Hybrid Electric Vehicle (HEV). This converter operation is of two modes namely dual source powering mode and energy re generation mode along with power flow control in both the directions. And also the independent power flow control across two sources (i.e. the dual source buck-boost mode). The operation, closed loop control of artificial neural network (ANN) and the comparison between PI and ANN control are provided in simulation results.

I. INTRODUCTION

The emission of harmful gases from the internal combustion engines (ICE) and the merits of hybrid electric vehicles and electric vehicles are discussed in [1]. The energy control and management of driving cycles of charge and discharge of battery, which impacts on the life time battery is verified, in different operating stations like urban and sub urban areas in [2].The importance of optimal energy management controllers and future driving conditions are discussed [3].The dynamic response of bidirectional DC converter with minimal phase for buck and boost modes for different load changing conditions are validated [4]. A bidirectional DC/DC converter for electric vehicle (EV) and DC-microgrid with interleaved charge-pump topology and increased two phase voltage ratio [6]. A novel BDC offering with less current ripples and greater voltage conversion ratio has been implemented [7]. The analyses of power transmission of IBDC under control of DPS have been conducted for wide range of power transmission than SPS control , the designing steps along with detailed operating principal and modes of a non-isolated BDC with soft switching was achieved with ZVC is verified [8-9]. The development of a seven phase voltage source inverter with ANN based SVPWM with the advantage of real time DSP implementation and increased computational efficiency[10]. Stability analysis of voltage with ANN based back propagation algorithm with Global Stability Voltage[11]. The schedule of charging and discharging of a battery in electric vehicle using artificial neural network is proposed along with the weight adjustment process (training or learning), performance measurement, evaluation, of network[12].

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Application of neural networks for estimation of power levels in the battery of electric vehicle and the behaviour of battery at different temperatures is proposed and verified by Ala A. Hussein [13]. A newly proposed BDC in Fig.1 with two voltage sources, operational configuration with step up and step down modes and a prototype of 1KW is done and proven in simulation [5].

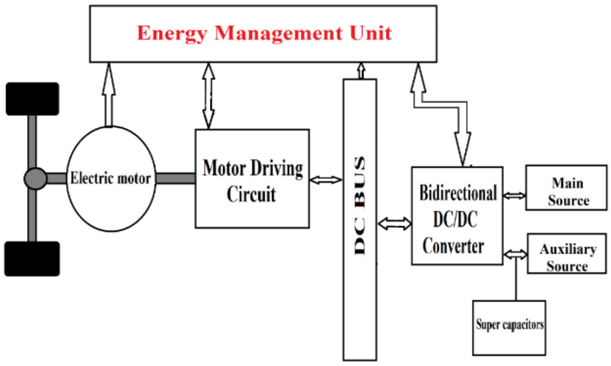


Fig.1 The Functional Block Diagram Of BDC

The main properties of the proposed circuit are it interfaces two DC energy sources with different voltages. The independent control of power flow between two energy sources as well as power flow control from dc bus to voltage sources.

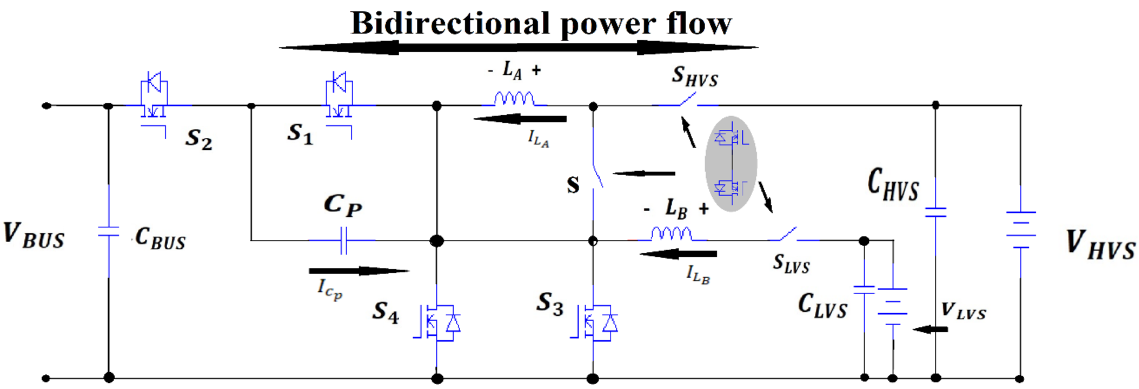


Fig.2 Bidirectional DC to DC converter with dual voltage sources

Modes of operation	On Switch	Off Switch	Controlling Switch	Synchronous Rectifier (SR)
Dual-Source Low Voltage Powering Mode (Accelerating)	S_{HVS}, S_{LVS}	S	S_3, S_4	S_1, S_2
Dc-Bus High-voltage Energy-Regenerating Mode (Braking)	S_{HVS}, S_{LVS}	S	S_1, S_2	S_3, S_4
Dual-Source Low Voltage Buck Mode	S_{HVS}, S_{LVS}	S_1, S_2, S_4	S	S_3
Dual-Source Low Voltage Boost Mode	S_{HVS}, S_{LVS}	S_1, S_2, S_4	S_3	S
Shutdown	--	S_{HVS}, S_{LVS} S_1, S_2, S_3, S_4	--	--

Table 1 Modes Of Operation

II. MODES OF OPERATION

A present bidirectional dc to dc converter with dual-battery voltage sources is given in Fig. 2. where V_{BUS}, V_{HVE}, and V_{LVE} represent the DC-Bus voltage, main source (HVS) and auxiliary source (LVS) respectively. The power switch S_{HVS} used to switch on and the S_{LVS} is used to switch off the converters current loops of V_{HVE} and V_{LVE}, respectively. A pump capacitor (C_P) is introduced as voltage divider for four active switches (S_1, S_2, S_3, S_4) and two inductors (L_A, L_B) to increases the voltage gain between low-voltage sources V_{HVE}, and V_{LVE}. C_P decreases the voltage stress across the switches and eliminates the need of extreme duty . The four-quadrant operation of circuit is possible by the bidirectional switches (S, S_{HVS}, S_{LVS}), and allows the power flow control between two low voltage sources V_{HVE}, and V_{LVE}, and also helps in blocking positive and negative voltages. The bidirectional switches (S, S_{HVS}, S_{LVS}) are MOSFETS connected back to back as shown in fig.2 the concept and modes are given in detail in the table.1.

a. *Dual-Source low voltage powering mode*

In this mode of operation the switch S is turned off and the switches S_{HVS}, S_{LVS} are turns on and the two voltage sources supplies the energy to the DC-Bus, the schematic circuit shown in Fig.3.

The switches S_3, S_4 are used as control switches and operates at 180 degree phase shift, and S_1, S_2 acts as the synchronous rectifiers.

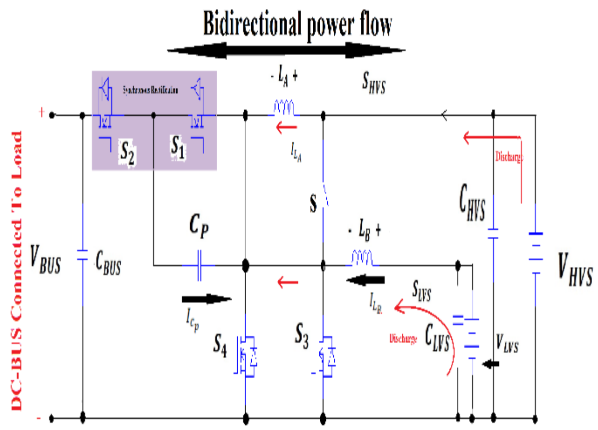


Fig.3 Dual-Source Low Voltage Powering Mode

steady-state waveforms of the gate currents and inductors currents are shown in the fig.4

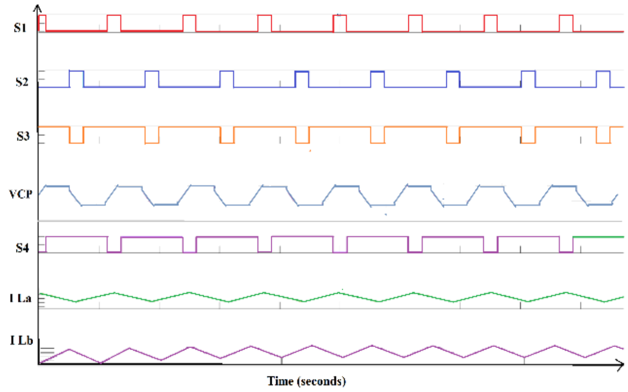


Fig.4 Steady-State Gate Currents And Inductors Currents

During the state S_1, S_3 are ON and S_2, S_4 are off then voltage across the inductor is given by

$$L_A \frac{di_{La}}{dt} = V_{LVS} - V_{CP} \qquad (1)$$

$$L_B \frac{di_{Lb}}{dt} = V_{LVS} \qquad (2)$$

where V_{CP} is voltage across the capacitor C_P

During the state S_3, S_4 are ON and S_1, S_2 are off then voltage across the inductor is given by

$$L_A \frac{di_{La}}{dt} = V_{HVS} \qquad (3)$$

$$L_B \frac{di_{Lb}}{dt} = V_{LVS} \qquad (4)$$

b. Dc-Bus High-voltage Energy Regenerating Mode

During regenerating mode the kinetic energy from the motor is fed back to the storage devices regenerating power may be higher than the storage capacity of the battery so, the excess energy is stored in the capacitors connected in the parallel to storage devices. , the schematic circuit shown in Fig.5.

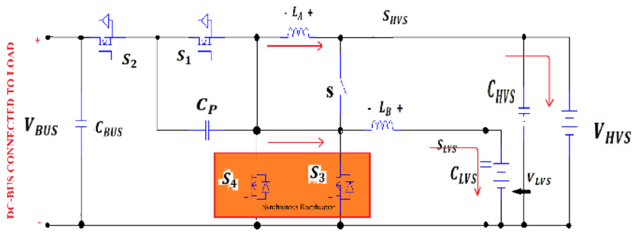


Fig.5 Dc-Bus High-Voltage Energy Regenerating Mode

The switches S_1, S_2 are used as control switches and operates at 180 degree phase shift, and S_3, S_4 as the synchronous rectifiers which increases the converter performances. steady-state waveforms of the gate currents and inductors currents are shown in the fig.6

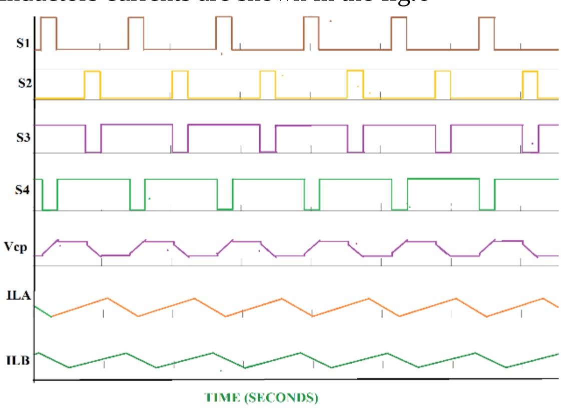


Fig.6 Steady-State Gate Currents And Inductors Currents

During the state S_1, S_3 are ON and S_2, S_4 are off then voltage across the inductor is given by

$$L_A \frac{di_{La}}{dt} = V_{HVS} - V_{CP} \qquad (5)$$

$$L_B \frac{di_{Lb}}{dt} = V_{LVS} \qquad (6)$$

During the state S_3, S_4 are ON and S_1, S_2 are off then voltage across the inductor is given by

$$L_A \frac{di_{La}}{dt} = V_{HVS} \qquad (7)$$

$$L_B \frac{di_{Lb}}{dt} = V_{LVS} \qquad (8)$$

c. Dual-Source Low Voltage Boost/Buck Mode

Energy stored in the main voltage source to auxiliary voltage source and from auxiliary voltage source to main voltage source is presented in the schematic circuit Fig.7

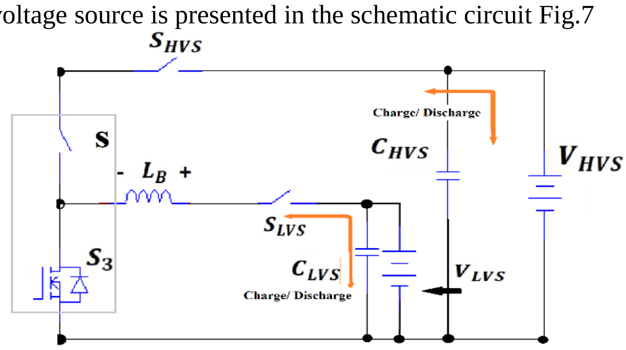


Fig.7 Dual-Source Low Voltage Boost/Buck Mode

The buck and boost mode depends on the duty ratio of the switches S and S_3 respectively.

III. CONVERTER CONTROL

The schematic control circuit shown in fig.8 consist of operating mode selector energy management unit and electrical load demand estimator. The management unit increases the use of voltage sources that fulfils the load requirement. The inductor currents I_{LA} and I_{LB} are measured and compared with the reference converter currents.

The mode of operation of the controller depends on the power demand by the load/HEV then it selects the appropriate $I_{LA\ Ref}$ and $I_{LB\ Ref}$ and then the triggering of the switches S_1, S_3, S_2, S_4 takes place with the help of Artificial Neural Network. The switch selector Y_1 *and* Y_2 of BDC controller are responsible for selection of operating modes, the pulse width modulation (PWM) switching scheme is employed to trigger the gate switches.

During Low voltage and high voltage dual sources DC bus the $I_{LA\ Ref}$ is taken as the reference to control the power flow . During Buck/Boost mode the $I_{LB\ Ref}$ is taken as reference to control the power flow between high voltage source and low voltage source and vice versa.

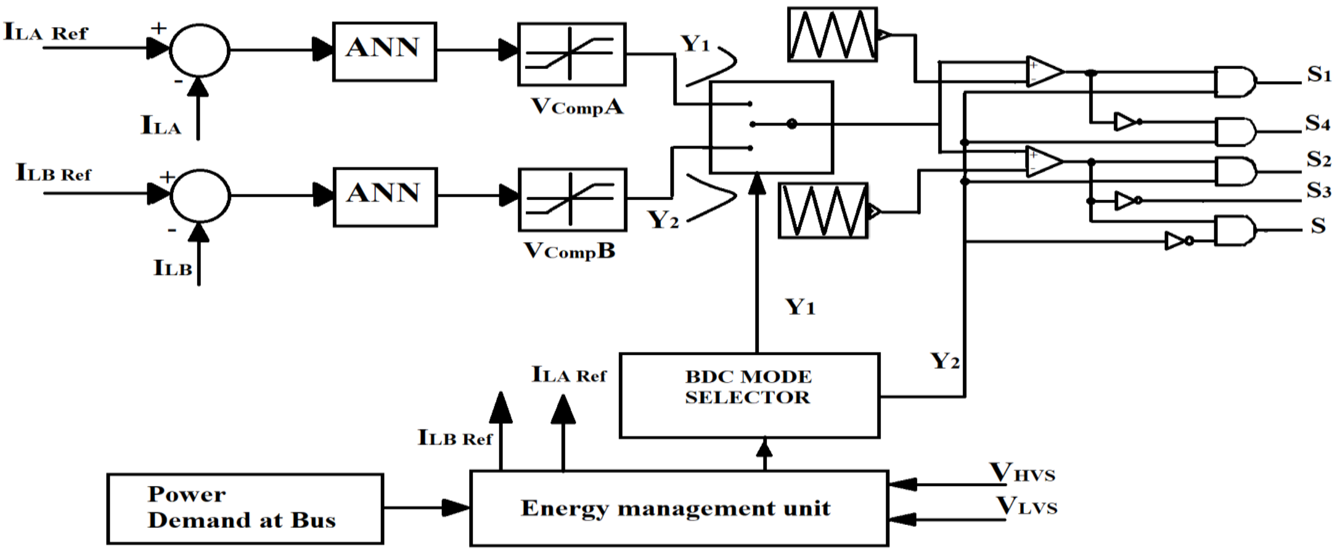


Fig.8 ANN Based Control Circuit

On average inductor current I_{LA} and I_{LB} are equal due to the uniform current sharing of sources, depending on the power demand of Load/HVE the operating mode changes this mode selection is discussed in the Table2

Modes of operation	Y_1	Y_2	Relation/condition
Dual Source Low Voltage Powering Mode	1	1	$P_{Demand} > 0$ $IL_A Ref > 0$
Dc Bus High voltage Energy Regenerating Mode	1	1	$P_{Demand} > 0$ $IL_A Ref < 0$
Dual-Source Low Voltage Buck Mode	0	0	$P_{Demand} < 0$ $V_{HVS} < 48$ $IL_B Ref < 0$
Dual-Source Low Voltage Boost Mode	0	0	$P_{Demand} < 0$ $V_{HVS} < 96$ $IL_B Ref > 0$

Table.2 Mode Selection

When vehicle is in running state then $P_{Demand} > 0$ and $IL_A Ref > 0$ then the control is over IL_A and control loop change $Y_1 = 1$ and the vehicle will operating accelerating mode or braking if $IL_A Ref < 0$ if none of the condition gets satisfied then the controller checks for $P_{Demand} < 0$ then the controller if IL_B control loop change $Y_1 = 0$,in this condition the switching controller checks for $V_{HVS} and\ V_{LVS}$ and if $V_{HVS} < 96$V then the control changes to the boost mode and changes $IL_B Ref > 0$ and the circuit operates in boost mode and the voltage is boosted from V_{LVS} to V_{HVS}, if $V_{LVS} < 48V$ then the control changes to the boost mode and changes $IL_B Ref < 0$ and the circuit operates in buck mode and the voltage is chopped from V_{HVS} to V_{LVS}. Fig.9 shows the implemented ANN controller used for the current control of the BDC [Bidirectional DC to DC Converter]

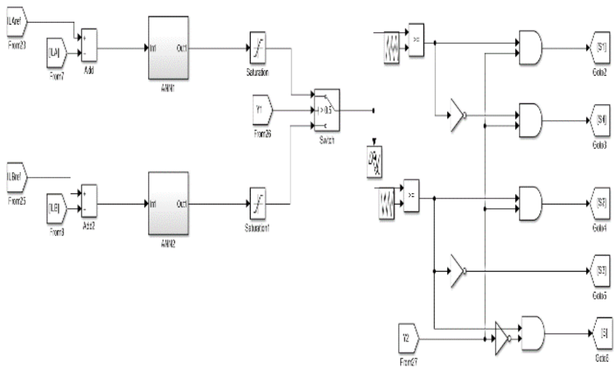


Fig.9 Implemented ANN Controller

the power demand estimation/calculation of load/HEV and the decision making control unit is shown in the fig.10

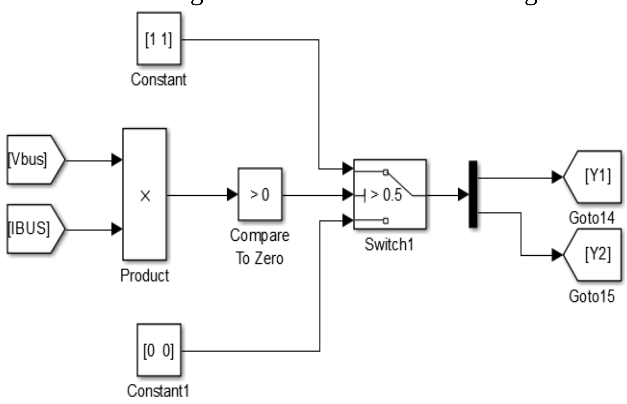


Fig.10 Power Demand Estimation

The buck and boost modes, the controller unit for decision making to trigger the switch accordingly is shown in the fig.11

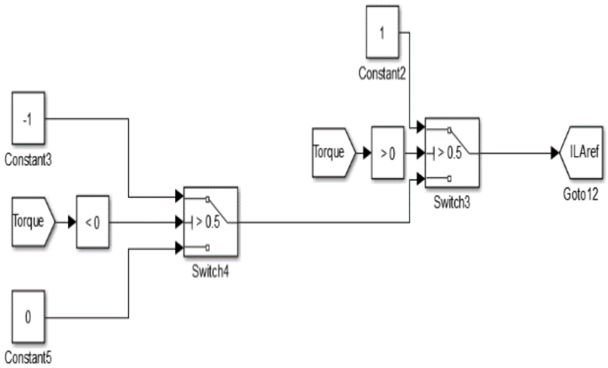


Fig.11 Switching Mechanism

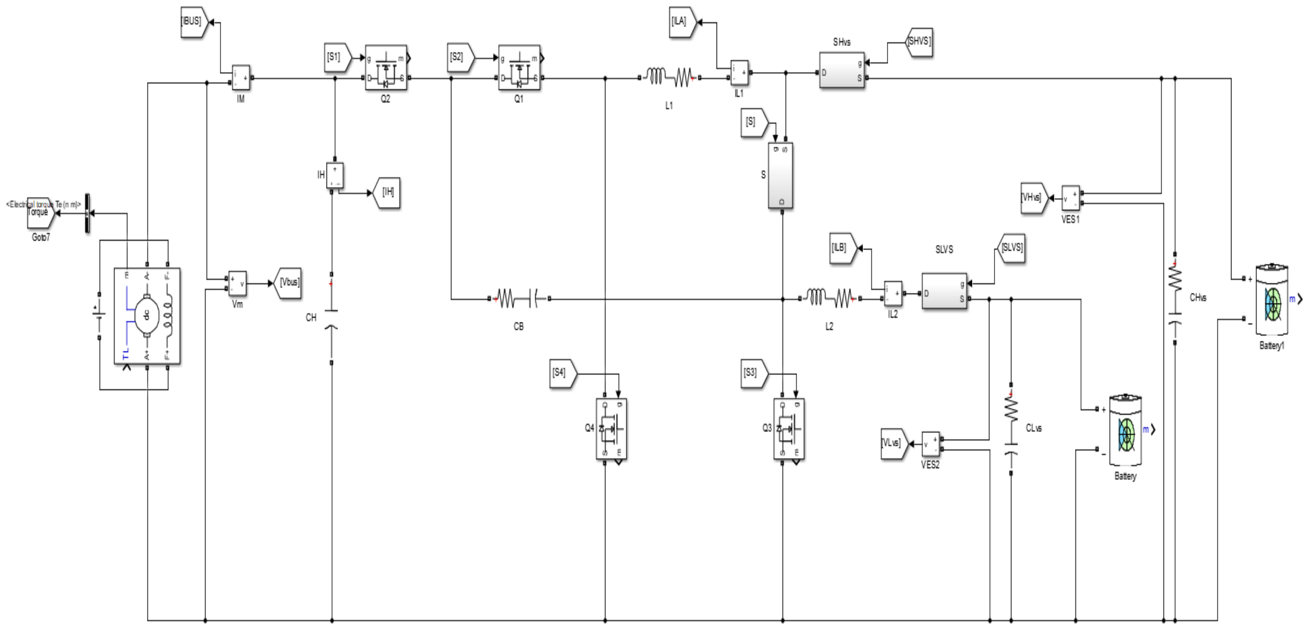


Fig.12 Simulation Circuit

IV. SIMULATION RESULTS

A MATLAB simulation is performed to verify the converter performance and the simulation circuit Fig.12 Dual Source low voltage powering mode shown in Fig.12(a), that both sources powerup the dc bus for electric motor and sufficiently maintains the dc bus voltage

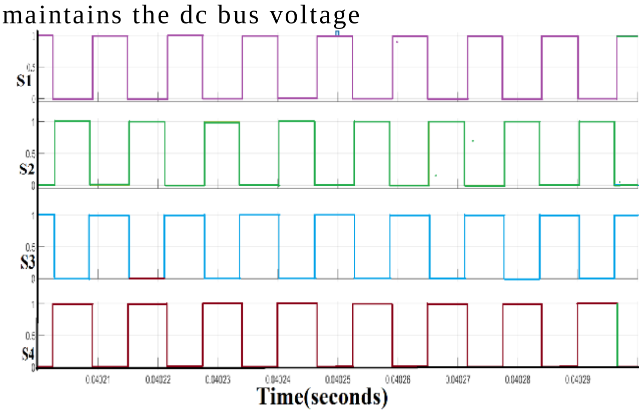


Fig.12(A) The Gate Pulses Dual Source Low Voltage Powering Mode

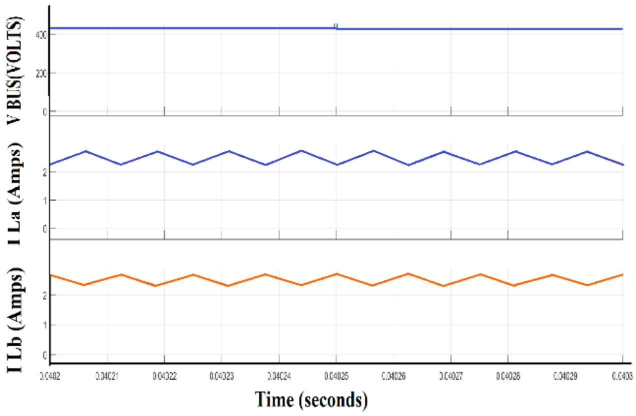


Fig.12(B) Output Dc-Bus Voltage And Inductor Currents Dual Source Low Voltage Powering Mode

Fig.12 (A) is the gate pulses given to the switches S_1, S_2, S_3, S_4 respectively and the Fig.12(B) is the Output Dc-Bus voltage and inductor currents of L_A and L_B.

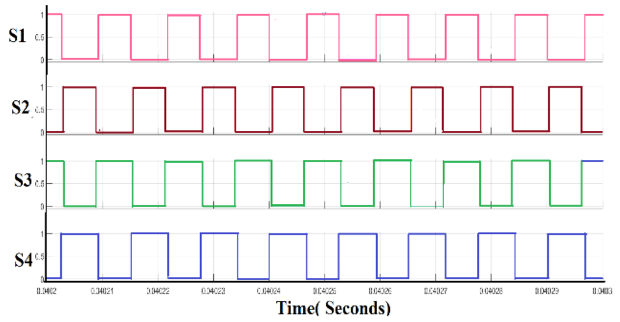


Fig.13(A) Gate Pulses DC Bus High Voltage Regenerating Mode

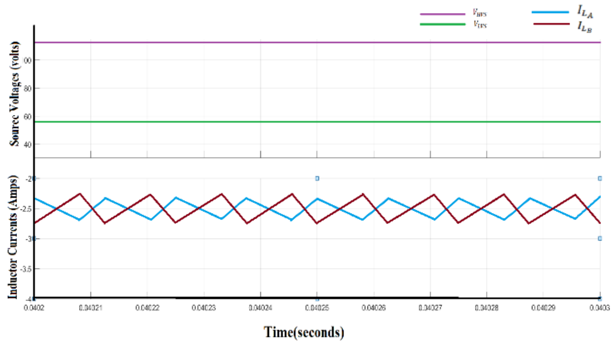


Fig.13(B) Output Source Voltages And Inductor Currents Of DC Bus High Voltage Regenerating Mode

DC bus high voltage regenerating mode Fig.13 (A) is the gate pulses given to the switches S_1, S_2, S_3, S_4 and the Fig.13(B) is the Output source voltages and inductor currents of L_A and L_B respectively.

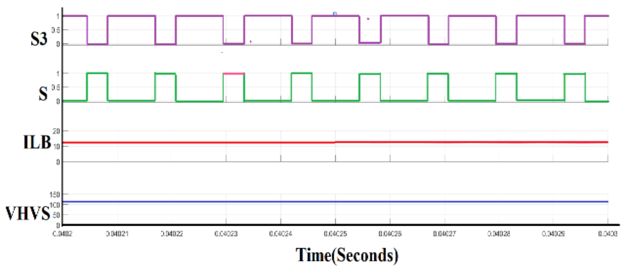


Fig.14(A) Gate Pulses, Source Voltage And Inductor Current Dual-Source High Voltage Boost Mode

Dual-Source High Voltage Boost Mode Fig.14(A) is the gate pulses given to the switches S_3, S and Output source voltages and inductor currents of L_B.

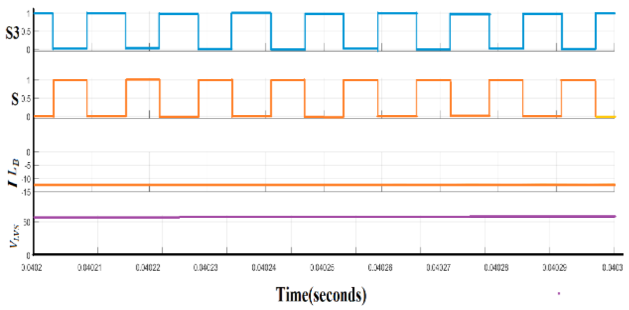


Fig.14(B)) Gate Pulses, Source Voltage And Inductor Current Dual-Source High Voltage Buck Mode

Dual-Source Low Voltage Buck Mode Fig.14(B) is the gate pulses given to the switches S_3, S and Output source voltages and inductor currents of L_B.

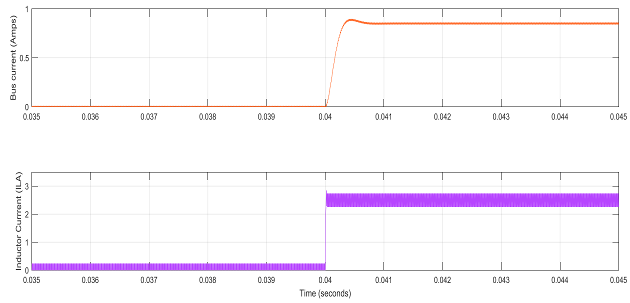


Fig.15 Step Change In Current In Dual Source Low Voltage Powering Mode

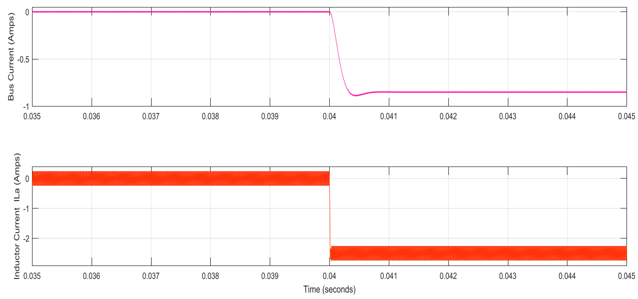


Fig.16 Step Change In Current In DC Bus High Voltage Regenerating Mode

The fig.16 represents the controlled step change in current in DC Bus High Voltage Regenerating Mode.

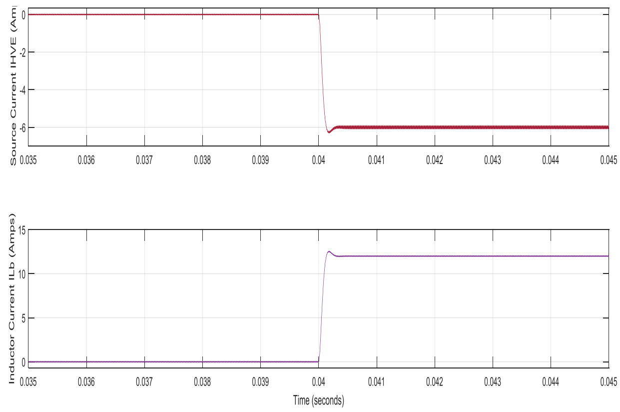


Fig.17 Step Change In Current Of High Voltage Source In Dual-Source High Voltage Boost Mode

The fig.17 represents the controlled step change in current of High voltage source in Dual-Source High Voltage Boost Mode.

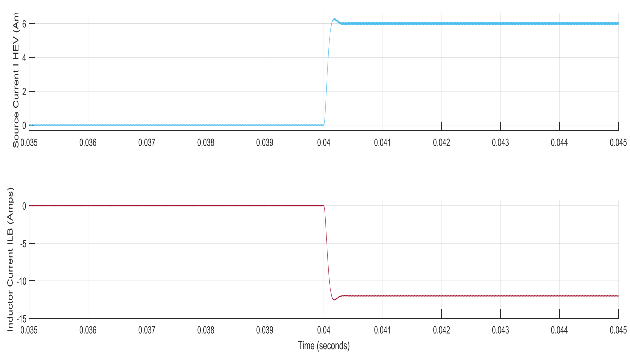
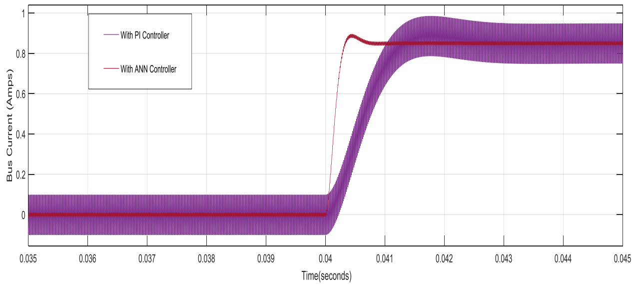


Fig.18 Controlled Step Change In Current Of High Voltage Source In Dual-Source Low Voltage Buck Mode

The fig.18 represents the controlled step change in current of high voltage source in Dual-Source Low Voltage Buck Mode.



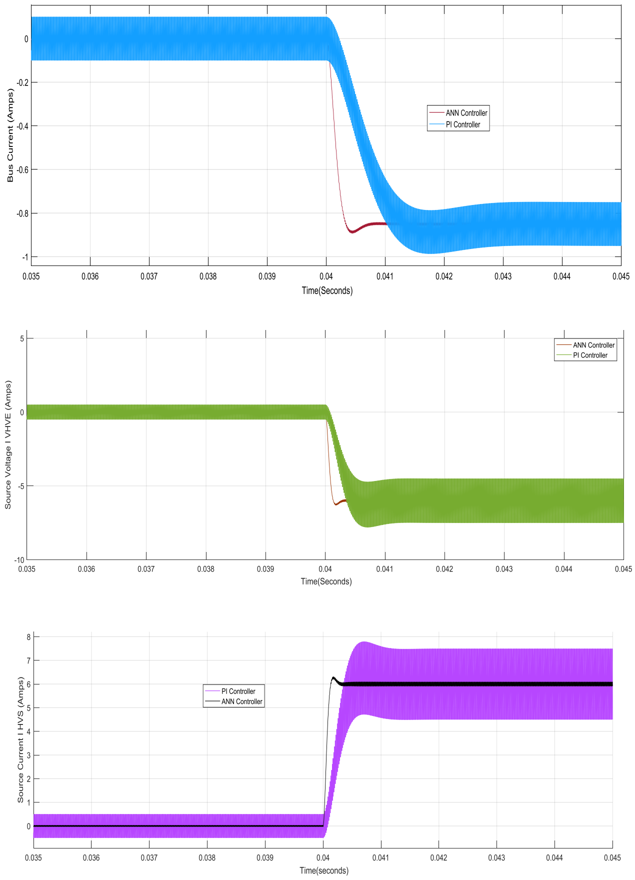


Fig.19 Comparison Of PI And ANN

The comparison between PI controller and the ANN controller is shown and the observation clearly proves that the ANN controller has much faster step time response of currents and the current ripples in the current signal has reduced which can be visible from the Fig.19.

V. CONCLUSION

A bidirectional DC to DC converter(BDC) is presented interface main source (HVS), auxiliary source (LVS) and a DC-Bus with different voltage levels which is implemented in Hybrid Electric Vehicle (HEV). The circuit operating principle and modes of operation of bidirectional dc to dc converter were discussed and Simulation waveforms of Dual Source Low Voltage Powering Mode, DC Bus High Voltage Regenerating Mode, Dual-Source High Voltage Boost/Buck Mode and the comparison between PI and ANN are demonstrated that it can be successfully implemented for the hybrid electric vehicle.

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