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Design and Simulation of Two Phase Interleaved Bidirectional DC to DC Converter

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ABSTRACT

DC-DC converters are used as a suitable power electronic converter interface for Hybrid Electric Vehicle (HEV) Applications. A bidirectional DC-DC converter can move power in either direction, which is useful in applications including regenerative braking. This paper presents the design and simulation results of a two-phase interleaved bidirectional DC-DC converter for HEV applications. An interleaved bidirectional converter is having the advantages of increased efficiciency, reduced input current ripple and greater reliability. Simulation has been carried out in MATLAB-SIMULINK environment and the results are presented.

***Key words*: HEV, Bidirectional DC-DC converter, IBC**

I. INTRODUCTION.

The large number of automobiles in use around us continuous cause serious problems such as rapid depletion of earth's petroleum sources, air pollution, global warming etc..This has aroused a tremendous interest for the design of vehicles that has lesser or no dependency on petroleum resources. Thus the Hybrid Electric Vehicle (HEV) technology has seen a tremendous development in the past two decades. HEVs have been proposed to replace the conventional vehicles in the near future. A hybrid electric vehicle is a type of electric vehicle with at least two sources of power. An HEV is a vehicle in which propulsion energy is available from two or more types of energy sources and at least one of them can deliver electrical energy [1].

An HEV uses a combination of different energy sources such as Fuel Cell (FC) stack, Batteries, Super Capacitors to power an electric drive system as shown in Fig:(1). The different configurations of the HEV system show that a DC-DC converter is necessary to interface the Fuel cell, Battery or the Super Capacitor module to the DC link. A DC-DC converter is an electric circuit which takes the DC voltage as the input and converts it to a high or low value depending upon the requirement. An additional advantageous feature of the introduction of a DC-DC converter is having a regulated DC voltage, which results in the better performance of the motor drive. Usually the DC-DC converters are designed to transfer power only in one direction. But usage of alternative energy sources has raised interest in the Bidirectional DC-DC converters. Here electric energy flows in both directions, from motor to battery (step-down mode) and from battery to motor side (step – up mode) in Battery fed Electric Vehicles.

Bidirectional DC-DC Converters boost up the voltage level of the energy storage system to a higher voltage level and thereby reduces the current level and the losses. Also bidirectional DC-DC converter provides the reverse power flow back into the Energy Storage system (ESS) during regenerative braking and thereby increasing the efficiency. These two features of bidirectional DC-DC Converter makes it a better option for power conversion in the HEV drive train thereby reducing overall cost, weight, and size of the system along with increasing efficiency and achieving regenerative energy.

Basically a non-isolated bidirectional DC-DC converter can be derived from the unidirectional converters by replacing their unidirectional conduction capability by the bidirectional conducting switches. The basic buck and boost converter do not have the inherent property of bidirectional power flow due to the presence of diode in the circuit. This limitation can be overcome by introducing a power MOSFET or IGBT having an anti parallel diode across them to form a bidirectional switch and hence allowing current conduction in both the directions.

Interleaved method is employed to improve the converter performance in terms of efficiency, size, conducted electromagnetic emission and transient response. Further, interleaved Bidirectional Converters have been proposed which reduces the switching and conduction losses along with ripple reduction in the input and output circuits. This paper presents a two phase Interleaved Bidirectional DC-DC Converter (IBC) used in HEV applications. The Block diagram of the entire system is shown in Fig. (1)[2].

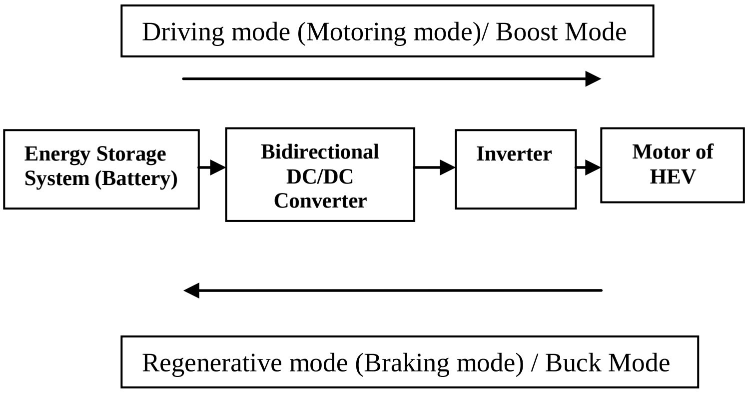

Fig.1 Block Diagram of a fuel cell based system

II. WORKING PRINCIPLE OF INTERLEAVED DC TO DC CONVERTER

A two phase interleaved bidirectional DC-DC converter consists of two power modules connected in parallel. The parallel connection of two power modules results in the cancellation of low frequency harmonics which will reduce the size and cost of the filtering stages. The pulses fed to the switches of the two parallel connected power modules are generally shifted by 180 degree to get the interleaving operation. In a two phase interleaved converter the current from the input source gets divided into two parallel paths. As the two devices are phase shifted by 180 degrees, the input current ripple produced is the smallest. There are two modes of operation of the Bidirectional DC-DC converter [6].

A. BOOST MODE:

Basically in this mode the two phases interleaved DC to DC converter modes are respectively formed when switches Q2 and Q3are triggered. Here Q1 and Q4 act as diode. The boost mode operation is represented in Fig.2. The output voltage is boosted from the battery and two boost modules of the interleaved DC to DC converter. Each two IGBT switches of the same leg get ON complementary to each other. The DC link takes the power from the battery in order to discharge the battery which is supplying the power. The current is getting divided equally by the two modules [3].

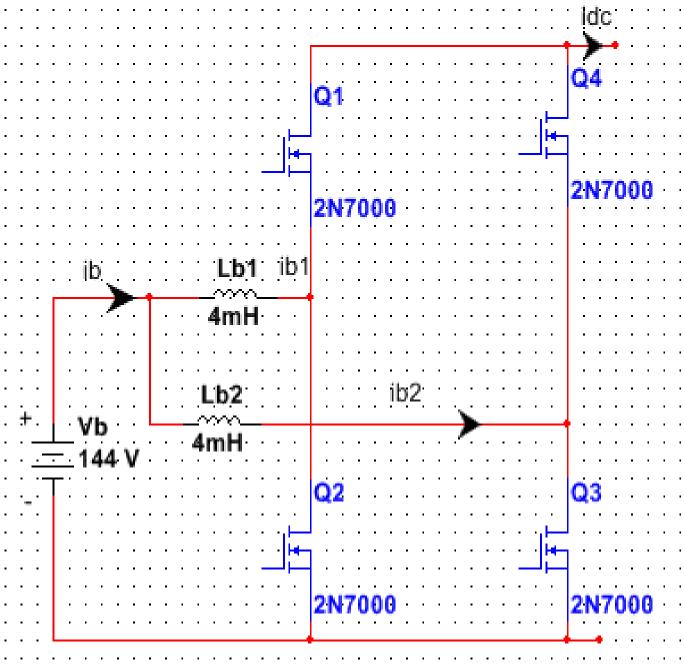

Fig. 2 Boost (motoring) mode

B. BUCK MODE

This mode generally forms the buck converter of the interleaved DC to DC converter respectively formed when switches Q1 and Q4 are triggered. Here Q2 and Q3 act as diode. The buck mode operation is represented in Fig.3 Here in this mode the power reversal generally takes place i.e. the motor is supplying energy to battery in order to charge it. The DC link current gets reversed (negative) thus the battery will be charged by the currents (I_b) following the two buck modes of the DC to DC converter. Because the power flowing is in the reverse direction the inductor current also becomes negative. The buck converter waveforms are same as that of the boost mode (CCM) with reversed direction of the current [3].

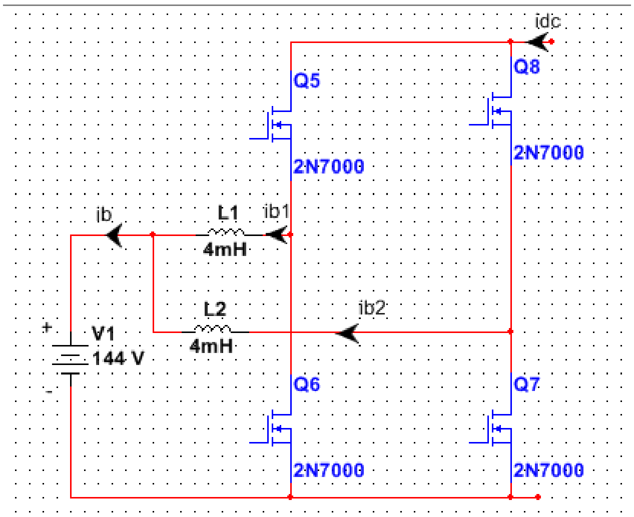

Fig 3 Buck (breaking) mode

III. CONVERTER DESIGN CALCULATIONS

The converter is operated under continuous conduction mode (CCM) operation. In motoring mode (i.e. boost mode), the output voltage is obtained (1) as shown below [5].

$$\frac{V_{in}}{V_o} = \frac{1}{1-D} \tag{1}$$

While operating in braking mode (buck mode), the battery voltage is obtained by (2)

$$\frac{V_{in}}{V_o} = D \tag{2}$$

The inductor value and capacitor values are found by (3) and (4) respectively:

$$L_b = \frac{\Delta i_L * f_s}{D * V_{in}} \tag{3}$$

$$C_o = \frac{D * V_o}{\Delta V_o * R_o * f_s} \tag{4}$$

Where, V_o is the output voltage, V_{in} is the battery voltage, D is the duty cycle, f_s is the switching frequency, L_b is the inductance of the required inductor for each converters, C_o is the output capacitor, R_o is the equivalent output resistance.

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IV. SIMULATION RESULTS

For a rated power of 1KW, the inductor and capacitor values are found out and the values are shown below in TABLE 1 [4].

TABLE 1:- SIMULATION PARAMETERS

Components	Symbol	Value
Inductances	L_{b1}, L_{b2}	4mH
Battery Voltage	V_{in}	144V
Output Voltage	V_o	400V
Rated Power	P_{dc}	1KW
Capacitance	C_o	12mH
Output Resistance	R_o	0.22Ω

The proposed topology (Interleaved Bidirectional converter) was simulated in MATLAB SIMULINK Environment. The switching frequency selected was 20 KHz. The inductor current ripple and the capacitor voltage ripple is assumed a 0.1 A and 0.1V respectively. The duty ratio for the motoring mode (boost mode) is 0.5 and for the breaking mode (buck mode) is 0.3.

The SIMULINK model of interleaved bidirectional converter in boost mode is given in Fig 4. This mode is used in motoring mode; here power flow is from left to right (i.e. from source to load).

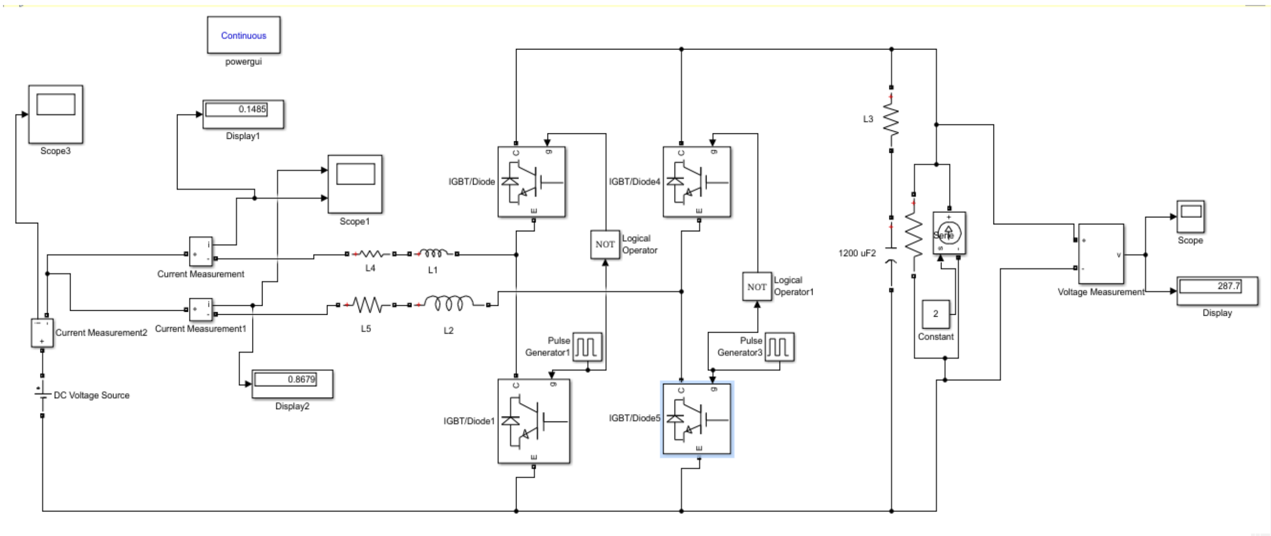

Fig 4 SIMULINK Model of the Converter in Boost Mode

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The waveforms for the inductor currents, I_{L1} and I_{L2} for the interleaved DC to DC converter in boost mode are sketched in Fig.5 and Fig. 6. Here we can see that both inductor current ripples are out of phase with each other by 180^0 and as a result the input current ripple is reduced.

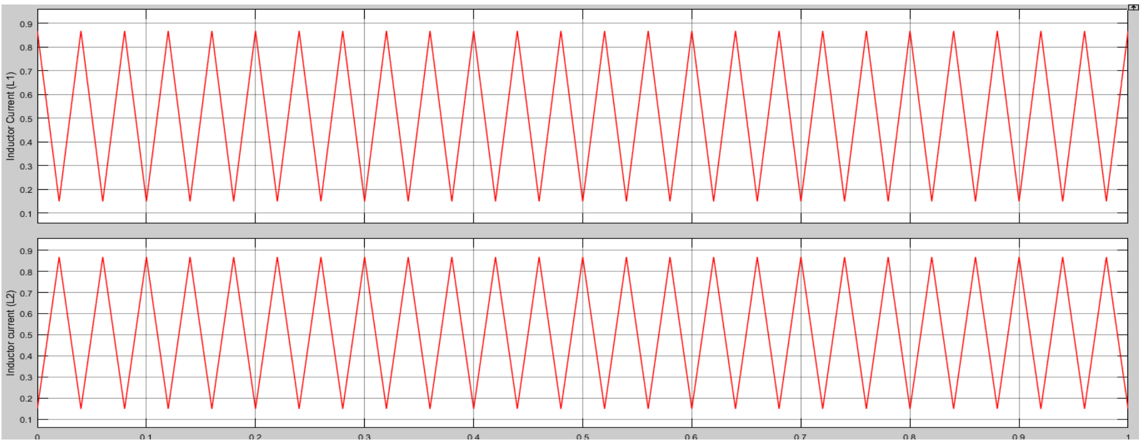

Fig. 5 and Fig.6 Inductor currents I_{L1} and I_{L2} (boost mode)

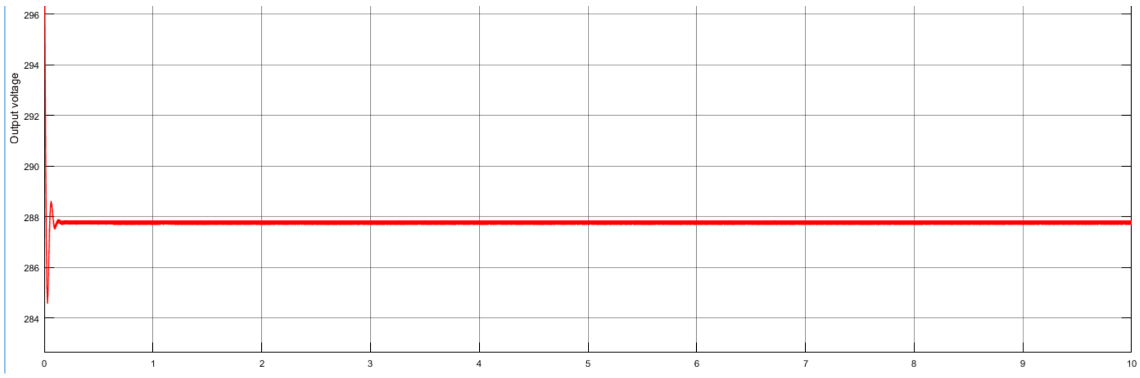

Fig. 7 Output voltage (boost mode)

Fig 7 shows the output voltage during boost mode of operation. Here an input DC voltage of 144V is given and an output voltage of 288V is obtained with a duty cycle of 0.5.

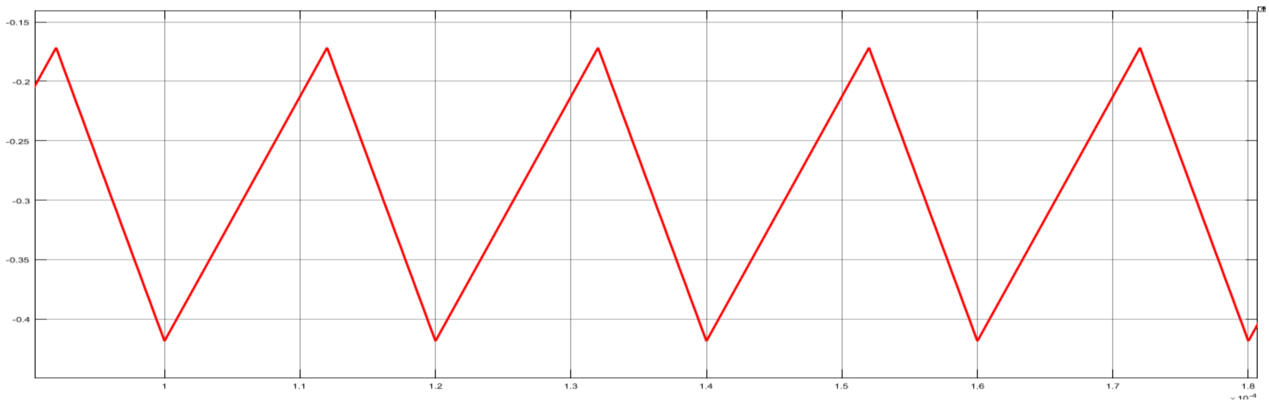

Fig. 8 Inductor Current during buck mode

Fig.8 shows the inductor current during the braking mode operation (Buck mode). A negative current is observed in the scope which indicates the power reversal and this current charges the battery during braking.

V. CONCLUSION

This paper presents the design and simulation results of a two phase interleaved bidirectional DC-DC converter operating in buck and boost mode for HEV system. The various waveforms of IBC are obtained in the MATLAB-SIMULINK environment. It is inferred that interleaved topology reduces the input current ripple and makes the system more efficient and reliable.

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