Interleaved DC-DC Converter Fed BLDC Motor Drive for Electric Vehicle Application

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Abstract – In this paper, an interleaved DC-DC boost converter is designed with both open loop and closed loop with PID controller and their performance is analyzed using MATLAB tool. The applications of Interleaved DC-DC boost converter may be seen in electric vehicles, photovoltaic (PV) systems, uninterruptable power supplies (UPS) and fuel cell power supplies. Interleaving is a method of paralleling converters, so that the input current can be shared among the inductors which increase the reliability and efficiency of the power electronic system. The design and simulation of the interleaved DC-DC converter has been presented in detail.

Index Terms – Interleaving, DC-DC converter, PID, Batteries.

1. INTRODUCTION

Efficiency and cost are the major concerns in the development of Electric Vehicles or Hybrid Electric Vehicles. The use of the Brushless Direct Current (BLDC) motor in these applications is becoming more common due to features of high efficiency, high flux density per unit volume and low maintenance requirements. In applications where step-up conversion ratio and high output current with low ripple are required, an interleaved boost converter has received a lot of attention due to its simple structure and low control complexity.

Reliability is an important issue for an Electric Vehicle. Interleaving approach is beneficial for the power converters in rating enlargement, ripple reduction and reliability enhancement.

In this paper, an interleaved DC-DC converter is designed and is placed between the existing battery system and the inverter DC-link to feed a BLDC motor drive. The existing BLDC drive is equipped with an interleaved DC-DC converter to boost the battery voltage for powering the followed motor inverter.

2. CIRCUIT DESCRIPTION

The Fig. 1 shows the proposed circuit of Interleaved DC-DC converter. It consists of inductors $L_1$and L_2, diodes $D_1$and D_2, MOSFET's M_1 and M_2, capacitors and a load. The two inductors operate with 180^0 phase shift in order to reduce the current ripple of the converter.

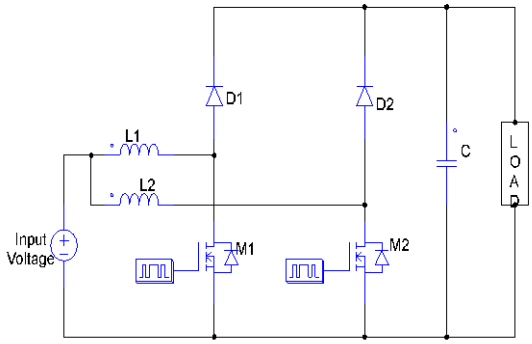

Fig. 1: Proposed Interleaved DC-DC boost converter

3. MODES OF OPERATION

Mode 1:

In this mode of operation, the MOSFET M_1 is turned ON and MOSFET M_2 is turned OFF through the gate pulse. The current through the inductor L_1 starts to rise (charges). The current through the inductor L_2 discharges through the diode D_2 and capacitance C to the load. The detailed circuit is shown in Fig. 2.

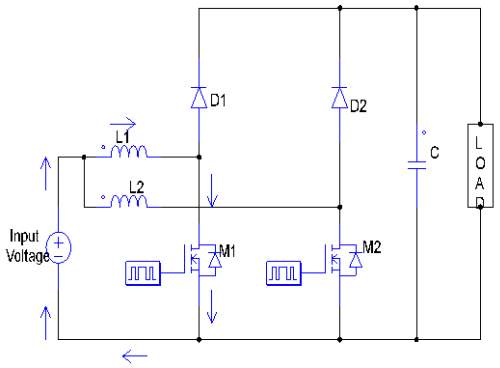

Fig. 2: Operating modes of Proposed Converter – Mode1

Mode 2:

During the next half cycle, the MOSFET M_1 is turned OFF and the MOSFET M_2 is turned ON by the gate pulse. The current flows through the inductor L_2 and the MOSFET M_2. The inductor L_1 discharges through the diode D_2 through the capacitor to the load. The detailed circuit is shown in Fig. 3.

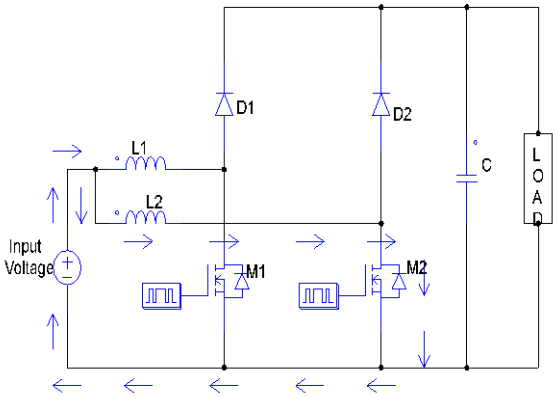

Fig. 3: Operating mode of Proposed Converter - Mode 2

4. DESIGN SPECIFICATIONS

The design of the interleaved DC-DC boost converter involves the calculation of Inductances L_1, L_2, Capacitance C and the Duty cycle D.

The two inductor's inductance values is calculated using the equation (1) as follows,

$$L = \frac{V_{in} * D}{\Delta i_L * F_S} \quad (1)$$

V_{in} represents the input voltage,

D represents the duty ratio,

Δi_L represents the current ripple

F_S represents the switching frequency.

On substituting the suitable values, the value of L can be obtained as $L_1 = L_2 = 651\mu H$.

The capacitance value can be calculated using the equation (2) as,

$$C = \frac{V_{out} * D}{R * F_S * \Delta v_{out}} \quad (2)$$

V_{out} represents the input voltage,

D represents the duty ratio,

Δv_{out} represents the voltage ripple

F_S represents the switching frequency

On substituting the various values, the value of C can be obtained as C = 0.0179 F.

The duty cycle for boost converter is considered in between 0.5 to 1. Selection of duty cycle depends on input voltage supply and required output voltage.

The various parameters and the values used in this project are tabulated in the Table I.

Table 1: Parameters and Ratings

Parameter	Range/ Ratings Used
Input Voltage V_{in}	24 V
Inductance L_1 , L_2	651µH
Capacitance C	0.0179 F
Switching Frequency F_s	20 kHz
Rated Power P_e	1kW
Number of Batteries	2
Output Voltage V_{out}	46.26 V
Output Current I_{out}	3.54 A

5. SIMULATION RESULTS AND ANALYSIS

An interleaved DC-DC boost converter is designed to boost the input voltage and drive the BLDC motor. The Fig. 4 shows the simulink block diagram of the open loop control of the interleaved DC-DC converter. The output voltage of the battery is given as input to the Interleaved Boost converter. The output is given to the R-L load.

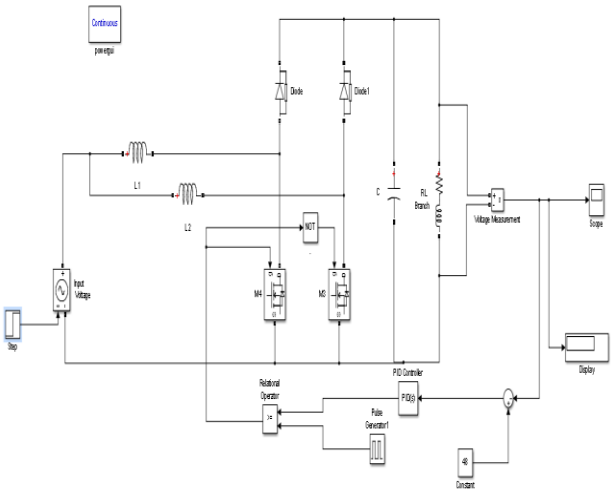

Fig. 4: Simulink Model of Interleaved DC-DC Converter – Open Loop Control

The Fig. 5 shows the output voltage waveform of the interleaved DC-DC converter is in open loop system and the output voltage is found to be 46.26V.

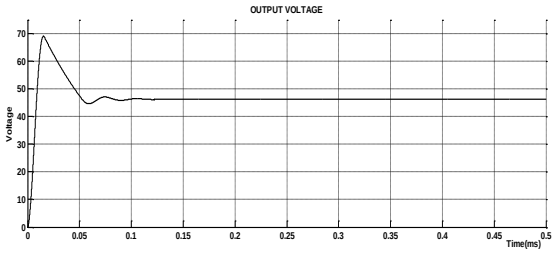

Fig. 5: Output Voltage of the Interleaved D-DC converter

The Fig. 6 shows the output current waveform of the Interleaved DC-DC converter in the open loop system and the output current is found to be 3.54 A.

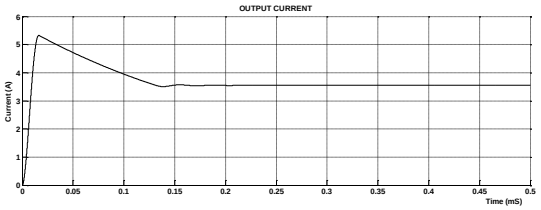

Fig 6: Output current of the Interleaved DC-DC converter

The Fig. 7 shows the simulink block diagram of the closed loop control of Interleaved DC-DC converter. A PID controller is attached with the designed controller to improve the performance of the existing conveter circuit. The Ziegler-Nichols method is used for tuning the PID controller.

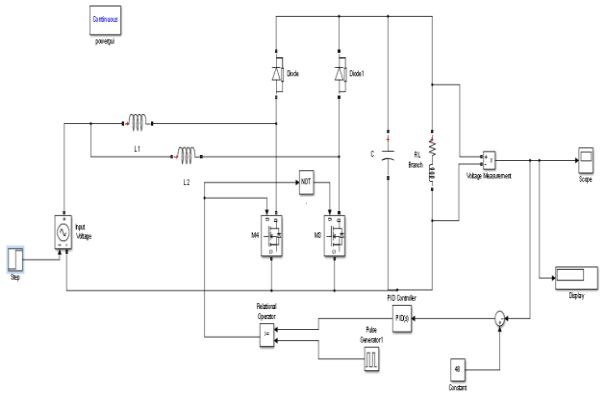

Fig. 7: Simulink Model of Interleaved Converter - Closed Loop Control

The Fig. 8 shows the output voltage of the Interleaved DC-DC converter with PID controller in the closed loop and the output voltage is obtained as 48.01V.

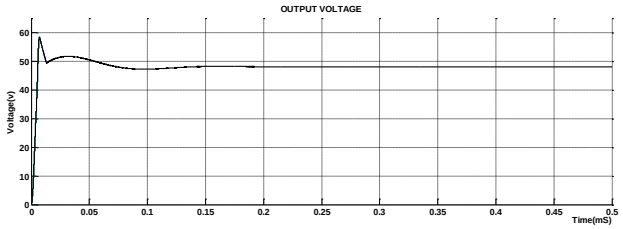

Fig. 8: Output Voltage of the Interleaved DC-DC converter – Closed Loop

The Fig. 9 shows the output current of the interleaved DC-DC converter for the closed loop control and the output current remains constant at a value of 3.5A.

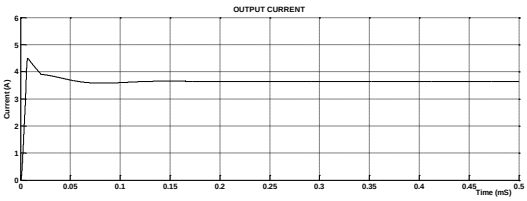

Fig. 9: Output Current of the Interleaved DC-DC converter- Closed Loop

The output voltages and currents for various variable values of the input voltages are tabulated in the Table II. This is done to ensure that the PID controller maintains a constant value of voltage and current even for small deviations in the input voltage.

TABLE II

Output Values from Variable Input Voltages

S.No	Input Voltage (V)	Output Voltage (V)	Output Current (A)
1	22	48.01	3.501
2	23	48.00	3.500
3	24	48.01	3.501
4	25	48.00	3.502

Thus, it can be seen that the output voltage gets boosted up to a constant output voltage irrespective of the small variation in the input voltages. Thus, the reliability of the designed interleaved DC-DC converter is found to be optimal.

6. CONCLUSIONS

In this project, an interleaved dc-dc converter fed BLDC motor drive was designed. The BLDC motor drive is powered from a 12V battery bank via a two-leg interleaved boost DC/DC converter to possess the advantages of DC-link voltage boosting. In this project, the interleaved boost converter was designed in both open loop and closed loop with PID controller and their performance was analyzed using MATLAB tool.

Therefore, Interleaved DC-DC Boost Converter is a suitable choice for electric vehicle applications.

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