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Interleaved Buck-Boost Converter with Magnetically Coupled I/O Inductors

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ABSTRACT:This paper demonstrates an interleaved buck boost converter with magnetically coupled I/O inductors. In comparison with a conventional buck-boost converter, the interleaved buck-boost converter has advantages such as higher efficiency, low voltage stress on switches and non-inverted output voltage. A MATLAB-SIMULINK model of the converter is prepared to analyse the operation of the converter circuit and a hardware model of the converter is implemented.A PID controller is employed to obtain better control of output voltage in closed loop control.

KEYWORDS: Buck-boost, interleaving, converter, dc-dc.

I.INTRODUCTION

Fuel cells are gaining much popularity nowadays because of its various advantages. Fuel cells are highly efficient and has high current capability compared to other energy sources. On the other hand, fuel cells are having an inherent issue. They demonstrate an unregulated output voltage with a wide range of variations under different load conditions. For getting rid of an unregulated fuel cell output voltage, employing an interface dc–dc converter is necessarily required. Different types of dc–dc converters have been widely used in various fuel cell applications. They are used for charging a battery bank through a fuel cell.For this purpose a dc–dc buck–boost converter is required.

A buck-boost converter is a dc-dc converter which has an output voltage which is either greater than or less than the input voltage. The output voltage of the converter is obtained by varying the duty cycle of the switch.Conventional buck boost converters are able to provide only inverted output voltage. The voltage stress on the switch is also high. They also exhibit internal oscillations while changing the operation modes from buck mode to boost mode and vice versa. The proposed converter is a non-inverting interleaved buck–boost converter with a damping network placed between the two-phase interleaved buck and boost parts with magnetically coupled I/O inductors. By using interleaving technique, benefits like better efficiency, reduction of component stresses, better thermal performance, and higher power density can be obtained.

II.CIRCUIT DIAGRAM AND WORKING

Fig. 1 shows the circuit of the existing interleaved buck-boost converter. The converter can operate in both boost and buck modes. Boost mode is achieved when switches 3 and 4 (Q_3 and Q_4) turn on permanently and switches 1 and 2 (Q_1 and Q_2) operate with PWM signals. Similarly, in buck mode, switches Q_1 and Q_2 are turned off permanently, and switches Q_3 and Q_4 operate in PWM.

The PWM activation signals ofQ1 and Q_2 are similar to each other with a phase shift of $T_s/2$ for catering the interleaved pattern. Their duty cycles are considered to be $d_{12}(t)$. The same is true for Q_3 and Q_4 activation signals with the duty cycle $d_{34}(t)$. The duty cycle of switches is adjusted so that the output voltage is regulated around a desired value. The voltage transfer ratio of converter is given by,

$$M_{(D_{12},D_{34})} = \frac{D_{34}}{1 - D_{12}}$$

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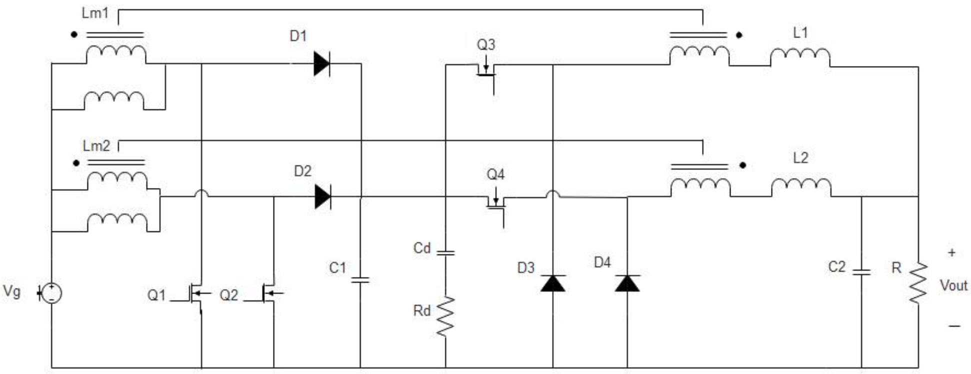

Fig. 1Circuit diagram of the interleaved buck-boost converter

V_g is the input voltage and V_{out} is the output voltage. A damping network, connecting a capacitor (C_d) and a resistor (R_d) in series, decays output voltage oscillations occurring during the transitions between the operating modes when the input voltage is near the output voltage.

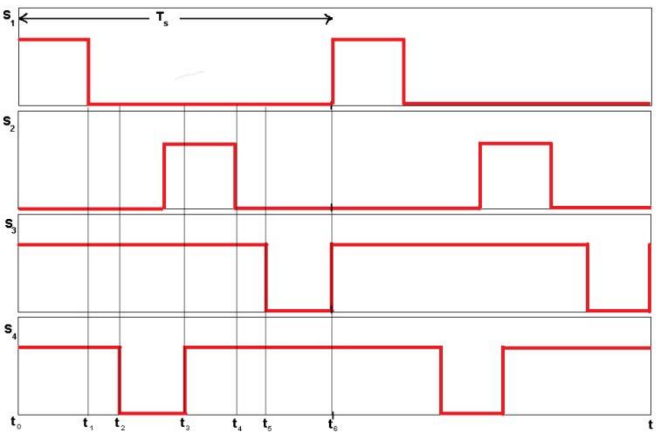

Fig. 2 Switching Pulses for MOSFETs

To explain the principles of operation of the converter, the switching pattern of fig. 2 is considered. Based on this figure, each period consists of six time intervals. As the intervals 2 and 5 have the same time portions and switching states the converter can be analyzed only in five states as follows.

INTERVAL 1

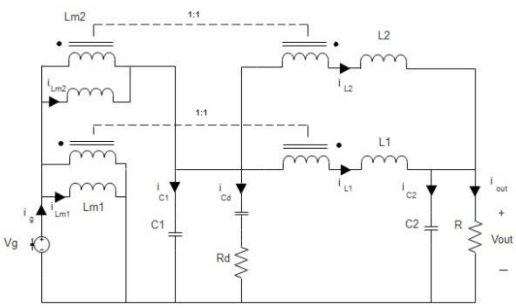

Fig. 3 Circuit diagram during interval 1

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Fig. 3 shows the circuit diagram during interval 1. In this time interval, Q_1, Q_3, and Q_4 are in conducting mode, causing the magnetizing inductor 1 to start saving energy and concurrently magnetizing inductor 2 to transfer its stored energy to the output load and inductors via D_2.

INTERVAL 2 AND 5

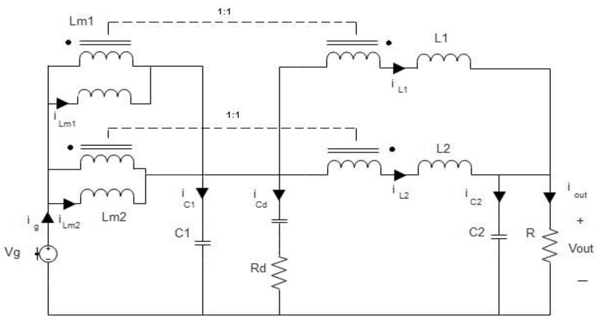

Fig. 4 Circuit diagram during intervals 2 and 5

Fig. 4 shows the circuit diagram during intervals 2 and 5. In these time intervals, Q_3 and Q_4 are in conducting mode, while Q_1 and Q_2 turn off. Therefore, the energy stored in magnetizing inductors 1and 2 starts transferring to inductors 1 and 2 via D_1 and D_2.

INTERVAL 3

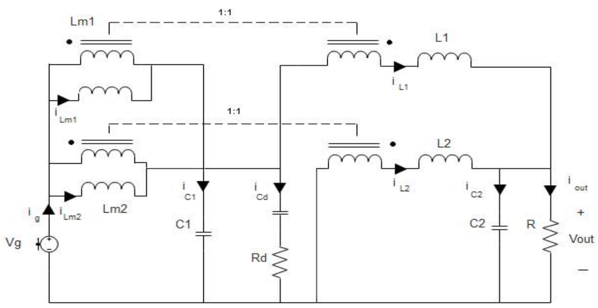

Fig. 5 Circuit diagram during interval 3

Fig. 5 shows the circuit diagram during interval 3. In this time interval, Q_3 is in conducting mode, while Q_1, Q_2, and Q_4 are off. The energy transfer in this interval is completely similar to the previous interval except that the energy stored in both input magnetizing inductors is transferred to inductor 1 only.

INTERVAL 4

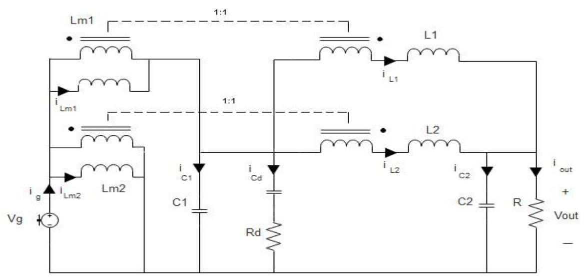

Fig. 6 Circuit diagram during interval 4

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Fig. 6 shows the circuit diagram during interval 4. In this time interval, Q_2, Q_3, and$Q_4$are in conducting mode, whileQ_1 is off. The energy transfer in this interval is also similar to that of interval 1 except that the functions of magnetizing inductors 1 and 2 replace each other.

INTERVAL 6

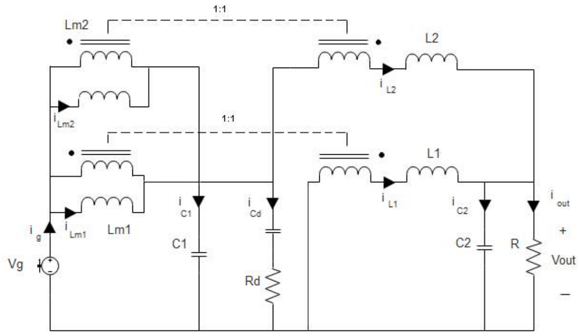

Fig. 7 Circuit diagram during interval 6

Fig. 7 shows the circuit diagram during interval 6. In this time interval, Q_4 is in conducting mode, while Q_1, Q_2, and Q_3 are off. Therefore, the energy stored in magnetizing inductors 1 and 2 is transferred to the output capacitor and inductor 2.

III.DESIGN EQUATIONS

Design equations of the proposed converter are shown below. The values of capacitors, resistors and inductors can be obtained by using the equations for the proper working of the circuit. V_g and V_{out} are the input and output voltages of the converter respectively. L_{m1} and L_{m2} are the coupled inductors. C_2 is the output capacitor. C_d and R_d are the capacitor and resistance of the damping circuit. The circuit is designed with input voltage of 14 V and output voltage of 12 V.

$$L_{m1}, L_{m2} = \frac{\Delta V_{c1} T_s}{16 \Delta i_{Lm1or2}} = 125\ \mu H$$

$$L_1, L_2 = \frac{(V_g - V_{out}) D T_s}{\Delta i_{L1or2}} = 60\ \mu H$$

$$C_1 = \frac{\frac{V_{out}}{R}(D-1)}{\Delta V_{c1}}(2D-1)\frac{T_s}{2} = 4\ \mu F$$

$$C_2 = \frac{1}{32}\frac{\Delta i_{L1or2} T_s}{\Delta V_{c2}} = 10\ \mu F$$

$$C_d = 8C_1 = 32\ \mu F$$

$$R_d = \sqrt{\frac{L_{m1or2}}{C_1}} = 3.6\ \Omega$$

IV.SIMULATION

A MATLAB-SIMULINK model of the proposed interleaved buck-boost converter with closed loop control is prepared and simulation is carried out to analyze the operation of the proposed converter. The overall simulation model is shown in fig. 8. The circuit parameters are designed as per the design equations. The simulation results are shown in fig. 9 and fig 10. The input voltage is compared with the reference voltage to select the mode of operation of the converter; that is either buck mode or boost mode. Here a reference voltage of 12V is selected.

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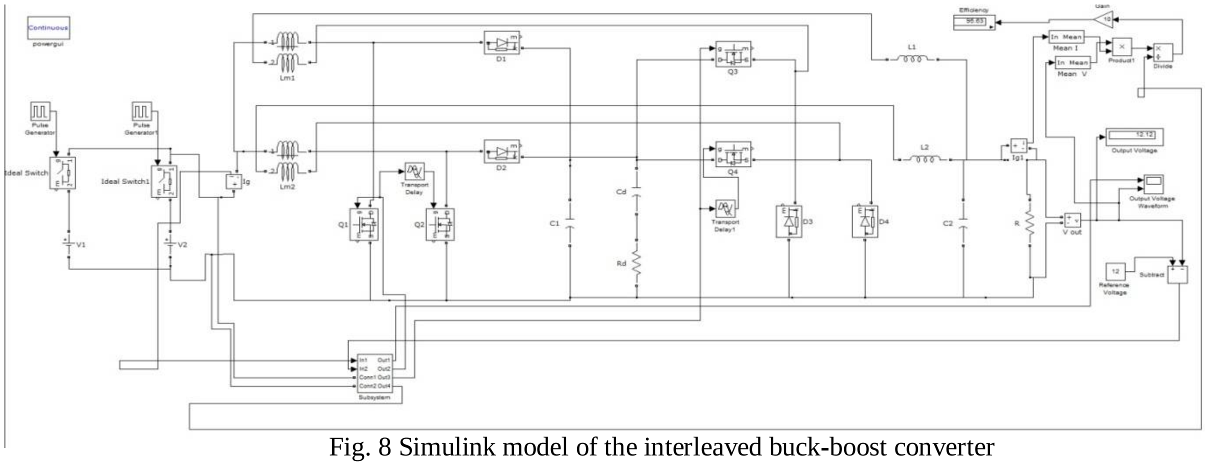

Fig. 8 Simulink model of the interleaved buck-boost converter

Simulation is carried out to obtain a constant output voltage of 12V in both buck mode and boost mode of operations. Input voltage is switched between 14V and 2V, and output is kept constant at 12V as shown in the output waveforms with the help of closed loop control.

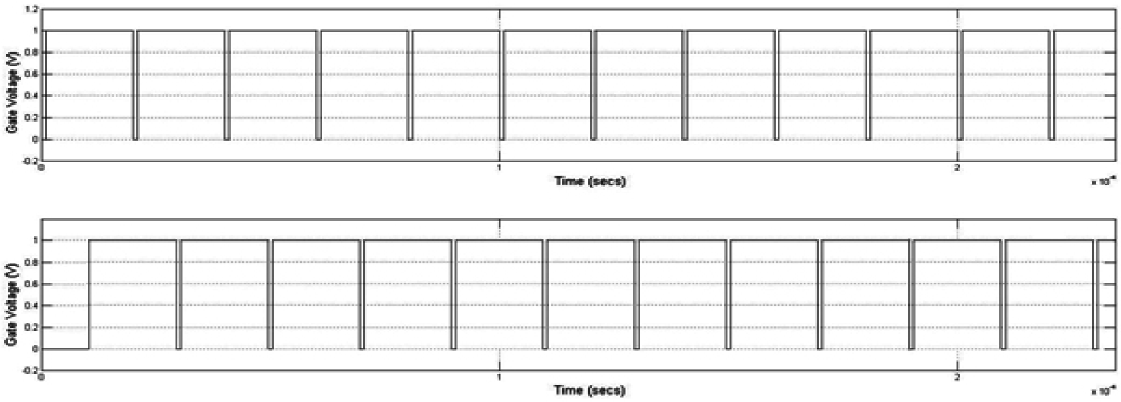

Fig. 9 Switching pulses

The switching pulses for the MOSFETs are shown in fig 9. The duty cycle for the two switches are same except for the difference that, both switching pulses are phase shifted by $T_s/2$. The switching pulses are phase shifted for the interleaved operation.

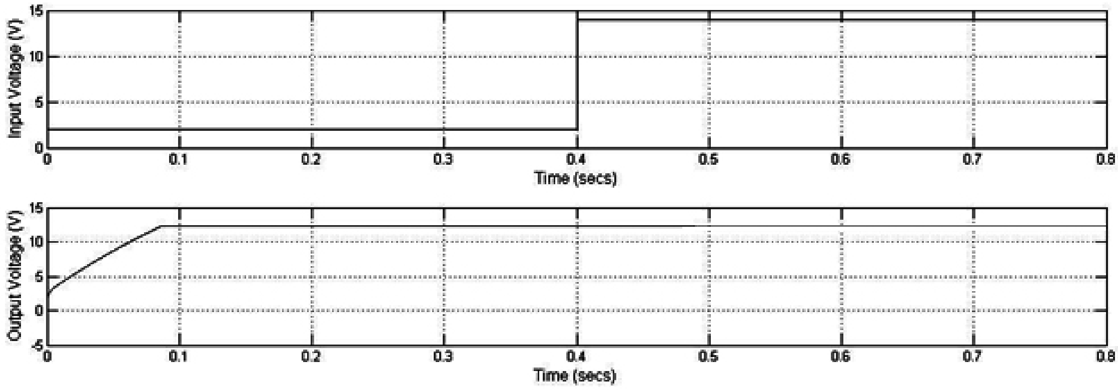

Fig. 10 Output voltage waveform

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When the input is 14V, the circuit acts as buck converter and 12V output is obtained. When the input is 2V, the circuit acts as boost converter to obtain the output voltage as 12V. The output voltage waveform is shown in fig 10.

V.HARDWARE IMPLEMENTATION

The hardware implementation of the proposed converter has been done using the hardware parameters as shown in Table1. Due to the safety purposes and to protect the laboratory equipments, a smaller scale prototype with lower voltage rating is preferred to serve as a proof of principle. Input voltage is switched between 14V and 2V to obtain output voltage as 12V.Atmega 328 microcontroller is used for the controlling purpose.

SL. NO.	COMPONENT	SPECIFICATIONS
1	Microcontroller	Atmega 328
2	$L_1 = L_2$	200 µH
3	$L_m = L_m$	200 µH
4	C_1	10 µF 63V
5	C_2	100 µF 100V
6	C_d	10 µF 63V
7	R_d	22 k Ω
8	R	5 k Ω

Table. 1 Components specifications

Atmega 328 is a 28 pin 8 bit microcontroller from Atmel. The MOSFETs used for the switching purposes are IRF840. The experimental setup is shown in Fig. 11. The power circuit consists of MOSFETs which are high power devices. Therefore, it is necessary to isolate the gate- pulse generating circuits from one another and from the MOSFETS. The isolation can be provided by using optocouplers or high frequency pulse transformers. Optocoupler TLP250 is used here.

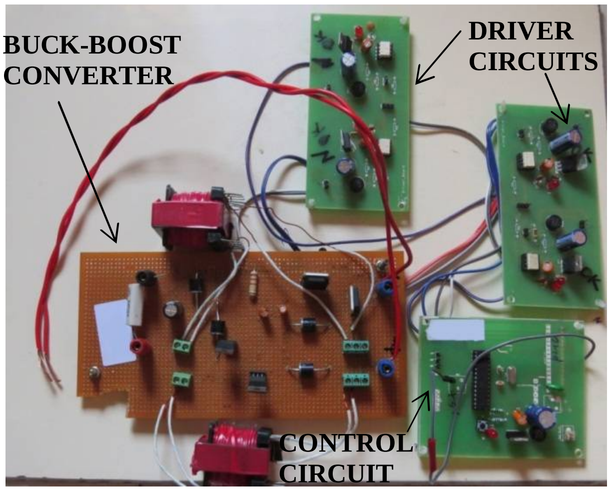

Fig 11 Experimental setup

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The hardware implementation consists of the main circuit of interleaved buck boost converter, the driver circuits for the MOSFETs and the control circuit which consists of Atmega 328 microcontroller.

VI. RESULTS AND DISCUSSION

The hardware implementation of the proposed interleaved buck-boost has been done and the converter was able to achieve 12V as output voltage in both buck and boost modes of operation. The inputs given are 14V and 2V. The switching frequency of 50 kHz is selected. The proposed converter has lesser voltage ripple of 9.7×10^{-4}. An efficiency of 95.6 % is achieved by the converter.

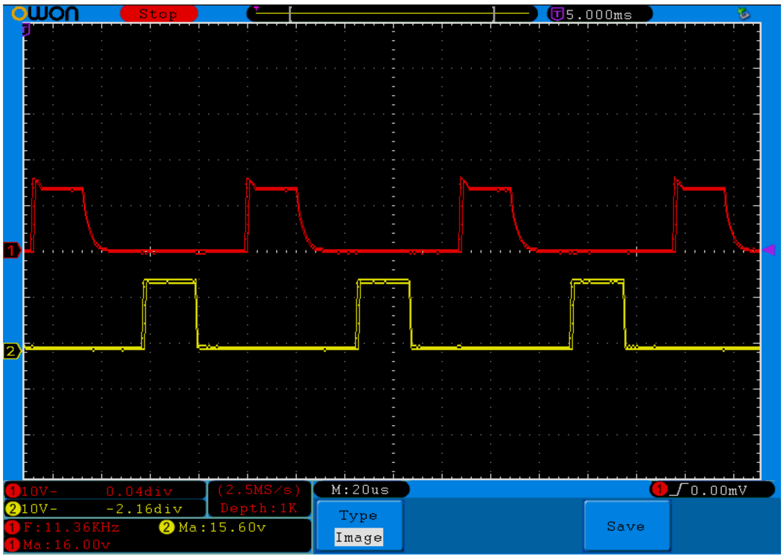

Fig 12 Switching pulses for buck mode

Switching pulses for the switches S_3 and S_4 during the buck mode of operation is shown in fig 12. The pulses are phase shifted by $T_s/2$ for the interleaved operation. Switches S_1 and S_2 are turned off during buck mode of operation.

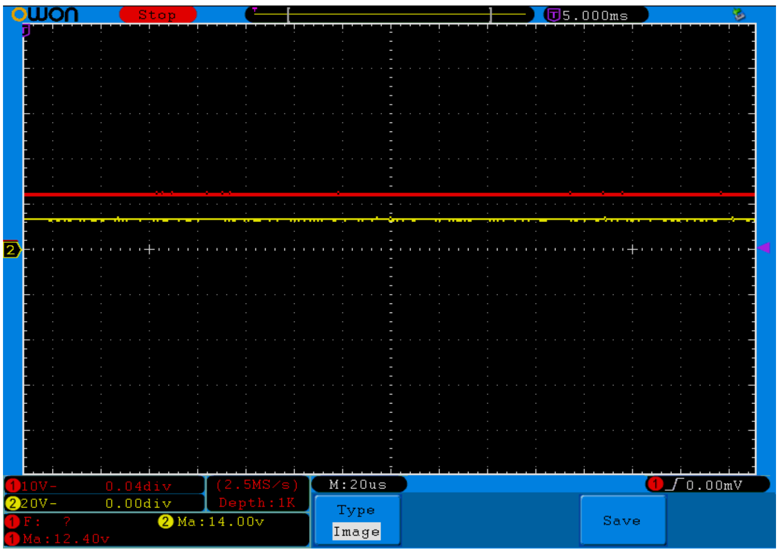

Fig 13 Output waveform for buck mode

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Output waveform for buck mode of operation is shown in fig 13. The yellow waveform shows the input voltage 14V and the red waveform shows the 12V output obtained.The output is obtained as per the design values.

VII.CONCLUSION

By employing interleaving technique, higher efficiency, lower stress on switches, high power capability etc can be obtained. A damping network is provided in the converter to cancel out the oscillations during the change of modes of operation. The proposed converter is a converter with closed loop controller, which will facilitate to maintain a desired voltage at the output. A PID controller is used for the controlling purpose.

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