Design and Implementation of Interleaved Boost Converter

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***Abstract*—This paper deals with the design and simulation of interleaved boost converter for sustainable nonconventional energy sources. Both low and high power application demands the use of DC/DC converter. Two Phase Interleaved DC-DC Boost converters have many advantages compared to conventional boost converter such as very less current ripple, high efficiency, faster dynamics. Two phase interleaved converter is used to boost the output voltage to 400V with higher efficiency of around 98%. Further using interleaving device stress can be lowered and result in increase in efficiency. The proposed work is simulated using matlab simpowersystem.**

Keyword- IBC, state space analysis, boost converter

I. Introduction

The increased environmental pollution have lead to the replacement of conventional sources by renewable sources like photovoltaic sources, windmills etc which result in turn an increase in the demand of DC- DC converters. Basically DC-DC converters are used to boost the input voltage to required output voltage and to get the high voltage gain [1]. The converter should be operated with the duty cycle of more than 50% to get higher gain in voltage level. The drawback of conventional boost converter is low voltage gain. Hence to overcome this problem an interleaved boost converter is proposed for renewable systems. As power densities continue to rise, interleaved boost designs become a powerful tool to manage input currents with increased efficiency. Two phase interleaved DC-DC boost converters are used for the application requiring demands such as low current ripple, high efficiency, faster dynamics, and higher power density. With the help of interleaving technique, the inductor current of interleaved boost converter can be reduced [2].In case of simple conventional boost converter current injected to the load is discontinuous and capacitor current has high ripple at the output. This is especially so in the emerging application areas of automotive power conversion, where the input voltage is low and large voltage boost are desired [3].

II. Two phase interleaved boost converter

The schematic diagram of two phase interleaved boost converter is as shown in Fig1. It contains inductor L1 in parallel with inductor L2, switch Q1 in parallel with another switch Q2, diode D1 in parallel with diode D2, thereby forming two parallel channels between input and output circuits. All identical components are used for the circuit to obtain interleaving operation. Two switches are provided the gate signal which is out of phase by 180°.

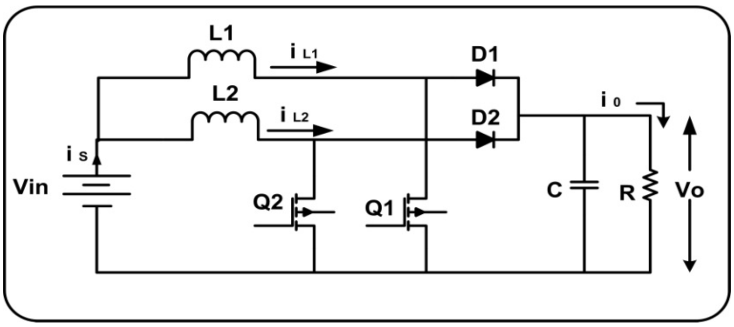

Fig 1: Schematic diagram of Interleaved Boost Circuit

Considering peak inductor ripple current as 20% of the average inductor current, the inductor value is obtained using the expression A. $D_{\max}$ is maximum value of duty cycle which 0.75 and $V_{\min}$ is the minimum of input voltage (100V).

$$L_{phase} = \frac{V_{in} D}{f_s \Delta i_L} \tag{A}$$

By taking 2% peak to peak capacitor ripple, capacitor value is obtained using given expression in B.

$$\Delta V_{out} = \frac{V_{in} D}{T_s \, C_{out} R} \tag{B}$$

This technique results in doubling of ripple frequency and resulting in reduction in ripple in the output voltage.

III. MODES OF OPERATION

The state space averaging technique is used for the analysis of interleaved boost converter. Using these equations mathematical model is obtained for the two phase interleaved boost converter. The operation of the converter is explained with the help of four switching modes of the converter. This converter comprises of four modes of operation. The state equations are derived as follows.

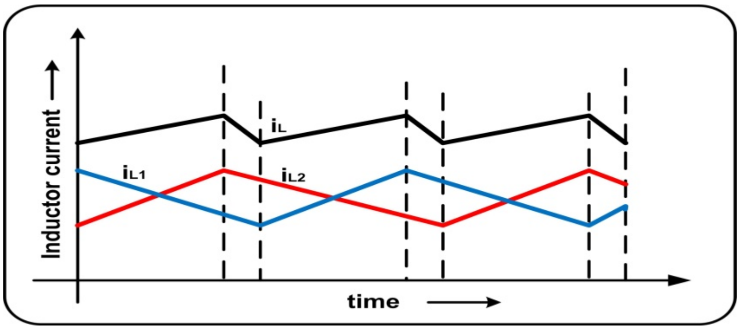

Fig 2: Ideal waveform for the interleaved converter

Mode-1: During mode 1 the switches Q1 and Q2 are switched on and the diodes D1and D2 are under off condition. Figure:1 shows the equivalent circuit for this mode.

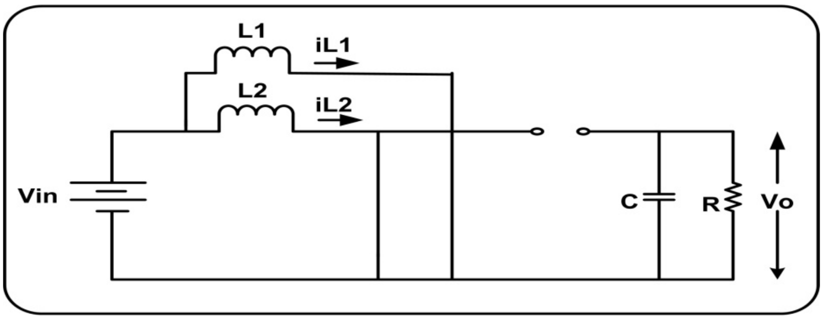

Fig 3: Equivalent circuit during mode 1

The following equations describes the mode 1 operation where inductor current i_{L1} and i_{L1} are taken as state variables . Also capacitor voltage Vo is considered as third state variable.

$$\frac{di_{L1}}{dt} = \frac{V_s}{L_1} \tag{1}$$

$$\frac{dv_0}{dt} = \frac{V_0}{RC} \tag{2}$$

$$\frac{di_{L2}}{dt} = \frac{V_s}{L_2} \tag{3}$$

$$A_1 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \frac{-1}{RC} \end{bmatrix} \text{ and } B_1 = \begin{bmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ V_0 \end{bmatrix} \quad (4)$$

During mode 2, the switch Q1 is in on condition and switch Q2 is in off condition and D1 is in off condition and D2 is in on condition respectively. The figure 4 represents the operation under mode 2.

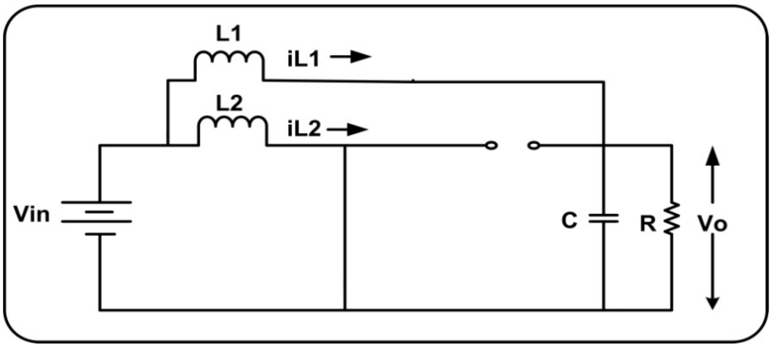

Fig:4 Equivalent circuit during mode 2

$$\frac{di_{L1}}{dt} = \frac{V_s}{L_1} \quad (5)$$

$$\frac{di_{L2}}{dt} = \frac{V_s}{L_2} - \frac{V_0}{L_2} \quad (6)$$

$$\frac{dv_0}{dt} = \frac{i_{L2}}{C} - \frac{V_0}{RC} \quad (7)$$

$$A_2 = \begin{bmatrix} 0 & 0 & \frac{1}{L_1} \\ 0 & 0 & 0 \\ 0 & \frac{1}{C} & \frac{-1}{RC} \end{bmatrix} \text{ and } B_2 = \begin{bmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ 0 \end{bmatrix} \quad (8)$$

In mode 3, the switch Q1 is in off condition and the switch Q2 is in on condition and the corresponding diodes such as D1 and D2 are in on and off conditions respectively. The figure:5 represents the operation of IBC under mode 3.

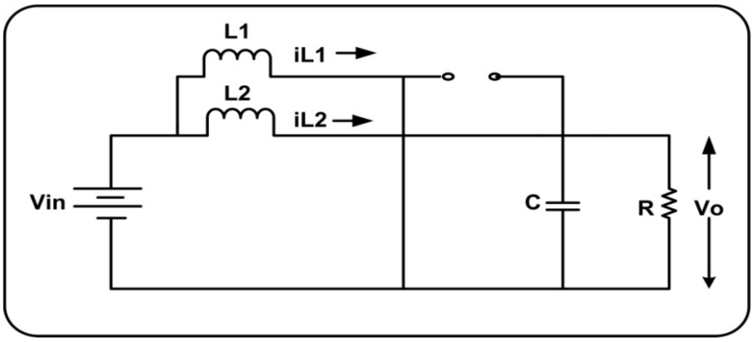

Fig 5 Equivalent circuit during mode 3

$$\frac{di_{L1}}{dt} = \frac{V_s}{L_1} - \frac{V_0}{L_1} \quad (09)$$

$$\frac{di_{L2}}{dt} = \frac{V_s}{L_2} \quad (10)$$

$$\frac{dv_0}{dt} = \frac{i_{L1}}{C} - \frac{V_0}{RC} \quad (11)$$

$$A_3 = \begin{bmatrix} 0 & 0 & \frac{-1}{L1} \\ 0 & 0 & 0 \\ \frac{1}{C} & 0 & \frac{-1}{RC} \end{bmatrix} \text{ and } B_3 = \begin{bmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ 0 \end{bmatrix} \quad (12)$$

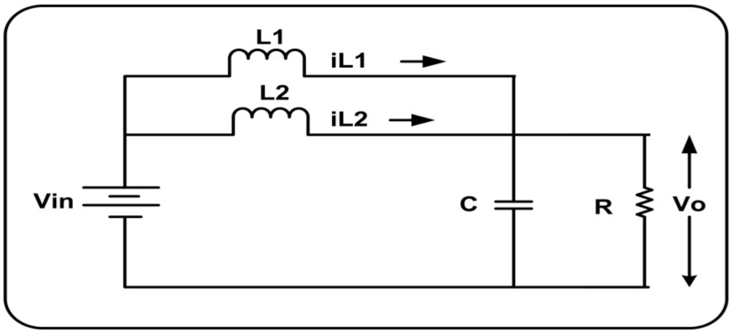

Fig 6: Equivalent circuit during mode 4

$$\frac{di_{L1}}{dt} = \frac{V_s}{L_1} - \frac{V_0}{L_1} \quad (13)$$

$$\frac{di_{L2}}{dt} = \frac{V_s}{L_2} - \frac{V_0}{L_2} \quad (14)$$

$$\frac{dv_0}{dt} = \frac{i_{L1}}{C} + \frac{i_{L2}}{C} - \frac{V_0}{RC} \quad (15)$$

$$A_4 = \begin{bmatrix} 0 & 0 & \frac{1}{L_1} \\ 0 & 0 & \frac{1}{L_2} \\ 0 & \frac{1}{C} & \frac{-1}{RC} \end{bmatrix} \text{ and } B_4 = \begin{bmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ 0 \end{bmatrix} \quad (16)$$

The state equations and the coefficient matrix for the interleaved converter is given below.

$$X^{\bullet} = AX + BU \quad (17)$$

$$Y = CX + DU \quad (18)$$

$$[A] = A_1 d_1 + A_2 d_2 + A_3 d_3 + A_4 d_4 \quad (19)$$

$$[B] = B_1 d_1 + B_2 d_2 + B_3 d_3 + B_4 d_4 \quad (20)$$

$$D = d_1 + d_2 + d_3 + d_4 \quad (21)$$

The tranfer function of the boost converter are given as below.

$$\frac{V_{o(s)}}{V_{in(s)}} = \frac{1+sRC}{(1-D)\left[1+s\dfrac{L}{R(1-D)^2}+s^2\dfrac{LC}{(1-D)^2}\right]} \qquad (22)$$

$$\frac{V_{in(s)}}{d_{(s)}} = \frac{1+sRC}{(1-D)^2\left[1+s\dfrac{L}{R(1-D)^2}+s^2\dfrac{LC}{(1-D)^2}\right]} \qquad (23)$$

TABLE 1: Design values of Interleaved Boost Circuit

Sl.No	Description	Design parameter values
1	Input voltage range	100-200V
2	Output voltage	400V
3	Output power	5.0KW
4	Load current	25A
5	Switching frequency	20KHz
6	Inductance L1, L2	757µH
7	Capacitance	1171µF
8	Load Resistance	32

IV. RESULT & DISCUSSION

The interleaved boost converter is designed for switching frequency of 20KHz. Switching pulse obtained have 180 degree phase shift for interleaving operation. The input voltage range taken is 100-200V. The nominal voltage of 100V is taken as input to the converter. The waveforms for output voltage, input current, output current and output power is shown in the figures given below. The load resistance of 32 ohm is selected to which power of 5KW is given. Duty cycle of 0.75 is taken for the switching MOSFET. The state space analysis is done for open loop operation of interleaved boost converter.

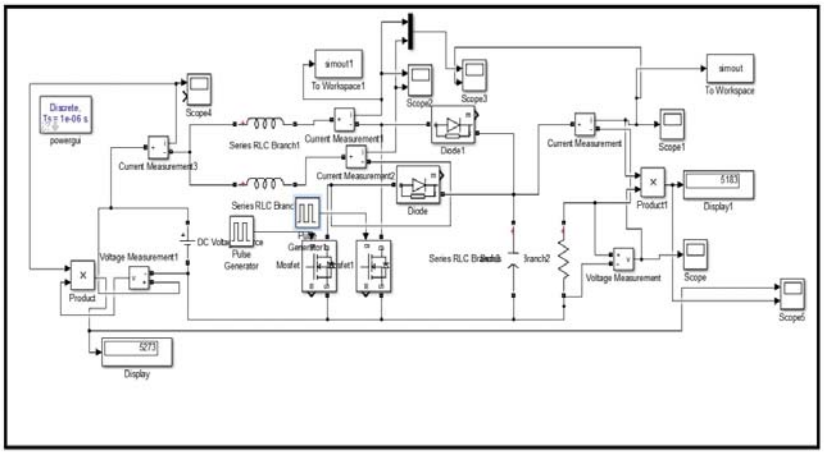

Fig 7: Simulation of interleaved Boost Converter

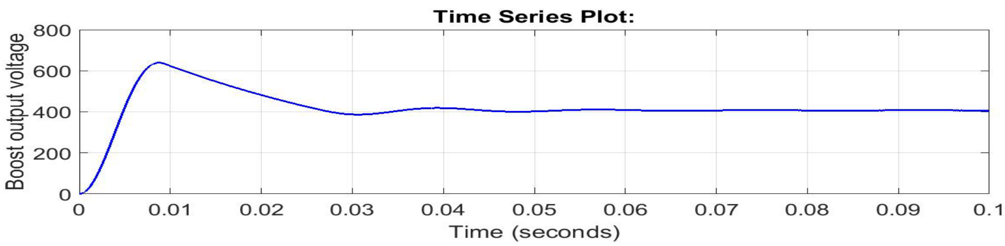

Fig 8 :Boost output voltage through load

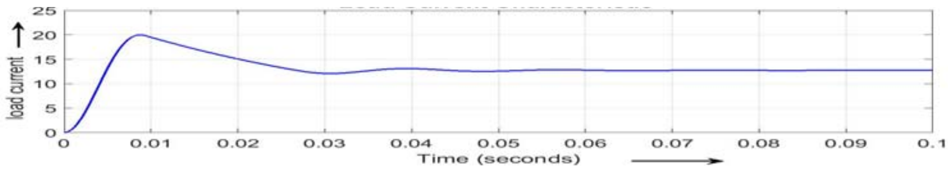

Fig 9 Output current through load

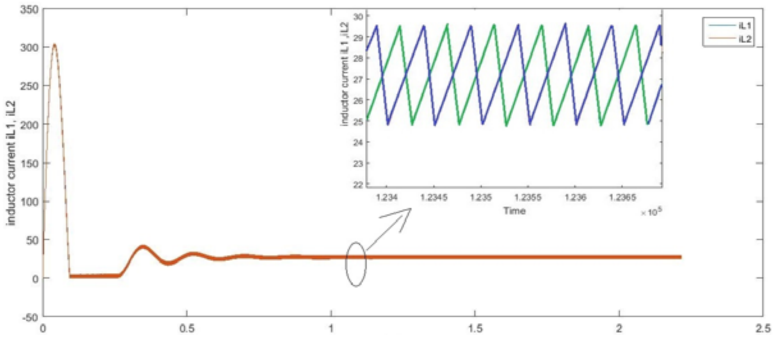

Fig 10 :. inductor current through L1, L2

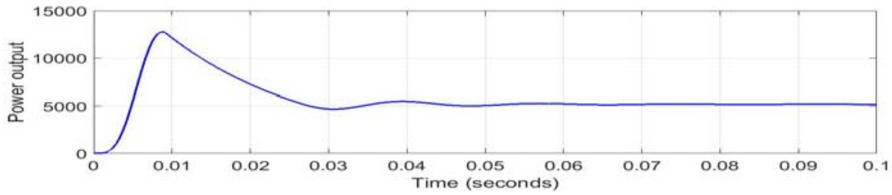

Fig: 11 Output power delivered to load

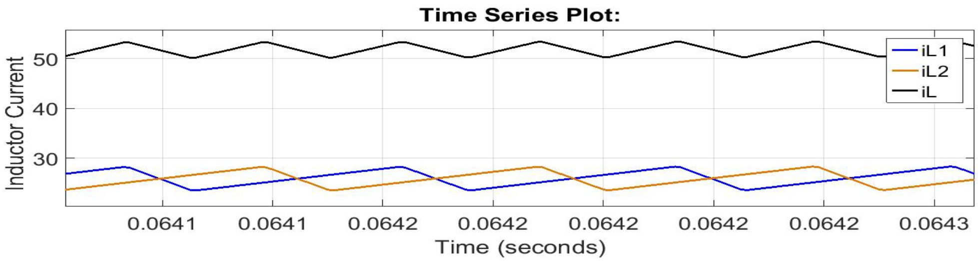

Fig 12: . Current through inductor L1, L2

V. CONCLUSION

Design and analysis of interleaved boost converter for renewable application is done in this paper. The input voltage of 100V is boosted to output voltage of 400V using interleaving technique. The operation is performed under open loop condition. The system is able to deliver the power to the load with higher efficiency. The efficiency of 98% is obtained using this technique. The evaluation by using mathematical model has been analyzed. The IBC has more advantages like high efficiency, low ripple etc. when compared to the conventional boost converters. This IBC can be applied to the grid connected system with the inverter circuit for converting DC to AC . The proposed interleaved boost converter is also suitable for the applications such as high-efficiency converters, a power-factor-correction circuit, and battery chargers.

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