Design and Analysis of Three Stage Interleaved Boost Converter for E-Vehicle Application

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Abstract. This paper deals with the design and analysis of interleaved three-stage DC -DC boost converter for E-vehicle energy sources. Both low power and high power E-vehicle application demands the use of this boost converter. When compared to conventional boost converters, three-stage interleaved DC-DC Boost converters have more advantages, such as higher efficiency, lower current ripple, and faster dynamics. Three stages interleaved converter is simulated and designed with the help of the PSIM software tool. Thus the resultant parameters of output voltage simulated with 400V from the source of (100-200) V input voltage source and 5.6KW output power capacity range of the load power are verified by the usefulness of the new proposed converter.

INTRODUCTION

In recent years, vehicle manufacturers have shown a keen interest in addressing the substantial environmental issues generated mostly by conventional automobiles. Solar, wind, and hydraulic energy are examples of renewable energy sources are used to generate electrical energy with cost and effective features [1, 2,3]. Electric vehicles (EVs) have provided some significant solutions in recent years that are promising for future renewable energy utilization. [4].Due to high voltage stress on the switch, conduction losses, and intense operating duty cycle difficulties, a normal boost converter cannot achieve such a high conversion ratio. [5]. In comparison to electric vehicles, the growing number of internal combustion vehicles causes pollution that is particularly destructive to global warming due to polluting greenhouse gas emissions [6, 7].Electric vehicle system consist of battery packs, ultra -capacitors, flywheels can be used to store the electricity whereas rechargeable batteries used for primary storage to meet the electric motors and auxiliary systems' dynamic power demands [8]. Various types of energy storage batteries, including lead acid, lithium-ion and Ni-MH have been implemented and verified for EVs. Due to its long lifespan, good energy density and peak performance, lithium- ion battery is extensively used [9, 10]. Battery stress can be reduced by parallel connection which help to operate EV during acceleration and deceleration with transient currents [11].A 16-phase interleaved converter can operate at higher frequency with higher efficiency is proposed[12].Voltage stress and current ripple is reduced and filter element size is minimized for dc micro grid and electric vehicles[13].

Three Stage Interleaved Boost Converter

The power electronic converter has high voltage stress across the switching devices due to increase in current. The reverse recovery current of diode is high compare to main switch. Power flow from energy sources to the EV through interleaved bidirectional dc–dc converter. This paper reviews the ripple input current and output voltage of three stage Interleaved Boost Converter with less component, low switching losses and high efficiency. During few decades, power electronic converter has concentrated on the expansion of multi stage parallel DC-DC converters used to realize the regulated output voltage from renewable input power sources such as a solar, wind, fuel cell. Among the several topologies, three stage interleaved boost converter has many advantages such as low component count, better electrical performance, less weight and small size for fuel cell systems. This provides output voltage without supplementary transformer .The power converter gives high reliability and increase the power processing capability by using interleaved dc-dc boost converter. When compare conventional single stage and two phase converters with proposed converter, this proposed topology minimizes number of total components and has simple structure. Interleaved boost converter has low ripple cancellation, lower ripple amplitude in input and output. In proposed converter conduction losses significantly reduced by parallel connection of inductors and overall efficiency can be increased by dividing conduction current into many paths. Input source is connected to Electric vehicles through three stage interleaved boost converter to operate the motors.

The DC/DC converter consists of three inductor connected in parallel as shown in Fig. 1. The circuit consists of three inductor with three switches are connected in parallel, there by forming three parallel paths between input and output. Triggering signals of the three modules are shifted by 120° to ensure interleaving of inductor currents. The input current is sharing between three stage converter modules which reduce the power rating of the switches used in the interleaved boost converter.

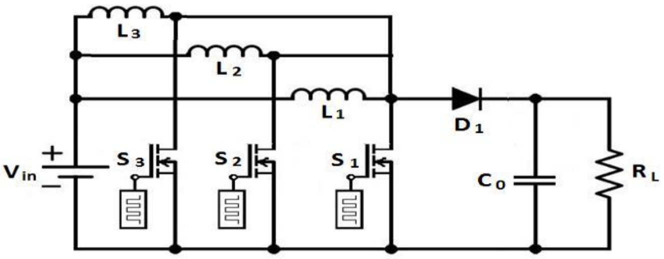


FIGURE 1. Three stage Interleaved DC -DC boost converter

$$\frac{\quad_0\quad}{} = \frac{\quad_0\quad}{} \tag{4}$$

Mode II: (t1-t2)

In this transition interval, switches S1, S2, S3 are turned OFF and Diode D1 is naturally turned ON as shown in figure 3. The inductor L1, L2 and L3 are discharging their stored energy to the load through the diode D1. At this duration t=t2, Capacitor C0 start to charge.

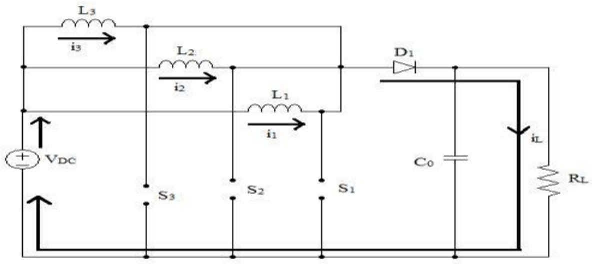


FIGURE 3. Equivalent Circuit during (t1-t2)

Modes of Operation

State space analysis and mathematical model is obtained for the three stage interleaved boost converter. The operation of interleaved boost converter is explained with the help of six switching modes. The inductor current iL1, iL2, iL3 are taken as input variables and capacitor voltage is considered as output variable for all mode of operation.

Mode I: (t0-t1)

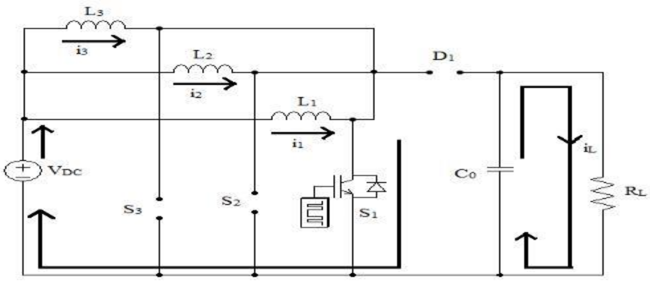


FIGURE 2. Equivalent Circuit during (t0-t1)

In this transition interval, switch S1 is turned ON while S2 and S3 are OFF, as well as the diode D is reverse biased. Figure 2 shows the equivalent circuit for mode I. At starting period, inductor L1 start to charge and get magnetizing but inductor L2 and L3 are keeping their stored energy to 2/3 and 1/3 level. Capacitor C0 discharge the energy to the load in this duration.

$$\frac{\quad_1\quad}{} = \frac{}{1} \tag{1}$$

$$\frac{\quad_2\quad}{} = \frac{}{2} \tag{2}$$

$$\frac{\quad_3\quad}{} = \frac{}{3} \tag{3}$$

$$A_1 = \begin{vmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{RC} \end{vmatrix} \quad \text{and} \quad B_1 = \begin{vmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ \frac{1}{L_3} \\ V_0 \end{vmatrix}$$

$$\frac{\quad_1\quad}{} = \frac{}{1} - \frac{\quad_0\quad}{} \tag{5}$$

$$\frac{\quad_2\quad}{} = \frac{}{2} - \frac{\quad_0\quad}{} \tag{6}$$

$$\frac{\quad_3\quad}{} = \frac{}{3} - \frac{\quad_0\quad}{} \tag{7}$$

$$\frac{\quad_0\quad}{} = \frac{1}{} - \frac{\quad_0\quad}{} \tag{8}$$

$$A = \begin{vmatrix} 0 & 0 & 0 & \frac{-1}{R} \\ 0 & 0 & 0 & \frac{-1}{R} \\ 0 & 0 & 0 & \frac{-1}{R} \\ 0 & 0 & \frac{1}{C} & \frac{-1}{RC} \end{vmatrix} \quad \text{and} \quad B = \begin{vmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ \frac{1}{L_3} \\ 0 \end{vmatrix}$$

Mode III: (t2-t3)

In this transition interval, switch *S*2 is turned ON while S3 and S1 are OFF, as well as the diode D is reverse biased as shown in figure 4.In this period, inductor *L2* is get magnetizing but inductor *L3* and *L1*are keeping their stored energy to 2/3 and 1/3 level. Capacitor *C*0 discharge the energy to the load in this duration t2-t3.

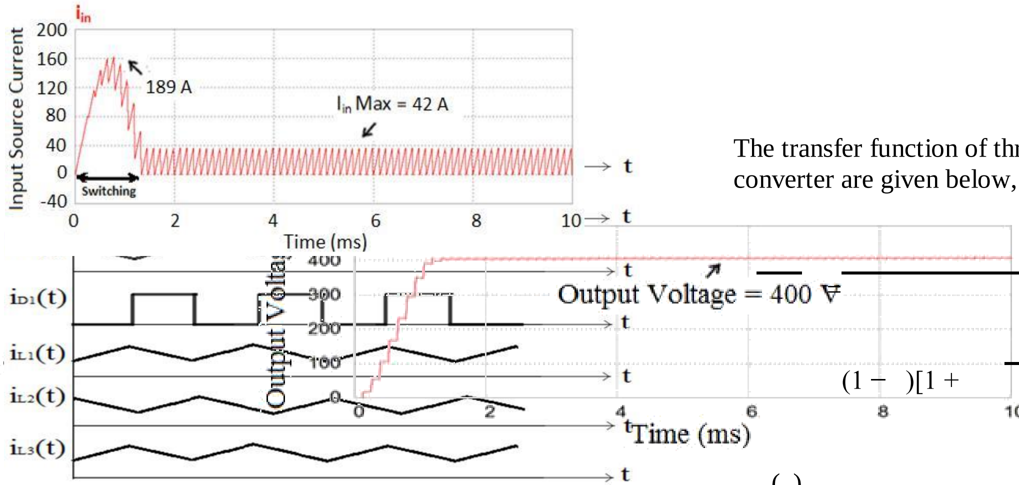


FIGURE 4. Equivalent Circuit during (t2-t3)

Mode IV: (t3-t4)

This mode of operation in figure 5 is identical to the second mode of operation.

FIGURE 5. Equivalent Circuit during (t3-t4)

Mode V: (t4-t5)

In this transition interval, switch S3 is turned ON while S1 and S2 are OFF, as well as the diode D1 is reverse biased is shown in figure 6. In this period, current i3 flows through inductor L3 and it start to charge but inductor L1 and L2 are keeping their stored energy to 2/3 and 1/3 level. Capacitor C0 discharge the energy to the load in this duration t4-t5.

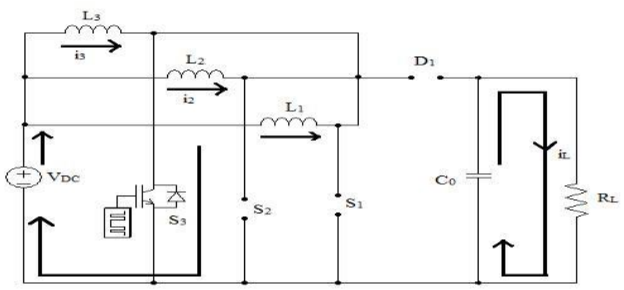


FIGURE 6. Equivalent Circuit during (t4-t5)

Mode VI: (t5-t6)

The mode of operation as shown in figure 7 is identical to the second mode of operation. Theoretical waveform of three stage interleaved DC-DC Boost Converter is as shown in figure 8.

FIGURE 7. Equivalent Circuit during (t5-t6)

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

= + (9)

= + (10)

[ ]= + + + (11)

[ ]= + + + (12)

= + + + (13)

The transfer function of three stage interleaved boost converter are given below,

1 + (14)

(1 −)[1 + 2+ 2 2

(1−) (1−)

( ) 1 + (15)

=

( ) (1 −)2 [1 + 2+ 2 2

(1 −) (1 −)

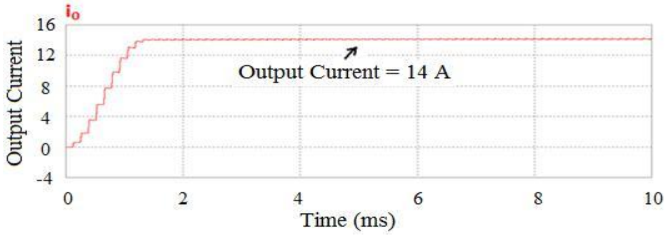
TABLE I. Design values of two stage and three stage interleaved dc-dc boost converter

S. no	Description	Two stage Design parameter values	Three stage Design parameter values
1	Input Voltage	100-200V	100-200V
2	Output Voltage	400V	400V
3	Output Power	5KW	5.6KW
4	Load Current	12.5A	14 A
5	Switching Frequency	25KHz	25KHz
6	Inductance L1,L2,L3	757µH	757µH
7	Capacitance	1171µF	1171µF
8	Load Resistance	32	32

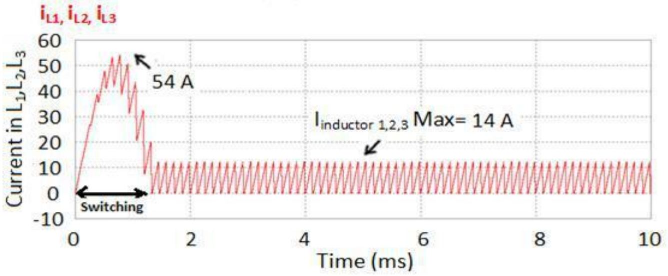
FIGURE 8. Theoretical waveform of interleaved three stage DC-DC Boost Converter

Simulation Result and Discussion

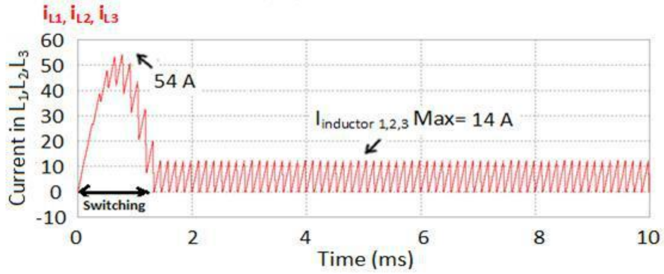
A three stage Interleaved DC-DC boost converter has been modelled by PSIM software and behaviour of interleaved converter is confirmed by simulation result. The converter is design for 25 KHz switching frequency. The input voltage 140V is applied to proposed Interleaved Boost converter. The waveform of output voltage, output current, input source current and Inductor current is as shown in figure 9.The transfer function is derived by using state space analysis for three stage interleaved DC-DC boost converter.



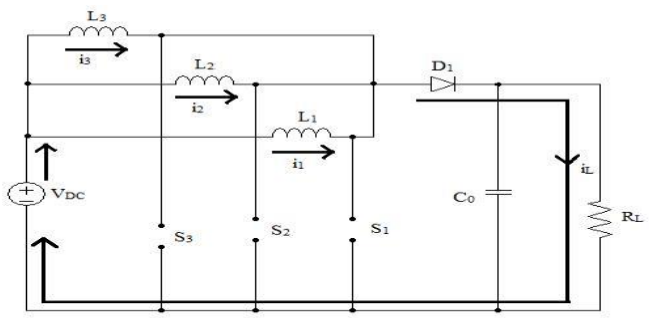
(a)



(b)



(c)



(d)

FIGURE 9. (a)Output voltage waveform (b) Output current waveform (c) Input source current waveform (d) Inductors current waveform

TABLE II. Comparison of two stage and three stage Ripple

parameter	Two stage IBC			Three stage IBC		
	Imax	Imin	I	Imax	Imin	I
Ripple current in L1	4.07	4.25	0.18	4.02	4.14	0.08
Ripple current in L2	4.10	4.32	0.22	4.06	4.16	0.10
Ripple current in L3	___	___	____	4.04	4.16	0.12
Input source current ripple	8.25	8.35	0.10	12.94	12.99	0.05

CONCLUSION

This paper presents Analysis and Design of three stage interleaved boost converter for E-Vehicle Application is proposed in this paper. The source voltage of 140V is boosted to 400V output voltage using three stage interleaving methods. When two stage IBC compared with three stage IBC, current ripple is notably better by increasing the number of stage and simulation wave forms have manifested. The mathematical model of proposed three stage interleaved dc - dc boost converter has been analyzed and also it has less component, low ripple and improved efficiency. This proposed IBC output response can be applied to electric vehicle motors and inverter.

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