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Analysis and Design of Two phase Interleaved Boost DC-DC Converter connected with Conventional Boost DC-DC Converter

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ABSTRACT

In this paper, new interleaved boost dc-dc converter is proposed by combining the two phase interleaved boost dc-dc converter with conventional boost dc-dc converter. The Output ripple voltage and Input ripple current of proposed converter are analyzed and compared with two phase interleaved boost dc-dc converter. The designs of converters were presented and parameters of the converters were calculated. The converters are tested with constant input voltage and different duty ratio. These converters are simulated using MATLAB/Simulink.

Key words: Interleaved Boost dc-dc converter, Design of Converters, Input Ripple current and Output Ripple voltage , Comparison.

INTRODUCTION

Nowadays, DC-DC converters are widely used in many applications like Photovoltaic (PV) system, Electric vehicles, Uninterruptable power supplies (UPS) and fuel cell system. Input current of the converter can be shared among inductors by paralleling the converters with same switching frequency with phase shift, hence high efficiency and reliability in power electronic systems can be obtained. Using interleaved converter we can get improved efficiency, reduced ripple voltage, reduced inductor current ripple, fast switching speed. Overall size of the inductor, EMI Filter and Switching loss will be reduced [1]-[2] by using high power factor regulator circuit in continuous current mode of interleaved boost converter. Voltage mode soft switching pulse width modulation method provides minimum redirection current and recovers the auxiliary circuit energy during entire load range [3].N-Identical boost converter can be connected in parallel operation using binary state transition diagram [4].Good Current sharing characteristics at large duty cycle can be obtained by consisting two interleaved and inter coupled boost converter cells. It also provides small input current ripple and zero boost rectifier reverse recovery loss [5].For medium power application, unity power factor boost converter can be operated in phase shifted parallel mode[6].Interleaved PFC Boost converter works on open loop control in continuous conduction mode and discontinuous conduction mode with master slave flip flop. The quality of the input current is determined by switching frequency limit, phase shift error, valley switching and inductance [8].Optimal design is used to select the number of phases, minimum number of switches and parasitic components of the converter for fuel cell application [9].DC-DC converters are mostly used as power electronic interfaces in renewable energy sources such as fuel cells and photovoltaic power systems. Most renewable sources are having quite low output voltage and they need booster in order to provide required output voltage. Buck boost series resonant full bridge and push pull converters are used to boost the voltage but they are not used because they produce more ripple content.

MATERIAL METHOD

DESIGN OF TWO PHASE INTERLEAVED BOOST DC-DC CONVERTER

Two phase Interleaved Boost dc-dc converter is shown in Fig. 1. It has two switches (M1, M2), two diodes (D1, D2), one capacitor(C) and input voltage source (Vin).

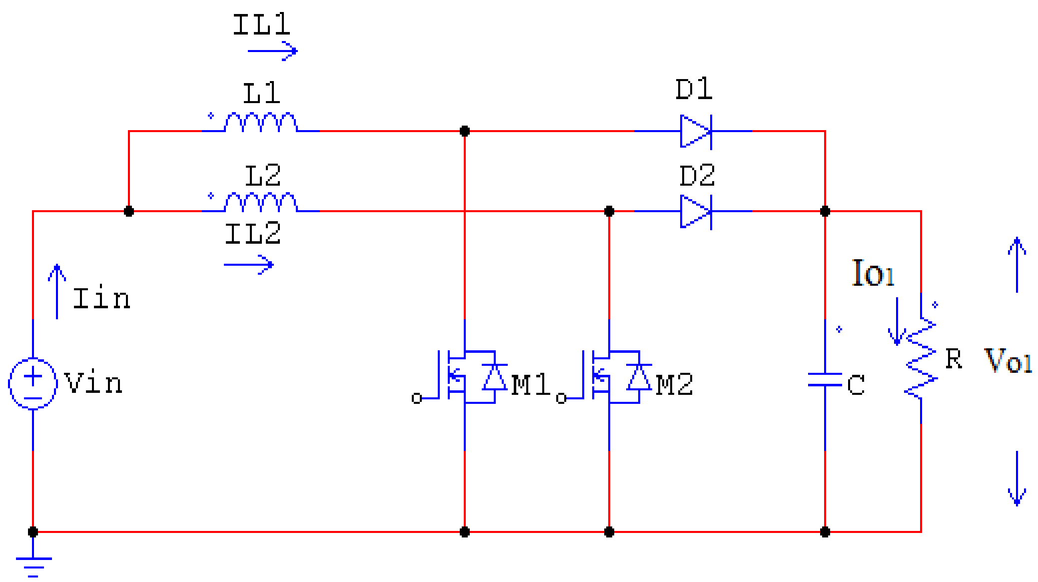

Figure. 1. Two phase Interleaved Boost dc-dc converter

Interleaving technique is achieved by interconnection of multiple switching cells in series with diode and parallel with inductors, hence it will increase the effective pulse frequency by synchronizing several smaller sources and operating them with relative phase shift. Energy can be saved and power conversion can be increased without affecting conversion efficiency by interleaving technique. Continuous current mode (CCM) and Discontinuous current mode (DCM) are the mode of operation used in interleaved boost converter. When switch M1 is turned ON, Inductor current (IL1) linearly increases. Energy is stored in inductor L1, during this period. When switch M1 is turned OFF, Diode D1 conducts and the energy stored in the inductor L1 ramp down. During this period, the stored inductor energy discharges and current is transferred to load via diode. The parameters of the converter [8][11] can be calculated by following equations (1) to (11).

Output Voltage (Vo1)

$$Vo_1 = \frac{Vin}{(1-D)} \quad (1)$$

Where D is the duty cycle

Vin=12V , D= 0.4, Vo_1 = 20 V.

Input Current (Iin)

$$Iin = \frac{Pin}{Vin} \tag{2}$$

Where Pin is the Input power, Vin is the Input voltage

Considering the Input power is 60 W, Vin=12V, Iin= 5A

Output Load current (Io1)

$$Io_1 = \frac{Vo_1}{R} \tag{3}$$

Where Io_1 is the Output load current, Vo_1 is the output voltage, R is the Load resistance

Vo1 = 20V, R= 10Ω Io_1 = 2A.

Output Power (Po)

$$P_{01} = Vo_1 \times Io_1 \tag{4}$$

Input ripple current peak to peak magnitude (ΔIin)

$$\Delta I_{in} = \frac{VinTD}{L} \tag{5}$$

Vin=12 V, D= 0.4 , T=100µS L=100 mH , ΔIin = 0.0016 A

The following equation (6) & (7) shows the peak to peak magnitude of input ripple current, when input voltage is known, at the certain period of duty ratio [9].

$$\Delta I_{in} = \frac{VinTD\,(1-2D)}{L(1-D)} \qquad \langle 0 \le D \le 0.5 \rangle \tag{6}$$

$$\Delta I_{in} = \frac{VinT\,(2D-1)}{L} \qquad \langle 0.5 \le D \le 1 \rangle \tag{7}$$

Inductor ripple current (ΔI_L)

$$\Delta I_L = \Delta I_{L1} = \Delta I_{L2} = \frac{VinD}{fL} \tag{8}$$

Where ΔI_{L1} is the current through inductor L_1

ΔI_{L2} is the current through inductor L_2 and f is the switching frequency

Vin=12 V, D= 0.4, f=10 kHz , L= 100 mH , ΔI_L = 0.0048 A

Equation (8) shows inductor ripple current for two phase interleaved boost converter.

Selection of Inductance (L)

$$L = L1 = L2 = \frac{VinD}{\Delta I_L\, f} \tag{9}$$

Vin=12 V, D= 0.4, f=10kHz, ΔI_L = 0.0048 A , L= 100 mH

Output ripple voltage ($\Delta V0_1$)

$$\Delta V_{01} = \frac{VoDT}{CR} \quad (10)$$

Vo1 = 20V, R= 10Ω, D = 0.4, T=100µS, C=1000 µF , ΔVo_1= 0.08V.

Selection of Capacitance(C)

$$C = \frac{Vo_1 DT}{R\Delta Vo_1} \quad (11)$$

Vo1 = 20V, R= 10Ω , D= 0.4 , T=100µS , ΔVo_1= 0.08V , C=1000 µF.

Selection of Number of Phases and Duty ratio

The ripple content will be reduced with the increase in number of phases [7], [10].It has limitation of increasing number of phases because it increases the size and cost of the converter. The selection of duty ratio is based on the number of phases and the ripple content will be minimum at certain duty ratio.

Table 1. Theoretical Values of Two Phase Interleaved Boost Dc-Dc Converter

Duty Cycle (D)	Vo1	ΔI_L	Output Ripple volt (ΔVo_1)	Output Load current (Io_1)	Input ripple current (ΔIin)	P_{01}
0.1	13.33	0.0012	0.01	1.33	0.0011	17.78
0.2	15.00	0.0024	0.03	1.50	0.0018	22.50
0.3	17.14	0.0036	0.05	1.71	0.0021	29.39
0.4	20.00	0.0048	0.08	2.00	0.0016	40
0.5	24.00	0.006	0.12	2.40	0	57
0.6	30.00	0.0072	0.18	3.00	0.0024	90
0.7	40.00	0.0084	0.28	4.00	0.0048	160
0.8	60.00	0.0096	0.48	6.00	0.0072	360
0.9	120.00	0.0108	1.08	12.00	0.0096	1440

The theoretical values of two phase interleaved boost dc-dc converter given in the Table.I. The input ripple current and Output ripple voltage will increased with respect to duty cycle [8].

DESIGN OF PROPOSED INTERLEAVED BOOST DC-DC CONVERTER

A new interleaved converter is proposed by connecting the output of the two phase interleaved boost dc-dc converter with conventional boost converter as shown in Fig.2. The parameters of the converter [8],[11] can be calculated by following equations (11) to (18).

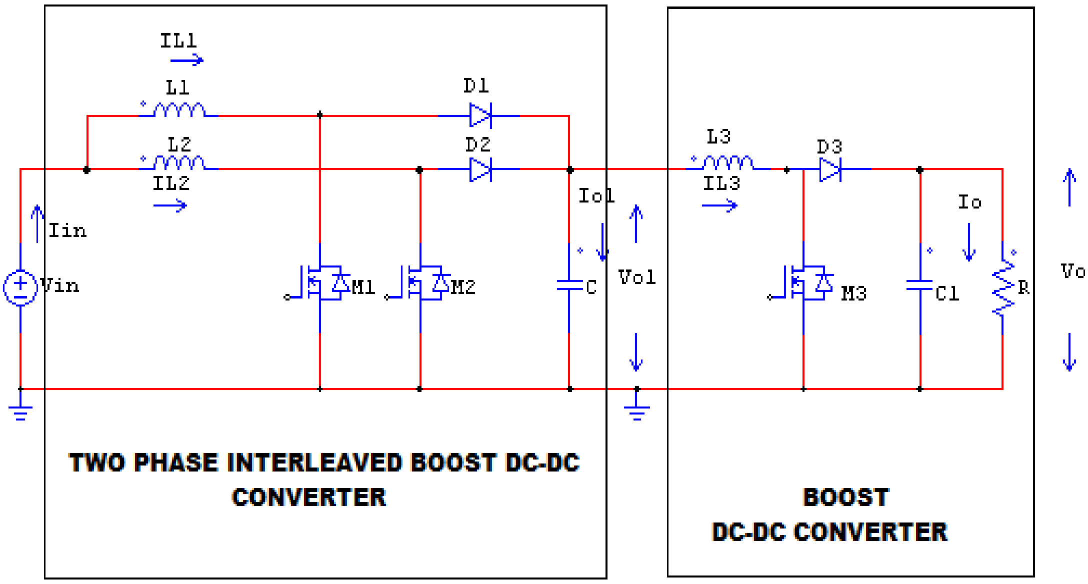

Figure. 2. Proposed Interleaved Boost dc-dc converter

Output voltage of the two phase interleaved boost dc-dc converter is denoted as Vo1 and proposed converter output is Vo.

Output Voltage (Vo)

$$Vo = \frac{Vo1}{(1-D)} \tag{12}$$

Where D is the duty cycle,

Vo1 is the output voltage of two phase interleaved boost dc-dc converter (Input for conventional boost dc-dc converter)

Vo1=20V, D= 0.4, Vo = 33.33 V.

Input Current (Iin)

$$Iin = \frac{Pin}{Vin} \tag{13}$$

Where Pin is the Input power, Vin is the Input voltage

Considering Input power source Pin=100 W, Vin =12V, V_{O1}=20V, Iin= 8.33A

Output Load current (Io)

$$Io = \frac{Vo}{R} \tag{14}$$

Where Io is the Output load current, Vo is the output voltage, R is the Load resistance

Vo = 33.33 V, R= 10Ω, Io = 3.33A.

Output Power (Po)

$$P_0 = Vo \times Io \quad (15)$$

Input ripple current peak to peak magnitude (ΔIin)

$$\Delta I_{in} = \frac{Vin\,TD}{(L+L3)} \quad (16)$$

Vin=12 V, D= 0.4 , T=100µS L=100 mH , ΔIin = 0.0024 A

Inductor ripple current (ΔI_L)

$$\Delta I_L = \frac{Vin\,D}{f(L+L3)} \quad (17)$$

Where ΔI_{L3} is the current through inductor L_3 and f is the switching frequency

Vin=12 V, Vo1=20V, D= 0.4, f=10kHz , L= 100 mH , ΔI_L = 0.0024 A

Selection of Inductance (L3)

$$L_3 = \frac{V0_1\,D}{\Delta I_L\,f} \quad (18)$$

Vin=12 V, Vo1=20V, D= 0.4, f=10kHz, ΔI_L = 0.0024 A , L1=L2=100 mH, L3=100 mH , (L+L3)= 200 mH

Equation (18) shows Inductance value (L3) for proposed interleaved boost converter

Output ripple voltage (ΔVo)

$$\Delta V_o = \frac{VoDT}{CR} \quad (19)$$

Vo = 33.33V, R= 10Ω , D= 0.4 , T=100µS, C=1000 µF ,ΔVo = 0.13V.

Selection of Capacitance(C1)

$$C_1 = \frac{VoDT}{R\Delta Vo} \quad (20)$$

Vo = 33.33 V, R= 10Ω , D= 0.4 , T=100µS ,ΔVo= 0.13V, C_1=1000 µF.

The theoretical values of proposed interleaved boost dc-dc converter is given in the Table.II.

Table 2. Theoretical Values of Proposed Interleaved Boost Dc-Dc Converter

Duty Cycle (D)	**Vo1**	**Vo**	**ΔI_L**	**Output Ripple volt (ΔVo)**	**Output Load current (Io)**	**Input ripple current (ΔIin)**	**P_0**
0.1	13.33	22.22	0.0006	0.02	2.22	0.0003	49.38
0.2	15	25	0.0012	0.05	2.50	0.0009	62.50
0.3	17.14	28.57	0.0018	0.09	2.86	0.0010	81.63
0.4	20	33.33	0.0024	0.13	3.33	0.0008	111.11
0.5	24	40	0.003	0.20	4	0	160
0.6	30	50	0.0036	0.30	5	0.0012	250
0.7	40	66.66	0.0042	0.47	6.67	0.0024	444
0.8	60	100	0.0048	0.80	10	0.0036	1000
0.9	120	200	0.0054	1.80	20	0.0048	4000

These are calculated by using the above equations (12) to (20). The input ripple current and Output ripple voltage will increase [8] with respect to duty cycle [11].

RESULTS AND DISCUSSION

SIMULATION MODEL AND RESULTS OF TWO PHASE INTERLEAVED BOOST DC-DC CONVERTER

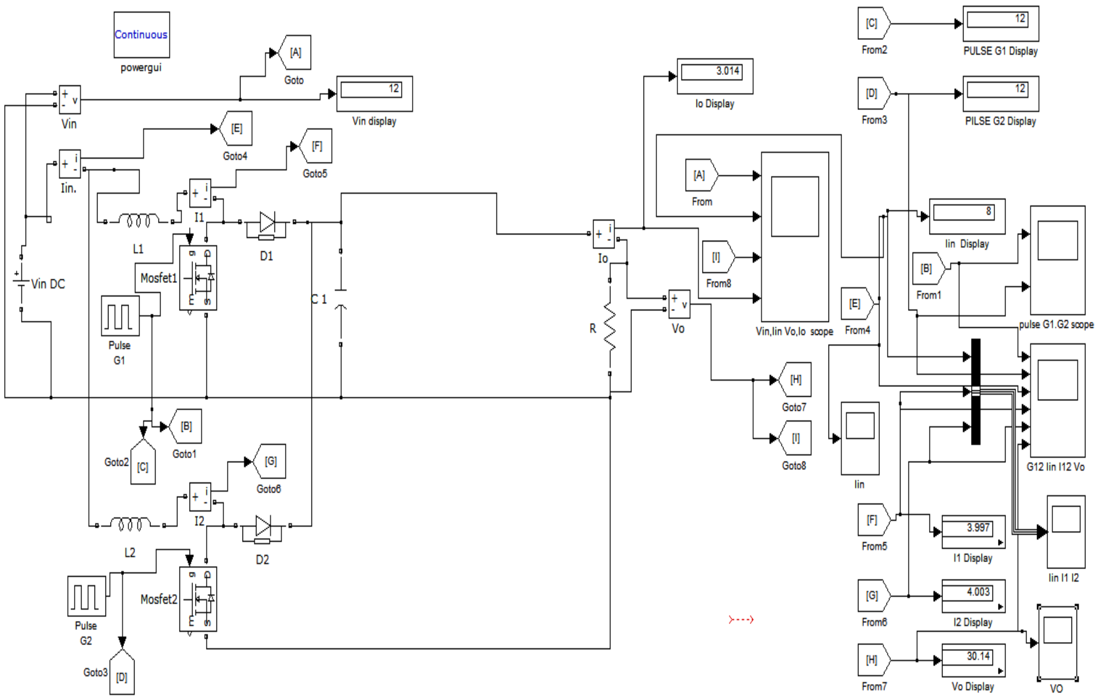

Figure. 3 Simulation model of two phase Interleaved Boost dc-dc converter

Fig.3 shows simulation model of two phase interleaved boost dc-dc converter using MATLAB/simulink. From the simulation model, two inductance value are considered equal, $L_1 = L_2 = L$ and equal duty cycles are $D_1 = D_2 = D$ (phase shifted by 180º) as shown in Fig.4. The inductor currents(IL1,IL2) is shown in Fig.5.

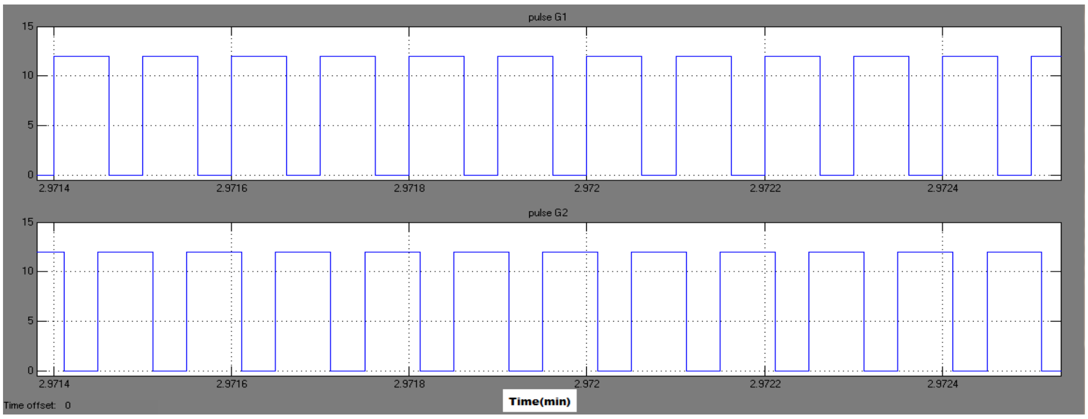

Figure. 4 Switching pulses of two phase Interleaved Boost dc-dc converter at duty cycle=0.62

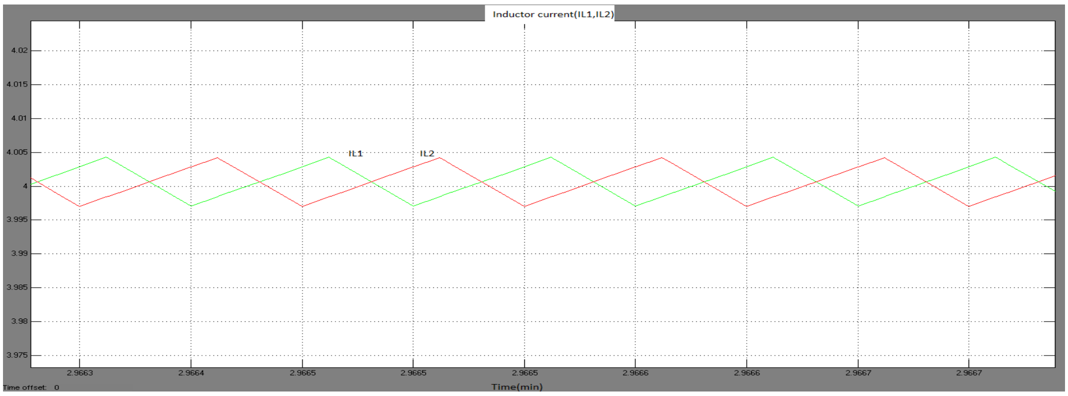

Figure. 5 Inductor currents of two phase Interleaved Boost dc-dc converter at duty cycle=0.62

The input currents of two phase Interleaved Boost dc-dc converter is shown in Fig.6. The input ripple current of two phase Interleaved Boost dc-dc converter is shown in Fig.7.

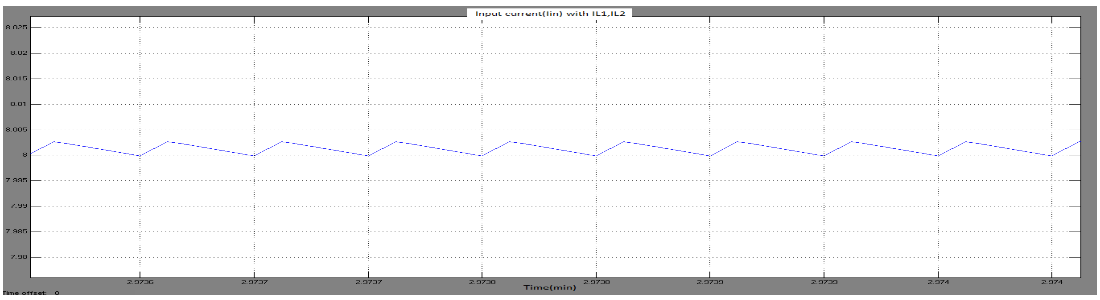

Figure. 6 Input current of two phase Interleaved Boost dc-dc converter at duty cycle=0.62

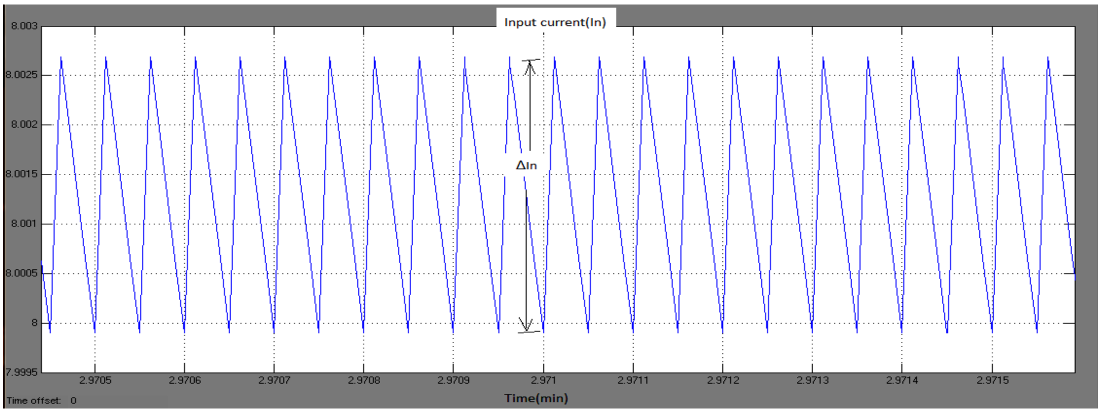

Figure.7 Input ripple current of two phase Interleaved Boost dc-dc converter at duty cycle=0.62

The Output ripple voltage of two phase Interleaved Boost dc-dc converter at 0.62 duty cycle are shown in Fig.8.

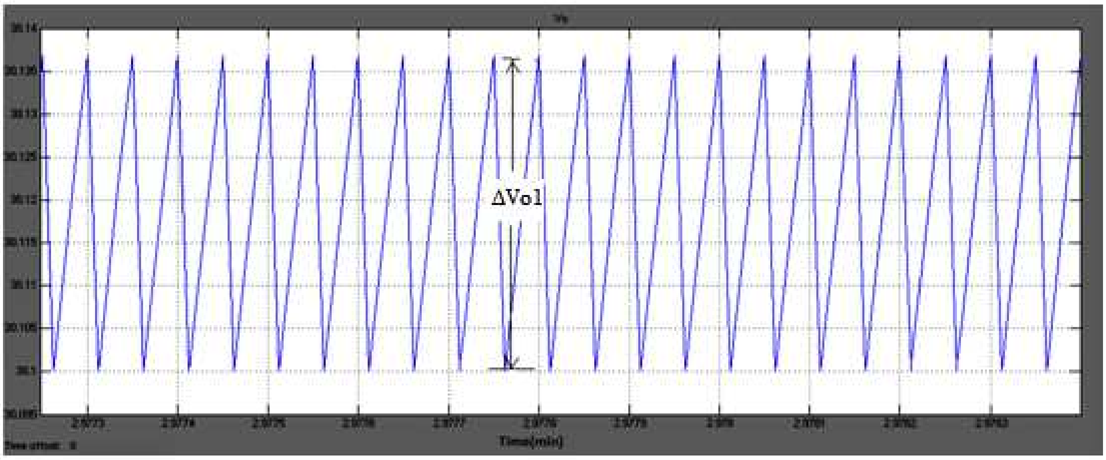

Figure.8 Output ripple voltage of two phase Interleaved Boost dc-dc converter at duty cycle=0.62

The Output ripple voltage of two phase Interleaved Boost dc-dc converter at 0.4 duty cycle is shown in Fig.9.

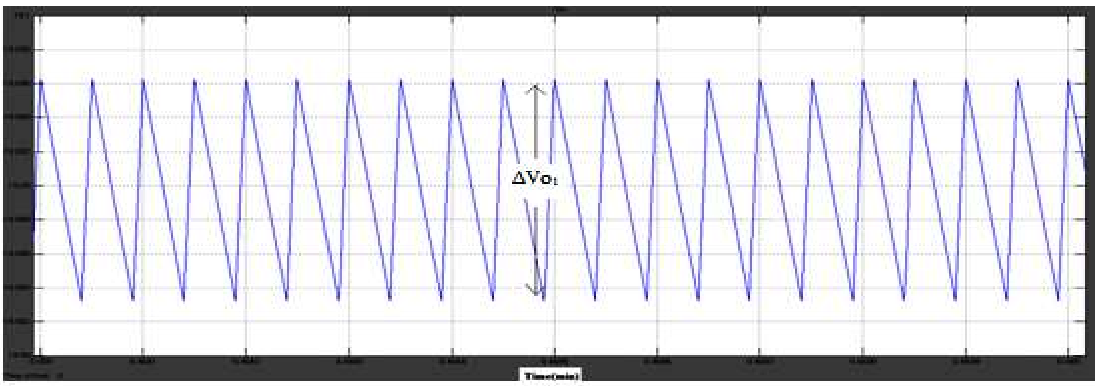

Figure. 9 Output ripple voltage of two phase Interleaved Boost dc-dc converter at duty cycle=0.4

The Output ripple voltage of two phase Interleaved Boost dc-dc converter at 0.8 duty cycle are shown in Fig.10.

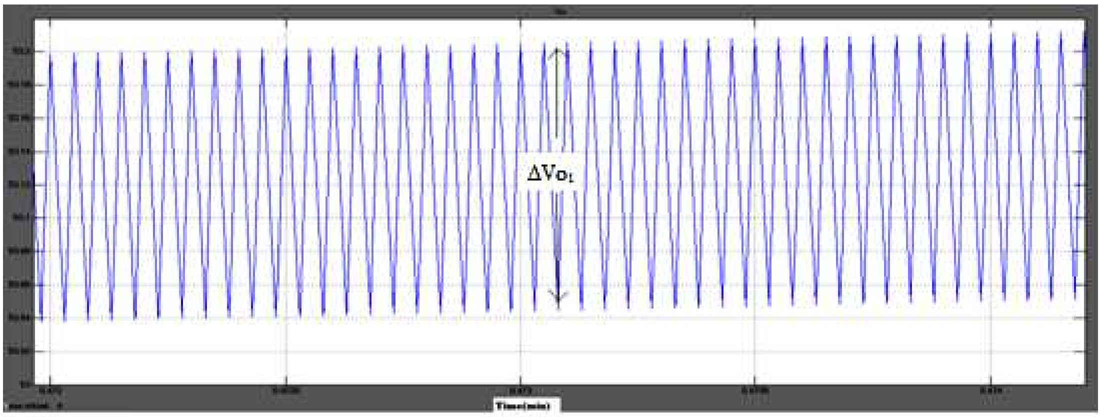

Figure.10 Output ripple voltage of two phase Interleaved Boost dc-dc converter at duty cycle=0.8

SIMULATION MODEL AND RESULTS OF PROPOSED INTERLEAVED BOOST DC-DC CONVERTER

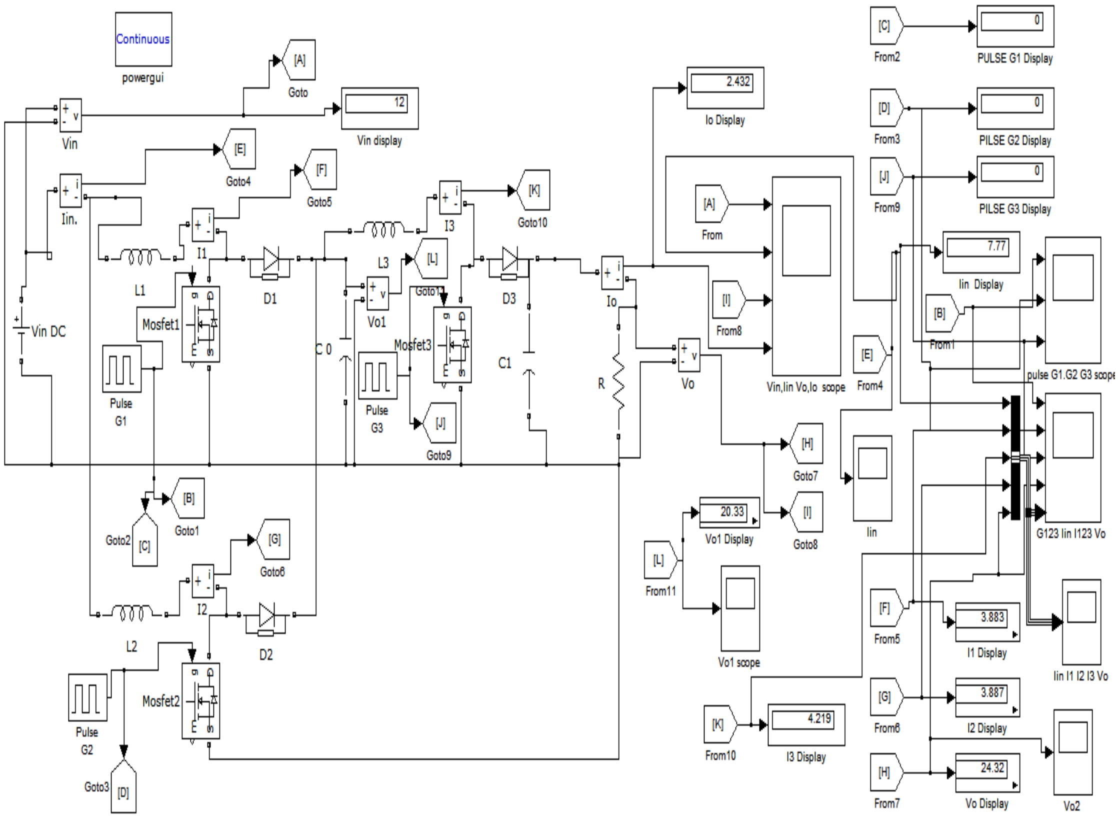

Figure 11 Simulation model of Proposed Interleaved Boost dc-dc converter

Simulation model of new interleaved converter is proposed by connecting the output of the two phase interleaved boost dc-dc converter with conventional single phase boost converter as shown in Fig.11.

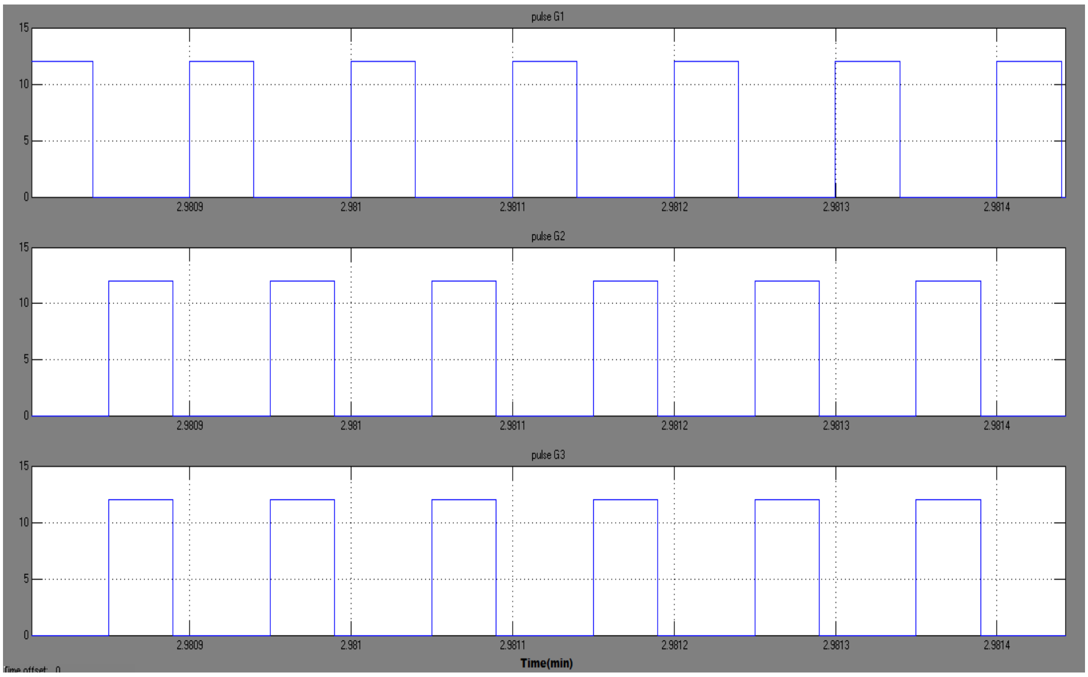

Figure. 12 Switching pulses of proposed Interleaved Boost dc-dc converter at duty cycle=0.4

Switching pulses of three switches is shown in Fig.12. Pulse1 and Pulse2 are shifted by 180 degree having same duty cycle of 0.4. Pulse 3 having duty cycle of 0.4. Inductor currents (IL1, IL2, IL3) are shown in the figs.13,14.

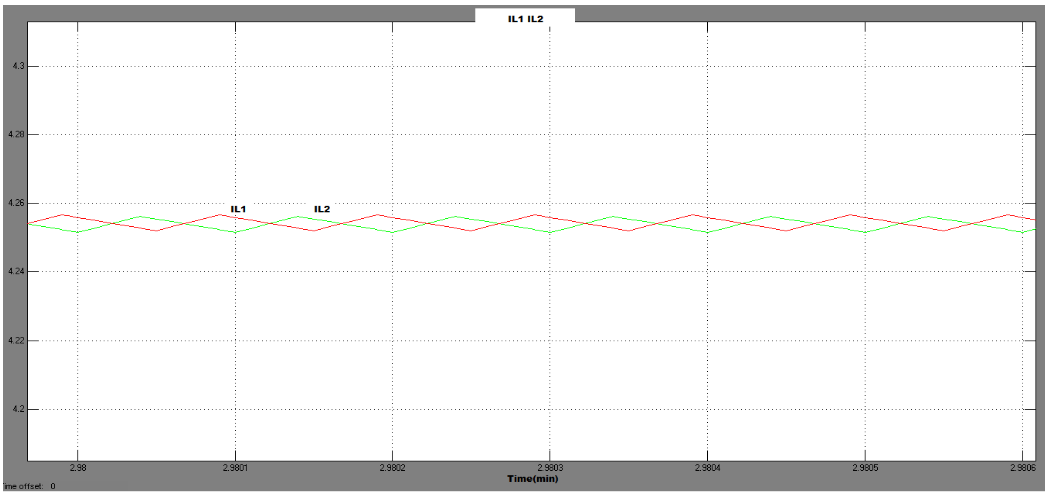

Figure. 13 Inductor currents (L1,L2) of proposed Interleaved Boost dc-dc converter at duty cycle=0.4

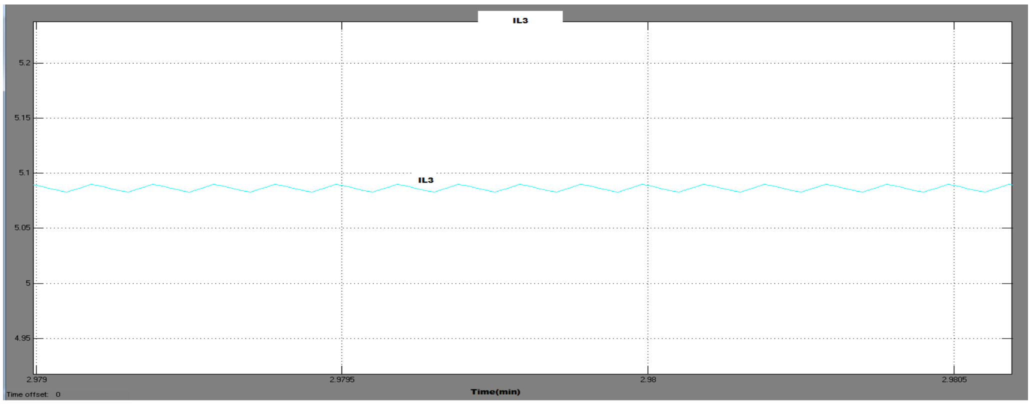

Figure.14 Inductor current (L3) of proposed Interleaved Boost dc-dc converter at duty cycle=0.4

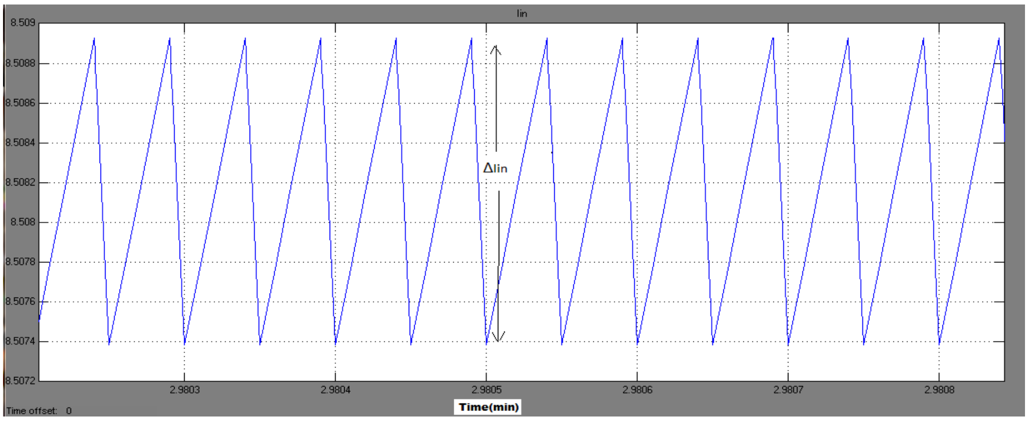

Figure. 15 Input ripple current of proposed Interleaved Boost dc-dc converter at duty cycle=0.4

Input ripple current of proposed interleaved boost dc-dc converter is shown in fig.15.Output ripple voltage of first stage of proposed converter is shown in fig.16.

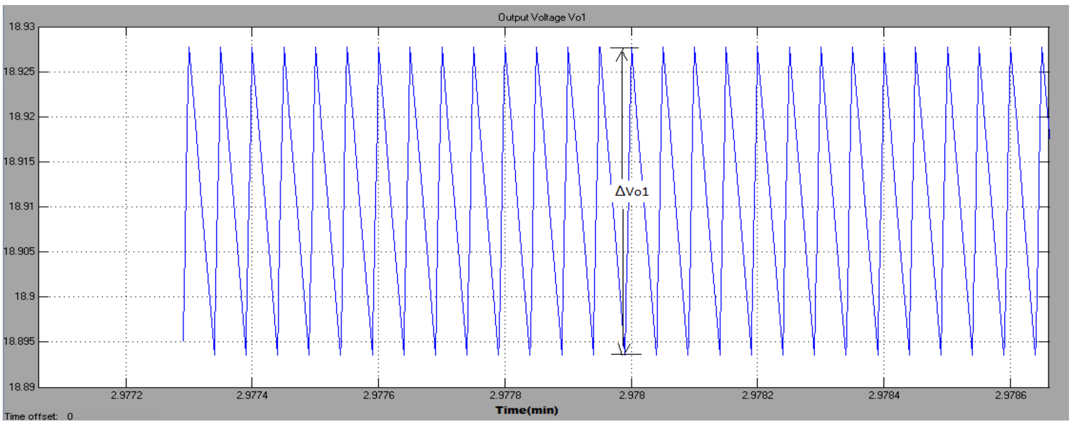

Figure. 16 Output ripple voltage of proposed Interleaved Boost dc-dc converter at first stage (two phase) at duty cycle=0.4

Output Ripple voltage of proposed interleaved boost dc-dc converter is shown in fig.17.

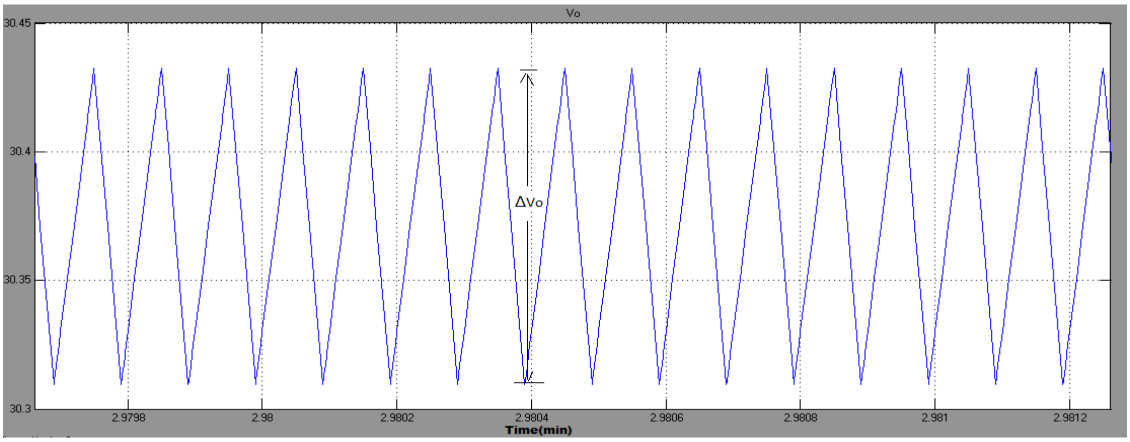

Figure.17 Output ripple voltage of proposed Interleaved Boost dc-dc converter at duty cycle=0.4

The two phase interleaved boost dc-dc converters are tested by simulation at three stages of duty cycle as shown in Table III. These duty cycles are selected based on the output voltage (Vo). For duty cycle=0.62, the two phase interleaved converter produces 30.14 volts. Simulated values of proposed converter as shown in the Table IV.

Table 3 Simulated Values Of Two Phase Interleaved Boost Dc-Dc Converter

Duty Cycle (D)	Vo	ΔI_L	Output Ripple volt (ΔVo)	Output Load current (Io)	Input ripple current (ΔIin)	Po1
0.4	19.1	0.163	0.00073	1.91	0.0056	36.481
0.62	30.14	0.006	0.0016	3.014	0.0026	90.84
0.8	53.35	0.290	0.0029	5.391	0.0115	290.62

Table 4 Simulated Values Of Proposed Boost Dc-Dc Converter

Duty Cycle (D)	Vo	Vo_1	Output Ripple volt (ΔVo)	Output Ripple volt (ΔVo_1)	ΔI_L	Output Load current (Io)	Input ripple current (ΔIin)	Po
0.4	30.34	18.95	0.00395	0.033	0.004	3.034	0.0016	92.05

The purpose of using interleaved converter is to minimize output ripple voltage and input ripple current and also minimum duty cycle. To produce voltage (30.14 volts), the two phase interleaved boost dc-dc converter needs 0.62 duty cycle, but the proposed interleaved boost dc-dc converter needs only 0.4 duty cycle and produces the output voltage of 30.34 volts. Output ripple voltage of proposed converter is high (0.395%) when compared to two phase interleaved boost converter (0.07%) at 0.4 duty cycle. It is a drawback of this proposed converter. Input ripple current of the proposed converter is low when compared to two phase interleaved boost converter is shown in Table IV. The comparative chart of output ripple voltage when duty cycle is 0.4 is shown in Fig.18.

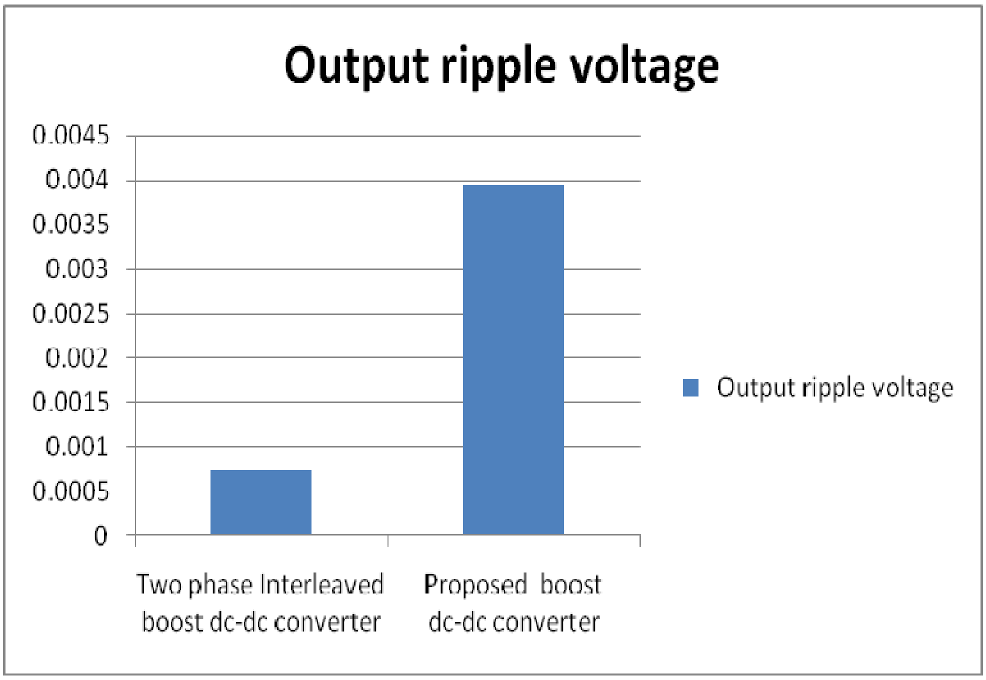

Figure.18 Comparison chart of Output ripple voltage when duty cycle is 0.4

The comparative chart of output voltage when duty cycle is 0.4 is shown in Fig.19.

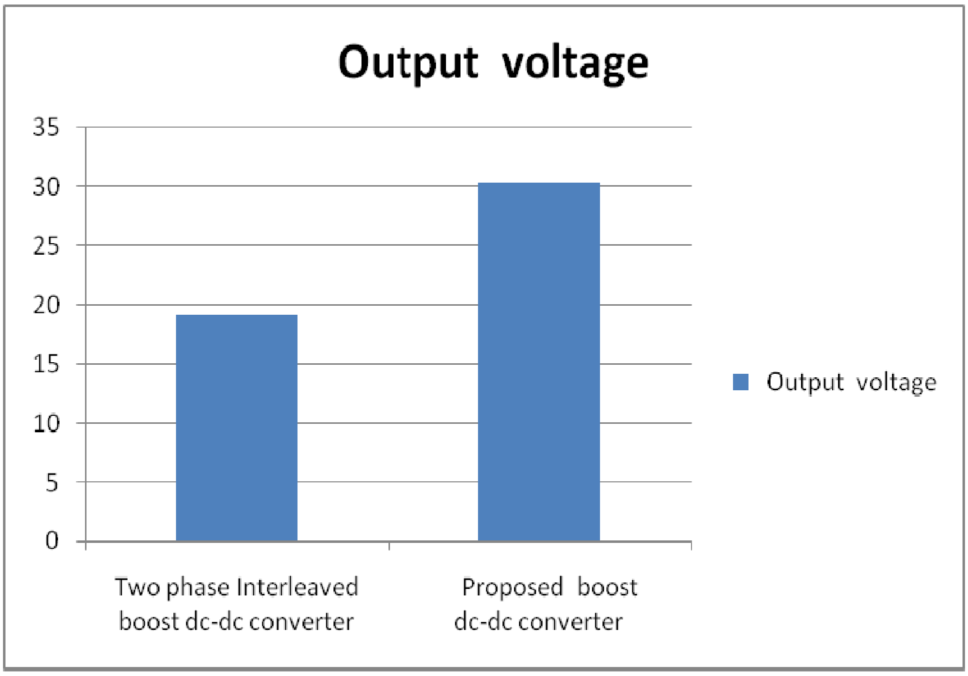

Figure.19 Comparison chart for Output voltage when duty cycle is 0.4

The comparative chart of input ripple current when duty cycle is 0.4 is shown in Fig.20

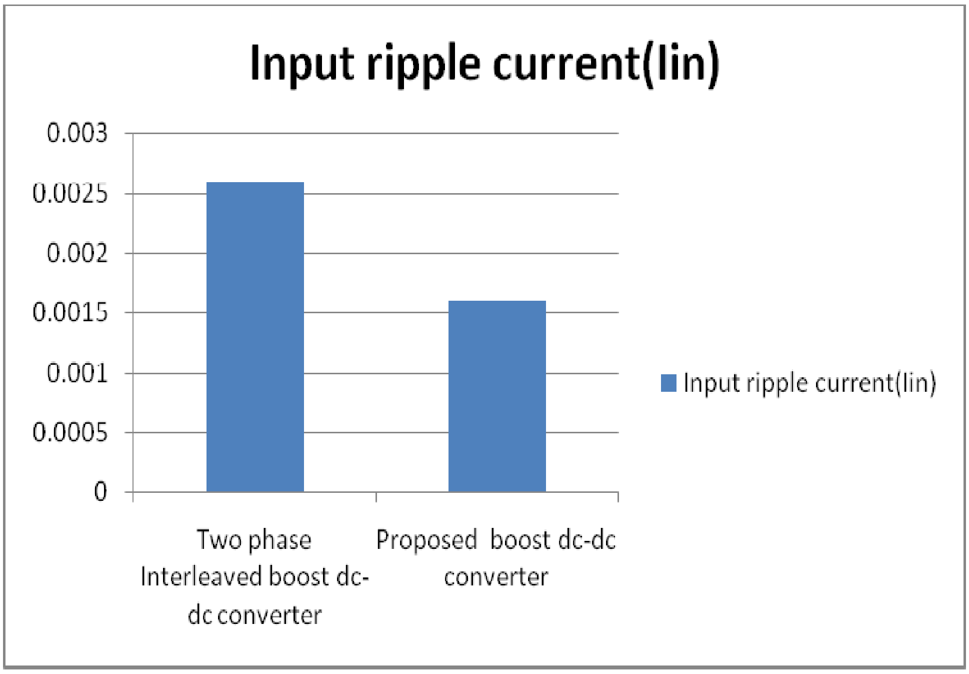

Figure.20 Comparison chart for Input Ripple Current when duty cycle is 0.4

CONCLUSION

The analysis of two phase and proposed interleaved boost dc-dc converter has been conducted with the help of MATLAB/Simulink. The dc-dc converters were designed and parameters were calculated. The calculated values are used for simulation. The proposed dc-dc converter provides reduced input ripple current and high output voltage at minimum duty cycle .The drawback of the proposed converter is increased output ripple voltage when compared to two phase interleaved boost dc-dc converter at a duty cycle 0.4.

REFERENCE

[1] R.Redl and L.Balogh "Power Factor correction with interleaved boost converters in Continuous inductor current mode" In proc. APEC' ,**1993**;pp 168-174.

[2] R.Redl and L.Balogh "RMS, DC, Peak and Harmonic currents in High Frequency power factor correctors with Capacitive Energy storage " In proc.. APEC **1992**;pp. 533–540.

[3 K.M.Smith and K.M Smedley "A Comparison of voltage mode soft switching methods for PWM converters", *IEEE Transaction on Power Electronics*,March, **1997**;12(2): 376-386.

[4] R.Giral, L.Martinez-salamero and S.Singer, "Interleaved converters operation based on CMC" *IEEE Transaction on Power electronics*,July, **1999**;14(4): 643-652.

[5] Po-Wa Lee Yim-Shu Lee ; D. K. W. Cheng ; Xiu-Cheng Liu "Steady state Analysis of and Interleaved boost converters with coupled inductors" *IEEE Trans. on Industrial Electronics*,Aug, **2000**;47(4): 787-795.

[6] I.Cadirci,A.Jafari and M.Ermis "Unity power factor boost converter with phase shifted parallel IGBT Operation for medium power applications", *IEEE proc. Electr power Appl.*,May, **2002**;149(3): 237-244 .

[7] Yao-Ching Hsieh, Te-Chin Hsueh and Hau-Chen Yen "An Interleaved Boost Converter with Zero-Voltage Transition" *IEEE Transactions on Power Electronics*,April, **2009**;24(4): 973-978.

[8] Laszlo Huber, Brian T. Irving and Milan M. Jovanovic"Open loop Control methods for Interleaved DCM/CCM Boundary Boost PFC Converters" IEEE Transaction on Power electronics, vol. 23, pp. No. 4,.pp 1649-1657, **(2008).**

[9] Gyu-Yeong choe , Jong-Soo kim,Hyun-Soo Kang and Byoung-Kuk Lee"An Optimal Design Methodology of an Interleaved Boost Converter for Fuel cell Application" *Journal of Electrical Engineering and Technology* ,**2010**;5(2): 319-328.

[10] Mounica Ganta,Pallam reddy Nirupa,Thimmadi Akshitha, Dr.R.Seyezhai "Simple and Efficient Implementation of Two phase Interleaved Boost Converter for Renewable Energy Source" *International Journal of Emerging Technology and Advanced Engineering*,April, **2012**;2(4): 676-681.

[11] Alireza Khosroshahi, Mehdi Abapour, and Mehran Sabahi "Reliability Evaluation of Conventional and Interleaved DC–DC Boost Converters" *IEEE Transactions on Power Electronics*, Oct, **2015**;30(10): 5821-5828.