Performance Analysis of Boost and Interleaved Boost Converter with a novel switching technique

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Abstract.

The Boost Converters are extremely used in today's world, especially in the high-power application such as household applications and automotive converters. Interleaved Converters are another topology of DC-DC converters. With the use of Interleaved Boost Converter, the size of the passive components of the circuit can be significantly reduced and thus voltage stress across the switches can be reduced. With increased number of phases, the stress on the switches and component size can be further reduced. In this paper, comparison of closed loop Conventional Boost Converter (CBC) and Interleaved Boost Converter (IBC) is carried out with a novel switching technique applied for the IBC.

Keywords: DC-DC Converter, Boost Converter, Interleaved Boost Converter, PI controller, Switching Technique.

1. INTRODUCTION

DC-DC Converters are more widely used converters in day-to-day applications. These converters are used in Automobile industry, in mobiles and laptop charging devices. DC-DC converters are those, which are used to get desired DC output with different DC-DC converter topologies such as Buck Converter, Boost Converter, Buck-Boost Converter etc.

In Conventional Boost, the output voltage rating depends upon the duty ratio of the switch. These are used in Hybrid Vehicles or Electric Vehicles and High-power applications. The duty ratio should be very high to provide desired output with large passive circuit components. This results in higher input current and output voltage ripple. With use of Interleaved Boost Converter, these problems can be reduced. Inductor and capacitor can be split into number of phases, which reduces the switching losses and size of the circuit components. With inductors connected in parallel, input current is shared between them and reduces the stress on switches.

Multiphase converter topologies that are used in high performance and low voltage applications have been increasing in recent years [1]. With the rise in the pollution and climate change, there is an increased demand for green energy. Hence, the need for Electric Vehicles is increasing, for which DC-DC converter are needed to step-up and step-down the energy from the battery and supply to the motors [2]. The Electric Vehicles can be classified as Battery Electric Vehicle (BEVs), Hybrid Electric Vehicles (HEVs), and Plug-in Electric Vehicles (PHEVs) [2].

Interleaved DC-DC Boost converters have gained prominence in modern automotive industry as attempts are being made to replace mechanical and hydraulic systems with their electrical counterparts [3]. As the electrical systems undergo technological revolution with power electronics as one of the driving forces, leaps have been made in terms of system efficiency, reliability and safety. The interleaved boost converter is a desirable DC-DC converter topology in applications that require less ripples in input current and output voltage when compared with that of a conventional boost converter. In this converter topology, the input current is shared between the two parallelly connected interleaved inductors [4]. In applications such as EV, HEV etc., the ratio of the output voltage to the input voltage, for a step-up DC-DC converter, could be as high as 6. Such a step-up ratio is obtained by the proper tuning of the duty ratio of the power semiconductor switch and, in effect, through an efficient power converter design. In the interleaved boost converter topology, the voltage across the switch and the on-state losses are reduced [5]. This is accomplished by collecting the energy leaked from the interleaved converter and storing it in the clamped capacitor. This stored energy is later discharged to the load by the clamping boost converter. In [6], the author discusses about the interleaved DC-DC converter for electric vehicle charging application. Here the adaptive neuro-fuzzy inference system (ANFIS) approach has been employed. Such an approach to provides better stability and system performance under transient operating conditions. Simulations and analysis of the same were also presented. In [7], a novel technique of soft-switching interleaved boost converter was discussed. This converter consists of two boost converters connected in parallel along with an auxiliary inductor. In this converter topology, the output voltage ripples are reduced by turning on both the active power switches at zero voltage. Multi-device structure topology reduces the input current ripples, output voltage ripples, and the size of the overall converter design. This topology employs interleaved control strategy and is found to yield better efficiency in relation to the other converter topologies. This performance of the interleaved converter is compared to the conventional boost converter in [8]. A novel power-factor corrected (PFC) boost converter that has two inductors interleaved is discussed in [9]. This converter when operated with duty ratio above 0.5, displays voltage-doubler characteristic.

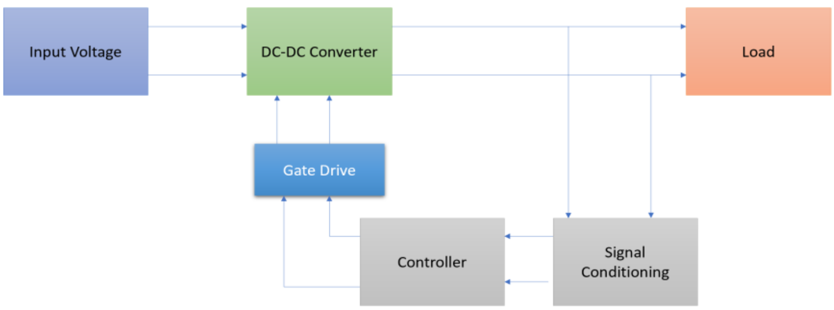

Figure 1: Block diagram of DC-DC Converter

Figure 1, is a generalized DC-DC Converter with closed loop controller to drive the gate of the switch to get desired outputs.

It has a signal conditioning block which senses the output voltage and input current for controlling the circuit.

The controller block has an outer voltage loop control that provides reference current for inner current loop control. Output voltage is sensed, and compared with the reference value and the error is given to a PI controller. Output from the PI controller is again compared with the input current, error is again sent through PI controller for the closed loop control.

Gate drive block is developed based on the proposed novel switching technique, that incorporates two sequence generators for generating the switching sequence which further will be explained in section III. The outputs from the sequence generator are compared with the PWM generator and are given to the MOSFET switches for controlling of circuit.

In this paper, performance, analysis of CBC and IBC is carried out using a new switching technique. The work carried out is presented as follows: Section I gives introduction for the work carried out in this paper. Section II describes the analysis and operation, design details of both the converter topologies. Section III describes the proposed switching technique for the Interleaved Boost Converter. Section IV has the simulation for converter topologies and results drawn from them. And the paper is concluded with a conclusion followed by references.

2. ANALYSIS AND OPERATION OF CONVENTIONAL AND INTERLEAVED BOOST CONVERTER

2.1. Operation of Boost Converter

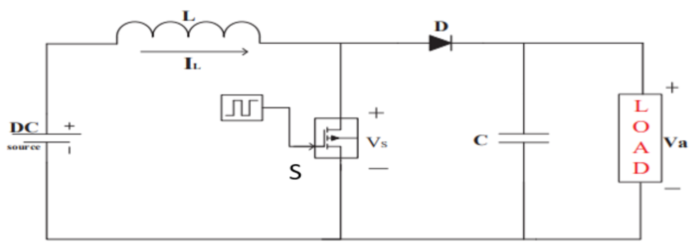

Figure 2: Boost Converter [2]

It consists of DC voltage source as input, inductor (L), diode (D), switch (S) and a capacitor (C). Based on the duty cycle value the voltage at the output can be changed.

When the switch(S) is closed, the diode is reverse biased and there is zero flow of current through the diode. The inductor voltage is equal to the input voltage [10].

When the switch(S) is opened, the diode is forward biased since the current of the inductor cannot change instantaneously, and thus diode provides a path for inductor current [10].

2.1.1. Design details of Boost Converter

The formulae used for the calculation of the circuit parameters of CBC are as follows [10]

$$D = 1 - \frac{Vs}{Vo} = 1 - \frac{10}{40} = 0.75 \quad (1)$$

When the switch is closed, the voltage across the inductor is,

$$V_l = V_s = L\frac{di}{dt} \quad \text{or} \quad \frac{d_{iL}}{dt} = \frac{Vs}{L} \tag{2}$$

The change in inductor current is given by,

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_s}{L} \tag{3}$$

Solving for Δi_L for the switch closed,

$$(\Delta i_L)_{closed} = \frac{V_s DT}{L} \tag{4}$$

Solving for Δi_L for the switch open,

$$(\Delta i_L)_{open} = \frac{(V_s - V_o)(1-D)T}{L} \tag{5}$$

$$L = \frac{I_L D}{\Delta i_L f} = \frac{5.33*0.75}{0.30*25000} = 0.5\ \text{mH} \tag{6}$$

Ripple voltage is given by,

$$\frac{\Delta V_o}{V_o} = \frac{D}{RCf} \tag{7}$$

And Capacitance is be given from the above equation as,

$$C = \frac{D}{R\left(\Delta V_o / V_o\right)f} = \frac{0.75}{30*0.01*25000} = 0.1\ mF$$

2.2. Operation of Interleaved Boost Converter

Figure 3 shows the schematic diagram of IBC

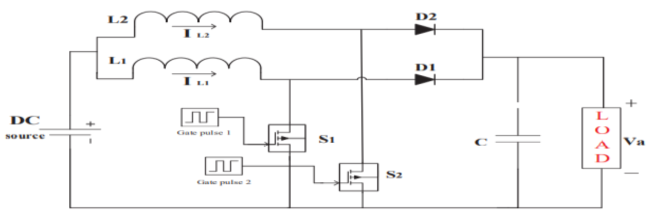

Figure 3: Interleaved Boost Converter [2]

In IBC, based on the number of phases the inductor is split and switches are used. The topology considered for the simulation is a two-phase IBC with equal inductance for each inductor.

Power Flow in Interleaved Boost Converter

The circuit is operated in four modes (M-1, M-2, M-3, M-4)

In M-1, switch S1 is ON and switch S2 is ON, thus both inductors will be conducting in this mode. Figure 4 shows the working of circuit in mode 1.

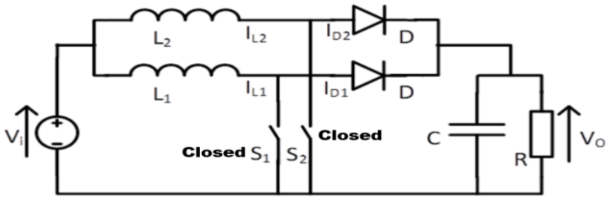

Figure 4:M-1[1]

Similarly, from Figure 4, In M-2, the switch S1 is ON and switch S2 is OFF, thus inductor L1 conducts during this period and S2 will be open circuit.

Similarly, from Figure 4, In M-3, switch S1 is ON and switch S2 is ON, working of mode 3 is same as M-1 conduction.

Similarly, from Figure 4, In M-4, the switch S1 is OFF and S2 is ON, thus the inductor L2 conducts during this period and S1 will be open circuit.

The switching table corresponding to the four modes of operation are shown in Table 1

Table 1: Switching Table

	M-1	M-2	M-3	M-4
S1	ON (1)	ON (1)	ON (1)	OFF (0)
S2	ON (1)	OFF (0)	ON (1)	ON (1)

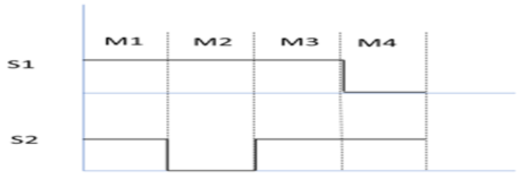

Figure 5: Switching Pulses for the two switches

Both the switches are ON for the 75% or 0.75 duty cycle of the entire cycle.

2.2.1. Design details of Interleaved Boost Converter

The formulae used for the calculation of the parameters of IBC are as follows [10]

The equations from 1 to 7 from section 2.1.1 is same for IBC

The inductor for Interleaved Boost Converter is given by,

Inductor value for IBC is given by,

$$\mathbf{L = \frac{V_s DT}{\Delta i_L} = \frac{V_s D}{\Delta i_L fn}} \quad \textbf{(8)}$$

Where, n is number of phases

$$\mathbf{L1{=}L2{=} \frac{5.33*0.75}{0.30*25000*2} = 0.25\ mH}$$

n= number of phases used in the IBC.

In this case n=2, as there are two phase Interleaved Boost Converter

Capacitor value is given by,

$$\mathbf{C = \frac{D}{R\left(\Delta V_o/V_o\right)fn} = \frac{0.75}{30*0.01*25000*2} = 0.05\ mF} \quad \textbf{(9)}$$

3. PROPOSED SWITCHING TECHNIQUE FOR INTERLEAVED BOOST CONVERTER

The proposed control technique is easy to implement as it has to generate 0 and 1 pulses at the given switching frequency, which can be generated using a microcontroller, which is very convenient compared to the conventional switching technique.

The block diagram to generate gate pulses using the novel switching technique is shown in Figure 6 for the closed loop IBC.

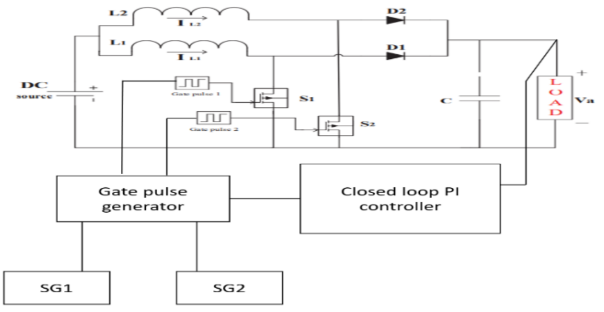

Figure 6: Block Diagram for Control Technique for closed loop Interleaved Boost Converter

The circuit involves two signal generators SG1 and SG2. The switching sequence for SG1 is considered as 1110 and that of SG2 is 1011 corresponding to 180^0 phase shift generated at 25 kHz frequency.

For the close loop control, PI controller is used for controlling output voltage and current. The output voltage and the reference voltage are compared and the error is given to the PI controller with P=1, I=7. The output of PI controller is compared with the input current and error is given as an input to another PI controller with P=1, I=100. From the second PI controller the signal is sent to the PWM generator, that converts the PI controller value to switching pulses i.e., 0 and 1. This PWM generator output is compared with the two signal generators and if the signal generator output is equal to the PWM generator output, then the signal is sent to the switch S1 and S2 respectively for switching of circuit.

The designed values of the circuit components for the CBC and IBC are shown in Table 2.

Table 2: Table of Specification

Parameter	Interleaved Boost Converter	Boost Converter
Input Voltage Range	10-22 V	8-18 V
V_s	10 V	10 V
V_o	35 V	35 V
I_o	1.16 A	1.12 A
L1	0.25 mH	0.5 mH
L2	0.25 mH	-
C	0.05 mF	0.1 mF
R	30 Ω	30 Ω
f	25 kHz	25 kHz

4. SIMULATION RESULTS

In this section, the simulation results of both the converter topologies are presented.

The CBC simulation is presented in Figure 7, closed loop control is carried out using the dual PI controller, one for outer voltage loop and other for inner current loop control. PI values for outer loop control is P=1, I=7. The PI controller values for inner loop is P=1, I=100.

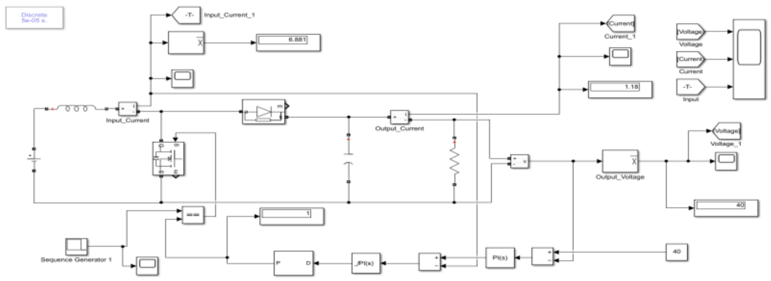

Figure 76: Simulink model of Conventional Boost Converter

The waveforms for CBC are given in Figure 8. The output voltage is at 35V, current has a mean value of 1.16A and mean value of input current 4.95A.

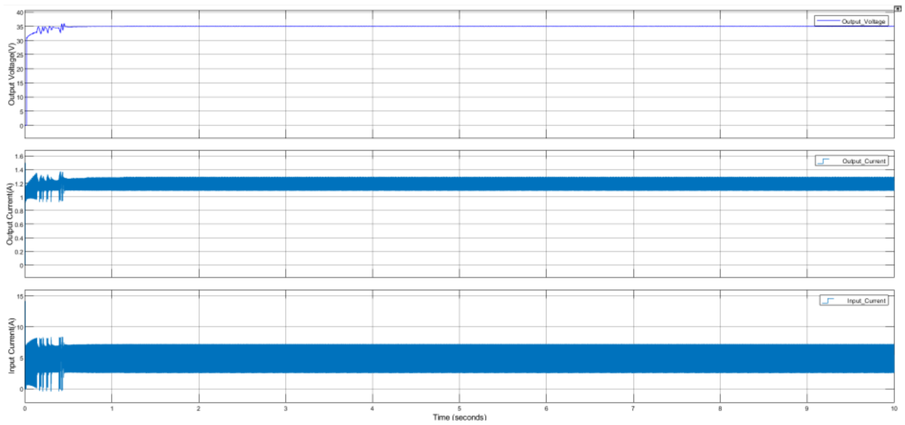

Figure 8: Waveforms of Boost Converter a) Output Voltage b) Output Current c) Input Current

Figure 10, is the IBC carried out in MATLAB Simulink with the parameter values mentioned in the table above.

The Interleaved Boost Converter simulation is presented in Figure 10, the closed loop control is done using dual PI controller, one for outer voltage loop and inner current loop. PI values for outer loop control is P=1, I=7. The PI controller values for inner loop is P=1, I=100.

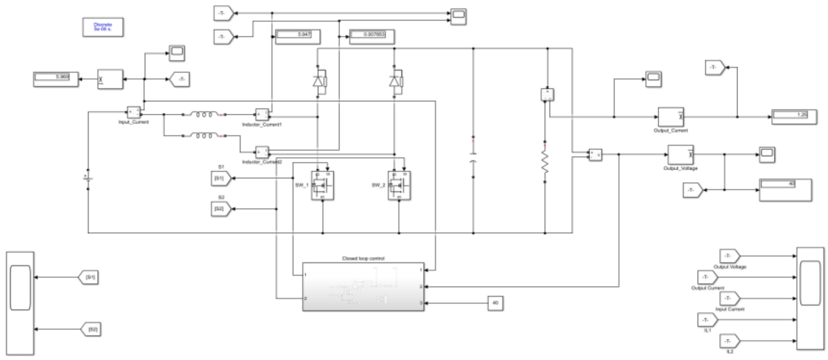

Figure 7: Simulation Model of Interleaved Boost Converter

The subsystem for the control loop of IBC is shown in Figure 10. The operation for the circuit is explained in section 3.

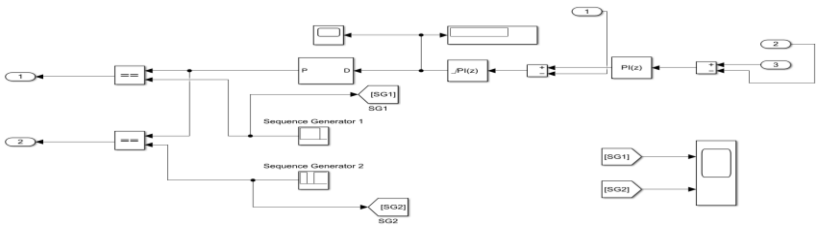

Figure 8: Novel switching technique for Interleaved Boost Converter

The waveforms for the IBC are shown in the Figure 11. The output voltage is at 35V, current has a mean value of 1.16A and mean value of input current 4.482A.

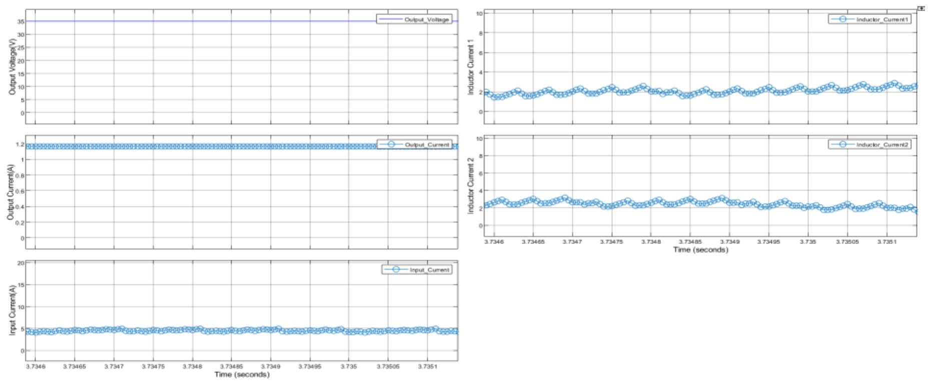

Figure 9: Waveforms of Interleaved Boost Converter a) Output Voltage b) Output Current c) Input Current d) Inductor Current 1 e) Inductor Current 2

The waveforms of switches for the IBC are shown in the Figure 12. Based on PI output and the input signal from the sequence generator are compared and the switches are controlled.

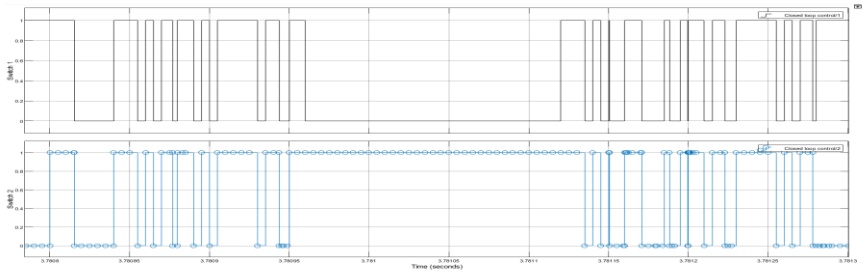

Figure 10: MOSFET switching waveforms a) S1 b) S2

The waveforms of sequence generators for the IBC are shown in the Figure 13. Both the sequence generators are ON for 75% duty cycle mention in section 2.2.

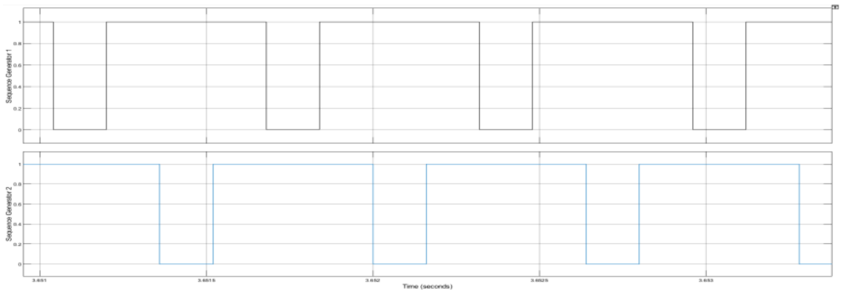

Figure 11: Sequence Generator waveforms a) SG1 b) SG2

5. COMPARISON OF BOOST CONVERTER AND INTERLEAVED BOOST CONVERTER

Results from the simulation of IBC and CBC are shown in Table 3.

Table 3: Simulation Results

Parameter	Boost Converter	Interleaved Boost Converter
V_{in}	10V	10V
V_{out}	35V	35V
ΔV	0.2V	0.05V
ΔI	0.2A	0.015A
$I_L(Mean)$	1.129A	1.167A
PI Controller	P=1, I=7 P=1, I=100	P=1, I=7 P=1, I=100

From the output waveforms it can be seen that stress on the MOSFET switches is been reduced due to the less current flowing through the switches, it is found that I^2R loses are less in IBC(0.5022W) compared to the CBC (2.4453W).

From Table 3, it can be seen that by using IBC the switching stress and size of the components. Thus, performance of IBC is better when compared to CBC, with IBC the input current ripple and output voltage ripple can be reduced significantly.

6. CONCLUSION

In this paper, a novel switching technique has been discussed to control the output voltage and input current of the Conventional Boost Converter and Interleaved Boost Converter. It is observed that, with the use of interleaved boost converters incorporating the proposed switching technique, the switching stress and size of the components is reduced when compared to the Convention Boost converter.

7. REFERENCES

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