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Interleaved Technique based DC-DC Buck-Boost using MATLAB/Simulink

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Abstract— This Renewable energy, plays a key role in modern society and therefore in research. This paper presents MATLAB simulation of interleaved technique based dc-dc buck-boost converter. Four switch converter, buck converter and boost converters are arranged in interleaved pattern with a damping circuit in between them. Input and output ripples of voltage and current of the converter is very low. The given system has very high efficiency with various applications.

Keywords— Interleaved, dc-dc converter, MATLAB/Simulink.

I. INTRODUCTION

According to current scenario, Renewable energies demands are increasing very quickly due to global warming caused due to very high pollution. Recently, in Paris a world summit was held to empower renewable energies more and more. Dc-Dc converters have various industrial and commercial applications. Applications of dc-dc converter covers fields such as, photovoltaic, batteries, fuel cell, and dc motors systems. Many researches are carried out continuously worldwide resulting in increasing number of topologies depending on their applications.

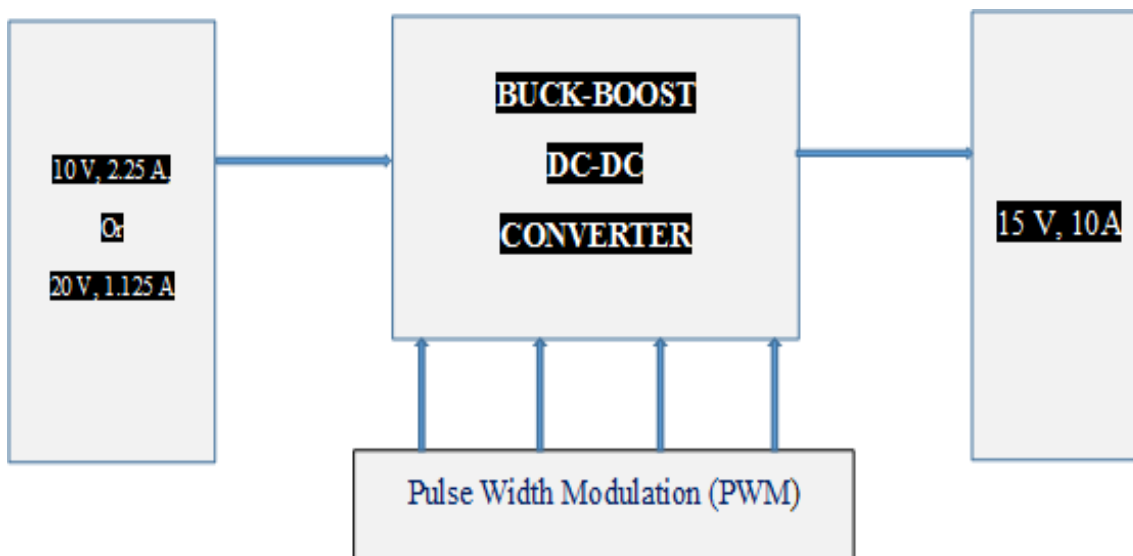


Figure 1 Block diagram of presented system.

III. MODES OF OPERATIONS

MODE 1: [T₁ – T₀]

M1, M3, & M4:- CONDUCTING SWITCHES.

M2:- NOT CONDUCTING SWITCH.

VOLTAGE ACROSS INDUCTORS:-

$$V_{L1} = L_1 \frac{di_{L1}}{dt} = L_1 \frac{\Delta i_{L1}}{t_1 - t_0} = V_s$$

$$V_{L2} = L_2 \frac{di_{L2}}{dt} = L_2 \frac{\Delta i_{L2}}{t_1 - t_0} = V_s - V_{C1}$$

$$V_{L3} = L_3 \frac{di_{L3}}{dt} = L_3 \frac{\Delta i_{L3}}{t_1 - t_0} = V_{C1} - V_{out}$$

$$V_{L4} = L_4 \frac{di_{L4}}{dt} = L_4 \frac{\Delta i_{L4}}{t_1 - t_0} = V_{C1} - V_{out}$$

CURRENT THROUGH CAPACITOR:-

$$i_{C1} = C_1 \frac{dV_{C1}}{dt} = C_1 \frac{\Delta V_{C1}}{t_1 - t_0} = i_{L2} - (i_{L3} + i_{L4}) - \frac{(V_{C1} - V_{Cd})}{R_d}$$

$$i_{C2} = C_2 \frac{dV_{C2}}{dt} = C_2 \frac{\Delta V_{C2}}{t_1 - t_0} = (i_{L3} + i_{L4}) - \frac{V_{out}}{R}$$

$$i_{Cd} = C_d \frac{dV_{Cd}}{dt} = C_d \frac{\Delta V_{Cd}}{t_1 - t_0} = \frac{(V_{C1} - V_{Cd})}{R_d}$$

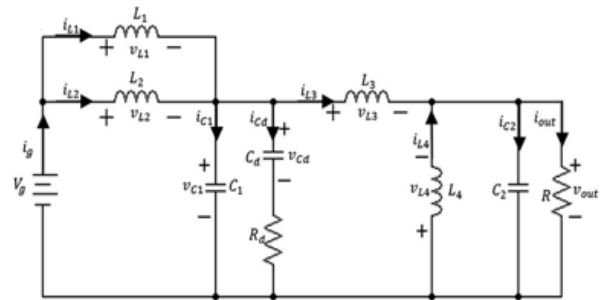


Figure 3 Mode 1: equivalent circuit.

MODE 2: [T₂ – T₁] AND MODE 5: [T₅ – T₄]

M3 & M4:- CONDUCTING SWITCHES.

M1 & M2:- NOT CONDUCTING SWITCHES.

VOLTAGE ACROSS INDUCTORS:-

$$V_{L1} = L_1 \frac{di_{L1}}{dt} = L_1 \frac{\Delta i_{L1}}{t_2 - t_1} = L_1 \frac{\Delta i_{L1}}{t_5 - t_4} = V_s - V_{C1}$$

$$V_{L2} = L_2 \frac{di_{L2}}{dt} = L_2 \frac{\Delta i_{L2}}{t_2 - t_1} = L_2 \frac{\Delta i_{L2}}{t_5 - t_4} = V_s - V_{C1}$$

$$V_{L3} = L_3 \frac{di_{L3}}{dt} = L_3 \frac{\Delta i_{L3}}{t_2 - t_1} = L_3 \frac{\Delta i_{L3}}{t_5 - t_4} = V_{C1} - V_{out}$$

$$V_{L4} = L_4 \frac{di_{L4}}{dt} = L_4 \frac{\Delta i_{L4}}{t_2 - t_1} = L_4 \frac{\Delta i_{L4}}{t_5 - t_4} = V_{C1} - V_{out}$$

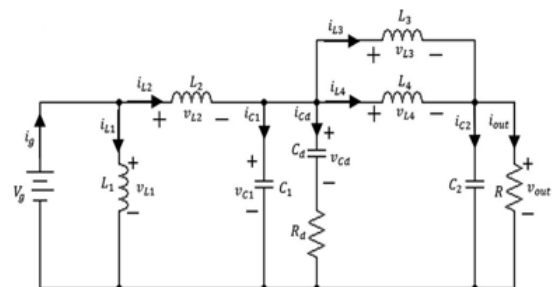


Figure 4 Mode 2 & 5: equivalent circuit.

CURRENT THROUGH CAPACITOR

$$i_{C_1} = C_1 \frac{dV_{C_1}}{dt} = C_1 \frac{\Delta V_{C_1}}{t_2 - t_1} = C_1 \frac{\Delta V_{C_1}}{t_5 - t_4} = [(i_{L_1} + i_{L_2}) - (i_{L_3} + i_{L_4})] + \frac{2(V_{C_1} - V_{C_d})}{R_d}$$

$$i_{C_2} = C_2 \frac{dV_{C_2}}{dt} = C_2 \frac{\Delta V_{C_2}}{t_2 - t_1} = C_2 \frac{\Delta V_{C_2}}{t_5 - t_4} = (i_{L_3} + i_{L_4}) - \frac{V_{out}}{R}$$

$$i_{C_d} = C_d \frac{dV_{C_d}}{dt} = C_d \frac{\Delta V_{C_d}}{t_2 - t_1} = C_d \frac{\Delta V_{C_d}}{t_5 - t_4} = \frac{V_{C_1} - V_{C_d}}{R_d}$$

MODE 3: [T3 - T4]

M4:- CONDUCTING SWITCH.

VOLTAGE ACROSS INDUCTORS:-

$$V_{L_1} = L_1 \frac{di_{L_1}}{dt} = L_1 \frac{\Delta i_{L_1}}{t_3 - t_2} = V_s - V_{C_1}$$

$$V_{L_2} = L_2 \frac{di_{L_2}}{dt} = L_2 \frac{\Delta i_{L_2}}{t_3 - t_2} = V_s - V_{C_1}$$

$$V_{L_3} = L_3 \frac{di_{L_3}}{dt} = L_3 \frac{\Delta i_{L_3}}{t_3 - t_2} = V_{C_1} - V_{out}$$

$$V_{L_4} = L_4 \frac{di_{L_4}}{dt} = L_4 \frac{\Delta i_{L_4}}{t_3 - t_2} = V_{out}$$

CURRENT THROUGH CAPACITOR:-

$$i_{C_1} = C_1 \frac{dV_{C_1}}{dt} = C_1 \frac{\Delta V_{C_1}}{t_3 - t_2} = (i_{L_1} + i_{L_2}) - [i_{L_3} - \frac{(V_{C_1} - V_{C_d})}{R_d}]$$

$$i_{C_2} = C_2 \frac{dV_{C_2}}{dt} = C_2 \frac{\Delta V_{C_2}}{t_3 - t_2} = (i_{L_3} + i_{L_4}) - \frac{V_{out}}{R_d}$$

$$i_{C_d} = C_d \frac{dV_{C_d}}{dt} = C_d \frac{\Delta V_{C_d}}{t_3 - t_2} = \frac{V_{C_1} - V_{C_d}}{R_d}$$

MODE 4: [T4 - T3]

CONDUCTING SWITCHES: M1, M3, M4.

L2: TRANSFERS STORED ENERGY.

VOLTAGE ACROSS INDUCTORS:-

$$V_{L_1} = L_1 \frac{di_{L_1}}{dt} = L_1 \frac{\Delta i_{L_1}}{t_4 - t_3} = V_s - V_{C_1}$$

$$V_{L_2} = L_2 \frac{di_{L_2}}{dt} = L_2 \frac{\Delta i_{L_2}}{t_4 - t_3} = V_s$$

$$V_{L_3} = L_3 \frac{di_{L_3}}{dt} = L_3 \frac{\Delta i_{L_3}}{t_4 - t_3} = V_{C_1} - V_{out}$$

$$V_{L_4} = L_4 \frac{di_{L_4}}{dt} = L_4 \frac{\Delta i_{L_4}}{t_4 - t_3} = V_{C_1} - V_{out}$$

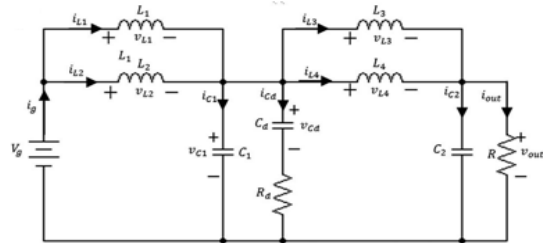


Figure 5 Mode 3: equivalent circuit.

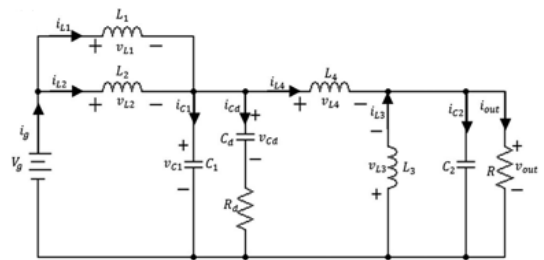


Figure 6 Mode 4: equivalent circuit.

CURRENT THROUGH CAPACITOR:-

$$i_{C_1} = C_1 \frac{dV_{C_1}}{dt} = C_1 \frac{\Delta V_{C_1}}{t_4 - t_3} = i_{L_2} - [i_{L_3} + i_{L_4}] - \frac{V_{C_1} - V_{C_d}}{R_d}$$

$$i_{C_2} = C_2 \frac{dV_{C_2}}{dt} = C_2 \frac{\Delta V_{C_2}}{t_4 - t_3} = (i_{L_3} + i_{L_4}) - \frac{V_{out}}{R}$$

$$i_{C_d} = C_d \frac{dV_{C_d}}{dt} = C_d \frac{\Delta V_{C_d}}{t_4 - t_3} = \frac{V_{C_1} - V_{C_d}}{R_d}$$

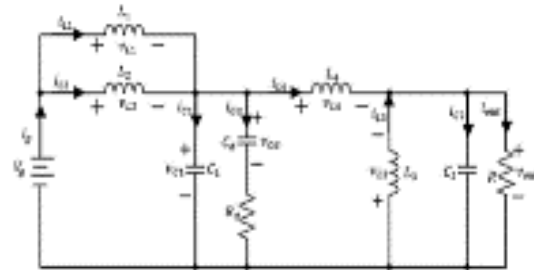


Figure 7 Mode 6: equivalent circuit.

MODE 6: [T₆ – T₅]

CONDUCTING SWITCHES: M₃.

L₂: TRANSFERS STORED ENERGY.

VOLTAGE ACROSS INDUCTORS:-

$$V_{L_1} = L_1 \frac{di_{L_1}}{dt} = L_1 \frac{\Delta i_{L_1}}{t_6 - t_5} = V_s - V_{C_1}$$

$$V_{L_2} = L_2 \frac{di_{L_2}}{dt} = L_2 \frac{\Delta i_{L_2}}{t_6 - t_5} = V_s - V_{C_1} \quad V_{L_3} = L_3 \frac{di_{L_3}}{dt} = L_3 \frac{\Delta i_{L_3}}{t_6 - t_5} = V_{out}$$

$$V_{L_4} = L_4 \frac{di_{L_4}}{dt} = L_4 \frac{\Delta i_{L_4}}{t_6 - t_5} = V_{C_1} - V_{out}$$

CURRENT THROUGH CAPACITOR:-

$$i_{C_1} = C_1 \frac{dV_{C_1}}{dt} = C_1 \frac{\Delta V_{C_1}}{t_6 - t_5} = [i_{L_1} + i_{L_2}] - [i_{L_4} + \frac{V_{C_1} - V_{C_d}}{R_d}]$$

$$i_{C_2} = C_2 \frac{dV_{C_2}}{dt} = C_2 \frac{\Delta V_{C_2}}{t_5 - t_5} = (i_{L_3} + i_{L_4}) - \frac{V_{out}}{R}$$

$$i_{C_d} = C_d \frac{dV_{C_d}}{dt} = C_d \frac{\Delta V_{C_d}}{t_6 - t_5} = \frac{V_{C_1} - V_{C_d}}{R_d}$$

APPLYING AVERAGING TECHNIQUE FOR ALL SIX TIME INTERVAL:-

$$L_1 \frac{di_{L_1}}{dT} = L_1 \frac{\Delta i_{L_1}}{dT} = L_2 \frac{di_{L_2}}{dT} = L_2 \frac{\Delta i_{L_2}}{dT} = V_s - V_{C_1} (1 - D_{12})$$

$$L_3 \frac{di_{L_3}}{dT} = L_3 \frac{\Delta i_{L_3}}{dT} = V_{L_3} = L_4 \frac{di_{L_4}}{dT} = L_4 \frac{\Delta i_{L_4}}{dT} = -V_{out} + V_{C_1} D_{34}$$

$$i_{C_{D1}} = C_{D1} \frac{dV_{C_{D1}}}{dt} = C_{D1} \frac{\Delta V_{C_{D1}}}{dt} = -\frac{2(V_{C_{D1}} - V_{C_{D2}})}{R_{D1or2}} + (i_{L_1} + i_{L_2})(1 - D_{12}) - (i_{L_3} + i_{L_4})D_{34}$$

$$i_{C_2} = C_2 \frac{dV_{C_2}}{dt} = C_2 \frac{\Delta V_{C_2}}{dt} = (i_{L_3} + i_{L_4}) - \frac{V_{out}}{R + R_2}$$

$$i_{C_{D2}} = C_{C_{D2}} \frac{dV_{C_{D21}}}{dt} = C_{D1} \frac{\Delta V_{C_{D2}}}{dt} = \frac{2(V_{C_{D1}} - V_{C_{D2}})}{R_{D1or2}}$$

BY APPLYING CAPACITOR CHARGE BALANCE AND INDUCTOR VOLT-SECOND:-

$$I_s = I_{L1} + I_{L1} \frac{D_{34}}{1 - D_{12}} \frac{V_{out}}{R}$$

$$I_{out} = I_{L3} + I_{L4} = \frac{V_{out}}{R}$$

$$V_{C_{D1}} = \frac{V_s}{1 - D_{12}} = \frac{V_{out}}{D_{34}}$$

$$V_{C_{D1}} = 0$$

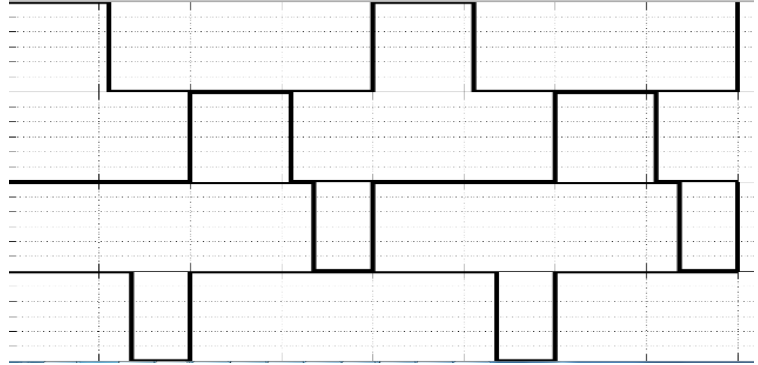


Figure 8 Switching Pattern for given modes of operation.

VOLTAGE TRANSFER RATIO

$$V_{out} = D_{34} V_{C_{D1}} = \frac{D_{34}}{1 - D_{12}} V_s$$

IV. SWITCHING FREQUENCY

The power semiconductor device present in power electronics circuit needs gate pulse to trigger or to turn on, and the pattern describing the various gate pulses is known as switching pattern.

Time taken to complete one switching pattern is known as switching time (T_s), and $1/T_s$ is switching frequency (f_s).

For the given system switching frequency is taken to be 50 KHz, i.e. switching time is 20 μ s. Fig. 8, shows switching frequency for the given modes of operations (two cycle are shown).

V. CIRCUIT SPECIFICATIONS

Component's parameters values

$$\text{➤ } L_1, L_2 = \frac{V_g(V_{out} - V_g)}{\Delta L_{1 \text{ or } 2} V_{out}} T_s = 133 \mu H$$

$$\text{➤ } L_3, L_4 = \frac{V_{out}(V_{out} - V_g)}{\Delta L_{1 \text{ or } 2} V_g} T_s = 300 \mu H$$

$$\text{➤ } C_1 = \frac{(V_{out} - V_g)}{\Delta V_{C1} R} T_s = 20 \mu H$$

$$\text{➤ } C_2 = \frac{V_{out}(V_{out} - V_s)}{\Delta V_{C2} R V_s} T_s = 130 \mu H$$

$$\text{➤ } R_d > 0.65 \sqrt{\frac{L_{12}}{C_1}} \text{ (taken } 2 \text{ ohms)}$$

$$\text{➤ } C_d > 8C_1 \text{ (taken } 200 \mu F)$$

VI. MATLAB/SIMULINK MODEL

MATLAB/Simulink is electrical circuit's simulation platform, which is used to verify the given interleaved technique based buck-boost dc-dc converter. MATLAB/Simulink model for the given converter is both modes have been explained.

BUCK MODE:-

As we know that in buck mode, the duty ratio for MOSFET1 and MOSFET2 is zero. That mean we can open circuit these switches. Based on this a MATLAB/Simulink model is shown in fig. 9 to obtain more efficient simulation results.

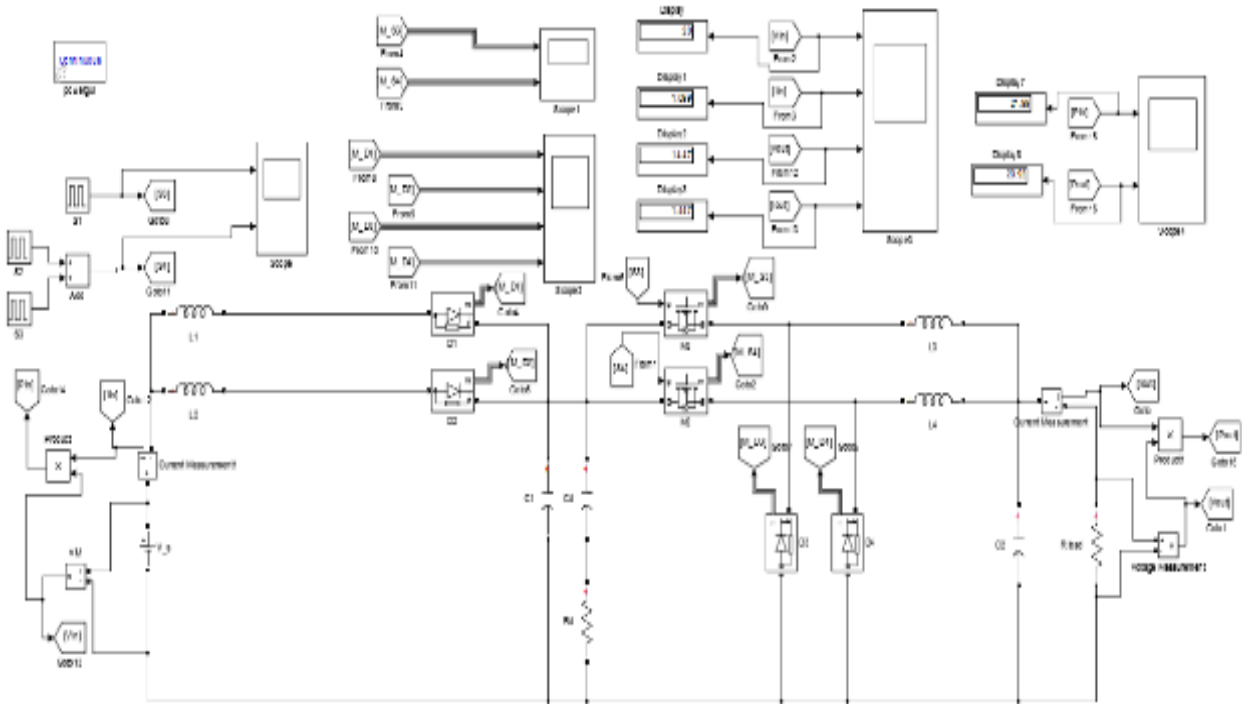


Figure 9 MATLAB/Simulink model of buck mode.

BOOST MODE:-

As we know that in boost mode, the duty ratio for MOSFET3 and MOSFET4 is unity. That mean we can short circuit these switches. Based on this a MATLAB/Simulink model is shown in fig. 9 to obtain more efficient simulation results.

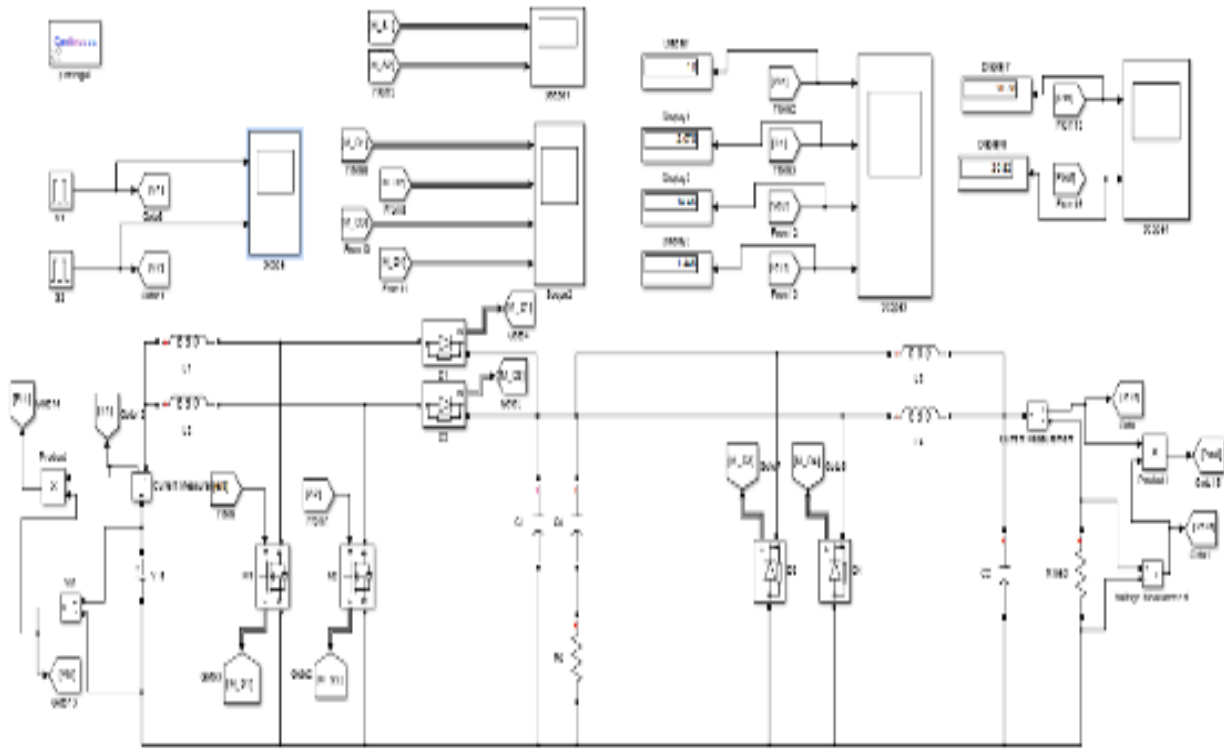


Figure 10 MATLAB/Simulink model of boost mode.

VII. RESULT

Waveforms obtained after simulating the given converter is shown below:-

1. BUCK MODE

SCOPE 1:- ΔI_s is around 0.005 A, and ΔV_{out} and ΔI_{out} are around 0.010 V and 0.010 A respectively. Shown in fig. 11.

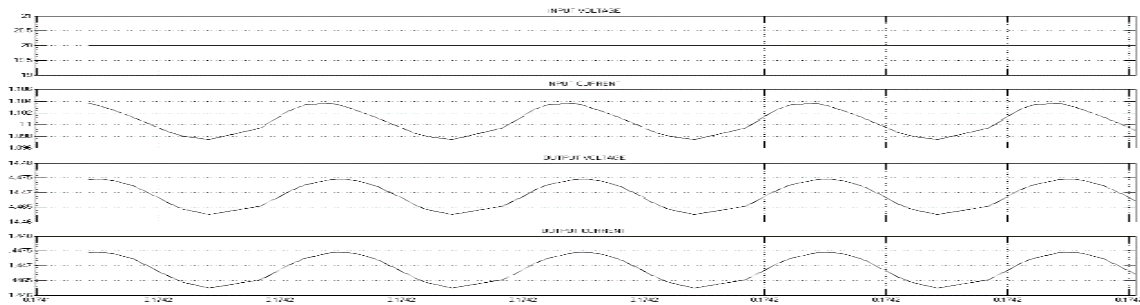


Figure 11 Output of scope1 in buck mode.

SCOPE2:- Voltage and current stress on switches. Shown in fig. 12.

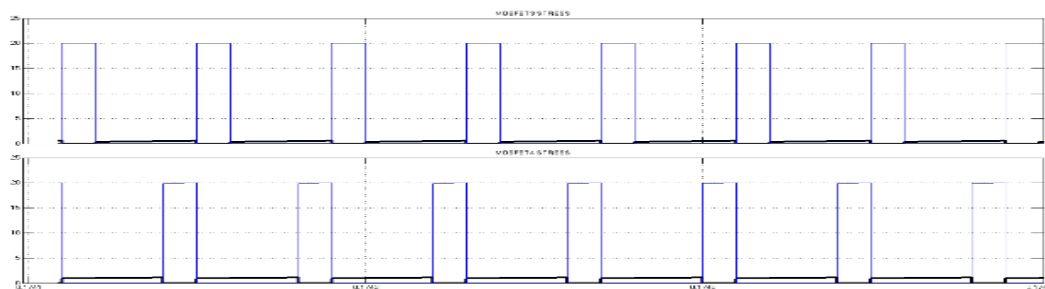


Figure 12 Output of scope2 in buck mode.

SCOPE3:- Pulse width modulation (PWM) for switches. Shown in fig. 13

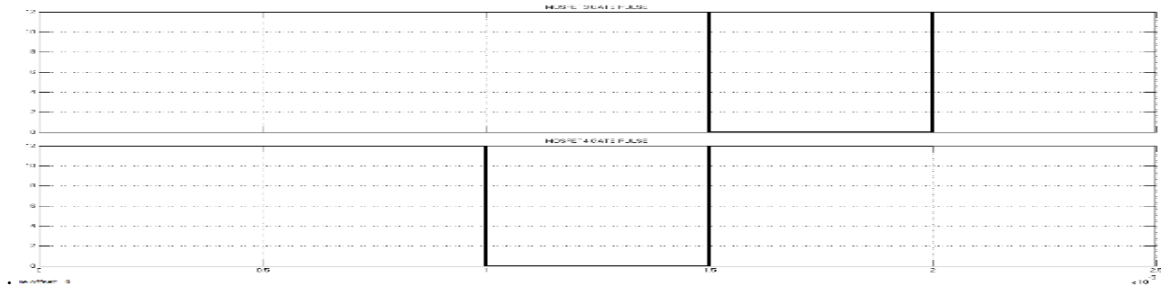


Figure 13 Output of scope3 in buck mode.

SCOPE4:- Voltage and current stress of diodes. Shown in fig. 14.

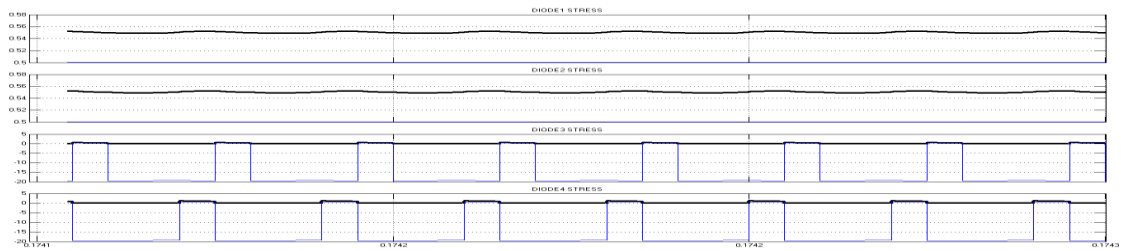


Figure 14 Output of scope4 in buck mode.

2. BOOST MODE

SCOPE 1:- ΔI_s is around 0.005 A, and ΔV_{out} and ΔI_{out} are around 0.010 V and 0.010 A respectively. Shown in fig. 15.

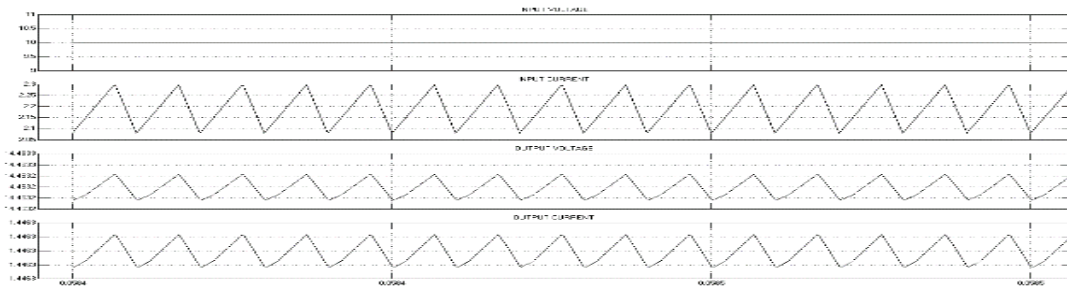


Figure 15 Output of scope1 in boost mode.

SCOPE2:- Voltage and current stress on switches. Shown in fig. 16.

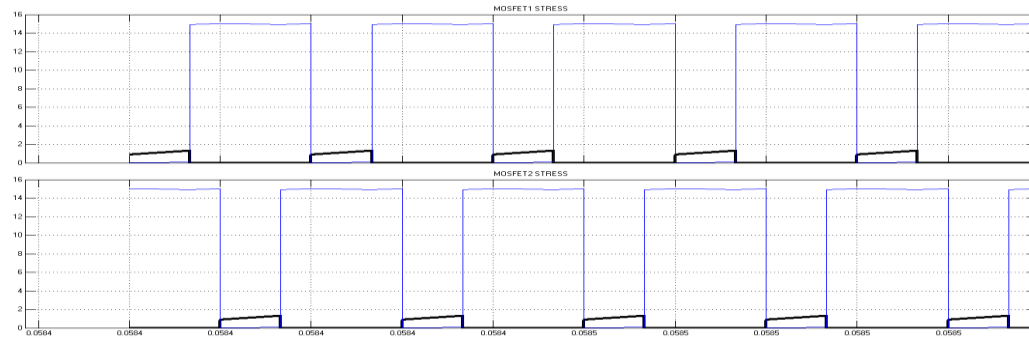


Figure 16 Output of scope2 in boost mode.

SCOPE3:- Pulse width modulation (PWM) for switches. Shown in fig. 17.

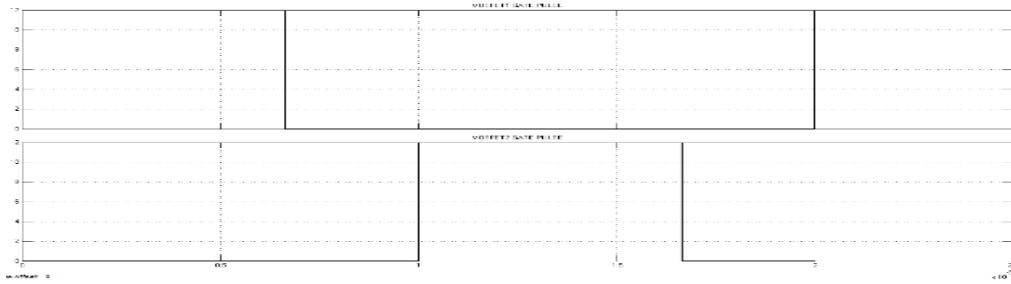


Figure 17 Output of scope3 in boost mode.

SCOPE4:- Voltage and current stress of diodes. Shown in fig. 18.

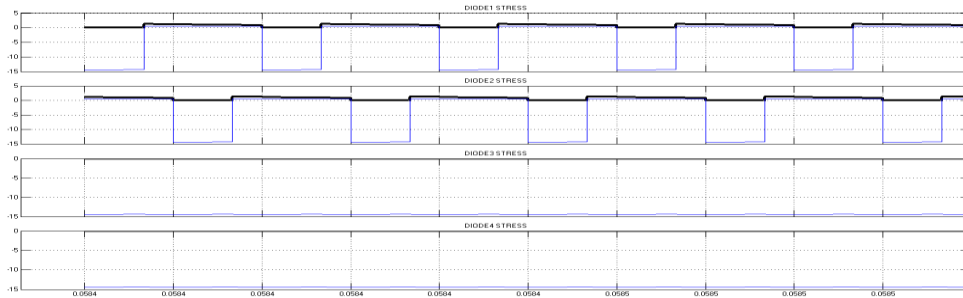


Figure 18 Output of scope4 in boost mode.

VIII. CONCLUSIONS

It is seen that the given interleaved technique based buck-boost dc-dc converter has very low I/O current ripples with a very high efficiency. This simulation technique can be utilized to select appropriate components for the converter. This converter though has four switches but can work with only two switches controller circuit, as only two switches are simultaneously operated with gate pulses.

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