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Design and Simulation of Interleaved DC-DC Converters For Fuel Cell Applications

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Abstract : Renewable energy is produced from natural resources that are replenished constantly. DC-DC Boost Converters serves many functions and normally involved in many applications which has a low output voltage for renewable energy sources such as Fuel cells, Batteries, Photo-voltaic cells. This paper introduces several types of Interleaved Boost Converter topologies for fuel cell applications. Four cases of interleaved Boost converter have been studied and analysed. The output voltage ripple input current ripple, inductor current ripple, efficiency and settling time of the four types of converters are compared. The wave forms of input, inductor current ripple and output voltage ripple are obtained using MATLAB/SIMULINK. The design equations for IBC have been presented. Applying the results obtained from simulation the best of the four IBC is inferred.

Keywords : Interleaved boost converters (IBC), ripple, MATLAB and efficiency.

1. INTRODUCTION

Worldwide, the renewable energy sources have received a great attention and lot of research work are reported in literature. The renewable energy sources are solar, wind, geo thermal, tidal and fuel cells recent years, fuel cells are used as a power source for various applications because of their cleanness, high efficiency, and high reliability. These power sources have quite low -voltage output and requires series connection of voltage booster to provide enough voltage output. DC-DC boost converter is generally used to further boost the voltage to the required level. Various other boosters such as boost, buck-boost series resonant full-bridge and push-pull converters are not recommended because they add objectionable ripples in the current flowing out of the fuel cell. To minimize the ripples, an IBC has been proposed as a suitable interface for this renewable source [1]. Two-phase boost converter operates at a very large duty cycle due to a high output voltage and a low input voltage. Interleaved method is used to improve converter performance in terms of efficiency, size, conducted electromagnetic emission and transient response. To minimize the amount of ripples, IBC has been proposed in addition to which it has improved performance characteristics of higher power capability, modularity and improved reliability [2, 15].However IBC improves converter performance at the cost of additional inductors, switching devices and output rectifiers.

Mathematical analysis of the current ripple and the design parameters included in this study. Simulation study has been performed to understand the efficiency of the IBC and the results have been validated.

The parallel connection of boost converters in high-power applications is a well-known technique. Its main advantage stems from the fact that sharing the input current among the parallel converters allows smoothing some of the design constraints of the switching cells. It also has an added advantage that the switching and conduction losses are less in interleaved boost converter than the conventional boost converter. The cancellation of low frequency harmonics eventually allows the reduction in size and losses of the filtering stages. The frequency of the current ripple is twice for two phase

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IBC than the conventional boost converter. Due to a phase shift of 180 degrees ripple cancellation takes place. This paper gives the overview on the various design aspects, steady state and transient response, device selection, operating principle, gating pattern and the various waveforms which compares with the conventional boost converter for fuel cells. Multidevice structure with interleaved control to reduce the input current ripples, output voltage ripples and the size of the passive components. The inductor size and the capacitor size of the MDIBC are reduced by two times compare to the IBC[5].

2. OPERATION PRINCIPLE OF INTERLEAVED BOOST CONVERTER

Interleaved boost converter mainly used for renewable energy sources has a number of boost converters connected in parallel which have the same frequency and phase shift. These IBC`s are distinguished from the conventional boost converters by critical operation mode, discontinuous conduction mode (DCM) and continuous conduction mode (CCM) so that the devices are turned on when the current through the boost rectifier is zero [4]. In the critical conduction mode the design becomes tedious as the critical point varies with load.

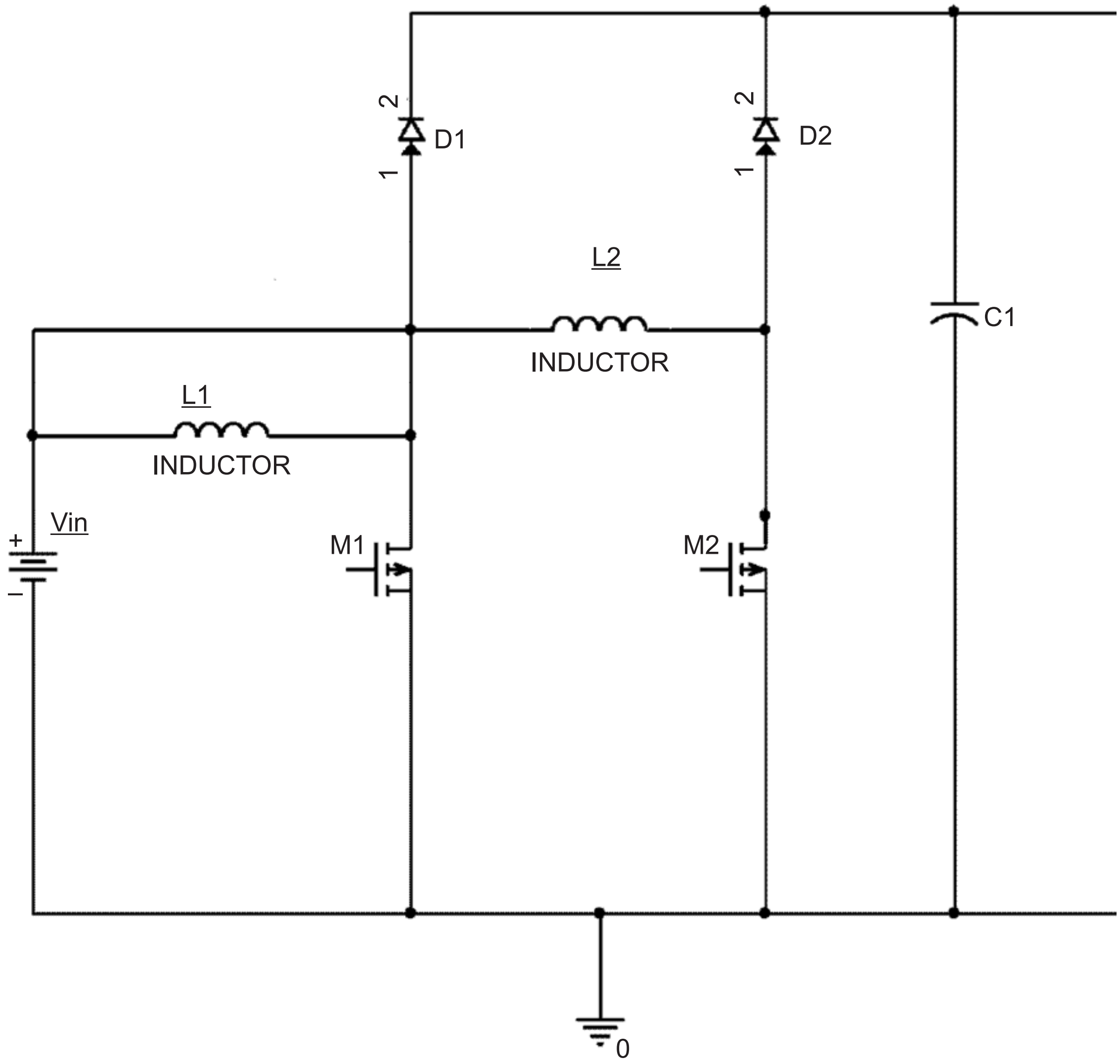

Figure 1: Circuit diagram of two-phase IBC - 1

In the DCM, the difficulties of the reverse recovery effects are taken care but it leads to high input current and conduction losses and it is not best suited for high power applications. CCM has lower input peak current, less conduction losses and can be used for high power applications. By dividing the output current into ‘*n*’ paths higher efficiency is achieved and eventually reducing the copper losses and the inductor losses.

Here the operation of two phase interleaved boost converter is explained which is shown in the figure. Firstly when the device S1 is turned ON, the current in the inductor iL1 increases linearly. During this period energy is stored in the inductor L1. When S1 is turned OFF, diode D1 conducts and the stored energy in the inductor ramps down with a slope based on the difference between the input and output voltage. The inductor starts to discharge and transfer the current via the diode to the load. After a half switching cycle of S1, S2 is also turned ON completing the same cycle of events. the power channels are combined at the output capacitor, the effective ripple frequency is twice than that of a single-phase boost converter. The amplitude of the input current ripple is small. This advantage makes this topology very attractive for the renewable sources of energy.

In the figure 1 it can be seen that the input current *i*, for two phase interleaved boost converter is the sum of each channels inductors currents. As the two devices are phase-shifted by 180 degrees, the input current ripple produced is the smallest [3].

The gating pulses of the two devices are shifted by a phase difference of 360/n, where n is the number of parallel boost converters connected in parallel[3]. For a two-phase interleaved boost converter $n = 2$, which is 180 degrees and it is shown in Fig.2.

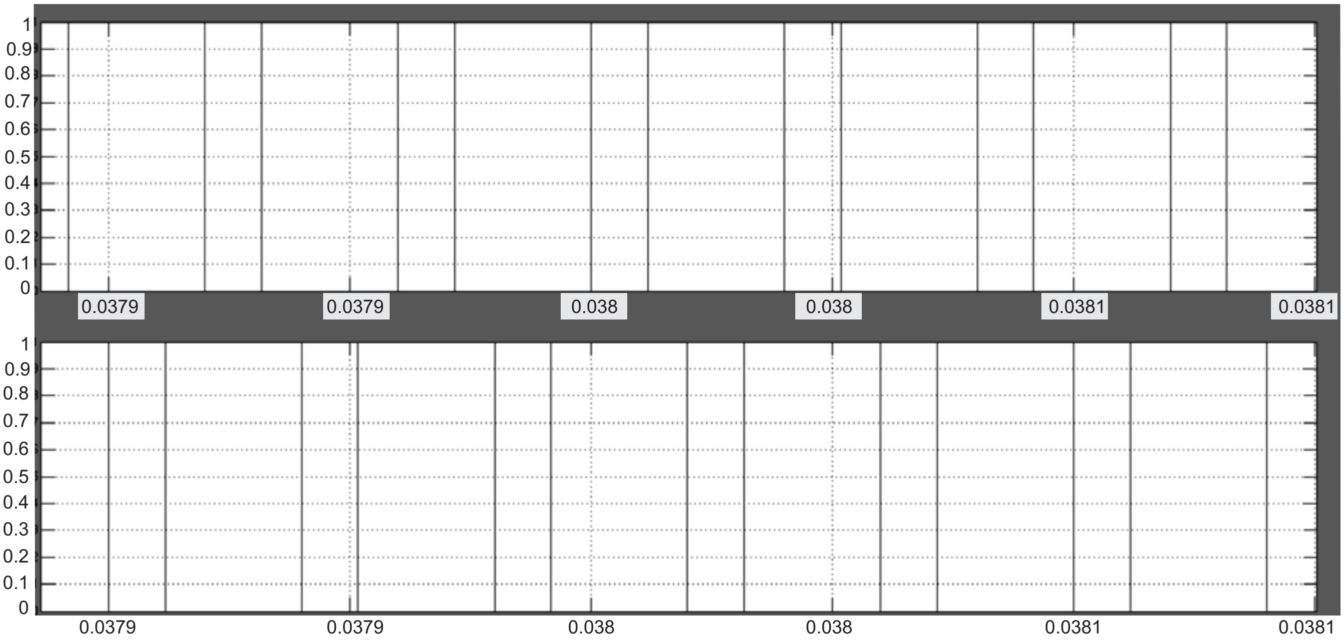

Fig 2: switching pattern of 2-phase IBC

3. DESIGN OF L & C VALUES

Power rating = 120W,

ΔI = 5%,

ΔV = 5%

Vi_n = 8*v*,

fs = 25kHz

V_o = 36v

$M = V_o / V_{in}$

$L_1 = L_2 = (V_{in} \times D) / (\Delta I \times fs)$

$C_1 = (I_o \times D) / (\Delta V \times fs)$

The design methodology for all types of IBC'srequire a selection of proper values of inductor, capacitor and proper choice of the power semiconductor devices to reduce the switching losses [4]. The steps involved in designing IBC are as follows [5]:

- Decision of duty ratio and number of phases
- Selection of Inductor values
- Selection of power semiconductor switches
- Design of output filter

A. Selection of duty ratio and number of phases

Two phase IBC is chosen since the ripple content reduces with increase in the number of phases. If the number of the phases is increased further, without much decrease in the ripple content, the complexity of the circuit increases very much, thereby increasing the cost of implementation. Hence, as a trade off between the ripple content and the cost and complexity, number of phases is chosen as two. The number of inductors, switches and diodes are same as the number of phases and switching frequency is same for all the phases.

B. Selection of inductors

Inductor value can be calculated by assuming peak to peak inductor ripple to a certain percentage of about 20% of the output current corresponding to the individual phase. The average inductor current is determined as,

$$I_L = \frac{0.5 \times I_o}{1 - Dm}$$

$$D_m = \frac{V_o + V_d - V_{in(\min)}}{V_o + V_d - V_{on}}$$

Assuming peak inductor ripple current per phase (IL) as 20% of the average inductor current, the peak inductor current is determined as follows,

$$I_{peak} = I_L + \frac{\Delta I_L}{2}$$

$$L = \frac{(V_{in(\min)} - V_{on}) \times D_{\max} \times (1 - D_{\max})}{f_s \times I_{out}}$$

C. Selection of Power Devices

The semiconductor device IGBT chosen for constructing the two phase interleaved boost converter [5]. The main benefits of IGBT are lower on state resistance, lower conduction losses and high switching frequency operation.

D. Output Filter

A capacitor filter is needed at the output to limit the Peak to peak ripple of the output voltage. The Capacitance of the output filter is function of the duty Cycle, frequency and minimum load resistance during Maximum load [15]. For 5% output voltage ripple, the value of the capacitance is given by the formula

$$\Delta V_{out} = \frac{I_{out(\max)} \times (1 - D_{\min})}{f_s \times C_{out}}$$

Fig 3 shows simulink model of interleaved boost converter topology 1.IBC1 driven by fuel cell input and output voltage doubled by principle of boost converter. The output voltage and current waveforms are settled very quickly for the final steady state value by inferring Fig.no5.

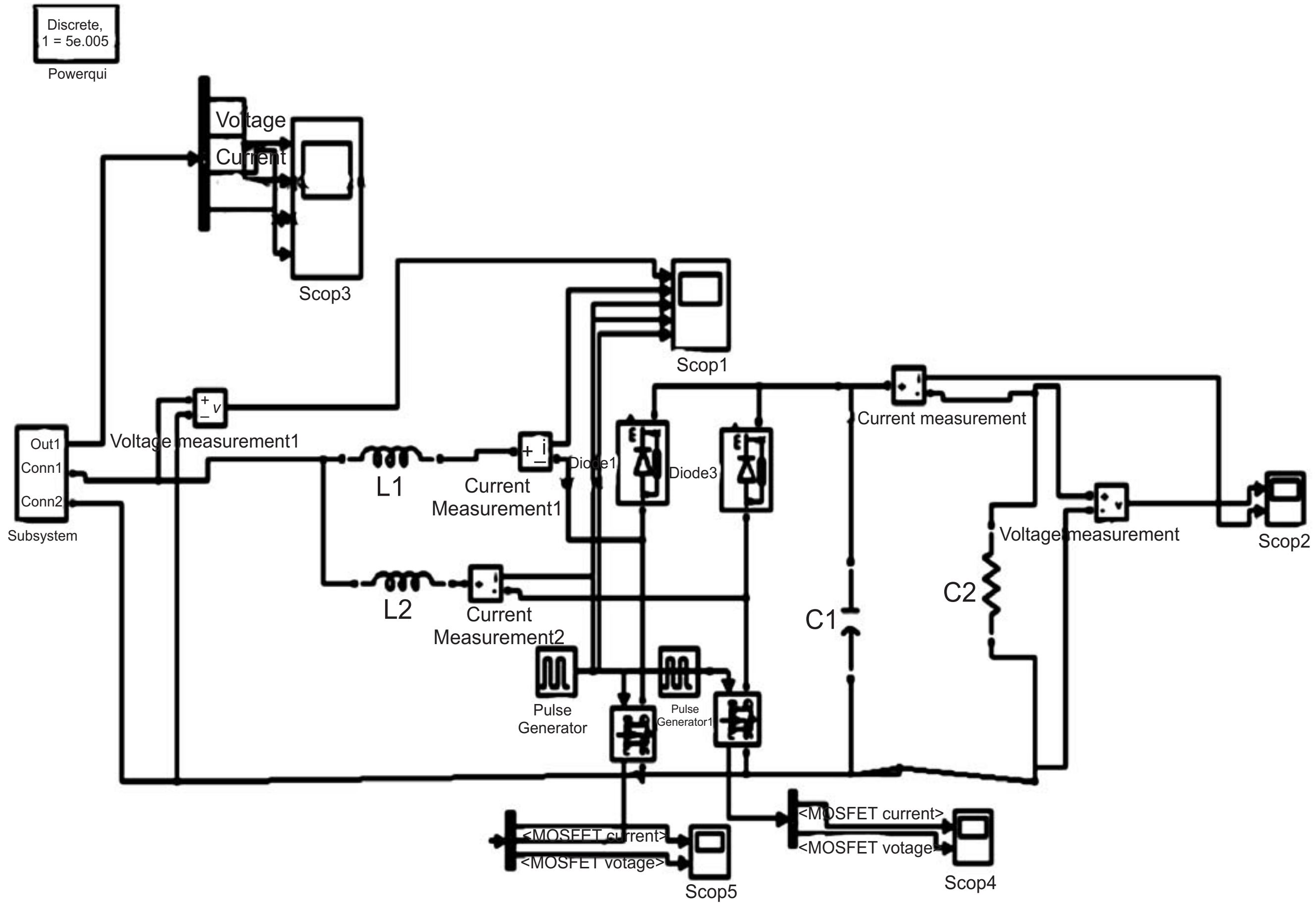

Figure 3: Simulink Model of IBC–1

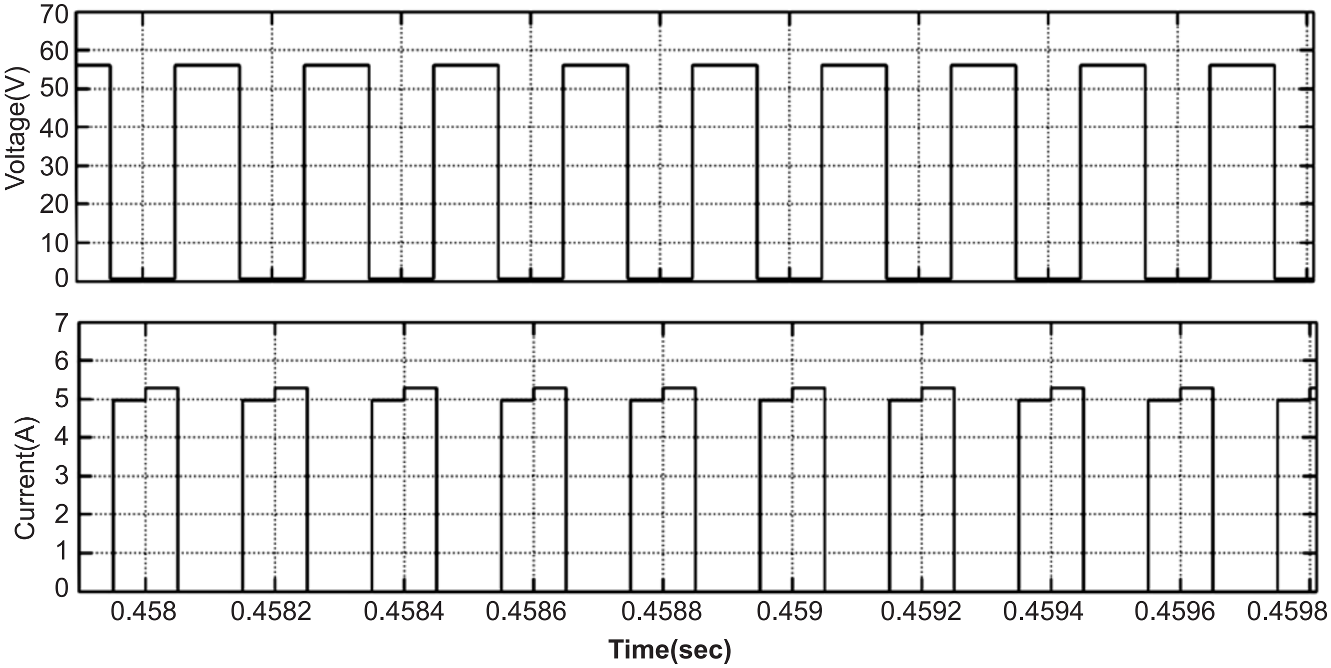

Figure 4: Voltage and Current across the switch

Fig 7 shows simulink model of interleaved boost converter topology. IBC2 driven by fuel cell input and output voltage doubled by principle of boost converter. From Fig.8 output voltage and current waveforms are taking some time to settle when comparing with IBC1.

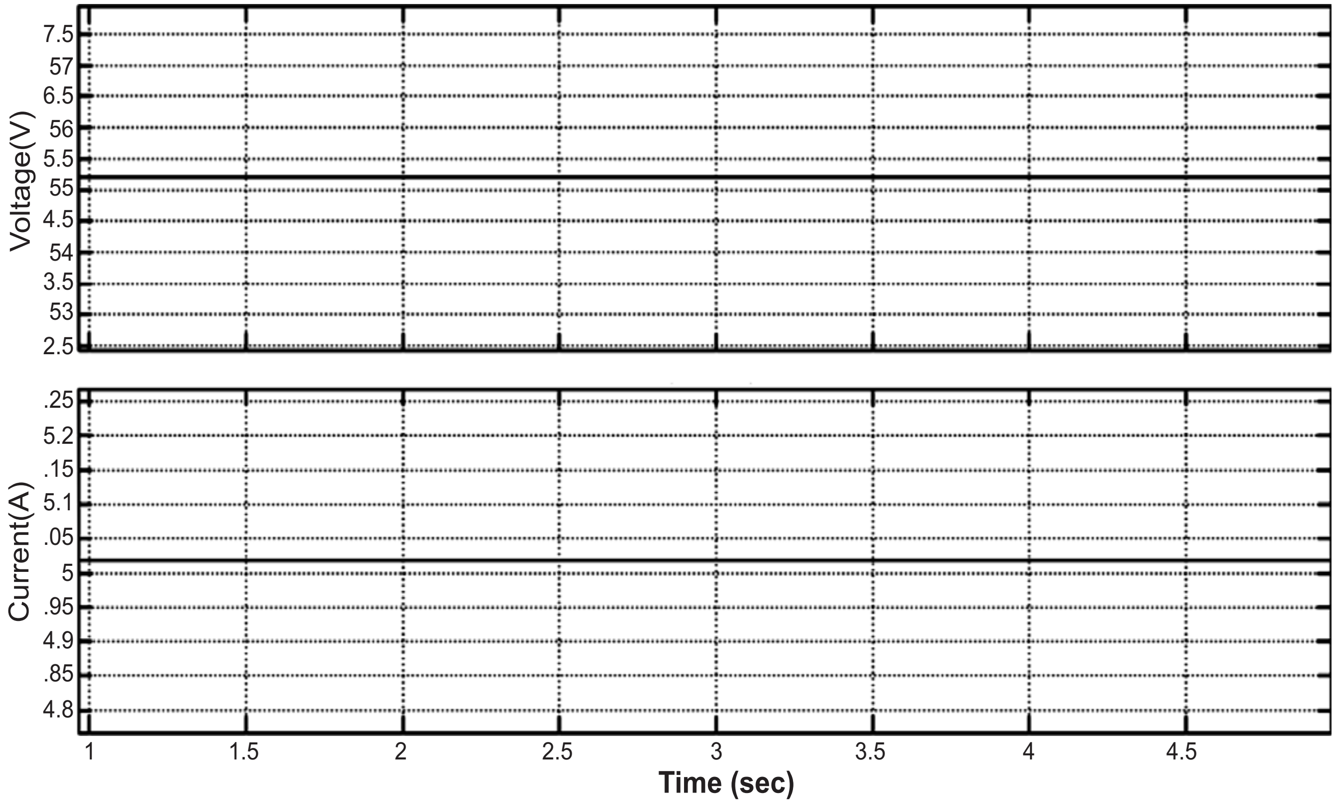

Figure 5: OutputVoltageand current

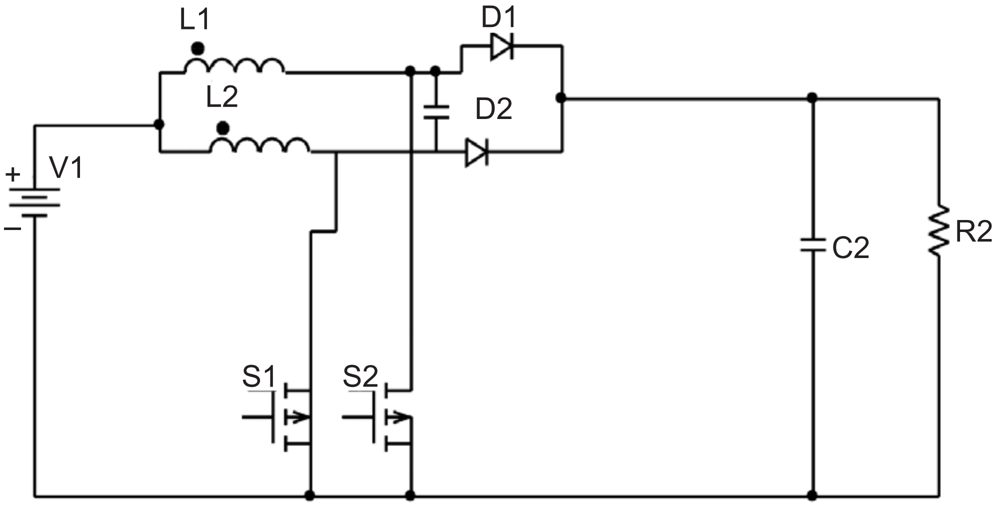

Figure 6: Circuit diagram of IBC – 2

Fig 9 indicates the current and voltage across the switch during on and off condition. Here smooth turn on and turn off is happened by referring fig 9.

Inter leaved topology 3 schematic circuit shown in Fig.10,in this circuit S1 and S2 conducting in the phase delay of 180° by this method of switching ripple current are get reduced and minimize the filtering component size.

Fig 11 shows simulink model of interleaved boost converter topology3 .IBC3 driven by fuel cell input and output voltage doubled by principle of boost converter. From Fig.12 output voltage and current waveforms are contains more ripple content when comparing with previous topologies. In other hand from Fig 13 current and voltage across the switch during on and off condition.

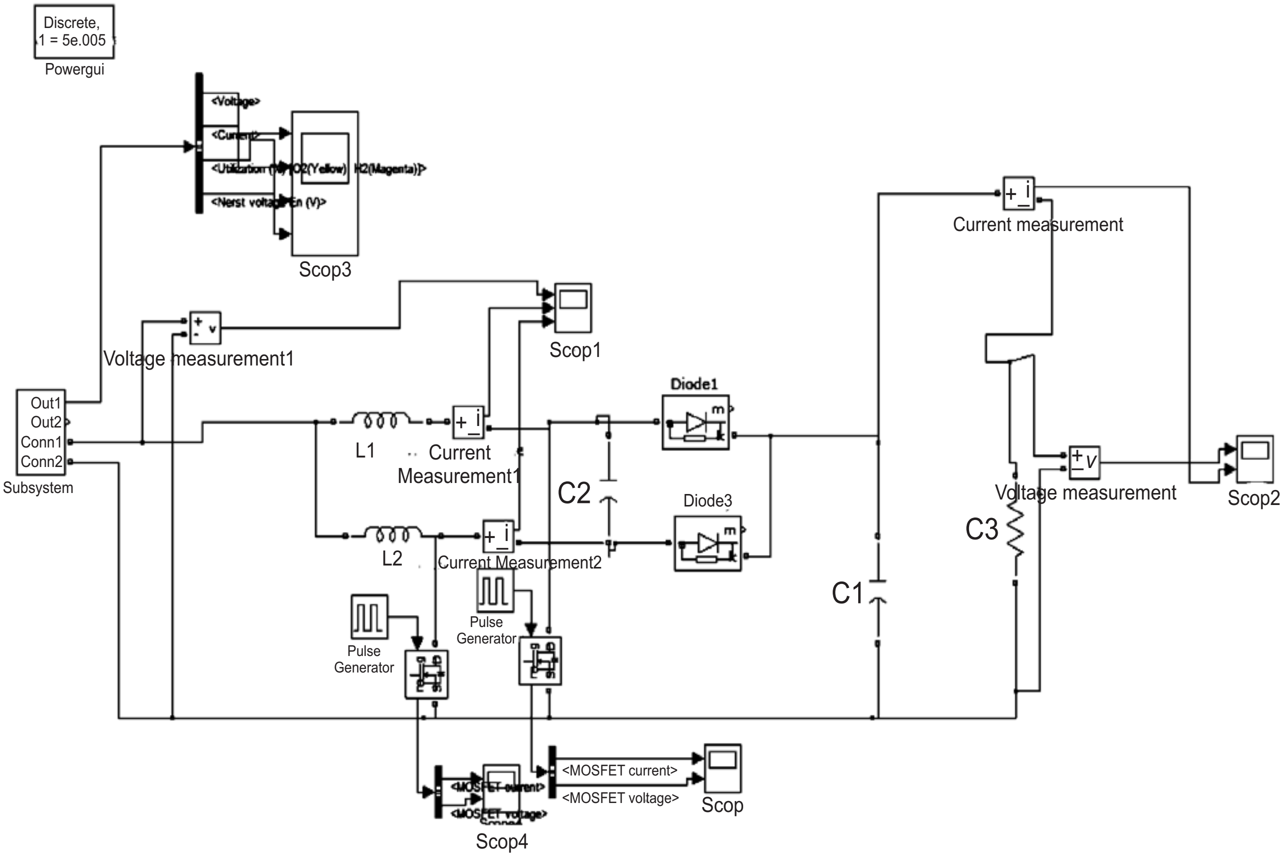

Figure 7: Simulink Model of IBC – 2

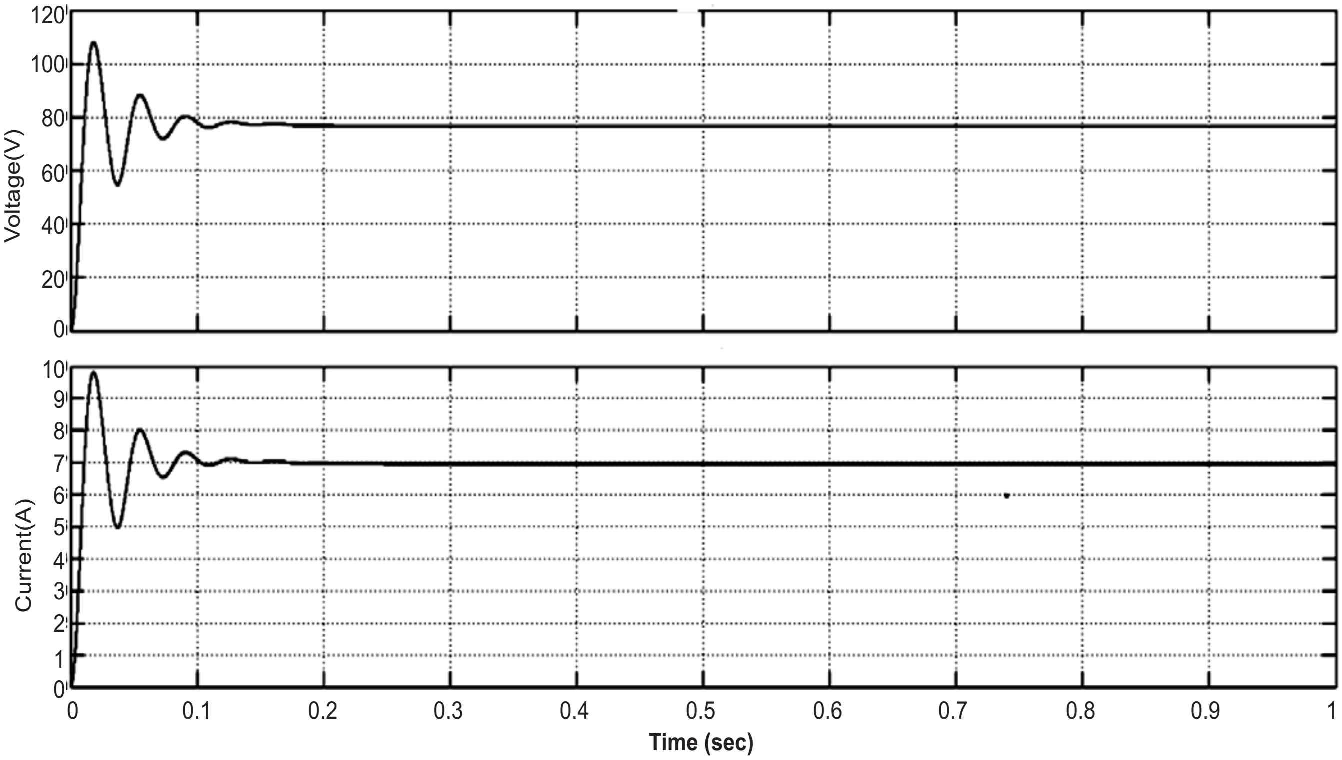

Figure 8: Output Voltage and Current

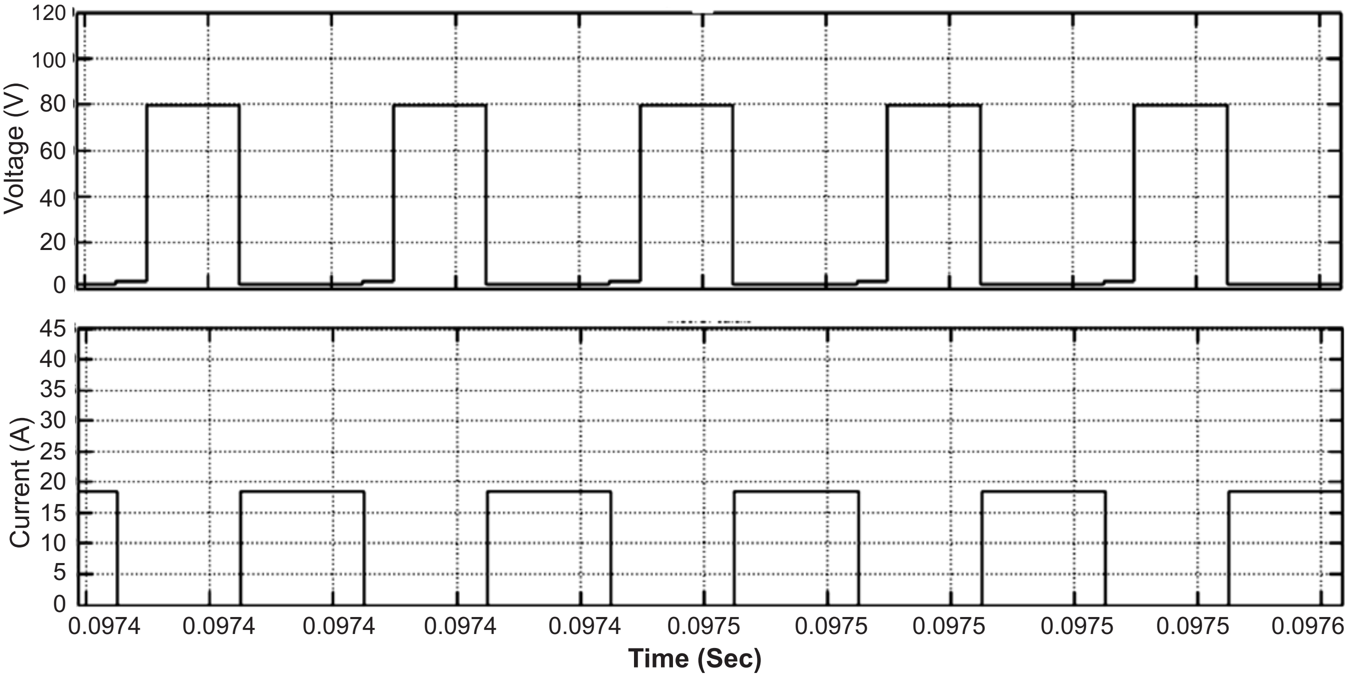

Figure 9: Voltage and Current across the switch

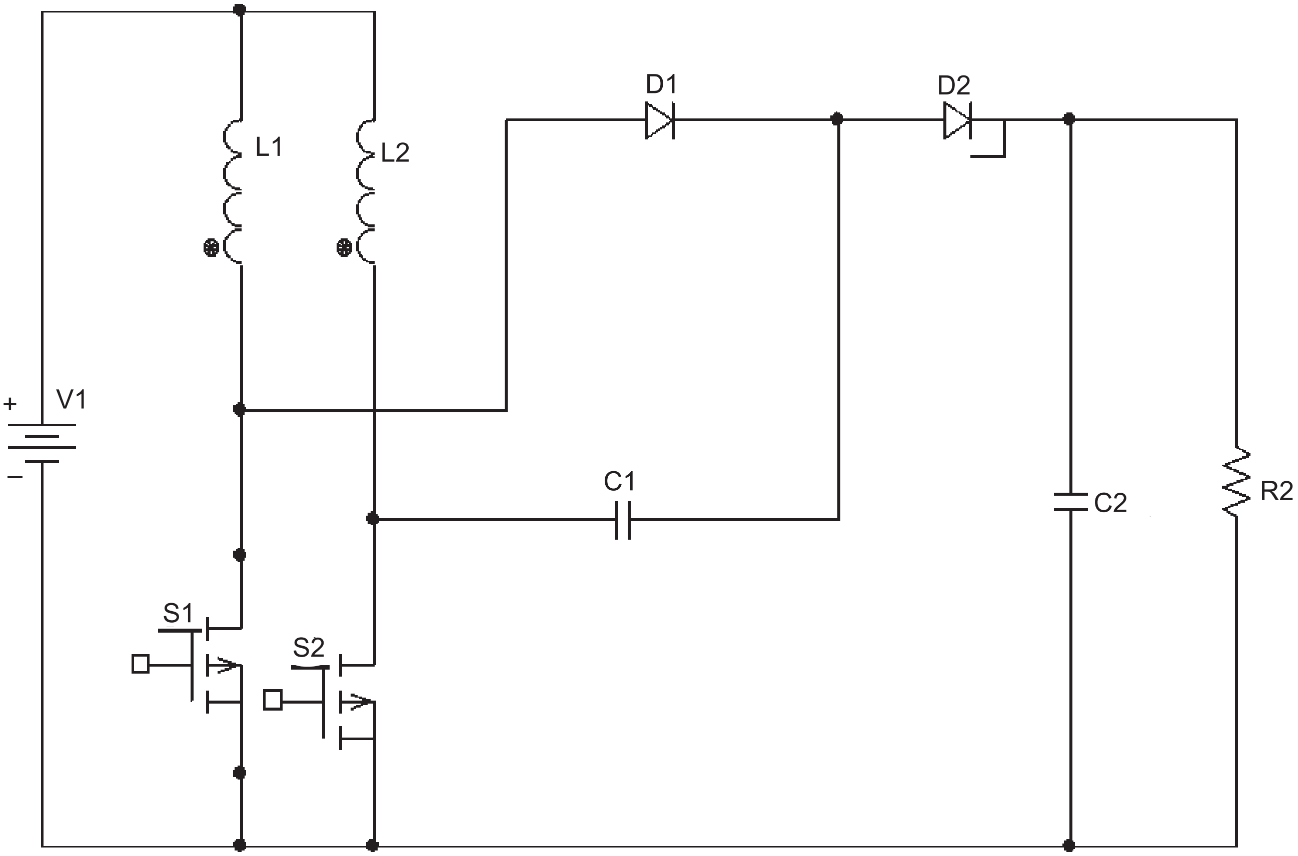

Figure 10: Circuit diagram of IBC – 3

Conventional boost converter schematic circuit shown in Fig.14, in this circuit single switch is operated, during ON state inductor gets charged and during OFF state inductor gets discharged.

Fig 15 shows simulink model of boost converter with fuel cell input. From Fig.16 output voltage and current waveforms are contains more ripple content when comparing with previous topologies. In other hand from Fig 17 current and voltage across the switch during on and off condition with more losses.

4. COMPARISON OF VARIOUS CONVERTERS

Table 1

Converters	*Efficiency*
IBC 1	96.61 %
IBC 2	70%
IBC3	89.84%
Boost Converter	72.1%

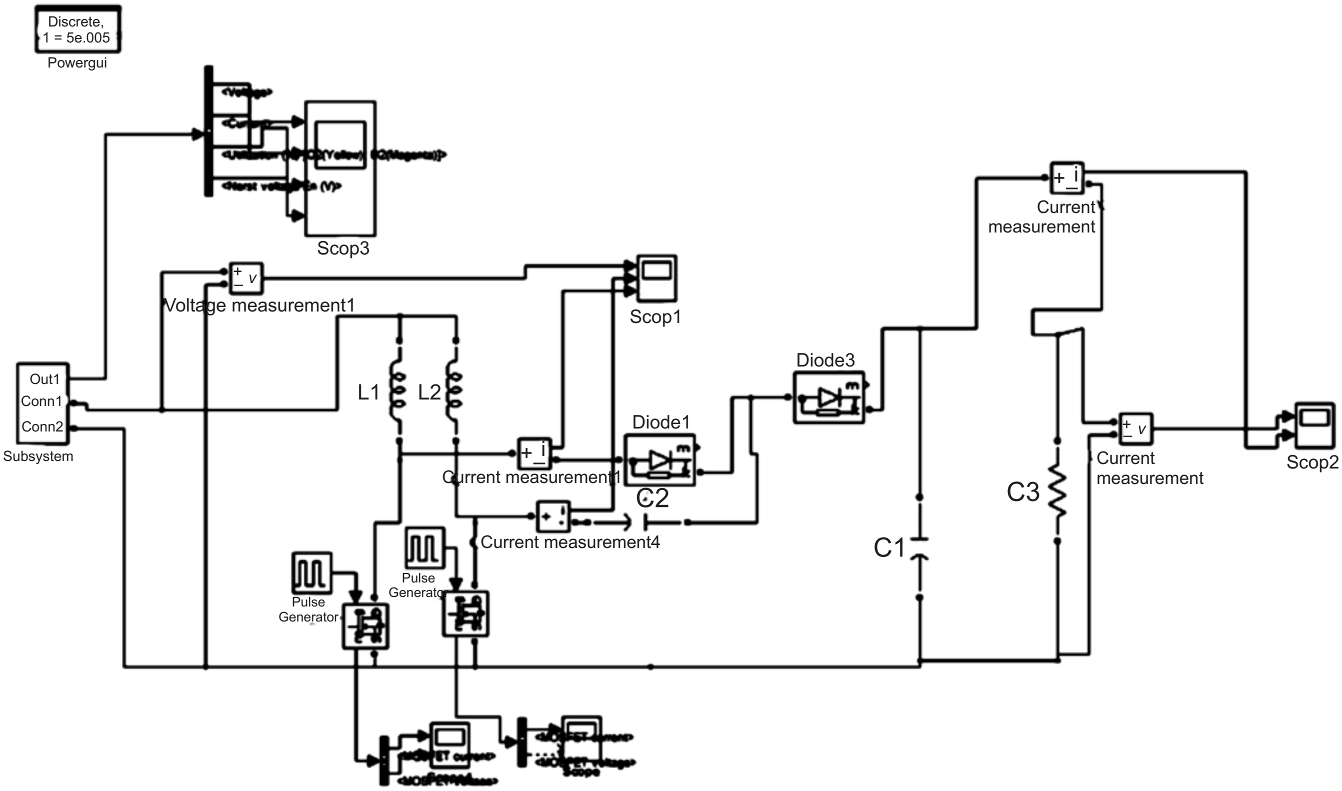

Figure 11: Simulink Model of IBC – 3

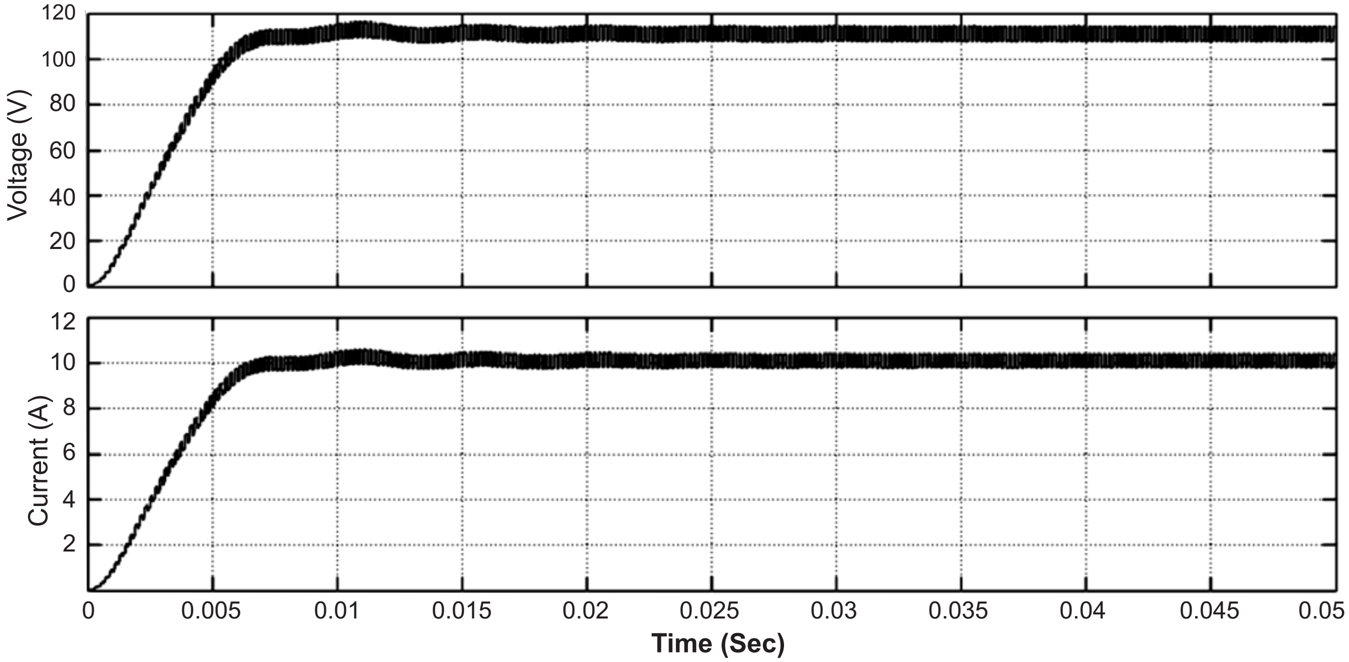

Figure 12: Output Voltage and Current

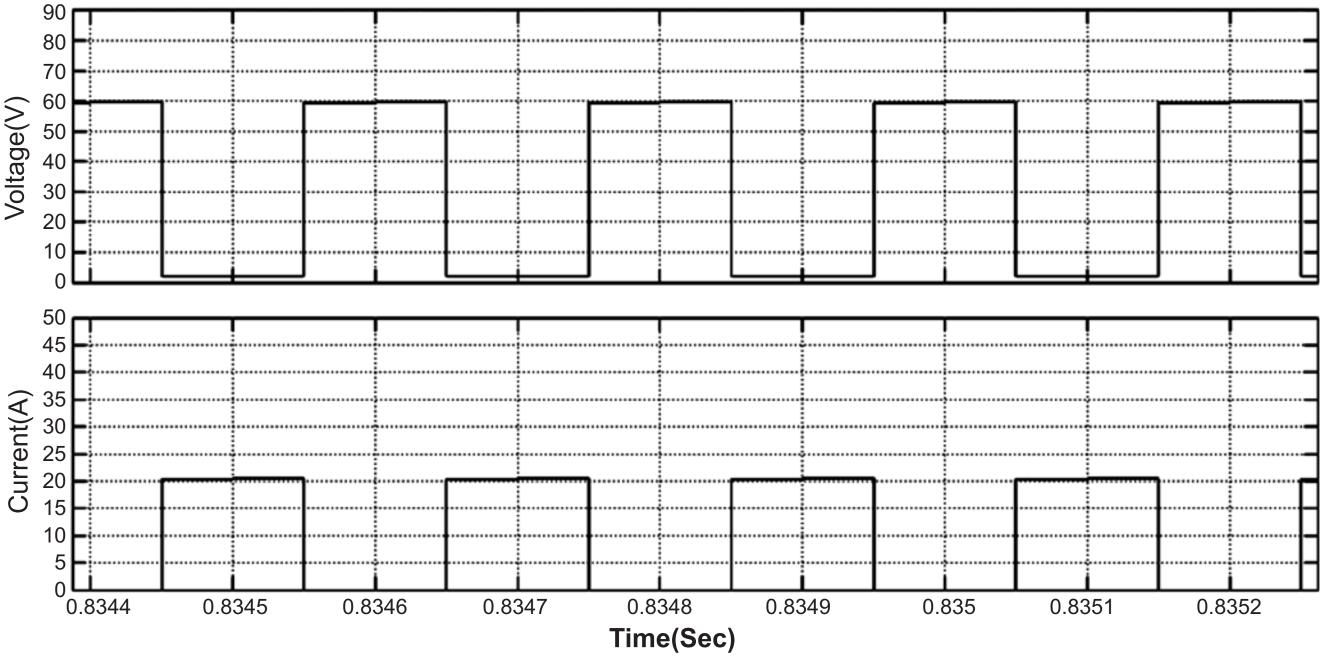

Figure 13: Voltage and Current across the switch

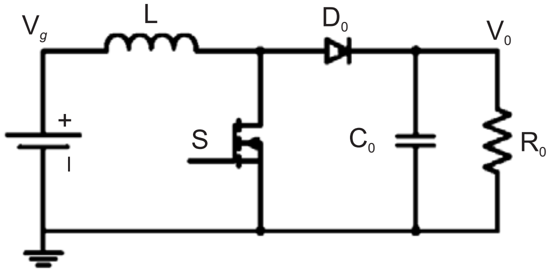

Figure 14: Circuit diagram of Boost Converter

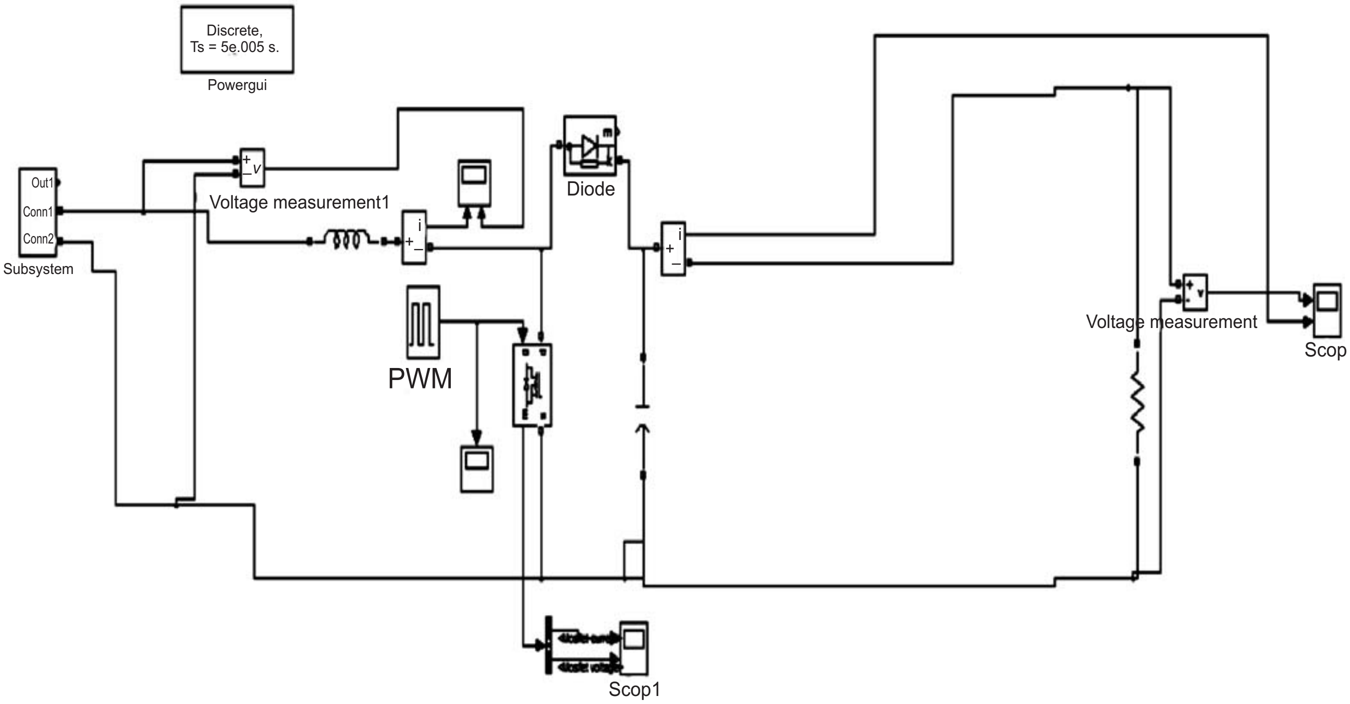

Figure 15: Simulink Model of Boost Converter

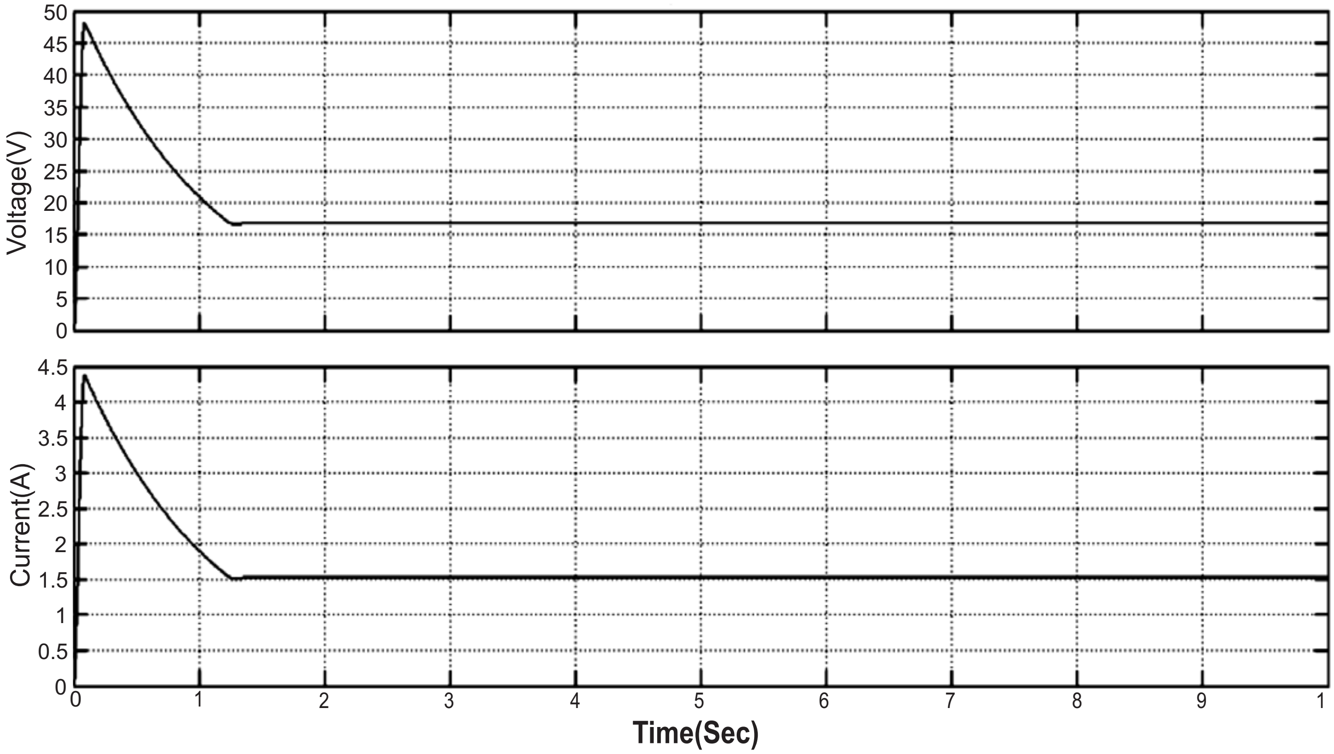

Figure 16: Output Voltage and Current

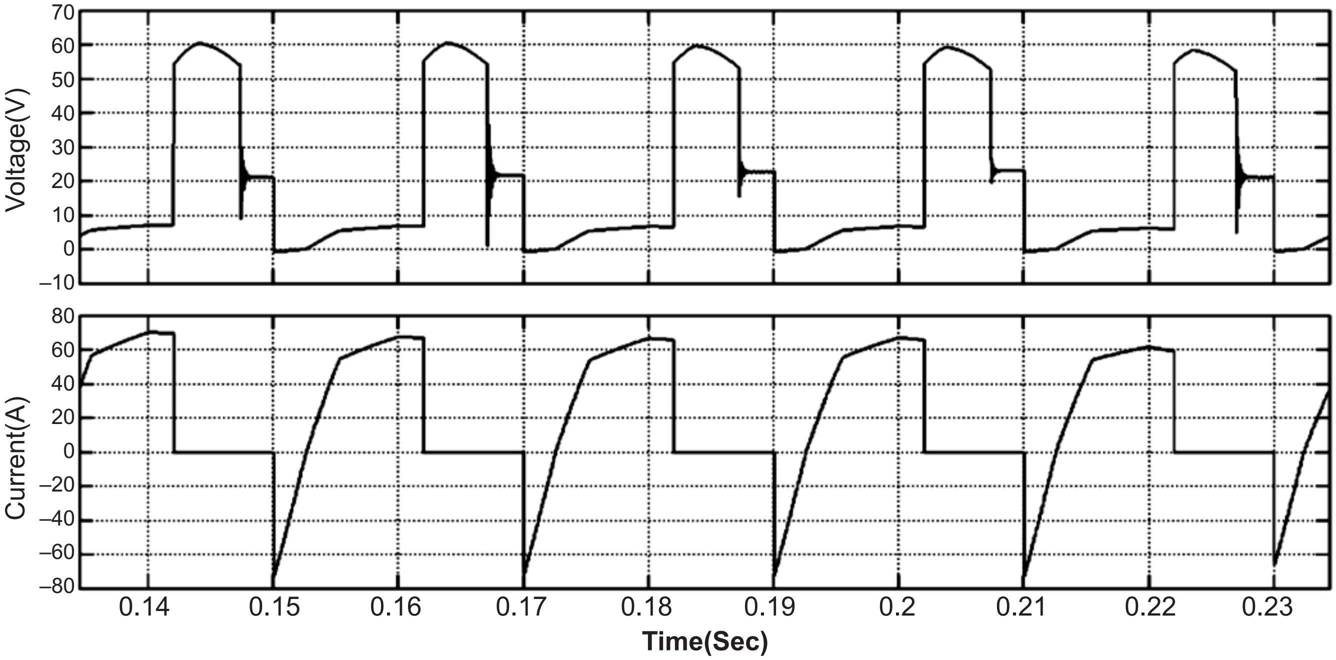

Figure 17: Voltage and Current across the switch

5. CONCLUSION

The principle and operation of interleaved boost converter and the various topologies of IBC have been discussed and presented. The various waveforms of IBC as well as the conventional boost converter have been simulated using MATLAB SIMULINK. The comparison of parameters like efficiency and the switching losses between interleaved boost converter topologies and the conventional boost converter is carried out. It is inferred that IBC1 having higher efficiency and reduced ripple content than other topologies.

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