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ANALYSIS AND HARDWARE IMPLEMENTATION OF INTERLEAVED BOOST CONVERTER

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ABSTRACT

The energy derived from natural sources which are replenished continuously is Renewable energy. The commonly used renewable energy systems include photovoltaic cells and fuel cells. A suitable DC-DC converter is proposed for highly efficient renewable energy systems. Interleaved Boost Converter (IBC) topology is discussed in this paper for renewable energy applications. The advantages of interleaved boost converter compared to the classical boost converter are low input current ripple, high efficiency, faster transient response, reduced electromagnetic emission and improved reliability. In this paper three cases are considered and analyzed. Two-phase IBC's with (i) the front end inductors magnetically coupled (ii) uncoupled inductors and (iii) inversely coupled inductors performance have been analyzed and compared. The output voltage ripple, input current ripple and inductor current ripple of the three types of converters are compared. Using MATLAB/SIMULINK the waveforms of input, inductor current ripple and output voltage ripple are obtained and the design equations for IBChave been presented. The best of the three IBC's is obtained from the simulation results .

Keywords-Uncoupled, Directly coupled, Inversely coupled IBC, ripple.

I. INTRODUCTION

The world virtually depends on the supply of fossil fuels like coal, oil and natural gas for the energy. But the common issue is that fossil- fuels are depleting. It would take millions of years to completely restore the fossil fuels that we have used in just a few decades i.e., they are non-renewable. Renewable energy comes into topic as a resolution for this global issue. Renewable energy is any natural source that can replenish itself naturally over a short amount of time. Energy from solar, wind running water and geothermal is renewable.

Renewable energy sources are wonderful options because they are limitless and these renewable sources do not pollute air and water. Any such renewable energy system requires a suitable converter to make it efficient and interleaved boost converter is one such converter. The Interleaved boost converter has high voltage step up, reduced voltage ripple at the output, low switching loss, reduced electromagnetic interference, faster transient response and the reduced steady-state voltage ripples at the output capacitors of IBC. It is preferred because of the low ripple content in the input and output sides though the topology is complex with large number of inductors compared to the conventional boost converter with. To reduce this complexity, this paper investigates the benefits of coupled, uncoupled and inversely inductors for IBC and detailed analysis has been done to study the ripple content of all the three types of the converter. The suitable IBC for fuel cell applications is proposed [1]. Gating pulses are generated using pulse generator and simulations have been performed to validate the concepts.

II. OPERATION OF IBC

The two phase converter is used in which the two phases are driven 180 degrees out of phase. The phase shift is given by 360/n where n is the number of phases.

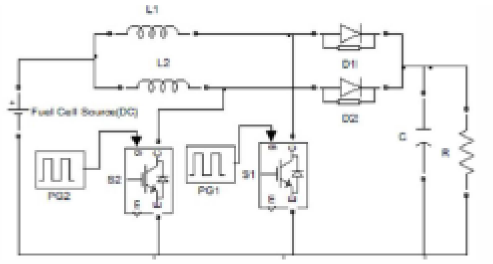


Fig.1 Circuit diagram of a two phase uncoupled IBC

The ripple frequency is doubled since two phases are used, thus resulting in the reduction of voltage ripples at the output side and also the input current ripple is reduced.

The current across the inductor is raised and energy is stored in inductor when the pulse is given to the first phase for time tj. The inductor and capacitor serve as a voltage source when the device in the first phase is turned OFF and the energy stored is transferred to the load through the output diode to extend the voltage gain and to reduce voltage stress on the switch. The inductances in the phase control the increasing current rate across the output diode. When the device in the first phase is turned off gate pulse is given to the second phase from time t1 to t2. The inductor charges for the same time and transfers energy to the load in a similar manner as the first phase when the device in the phase two is turned ON and therefore the load is fed continuously. The schematic diagrams of the two phase interleaved boost converter with uncoupled, directly coupled and inversely coupled IBC is shown in fig 1 to fig3. The current stress in each transistor is reduced as the output current is divided by number of phases. Each transistor is switched at the same frequency but at a phase difference of II [3]. Depending on the duty ratio switching sequence of each phase may overlap. Since the input voltage is 20V and desired output voltage 40V,the duty ratio should be 0.5.

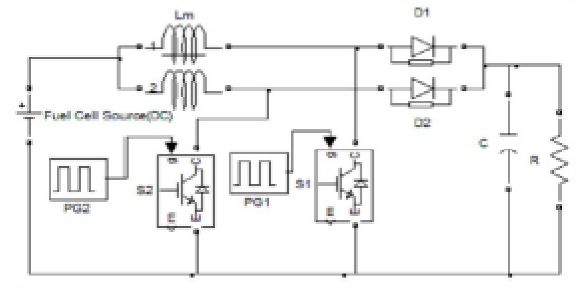


Fig.2 Circuit diagram of 2-phase directly coupled IBC

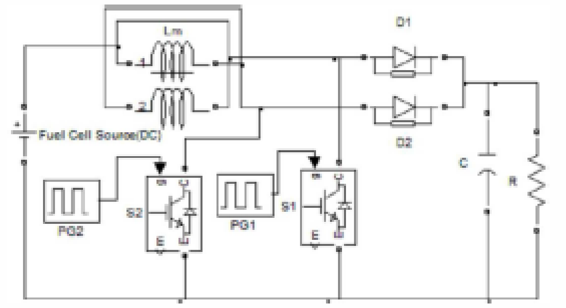


Fig.3 Circuit diagram of 2-phase inversely coupled IBC

III. DESIGN METHODOLOGY OF IBC

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

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

A) Selection of number of phases and duty ratio:

As the number of phases increases ripple content reduces. If the number of phases is further increased, complexity increases and cost of implementation also increases without much reduction in ripples. Hence, as a tradeoff between the ripple content and the cost and complexity, number of phases is chosen as two and switching frequency is same for all phases. The number of inductors, switches and diodes is same as number of phases.

$$\frac{V_{in}}{L}\left(\frac{2-3D}{D'}\right)\frac{T}{N}d \quad (0.34<D<0.66)$$

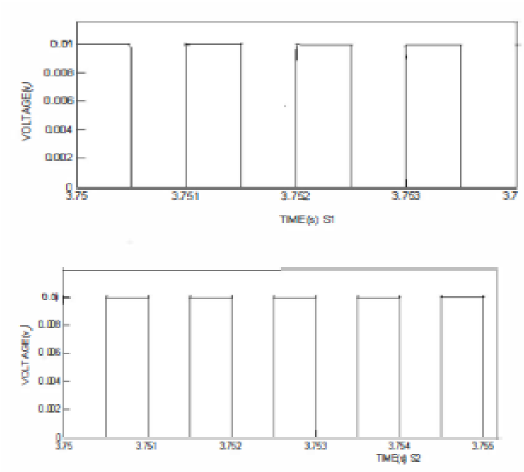


Fig.4: Switching pattern 2phase IBC

At specific duty ratios which are multiples of IIN, where N stands for the no of phases, the input current ripple will be zero. The duty ratio is taken as 0.5 since the number of phases are two. The switching pattern is show in Figure 4.

B) Selection of inductors

The design equation part for all the three converters to select inductor and capacitor is given below:

1. Uncoupled inductor

The value of inductance is given by equation

$$L = \frac{V_{in}DT}{\Delta I_{ph}}$$

2. Coupled Inductor

The equivalent inductance for directly coupled IBC is given by

$$L = \frac{V_{in}DT}{\Delta I_{ph}}$$

Where input voltage is given by Vin and duty ratio by D. The phase current ripple which is decided by Leq is given by

$$\Delta I_{phase} = \frac{V_{in}DT}{L} \frac{1+\alpha+2\alpha\frac{D}{D-1}}{1+\alpha-2\alpha^2}$$

To find out the values of mutual inductance (LrJ, the input current is calculated using the input voltage and power [6]. Witha coupling coefficient (a) of 0.61, the minimum self-inductance of the coupled inductor is found as

$$L = \frac{1+\alpha\frac{D}{1-D}}{1+\alpha-2\alpha^2} L_{eq}$$

The value of Lm is calculated as

$$L_m = \alpha L$$

Therefore, the overall input current ripple is derived as

$$\Delta I_{in} = \frac{V_{in}DT}{L}\left(\frac{(1-\alpha)\left(1-\frac{2D}{1-D}\right)}{1+\alpha-2\alpha^2}\right)$$

From the above equations it is clear that the input current ripple reduces effectively by increasing the value of coupling coefficient. Therefore, the value of coupling coefficient is carefully chosen as 0.61, so that the input current ripple is reduced and the phase current ripples are within the limits [8].

3.1nversely coupled inductor

The equation for inductance of a inversely coupled inductor is given by,

$$L \geq \frac{1+\alpha\frac{D}{1-D}}{1+\alpha^2}$$

The mutual inductance value is given by

$$L_m = -\alpha.L$$

C) Selection of Power Devices:

IGBT is used for constructing the two phased interleaved boost converter due to its low on state resistance, low conduction losses and high switching operation. The maximum voltage across the switching devices is given by

$$V_{switch} = V_{in} \frac{1}{1-D}$$

Where Yin is the input voltage, D is the duty ratio of the converter. The diode has less forward voltage, high reverse breakdown voltage and less reverse recovery current which results in reduced switching loss. There is no need of active snubber circuit for protection due to the absence of reverse recovery current. Hence the circuit complexity is reduced and hence design of the converter is simplified and reliability is improved.

D) Output Filter:

To limit the peak to peak ripple of the output voltage a capacitor filter is needed. The capacitance of the output filter is function of the duty cycle, frequency and minimum load resistance during maximum load [15]. The value of the capacitance for 5% putput voltage ripple is given by the formula

$$C = \frac{V_0DT}{R\Delta V_0}$$

Where R gives the load resistance, the output voltage by V0 and switching period by T

IV. SIMULATION RESULTS

The two phase interleaved boost converter with uncoupled, directly coupled inductors and inversely coupled inductors are simulated in MATLAB/ SIMULINK as per the design equations. The values for uncoupled IBC are L=2.5Mh ,C=781lF ,f=2KHz.and R=3.2fl.The output voltage is Vo=38V for an input Vin=20V. The values used for directly and inversely coupled IBC are summarized as Yin = 20V, R = 3.2fl, C =78uF, fs= 2 kHz, Lm = 7mH, Lkl = Lk2 = 4.3mH, Vo =37v, D=0.5and a = 0.61 for directly coupled. Inductor current ripple waveform and the output voltage waveform of uncoupled IBC are given by fig5 and fig6. The inductor current ripple and output voltage waveforms of a directly coupled IBC under steady-state condition are given by figs 7 and 8. Phase current ripple and input current ripple is lesser for directly coupled inductors compared to uncoupled inductors.

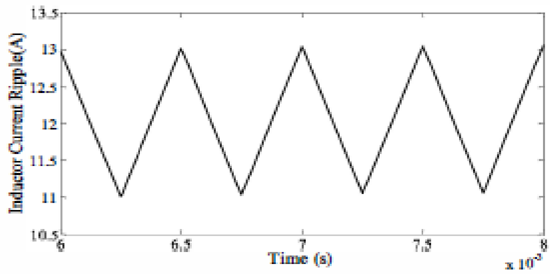


Fig.5: Inductor Current waveform for uncoupled IBC

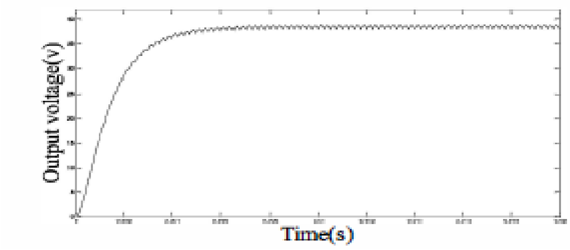


Fig.6:Output voltage waveform of 2phase uncoupled IBC

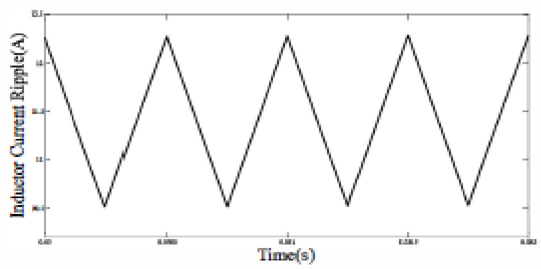


Fig.7: Inductor Current waveform for coupled IBC

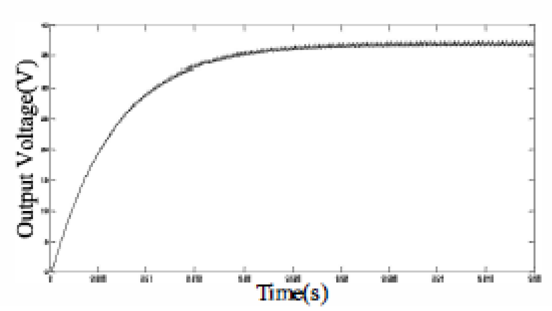


Fig.8:Output voltage waveform of Coupled IBC

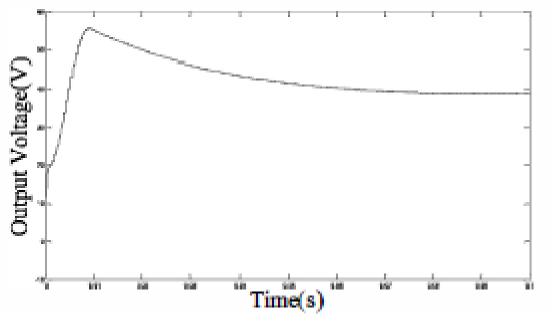


Fig.9:Output voltage waveform of inversely Coupled IBC

Fig 10 shows variation of the input current ripple of each phase according to duty ratio. For the conventional boost converter the input current ripple is linearly increased with increase in duty ratio. However, in N- phase IBC; the input current ripple can be zero at specific duty ratios, which are multiple duties of lIN, such as 0.5 in 2-phase IBC. The input current ripple is proportionally increased to the input voltage and is inversely proportional to inductance and frequency.

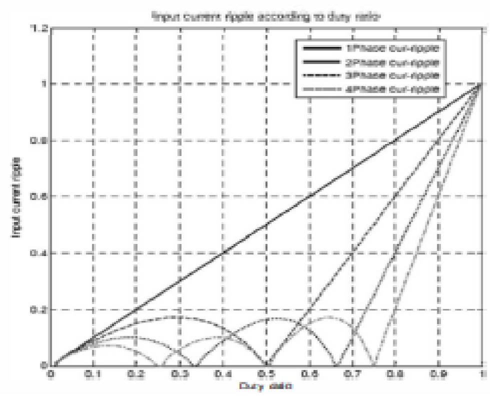


Fig.10: Input current ripple variation with duty ratio

The output voltage ripple of IBC isdramatically reduced as shown in fig11 compared with the conventional boost converte[16] As in case of the input current ripple, the output voltage ripple of the conventional boost converter is linearly increased and the output voltage ripple of IBC passes zero points according to specific duty ratios. The output voltage ripple is decreased by IINtimes.

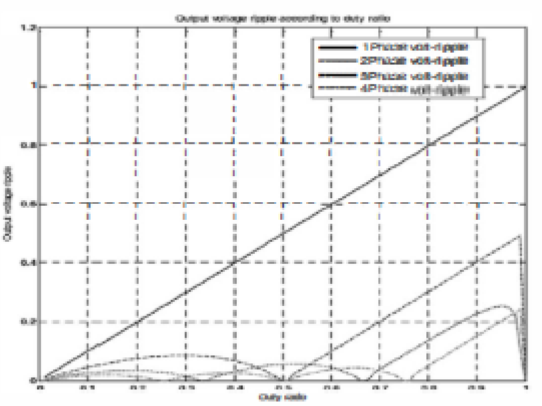


Fig.11:Output voltage ripple variation with duty ratio

From the results we infer that for inversely coupled converter inductor ripple is less compared to the others, however the input current ripple is higher for this . We know that whenever the inductor current ripple is less, efficiency is more. The higher value of input current ripple of inversely coupled is not suitable for certain applications which can be reduced by selecting proper value of duty ratio and coupling coefficient. Therefore from the results we can conclude that the directly coupled IBC gives a reduced input current ripple which is best suited for fuel cell applications.

V. HARDWARE IMPLEMENTATION

Components used in the kit:

MOSFET : IRF540n

Inductance used : 1mH

Load capacitance : 220uF

Diode: MUR1560.

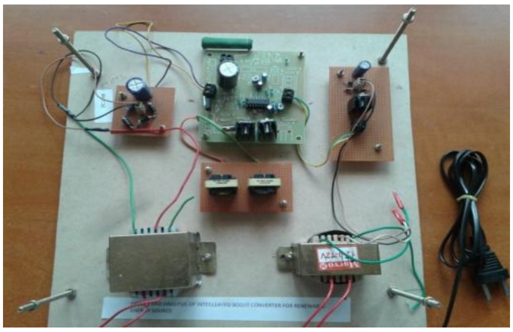
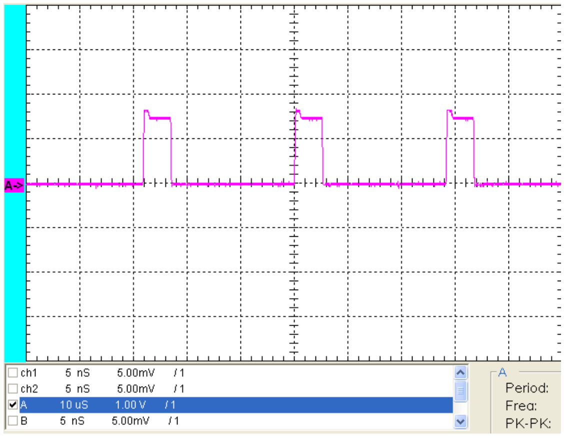


Fig.12:Experimental Prototype of an Interleaved Boost Converter

VI. EXPERIMENTAL RESULTS

The input to the boost converter is 16V. The pulses for the MOSFET are generated using a PWM controller IC SG3525A.The outputs of the SG3525A are obtained as follows

Gate pulses for switch1 and switch2 at Duty ratio



0.2:

Fig.13 Gate pulses for switch 1 at Duty ratio 0.2

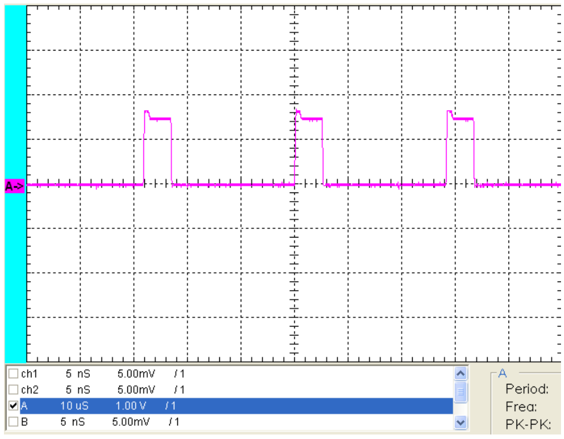


Fig.14.Gate pulses for switch 2 at Duty ratio 0.2

The output of the converter at 20% duty ratio is obtained as

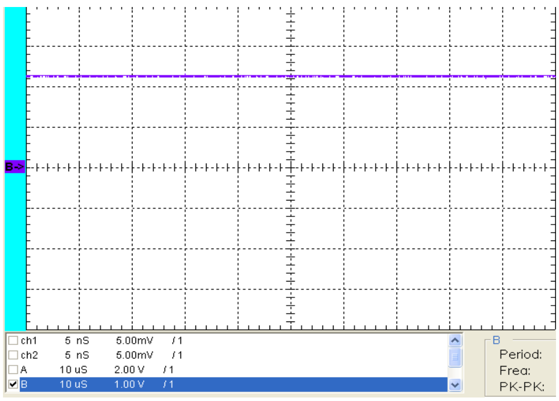


Fig15.Output voltage of the converter at Duty ratio 0.2.

Gate pulses for switch1 and switch2 at Duty ratio 0.35:

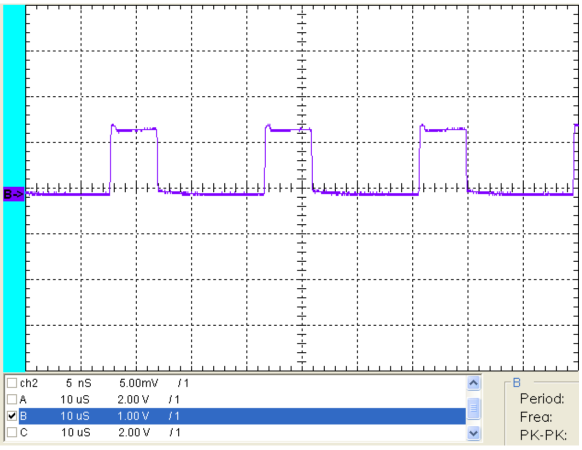


Fig16: Gate pulses for switch 1 at duty ratio 0.35

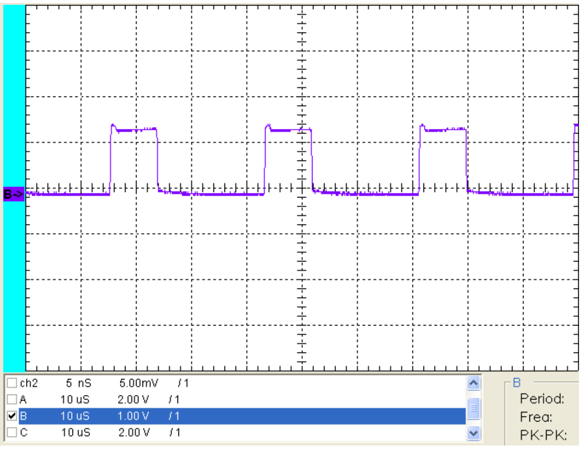


Fig17: Gate pulses for switch 2 at duty ratio 0.35

The output of the converter at 35% duty ratio is obtained as

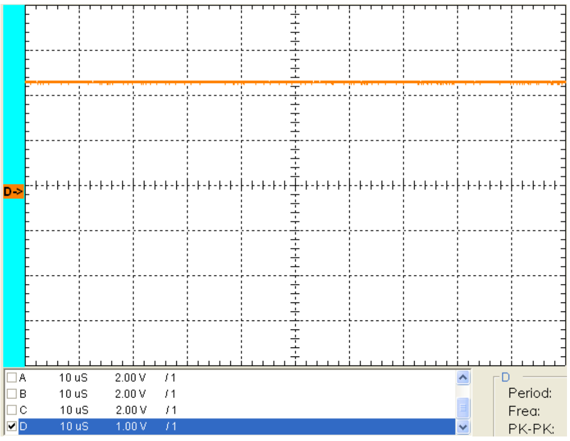


Fig18:Output voltage of the converter at Duty ratio 0.35.

Gate pulses for switch1 and switch2 at Duty ratio 0.5:

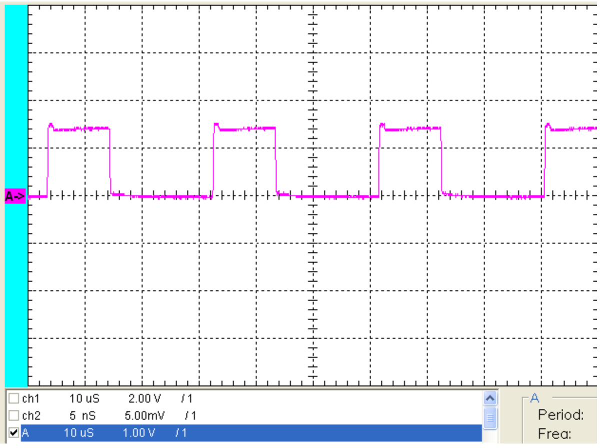


Fig19:Gate pulses for switch 1 at duty ratio 0.5.

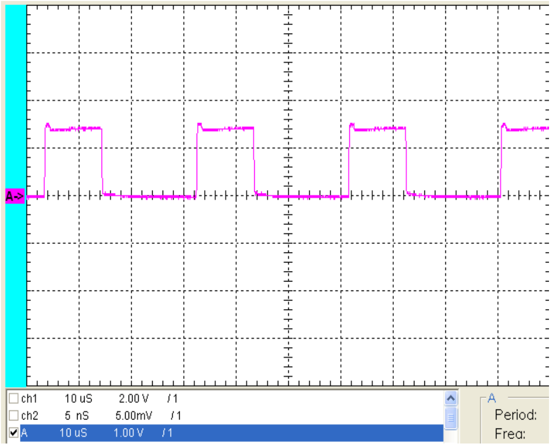


Fig20:Gate pulses for switch 2 at duty ratio 0.5.

The output of the converter at 50% duty ratio is obtained as:

Fig21:Output voltage of converter at duty ratio 0.5.

Duty Cycle	Output Voltage in MATLAB	Output Voltage in Hardware Kit
0.2	19.78	19.37
0.35	24.8	23.84
0.5	29.8	31

TABLE 1: Comparison Of Matlab Versus Hardware Results For Two Phase Uncoupled Interleaved Boost Converter

VII. CONCLUSION

Therefore Interleaved boost converter has so many advantages and is a suitable converter for renewable energy applications. Here we analyzed three cases of IBC using uncoupled, coupled and inversely coupled inductor for renewable energy applications. The design equations have been presented and performance parameters are compared using simulation. It is demonstrated that the directly coupled interleaved DC-DC converter effectively reduces the overall current ripple compared to that of uncoupled inductors. Therefore directly coupled Interleaved boost converter is more suitable for renewable energy applications.

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