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SIMULATIOM AND COMPARISION OF INTERLEAVED BOOST CONVERTER TOPOLOGIES FOR PHOTOVOLTAIC SOURCE

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ABSTRACT---Renewable energy is derived from natural resources that are replenished constantly. 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. Three cases of interleaved boost converter have been considered and analysed. Two-phase mc'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. The waveforms of input, inductor current ripple and output voltage ripple are obtained using MA TLAB/SlMULINK. The design equations for IBC have been presented. Usingthe results obtained from simulation the best of the three IBC is inferred.

I. INTRODUCTION

Fossil fuels are energy sources such as coal, oil and natural gas. The world virtually depends on the supply of fossil-fuel for energy. But the common issue is that fossil-fuels are running out. It would take millions of years to completely restore the fossil fuels that we have used in just a few decades. This means fossil fuels are non-renewable sources of energy. Renewable energy comes in as a resolution for this global issue. Renewable energy is any natural source that can replenish itself naturally over a short amount of time. Renewable energy comes from many commonly known sources such as solar power, wind, running water and geothermal energy. Renewable energy sources are wonderful options because they are limitless. Also another great benefit from using renewable energy is that many of them do not pollute our air and water, the way burning fossil fuels does. Any such renewable energy system requires a suitable converter to make it efficient. Interleaved boost converter is one such converter that can be used for these applications. The Interleaved boost converter has high voltage step up, reduced voltage ripple at the output, low switching loss, reduced electromagnetic interference and faster transient response. Also, the steady-state voltage ripples at the output capacitors of mc are reduced. Though IBC topology has more inductors increasing the complexity of the converter compared to the conventional boost converter it is preferred because of the low ripple content in the input and output sides. In order to reduce this complexity, this paper investigates the benefits of coupled, uncoupled and inversely inductors for mc. Detailed analysis has been done to study the ripple content of all the three types of the converter. The suitable mc for fuel cell applications is proposed [1]. Gating pulses are generated using pulse generator. Simulations have been performed to validate the concepts.

II. OPERATION OF IBC

The two phases of the converter are driven 180 degrees out of phase, this is because the phase shift to be provided depends on the number of phases given by 360/n where n stands for the number of phases[3].

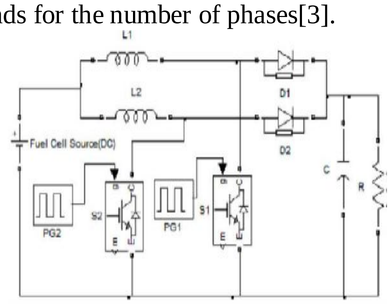

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Fig. 1 Circuit diagram of a two phase uncoupled IBC

Since two phases are used the ripple frequency is doubled and results in reduction of voltage ripple at the output side. The input current ripple is also reduced by this arrangement.

When gate pulse is given to the first phase for a time tJ, the current across the inductor rises and energy is stored in the inductor. When the device in the first phase is turned OFF, the energy stored is transferred to the load through the output diode D. The inductor and the capacitor serve as voltage sources to extend the voltage gain and to reduce the voltage stress on the switch. The increasing current rate across the output diode is controlled by inductances in the phases. Gate pulse is given to the second phase during the time t1 to t2 when the device in the first phase is OFF. When the device in the phase two is ON the inductor charges for the same time and transfers energy to the load in a similar manner as the first phase. Therefore the two phases feed the load continuously.

Fig.1 to 3 shows the schematic diagrams of the two phase interleaved boost converter with uncoupled, directly coupled and inversely coupled IBC. As the output current is divided by the number of phases, the current stress in each transistor is reduced. Each transistor is switched at the same frequency but at a phase difference of Π [3]. Switching sequences of each phase may overlap depending upon the duty ratio (D). In this case the input voltage to the IBC is 20V and the desired output voltage is 40V, therefore D has to been chosen as 0.5.

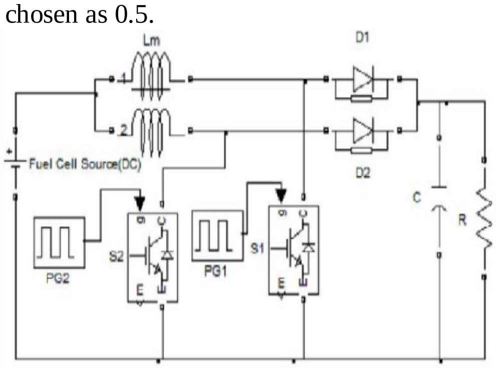


Fig. 2 Circuit Diagram of a 2-phase directly coupled IBC

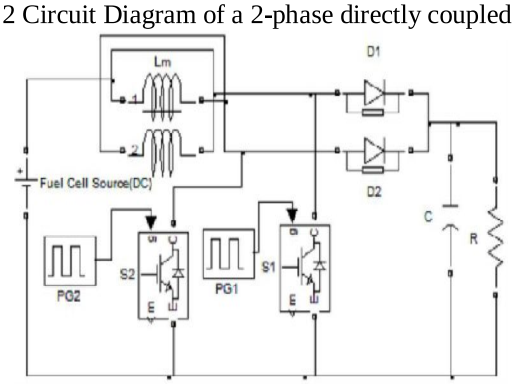


Fig. 3 Circuit Diagram of a two phase inversely coupled IBC

III. DESIGN METHODOLOGY OF IBC

The design methodology for all types of IBC's require 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 tradeoff 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.

— —— – (1)

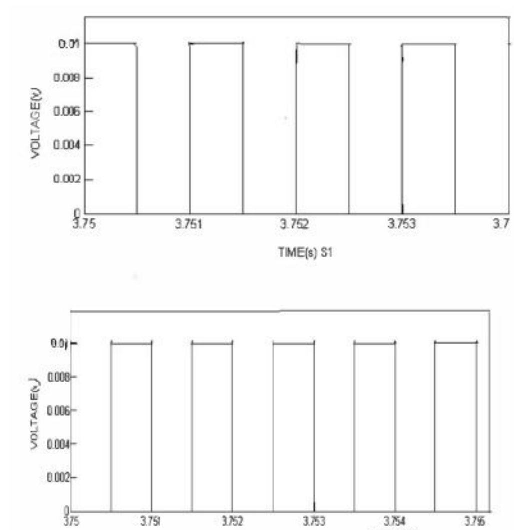


Fig. 4 Switching pattern for two phase IBC

The input current ripple can be zero at specific duty ratios which are multiples of lIN, where N stands for the no of phases. Here the number of phases is two therefore the duty ration is taken as 0.5. The switching pattern is shown in Figure 4.

B) Selection of inductors

For the selection of the proper inductor and capacitor the design equation part for all the three converters are given below:

1. Uncoupled inductor

The value of the inductance is given by equation

(2)

2. Coupled inductor

The equivalent inductance (Lcq) [9] expression for directly coupled mc is

(3)

Where V_{in} represents input voltage, D represents duty ratio. The phase current ripple which is decided by L_{eq} is given by

. (4)

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

(5)

The value of Lm is calculated as

Lm= α.L (6)

Therefore, the overall input current ripple is derived as

(7)

From the above equations it is clear that increasing the value of the coupling coefficient can effectively reduce the input current ripple, but the phase current ripple is increased [7]. 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 self inductance value for inversely coupled is obtained from the equation below:

(8)

The mutual inductance value is given by

Lm= - α.L (9)

C) Selection of Power Devices

The semiconductor device chosen for constructing the two phase interleaved boost converter is the IGBT [10]. The main benefits of IGBT are lower on state resistance, lower conduction losses and high switching operation. The maximum voltage across the switching devices is given by

(10)

Where V_{in} 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. Due to absence of reverse recovery current, there is no need of active snubber circuit for protection. Hence the circuit complexity is reduced. Circuit reliability is improved and design of the converter is simplified.

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

(11)

Where R represents the load resistance, V_0 represents the output voltage and T represents the switching period.

A. Solar Cell and PV Array Model

A PV generator is a combination of solar cells, connections, protective parts, supports, etc. In the present modeling, the focus is only on cells. Solar cells consist of a p-n junction; various modelings of solar cells have been proposed in the literature [14]–[16]. Thus, the simplest equivalent circuit of a solar cell is a current source in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell (photocurrent). During darkness, the solar cell is not an active device; it works as a diode, i.e., a p-n junction. It produces neither a current nor a voltage. Thus, the diode determines the *I*–*V* characteristics of the cell. For this paper, the electrical equivalent circuit of a solar cell is shown in Fig. 2 The output current *I* and the output voltage of a solar cell are given by

=

V=

Here, I_{ph} is the photocurrent, I_0 is the reverse saturation current, I_{d0} is the average current through the diode, n is the diode factor, q is the electron charge ($q = 1.6*10^{-19}$), k is

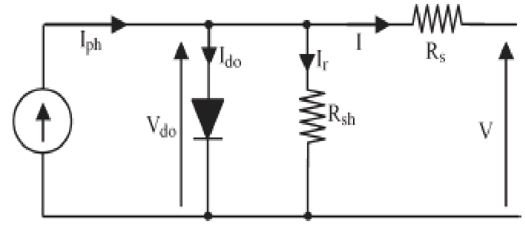


Fig. 2. Solar cell electrically equivalent circuit.

The Boltzmann's constant ($k = 1.38*10^{-23}$), and T is the solar

Array panel temperature. R_s is the intrinsic series resistance of the solar cell; this value is normally very small. R_{sh} is the equivalent shunt resistance of the solar array, and its value is very large. In general, the output current of a solar cell is expressed by

I=Iph-Io(exp(q/n.k.t(v+RsI))-1)-(V+RsI/Rsh)

In (3), the resistances can be generally neglected, and thus, it can be simplified to If the circuit is opened, the output current I = 0, and the If the circuit is shorted, the output voltage V = 0, the average current through the diode is generally neglected, and the short circuit current I sc is expressed by using

I sc = I = _ Iph/(1+Rs/Rsh)

Finally, the output power P is expressed by

$P = V I =$(Iph – I do – V do/Rsh)V.

IV. SIMULATION RESULTS

As per the design equations, a two phase interleaved boost converter with uncoupled, directly coupled inductors and inversely coupled inductors are simulated in MATLABI SIMULINK .The values for uncoupled mc 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 mc are summarized as Yin = 20V, R = 3.2 fl, C =78uF, fs= 2 kHz, Lm = 7mH, Lkl = Lk2 = 4.3mH, Vo =37v, D=0.5and a = 0.61 for directly coupled. Fig 5 and 6 shows inductor current ripple waveform and the output voltage waveform of uncoupled me. Figs. 7 and 8 show the inductor current ripple and output voltage waveforms of a directly coupled mc under steady-state condition. For directly coupled inductors, phase current ripple and input current ripple is lesser compared to uncoupled inductors.

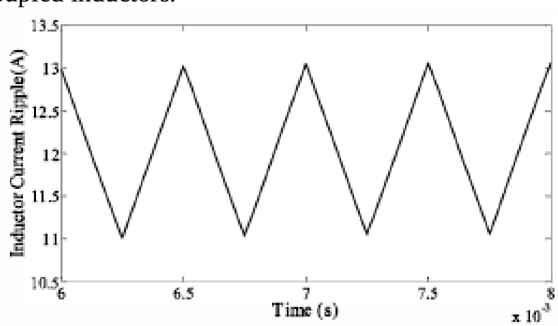
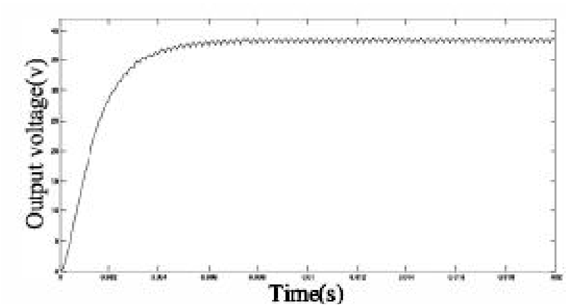


Fig. 5 Inductor current waveform for uncoupled IBC



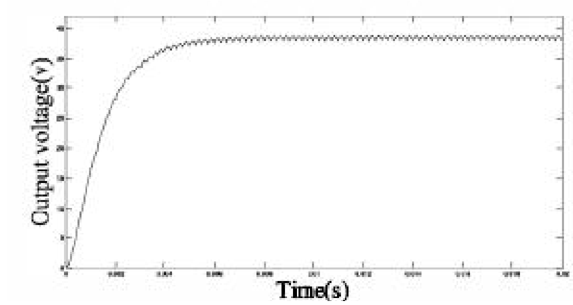


Fig. 6 Output voltage waveform of 2-phase uncoupled IBC

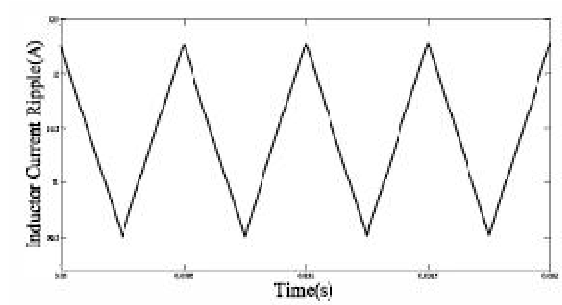


Fig. 7 Inductor current waveform for coupled IBC

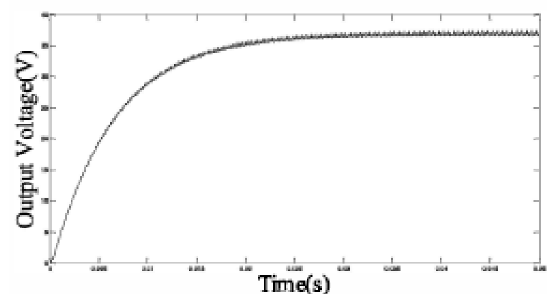


Fig. 8 Output voltage waveform for Coupled IBC

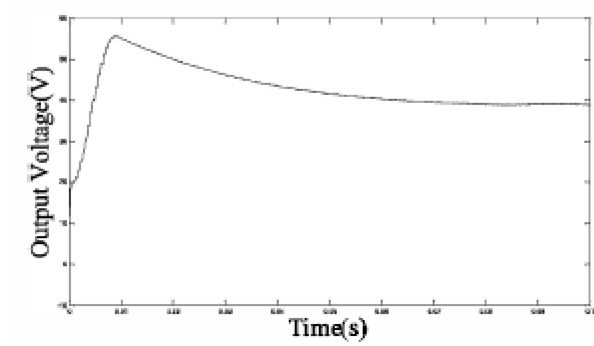


Fig. 9 Output voltage waveform for Inversely Coupled IBC

Fig 10 shows variation of the input current ripple of each phase according to duty ratio. The input current ripple of the conventional boost

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

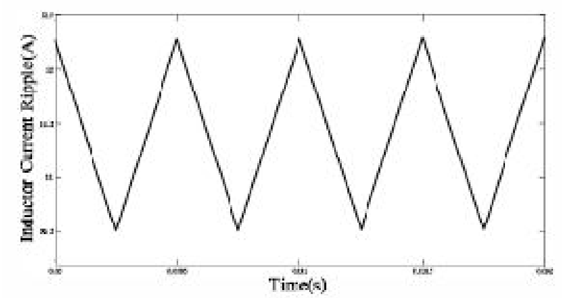

Fig. 7 Inductor current waveform for coupled IBC

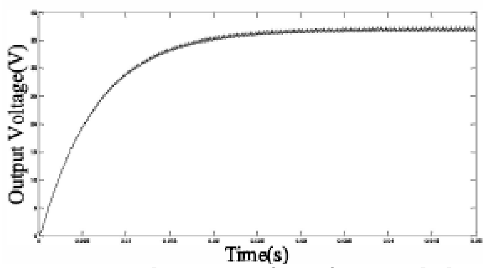

Fig. 8 Output voltage waveform for Coupled IBC

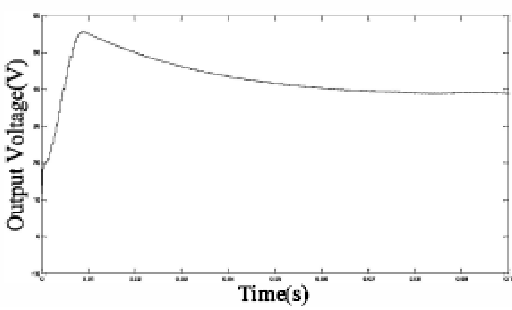

Fig. 9 Output voltage waveform for Inversely Coupled IBC

Fig 10 shows variation of the input current ripple of each phase according to duty ratio. The input current ripple of the conventional boost converter 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 l/N, such as 0.5 in 2-phase IBC. The input current ripple is proportionally increased to the input voltage. On the other side, it is inversely proportional to inductance and frequency.

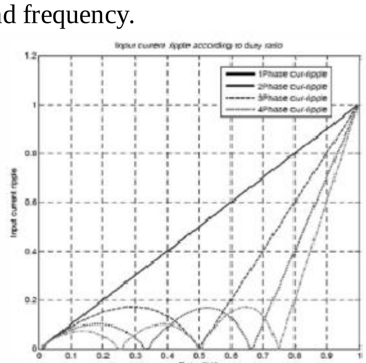

Fig. 10 Input current ripple variation with duty ratio

Fig.1l depicts the output voltage ripple. Compared with the conventional boost converter, the output voltage ripple of IBC is dramatically reduced [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 l/N^2 times.

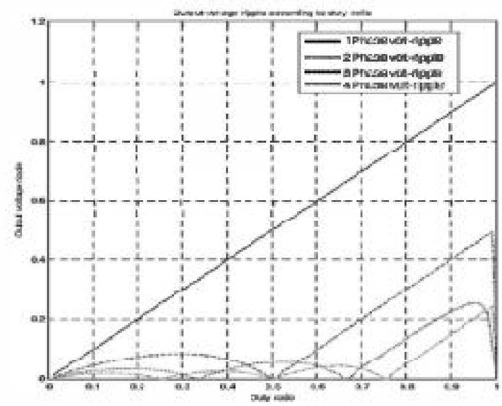

Fig. 11 Output voltage ripple variation with duty ratio

TABLE I

Simulation results for uncoupled, directly coupled and inversely coupled IBC

Parameters	Uncoupled IBC	Directly coupled IBC	Inversely coupled IBC
Output voltage ripple	0.5%	0.4%	0.42%
Inductor current ripple	16.67%	0.03%	0.06%
Inductor current ripple	0.08%	0.03%	0.06%

From the results we infer that the inductor ripple is lesser for inversely coupled compared to the others, however the input current ripple is higher for inversely coupled IBC. 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. This higher current ripple can be reduced by selecting proper value of duty ratio and coupling coefficient. The results indicate that the directly coupled IBC gives a reduced input current ripple which is best suited for fuel cell applications.

V. CONCLUSION

Interleaved boost converter has so many advantages and is a suitable converter for renewable energy applications. Three cases of IBC using uncoupled, coupled and inversely coupled inductor have been analyzed for renewable energy applications. Their design equations have been presented and performance parameters of all three cases have been 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 IBC is a suitable choice for fuel cells.

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