ANALYSIS AND EXPERIMENTATION OF TWO-PHASE INTERLEAVED BOOST CONVERTER WITH RIPPLE CANCELLATION NETWORK FOR PV APPLICATIONS

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ABSTRACT

Conventional sources like fossil fuels were used earlier to satisfy the energy demands. Nowadays these are being replaced by renewable sources like photo-voltaic sources. Photo-voltaic is a method of generating electrical power by converting the energy from the sun into direct current with the use of semiconductor devices that exhibit photovoltaic effect. They do not cause environmental pollution and do not require any moving parts. Different types of DC-DC Converters have been proposed in literature but Inter-leaved boost Converter (IBC) is widely used because of its fast dynamic response and high power density. This paper presents an analysis of the Ripple Cancellation Network (RCN) based two phase Interleaved boost Converter (IBC) for photo-voltaic applications. The results illustrate that IBC is more efficient than conventional boost converter as it reduces the input current ripple, output voltage ripple, component size and improves its transient response. On adding the Ripple Cancellation Network to the conventional IBC, the output voltage and input current ripple are further reduced without increasing the diode current stress. Simulations are carried out using MATLAB/Simulink software to verify with the theoretical results. Experimental set-up is developed for the proposed converter and the results are verified.

KEYWORDS

Coupled Inductor, Interleaved Boost, Photo Voltaic, Ripple, Ripple Cancellation

1.INTRODUCTION

Solar energy is converted to electricity using an electronic device called solar panel using photo-voltaic effect. PV applications can be grouped into utility interactive and stand-alone applications. Utility interactive applications provide a backup system to ensure that electricity is produced throughout the year irrespective of the weather conditions. While stand-alone systems without the utility connection uses the electricity where it is produced. However, to cater to the energy needs during non-sunny and cloudy period PV-charged battery storage system is used. PV systems with batteries can be used to power dc or ac equipment. PV systems with battery storage are being used all over the world to power lights, sensors, recording equipment, switches, appliances, telephones, televisions, and even power tools. PV serves as an ideal source using the availability of low DC power requirement for mobile and remote lightning requirements [1]. Systems using several types of electrical generation combine the advantages of each. Engine generators can produce electricity anytime. Thus they provide an excellent backup for the PV modules, which produce power only during daylight hours, when power is needed at night or on cloudy days. On the other hand, PV operates quietly and inexpensively, and it does not pollute.

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This paper presents an analysis of a two-phase Interleaved Boost Converter with Ripple Cancellation Network, which can be used for photo-voltaic applications[2]. A brief explanation of RCN is given and the reasons why IBC with RCN is considered the best topology are also discussed among other topologies. A simple DC-DC boost converter only steps-up the voltage, without taking into account the input current, output voltage ripple and passive component size.

Interleaved parallel structure has been used in many power density applications to reduce its input current ripple because of its frequency doubling characteristic, output voltage ripple, passive component size and improved transient response[3]. The drawback in a conventional IBC is that when the input current ripple is minimized, the inductor size increases adding to the converter weight which poses a huge difficulty. This drawback is eliminated by employing a coupled inductor. In coupled inductor IBC, higher ripple cancellation is achieved due to coupling of the inductor and also reduces the passive component size[4]. Disadvantages with this topology are the presence of leakage inductance and also the diode current stress increases causing extra EMI (Electromagnetic Interference) problem. RCN based IBC eliminates the above shortcomings. RCN based IBC achieves maximum ripple cancellation in both input current and output voltage and also eliminates the extra EMI problems seen in the previous topology. Hence this is chosen as the best topology for PV applications.

The paper (in four sections) initially presents a brief explanation of the working of a two-phase interleaved boost converter with ripple cancellation network. The number of phases is chosen as two as a trade-off between the converter size and ripple[5]. Next, the operation analysis and the design aspects of the proposed converter are presented. Further, the simulation results of the proposed converter demonstrating the input current ripple, output voltage ripple, inductor current ripple and diode current are presented. The parameters compared are input current ripple, output voltage ripple, diode current ripple and input/inductor current ripple ratio. Then, the experimented results of the proposed converter are verified with the simulated results. The hardware results are also presented. Finally, a conclusion is made based on the presented analysis. The software simulations for the analysis of the proposed converter are done using MATLAB/SIMULINK software.

2. INTERLEAVED BOOST CONVERTER WITH RIPPLE CANCELLATION NETWORK:

IBC with RCN achieves input current ripple cancellation without significantly increasing the current stress and loss of the converter. The topology comprises of two capacitors, two inductors and two coupled inductors. The coupled inductors in the network share the same core as that of the main inductors. It achieves maximum ripple cancellation at both the input current and output voltage and also it does not introduce any extra EMI problems[5]. The circuit of IBC with ripple cancellation network is shown in Fig.1.

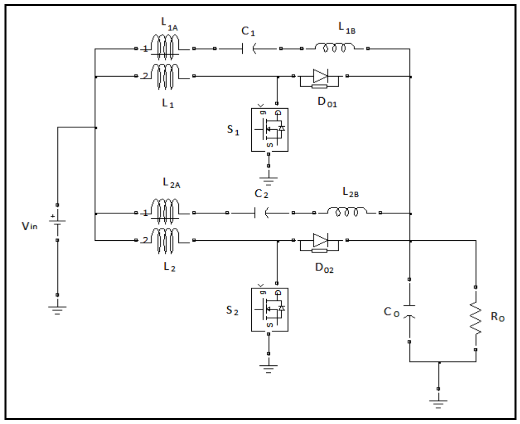

Fig.1. Schematic of IBC with RCN

The key steady waveforms of IBC with RCN are shown in Fig.2

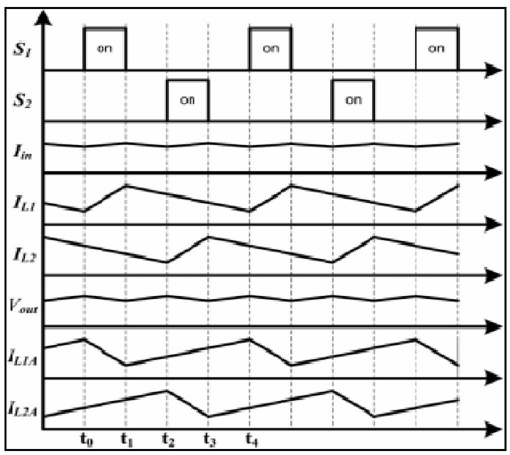

Fig.2. Steady waveforms of IBC with RCN

The selection of duty cycle, number of phases, coupling coefficient, design of inductors and capacitors are very important for reduction of both input current and output voltage ripple.

3. DESIGN EQUATIONS:

The number of phases, power devices and duty cycle chosen is same for all the three topologies of IBC.

3.1 Selection of number of phases:

The ripple content decreases with increase in number of phases. Increasing the number of phases does not decrease the ripple content to a great extent and further the circuit becomes more complex. Hence, as a trade-off between the ripple content and the cost and complexity, the 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.

3.2 Selection of duty cycle:

The decision of the duty cycle is based on the number of phases. Depending upon the number of phases, the ripple is the least at a certain duty ratio. For two phase interleaved boost converter, the ripple is the least at a duty ratio of 0.45 to 0.5. Hence, the design value of the duty ratio is chosen as 0.5 [6,7]. The duty cycle D can be calculated by the following formula

$$D = \frac{V_o - V_{in}}{V_o} \quad (1)$$

where V_0 is the output voltage and V_{in} is the input voltage.

3.3 Selection of power devices:

The semiconductor devices chosen for constructing the two phase interleaved boost converter is MOSFET (IRFP90N20D) and a fast recovery diode (MUR 3020WT). The power MOSFET has lower switching losses and also higher switching frequency. The fast recovery diode has an advantage of ultra-fast recovery time[8].

The parameters chosen are V_{in}=36V, V_0=50V, D=0.5, F=100 kHz and Pout=1000W.

3.4 Design of inductance and capacitance:

When the switch S1 is ON, the other switch S2 remains OFF. During this time, the main inductor L1 is charged linearly. In the meantime, the main inductor L2 starts to transfer its energy to the load Ro. Similarly during the next cycle, the switch S2 is ON and the switch S1 remains OFF.

The main inductor L2 is charged linearly and at the same time the inductor L1 starts transferring its energy to the load Ro. In the proposed converter, $L_1=L_2=L$, $L_{1A}=L_{2A}=L_A$,$L_{1B}=L_{2B}=L_B$ and $M_1=M_2=M$[9]. So, the input current ripple is expressed as

$$\Delta I_{in} = \frac{(M - L_A - L_B)(2V_{in} - V_{out})}{(M^2 - LL_A - LL_B)} \frac{(V_{out} - V_{in})}{V_{out}} \quad (2)$$

The current stresses of the switches and diodes in the converter are equal to the maximum inductor current value as follows

$$I_{Lmax} = \frac{P}{V_{in}} + \frac{\Delta I_{L1}}{2} \quad (3)$$

Inductor value is calculated in the following manner and ΔI_1 is the inductor current ripple

$$L_{eq} = \frac{V_{in} DT}{\Delta I_l} \quad (4)$$

A capacitor filter is needed at the output to limit the peak to peak ripple of the output voltage. The value of capacitance is given by the formula

$$C_o = \frac{V_o DT}{R \Delta V_o} \qquad (5)$$

where ΔV_0 is the output voltage.

Based on the above equations, the simulation parameters for IBC is shown in Table 1

Parameters	Value
Input Voltage, V_{in}	25V
Output Voltage, V_o	50V
Output Power, P_{out}	1000W
Switching Frequency, F	21kHz
Coupling coefficient, α	0.61
Main inductor, L_1, L_2	15μH
Coupled inductor, L_{1A}, L_{2A}	2 μH
Inductor, L_{1B}, L_{2B}	3.5 μH
Mutual inductance	35uH
Capacitor, C_1, C_2	10 μF
Output capacitor, C_o	6800 μF

Table 1: Parameters for IBC with RCN

The values of C1 and C2 in the RCN depends on the voltage ripple of the capacitor and current ripple of the conventional IBC[10]. With 5-10% voltage ripple of the voltage difference between input and output on the capacitor and current ripple of the conventional IBC, the value of C1 and C2 are calculated.

4. SIMULATION RESULTS:

4.1 Gating pattern:

The gate pulses for the MOSFETs are shifted by 360/n for an 'n' phase design. Since the number of phases chosen here is 2, the pulses are shifted by 360/2 i.e., 180 degrees apart. The gating pattern is similar for both coupled and uncoupled topologies[11].

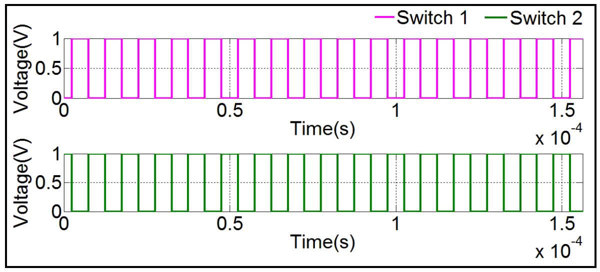

Fig.3 Gating pattern

4.2 Voltage waveform of IBC with RCN:

The output waveform for IBC with RCN was observed as shown in Fig.4

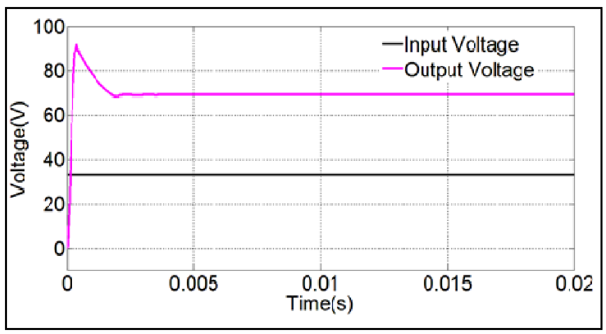

Fig.4 Input/Output voltage of IBC with RCN

The ripple waveforms were observed as shown in Fig.5

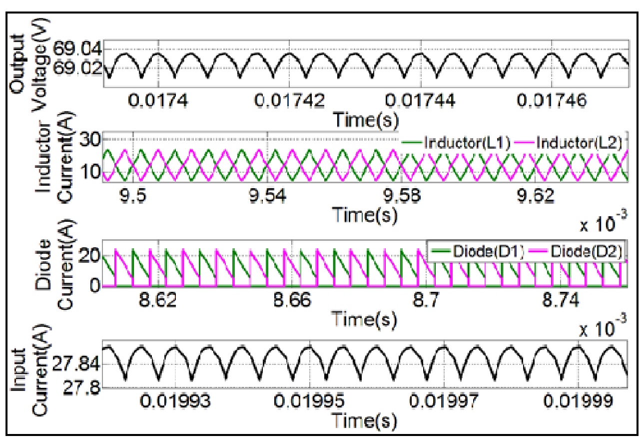

Fig.5 Ripple waveforms for IBC-RCN

From the above waveforms, the output voltage ripple was found as 0.0315% and the input current ripple was found as 0.1743%. The diode current stress was calculated as 28.367A.

A comparison between three different topologies, coupled, uncoupled and IBC with RCN is presented in Table 2. The table illustrates that for two different values of coupling coefficients, the input current, output voltage and the ratio of input current to inductor current ripple is the least in IBC with RCN topology. It can also be found that the diode current stress is minimum for the same.

Parameters	Uncoupled IBC	Coupled IBC		IBC-RCN	
Coupling co-efficient		K=0.61	K=0.7	K=0.61	K=0.7
Input Current Ripple (%)	0.15	0.19	0.18	0.017	0.172
Output Voltage Ripple (%)	2.052	2.016	2.024	1.015	1.061
Diode Current Stress (A)	28.2	28.37	28.41	28.36	28.46
Ratio (Input Current Ripple/Inductor Current Ripple)	0.001976	0.001549	0.001418	0.001477	0.001259

Table 2: Comparison between uncoupled, coupled IBC and IBC based RCN

5.EXPERIMENTAL PROTOTYPE OF TWO PHASE INTERLEAVED BOOST CONVERTER WITH RIPPLE CANCELLATION NETWORK:

A prototype of 2-phase IBC with ripple cancellation network (RCN) has been developed as shown in Fig.6 in order to verify the simulation results. The hardware set-up consists of the main power circuit, astable multivibrator circuit for pulse generation and power supply circuit for optocoupler[12]. The main power circuit consists of two boost converters in parallel with MOSFET (IRF840) for switching of the converter circuit. Two sets of optocouplers (MCT2E) are used to isolate the power circuit from the pulse generation circuit. NE555 timer is employed to generate the pulses required to trigger the two MOSFETs. A NOT gate (IC 7404) is used to phase shift the NE555 timer's output by 180°. The main power circuit has two sections. They are the converter section which consists of the ripple cancellation network (RCN) and the output section. The converter circuit consists of two sets of coupled inductors. The Ripple Cancellation Network consists of a pair of capacitors and a pair of single inductors one for each phase. The output section consists of a filter capacitor and an output resistor[13].

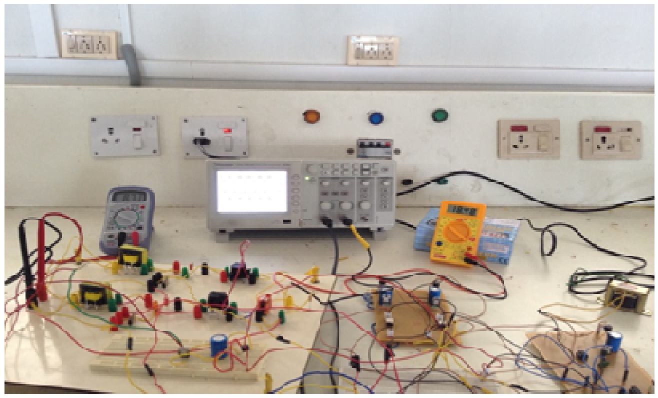

Fig.6 Hardware prototype for two phase IBC with RCN

6. WORKING:

The NE555 timer circuit generates the triggering pulses for the MOSFETs. A NOT gate (IC 7404) is used to produce a 180° phase shifted pulse for one of the MOSFET. The output pulses are then given to the optocouplers as they provide isolation. The optocouplers reproduce the input pulses given to them. The pulses from the optocouplers are given to the MOSFETs. The outputs from the optocouplers are as shown in Fig.8. The pulses are in such a way that when one phase of the converter is turned ON, the other remains OFF. The phases are switched ON alternatively at a high frequency of about 21 KHz. The voltage at the output is boosted and in addition to it due to the high switching frequency, the ripple in the output voltage is also reduced [14]. With the inclusion of the ripple cancellation circuit together with the interleaved boost converter, the ripple value is further reduced [15]. The output voltage and input current ripple waveforms are shown in Fig.10. The ripple values are measured with the help of a PQ clamp meter.

Fig.7 Gate pulses phase shifted by 180°

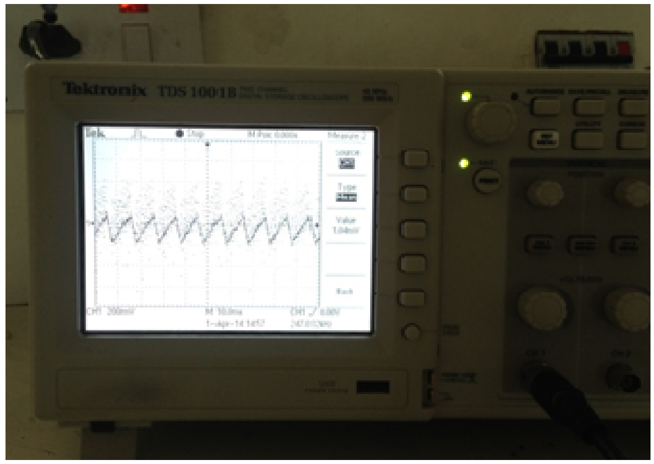

Fig.8Output voltage ripple of IBC with RCN

Fig.9Output voltage ripple of IBC with RCN using PQ Analyser

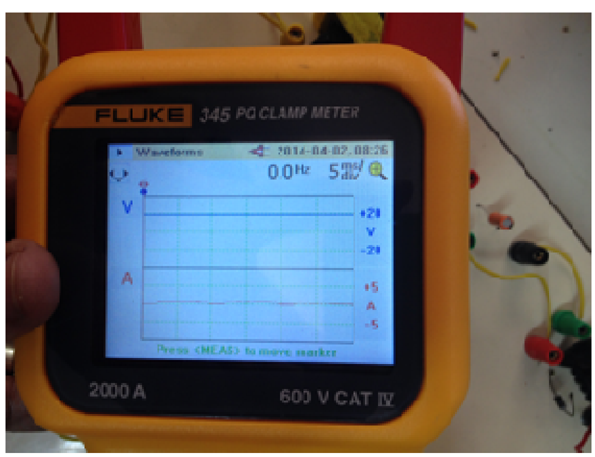

Fig.10 Output voltage and current waveforms from PQ Clamp Meter

Table 3: Comparison of simulation and experimental results:

Parameters	Simulation	Experiment
Input	**10 V**	**8.71 V**
Output	**20 V**	**20.96 V**
Output Voltage Ripple	**1.015%**	**1.4%**

7. CONCLUSION:

This paper has introduced a two-phase Interleaved Boost Converter with Ripple Cancellation Network for photo-voltaic applications. The parameters such as input current ripple, inductor current ripple, diode stress and the ratio of input and inductor current ripple are compared to analyse the ripple cancellation effect. The design equations have been presented. It is found that RCN based IBC achieves the highest ripple cancellation at the input current and output voltage. The addition of a Ripple Cancellation Network has led to a reduction in diode current stress, loss and converter weight in the proposed converter. Moreover, it has been recorded that the input current ripple is minimum for a high coupling coefficient. The output voltage ripple is observed to be 1.4%. It is found that IBC with RCN achieves highest input current ripple cancellation with an increasing efficiency at all power ranges. The results have been validated by simulations and experimental analysis. From these results, two-phase IBC with RCN proves to be a suitable topology for PV applications and high power, high efficiency dc-dc conversion.

8. ACKNOWLEDGEMENT:

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