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Ripple Current Reduction Technique for DC to DC Converter Using Tapped Inductor

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Abstract: A new ripple current cancellation network (RCN) using Tapped inductor at the input of the boost converter with high conversion ratio is presented in this paper. This converter provides continuous input current and reduces the size and weight of the converter compared with the conventional Boost Converter (CBC). The tapped inductor can be easily realized by adding an extra tap in the main inductor of the CBC. Since the capacitor and inductor in the RCN do not need to handle the main power as the conventional LC input filter. A ripple current cancellation technique injects alternating current into the output voltage bus of a converter that is equal and opposite to the normal converter ripple current. The proposed converter is compared with conventional Interleaved Boost topology (IBC) shows that input current ripple cancellation in various power ranges without increasing the losses. The tapped inductor technology based DC—DC converter is an integration of boost converter with coupled inductors. The tapped converter of the classical switch –mode power converter is an extension of the conventional switch mode power converters. Using the tapped configuration the control parameter of the converter can be using tapping. The proposed converter has two modes in one operational period. This converter is controlled by switch S. Design for a 500W converter is conveyed in this paper with input voltages taken as 36V and output voltages of 50V is done for a switching frequency of 100 kHz. The duty cycle of the boost converter during the steady operation is 0.3 and turns ratio of tapped inductor is 2(10:20). The converter is simulated for both modes of operation using PSIM. Output levels are obtained as per the design values for converter operations. This converter shares the same characteristic of CBC and input current ripple cancellation can be achieved by adding one capacitor and one inductor without significantly increasing the current stress and losses. Simulation results conveys the operability of the converter structure.
Keywords: TAPPED INDUCTOR,INTER LEAVED BOOST CONVERTER

I. INTRODUCTION

The DC to DC converter with high step-up voltage gain is widely used for many applications such as fuel-cell energy-conversion systems, solar-cell energy-conversion systems, and high-intensity-discharge lamp ballasts for automobile headlamps. Conventionally, the DC–DC boost converter is used for voltage step-up applications, and in this case, this converter will be operated at extremely high duty ratio to achieve high step-up voltage gain. A practical limitation of switch mode power converters is the presence of inductor ripple current. This ripple current creates filtering difficulties, control issues, output voltage noise, and other problems.Low noise supplies are required for signal processing, high performance imaging, instrumentation equipment, and other signal to noise sensitive applications. In order to minimize the input current ripple of the conventional boost converter (CBC), large input inductor value has to be chosen. However, large inductor values not only increase the total weight of the converter but also lead to worse dynamic response. A well-designed input filter is able to reduce the input current ripple, but the size and weight of the filter are quite unacceptable particularly in high-power applications.A ripple current cancellation technique injects alternating current into the output voltage bus of a converter i.e; equal and opposite to the normalconverter ripple current.

Coupled inductor based boost topology reduces the input current ripple when the coupling coefficient is equal to K= $\sqrt{\frac{L_1}{L_2}}$ .This is very impractical to fix the coupling coefficient.

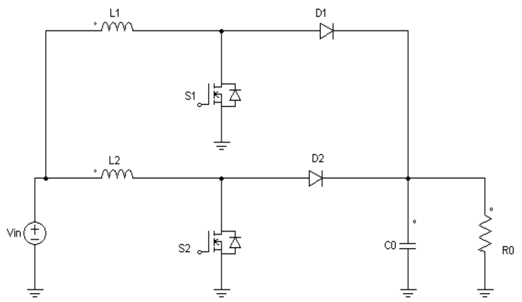


Fig -1:conventional interleaved boost converter

Using the interleaved boost topology with RCN such that input current ripple cancellation is achieved by adding two capacitors ,two coupled inductors and two inductors as RCN which seems to solve the unpredictable coupled coefficient but these extra parameters increases the total weight of the converter. The tapped converter of the classical switch mode power converter is an extension of the conventional switch mode power converters. Using the tapped configuration the control parameter of the converter can be using tapping. A boost converter with tapped inductor RCN (TIRCN) is developed in this paper. The tapped inductor is similar to an auto transformer ie energy is stored in the inductor when the switch is on and is delivered to the output through the diode. In order to analyze the dynamic and static characteristics of CBC after adding RCN shows that the proposed converter has the same characteristics as the CBC and input ripple cancellation can beachieved in all power ranges. The proposed TIRCN minimizes the input current ripple of the boost converter without introducing extra EMI problem and deteriorating the reverse-recovery problem of the output diodes by adding an extra capacitor and an extra inductor. In Section II, the operating principle and design consideration of the proposed converter are presented. Section III presents the simulation results obtained and concluding remarks are presented in section IV.

Converter Structure and Operation

The paper proposes a new ripple current cancellation network (RCN) using tapped inductor at the input side of the boost converter shown in fig 2. The tapped inductor can be easily realized by adding an extra tap in the main inductor of the conventional boost converter. The RCN consisting of an auxiliary circuit which is a combination of inductor and capacitor .These inductor and capacitor do not needed to handle main power as conventional boost converter and Interleaved boost converter(IBC).

A. Converter Structure

For a tapped inductor ripple current cancellation network (TIRCN) for a boost converter following specifications are taken.

i. Input voltage source, Vin.
ii. Tapped inductor, one switch, one capacitor and one inductor
iii. R_0 and C_0 are the output resistance and filter capacitor

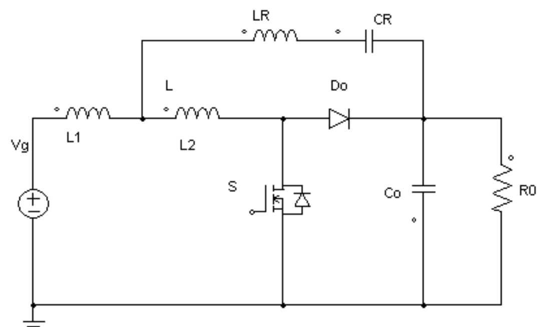


Fig-2: Proposed Converter Structure

Based on Kirchhoff's circuit law, the proposed TIRCN converter can be replaced by three equivalent non coupled inductors. By proper switching, controlled power flow between inputs and outputs are possible. Circuit of proposed TIRCN converter is shown in fig 2.

B. Operation

The proposed converter has two modes in one operational period. The equivalent circuit of proposed TIRCN as shown in fig 3 includes three equivalent inductors L_A, L_B, and L_C , main switches S, auxiliary capacitor C_R, output capacitor C_o, and output diodes D_o. The corresponding equivalent inductors are $L_A = L_1+M$, $L_B=L_2+M$, and $L_C=L_R-M$.The corresponding equivalent circuits for each operational stage are shown in Fig. 4 and Fig 5.Its operation can be explained with assumption that the circuit comprises of ideal components, unit coupling coefficient and under continuous conduction mode

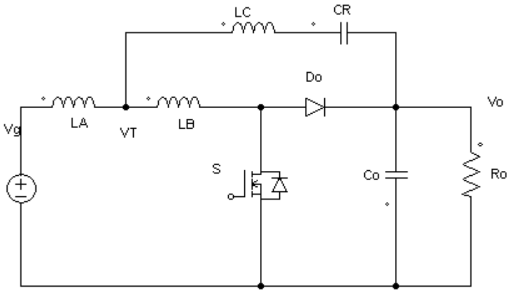


Fig- 3: Equivalent circuit of proposed converter

Mode 1[t_0-t_1]

At this mode the switch *S* isturned on, the main inductors $L_A$and $L_B$of the converter are charged linearly by the input voltage, causing their current i_1 and i_2 to increase linearly with different slopes. The output diode *Do* maintains off with the voltage stress equivalent to the output voltage. The auxiliary inductor current i_3 decreased linearly in order to achieve input current ripple cancellation of the proposed converter. The differential equations of proposed converter during the on-state can be expressed as

$$L_A \frac{di_{1-on}}{dt} + L_B \frac{di_{2-on}}{dt} = V_g \quad (1)$$

$$L_A \frac{di_{1-on}}{dt} + L_C \frac{di_{3-on}}{dt} = V_g - V_{CR} - V_0 \quad (2)$$

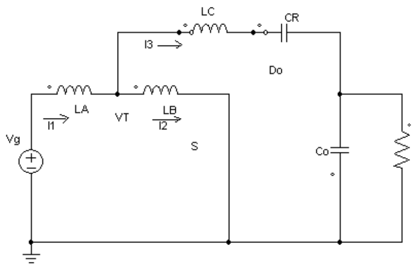


Fig-4:Mode 1[t_0-t_1]

Mode 2[t_1-t_2]

At this mode the switches *S* is turned off, both the main inductors $L_A$and $L_B$start to transfer their energy to the load Ro, so the inductor currents i_1 and i_2 decrease linearly with different slopes. The auxiliary inductor i_3 increased linearly in order to achieve input current ripple cancellation at this stage. The differential equations of proposed converter during the off-state can be expressed as

$$L_A \frac{di_{1-off}}{dt} + L_B \frac{di_{2-off}}{dt} = V_g - V_0 \quad (3)$$

$$L_A \frac{di_{1-on}}{dt} + L_C \frac{di_{3-on}}{dt} = V_g - V_{CR} - V_0 \quad (4)$$

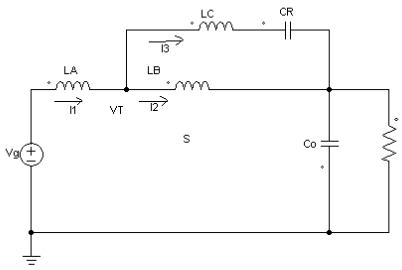


Fig-5: Mode 2[t_1-t_2]

The key steady state waveform of the proposed TIRCN converter are depicted in Fig 6

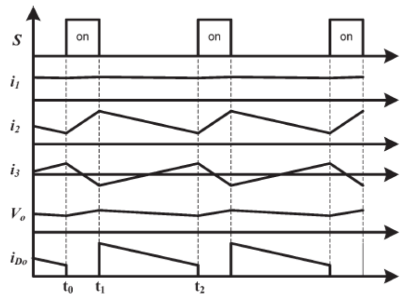


Fig-6: Steady state Waveforms

Based on the above equations, the input current ripple $\Delta i_{in}$of the boost converter with proposed TIRCN can be expressed as

$$\Delta_{in} = \Delta_{i_1} = \frac{V_g L_C}{L_A L_B + L_A L_C + L_B L_C} DT \qquad (5) \qquad \Delta_{i_2} = \frac{V_g}{L_B} DT \qquad (6)$$

Under the same operating condition, the current ripple of IBC can expressed as

$$\Delta_{in} = (\frac{2V_{in} - V_{out}}{L})(\frac{V_{out} - V_{in}}{V_{out}})T \qquad (7)$$

II. DESIGN

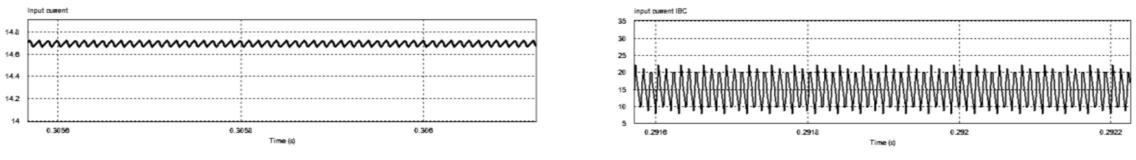
The proposed converter is controlled by switch S. Design for a 500W converter is conveyed in this paper. With input voltages taken as 36V and design for output voltages of 50V is done for a switching frequency of 100 kHz.The duty cycle of the boost converter during the steady operation is 0.3 and turns ratio of tapped inductor is 2(10:20). Load resistance are taken equal and slightly above the design values. Inductor and capacitor values are calculated for the proposed converter. Design parameters are detailed in the table 1

Table 1- Simulation Parameters

parameters	**IBC**	**TIRCN converter**
V_{in}	36 V	36 V
V_{out}	50 V	50 V
Switching Frequency	100 KHz	100 KHz
L_1,L_2	9.11μH,27.67 μH	15 μH
Coupling Coefficient k	0.693	0.985
Mutual Inductor M	11μH	10.6 μH
Auxiliary Inductor L_R	11.25μH	
R	5 Ω	5 Ω
Capacitor C_R,C_0	3.3μF,470μF	470μF

III. SIMULATION

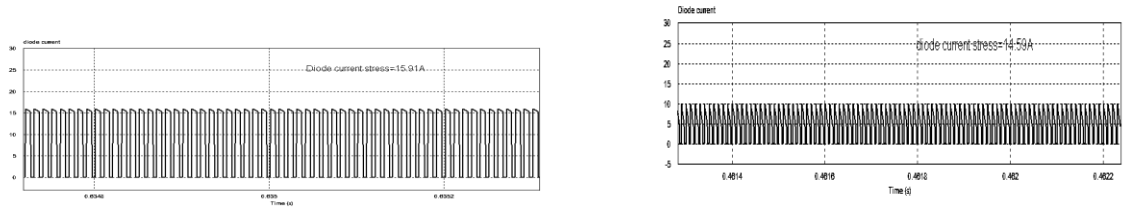
The PSIM simulation tool is used to simulate the DC to DC converter. An input voltage of 36V and switching frequency of 100 kHz is chosen and an output of 50V/10A is obtained. Simulation results of input current under closed loop control is provided in fig. 8.



(a) (b)

Fig-7: Input Current waveform of two converter(a)IBC (b)TIRCN

The simulated input current waveforms of IBC and proposed converter as shown in fig 8.The input current ripple of IBC be 12.08A while the TIRCN converter dropped to 50mA.



(a)IBC (b) TIRCN

Fig-8: Diode current waveform of two converter

The closed loop simulated diode current waveforms of conventional IBC and proposed converter as shown in fig 9.The diode current stress of proposed converter was 15.91A which is slightly higher than IBCwhich is 14.59A

A. Line regulation

In order to check the line regulation 50% increase and decrease of input voltage applied as step voltage.

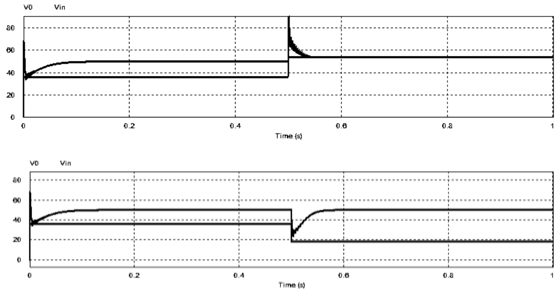


Fig-9:(a) 50% increase (b) 50% decrease

Fig 10 shows the output voltage(v_0) at 50% increase and decrease of input voltage (v_{in}) 36V . It shows that the transient voltage ripples are maintained at low level.

B. Load regulation

In order to check the effect of sudden change in any of the output, a step load that changes from 0 to 10A and 0 to 5A as load in the circuit.

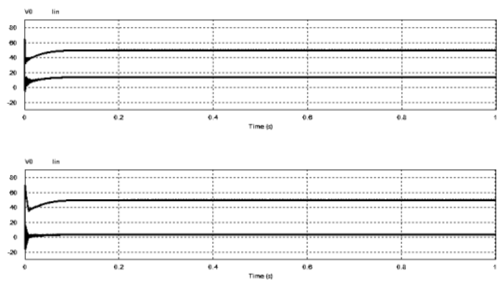


Fig-10: output voltage (v_0) and input current (I_{in})at (a) full load (b)half load

Fig 11 shows that the output voltage and input current at full load &half load with input voltage 36V . It shows that the output voltage was regulated at any load.

IV. CONCLUSION

This paper has introduced and developed boost converters with proposed TIRCN. The proposed converter shares the same characteristics of the CBC, and the input current ripple cancellation can be achieved in all power ranges.The input current ripple cancellation can be achieved by adding one capacitor and one inductor without significantly increasing the current stress and losses. The closed loop simulations are done using PSIM software and comparing with conventional IBC. It shows that the proposed converter achieve input current ripple cancellation in various power ranges without increasing the losses.

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