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Coupled-Inductor-Inverse High Step-Up Converter with Voltage Multiplier

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Abstract: The proposed converter includes a three winding coupled inductor inverse circuit combined with a boost converter. Hence the output voltage can be increased by reducing the turns ratio of the coupled inductor. Main switch suffers from high voltage stress due to the leakage inductance of the coupled inductor. A voltage multiplier circuit could further increase the voltage gain and output power. Voltage multiplier circuit can also reduce the voltage stress across the main power device. A clamping circuit consisting of a diode and capacitor could reduce the leakage inductance energy. The smooth operation of the proposed system is realised by sinusoidal pulse width modulation. A simulation of the proposed system is modelled and evaluated with desirable results in MATLAB/Simulink.

Keywords: PV-Photovoltaic, PWM – Pulse width modulation

I.INTRODUCTION

Renewable power sources such as Photovoltaic (PV) panels, geothermal sources, fuel cells, wind turbine are applicable for distribution generation systems. These power sources generate a low voltage thus for operating loads at high voltage a dc-dc converter is required. Various converters that convert power from low-voltage side to high voltage side is developed [9]. Conventional boost DC-DC converter having low cost and simple structure is normally adopted. Boost converter with an extreme duty cycle can have high voltage conversion gain [4]. This makes serious reverse recovery problem and peak current on the power device is relatively considerable. Thus, the performance of converter is deteriorated.

In transformer based converters such as forward, push-pull or fly-back converters by adjusting the turns ratio of the transformer high step-up voltage gain can be achieved [5]. The leakage inductor of transformer will cause serious problems such as voltage spike on the main switch and high power dissipation. Another method is the use of voltage-lift technique [10]. For very large conversion efficiency several diode-capacitor stages are required, which makes the circuit complex.

For ultra large conversion gain, there are three types of dc-dc converters-linear regulators, switching regulators, and switched-capacitor converters [3,7]. Linear regulators are available only for step down applications. For switching regulators their power conversion and transfer are performed by using inductors or bulky transformers. Thus simple circuit and low cost become impossible. Switched capacitors have high charging current, and induces high conduction loses.

Coupled-inductor based converters can also achieve high step-up voltage gain by adjusting the turns ratios [2]. Voltage gain can be directly proportional to the turns ratio of the coupled inductor. Since, energy is stored in the leakage inductor, the main switch may experience a voltage spike and deteriorates the conversion efficiency. Several active and passive clamping circuits were developed to recycle the leakage inductance energy [6]. Passive clamping circuits employ a diode-capacitor network to recycle the leakage energy. For achieving larger gains, it requires high number of winding turns. With large turns ratio several problems such as core losses, leakage inductances and parasitic capacitances among several windings, are of major concerns [1]. Thus a three winding inverse coupled inductor network can be implemented where gain is inversely proportional to turns ratio.

Voltage multiplier cells can be added or increased in a converter to get high output voltage and to reduce voltage stresses of components, which results in increased flexibility in device selection and output voltage across the load [8].

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II. SYSTEM DESCRIPTION

The three winding inverse coupled inductor is shown in Fig.1. A general structure of the converter consists of three parts: 3 winding inverse coupled inductor, DC-DC step up converter, voltage multiplier circuit and load. This is shown in Fig 2.

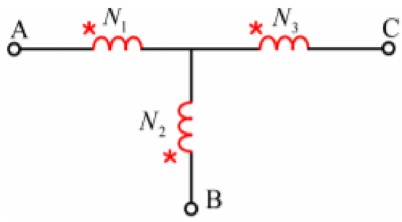

Fig. 1 Three winding inverse coupled inductor

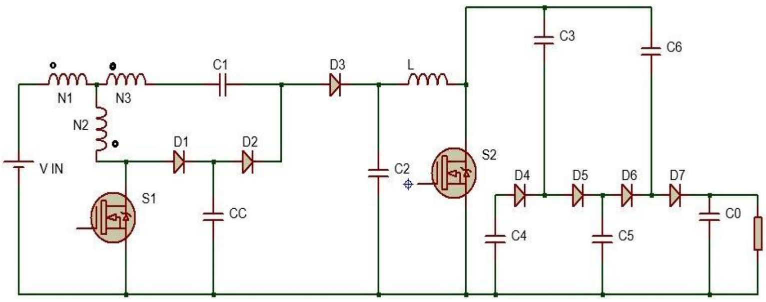

Fig 2. Circuit diagram of the proposed converter

The DC-DC converter is widely used in various kinds of standalone applications. It consists of an input DC voltage source, three winding inverse coupled inductor with magnetizing inductance L_M, switching device S1, passive clamped circuit (D1 and Cc), capacitors C1 and C2, diodes D2 and D3. The voltage multiplier cell consisting of inductor L, switching device S2, capacitors C3, C4, C5, diodes D4, D5, D6, D7 and a load consisting of Co and Ro.

III. PROPOSED SYSTEM

The three winding coupled inductor is modeled as ideal transformer with magnetizing inductance $L_{M,}$ and leakage inductor $L_{K..}$ Let us choose K as L_M / (L_M +L_k). Applying the volt-second balance principle on magnetizing inductance $L_{M,}$ the summation of inductor voltage over one period will be zero. The voltage expressions of capacitor C_C

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

The voltage expression of capacitor C_1

$$V_{C_1} = V_{in}\left(\frac{1}{1-D} + \frac{N_2+N_3}{N_1-KN_2}K\right)$$

Based on above equation the voltage conversion gain can be obtained as

$$M = \frac{1}{1-D} + \frac{1}{1-D} * \frac{N_1+KN_3}{N_1-KN_2}$$

When K=1 the ideal voltage conversion gain is

$$M = \frac{G}{(1-D)} = \frac{2n_{12}+n_{32}-1}{(1-D)(n_{12}-1)}$$

Where G = ((2N_1 + N_3 - N_2)/ ((N_1 -N2))), n_{12}=N_1/N_2 , n_{31}=N_3/$N_{1,}$ and n_{32}=N_3/N_2 are turns ratios of the three winding inverse coupled inductors. Thus the output voltage of the converter can be increased by reducing the turns ratio of the coupled inductors.

A. Smaller Turns Ratio

In the proposed converter, the smaller turns ratio is, the larger the gain is. Under the same operating condition, the smaller turns ratio not only reduces the leakage inductance and the parasitic capacitance formed by the secondary winding of the coupled inductor, but also increases the power density and reduces the core and copper losses. These

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changes efficiently improves the performance of the converter. Thus comparably less turn numbers can achieve comparably higher gain. The size, cost and losses are smaller under this condition. As the duty cycle is tended to 1, the voltage gain of the proposed converter is decreased ahead. Therefore, the proposed converter should operate away from duty cycle 1.

B. Magnetising Inductance

The inductance value is determined by the current ripple through the inductor. When the switch is turned on, the voltage stress on the magnetizing inductance makes the current increase linearly

$$L_M \frac{di_{LM}}{dt} = \frac{n_{12} V_{in}}{n_{12} - 1}$$

The average current through the magnetizing inductance can be expressed as

$$I_{L_M} = \frac{V_o(1 + n_{13})}{R(1 - D) n_{13}}$$

Finally, the magnetizing inductance is

$$L_M = \frac{n_{12} V_{in} D R (1 - D) n_{13}}{k V_o (1 + n_{13})(n_{12} - 1) f_s}$$

IV. CONTROL OF THE PROPOSED SYSTEM

Sinusoidal Pulse Width Modulation (SPWM) technique is used for switching the circuit. Fig 3 shows the PWM switching technique. The sinusoidal signal is generated by means of pulse generator. The required constant output voltage and the obtained value are given as input to the comparator. Whenever the output is below the required value the relay provides input to the AND logical operator. Thus when the relay reads high, the AND logical operator provides switching pulse. Switching and winding current waveforms of the proposed converter are shown in Fig 4.

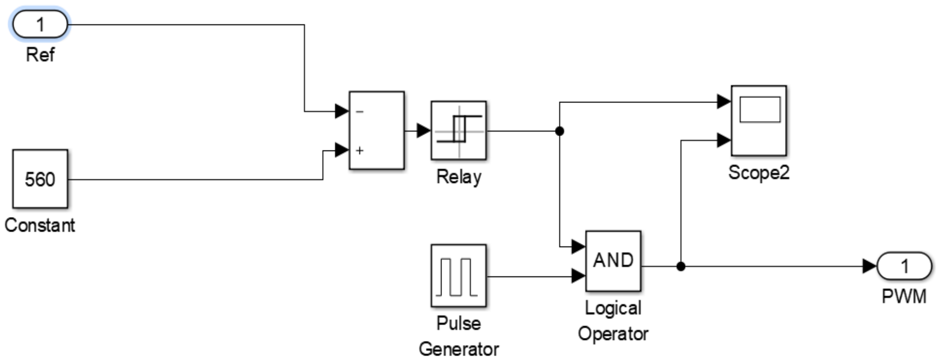

Fig. 3 PWM switching technique

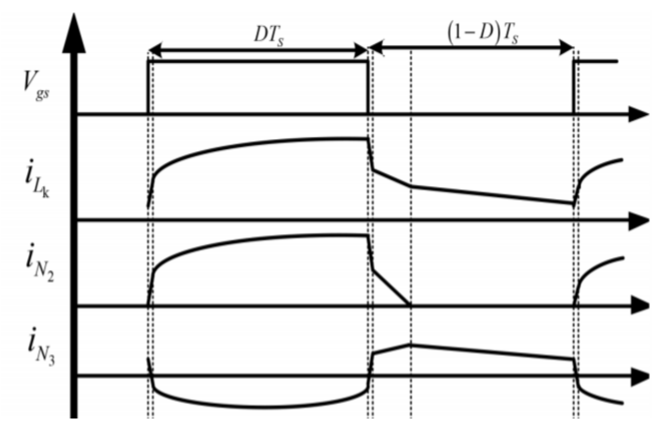

Fig. 4 Switching and winding current waveforms of the proposed converter

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V. SIMULATION RESULTS

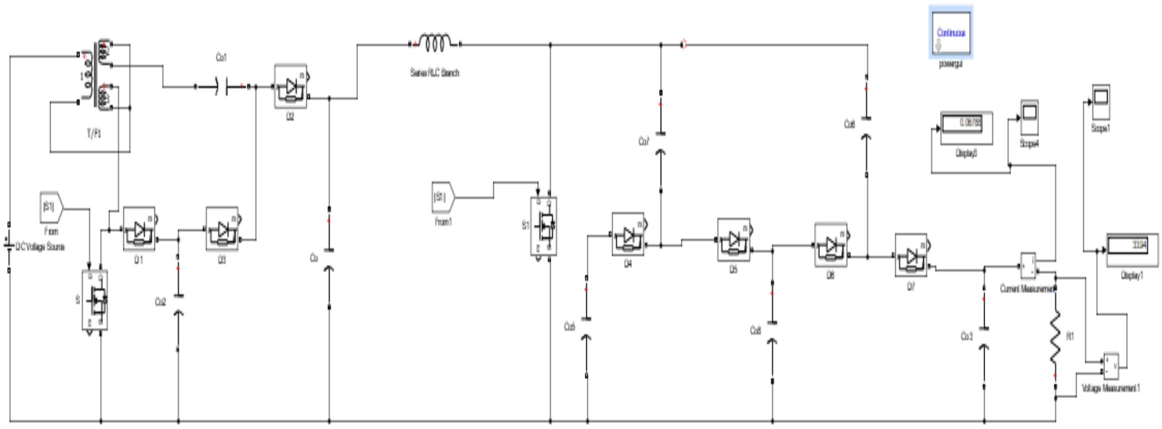

Fig 5. Simulation model of the proposed system

The proposed system has been simulated and analyzed in MATLAB/Simulink. The simulation of the overall proposed ststem is shown in Fig 5 .The input voltage is 50V. Fig 6. shows the input voltage, output voltage and current waveforms.

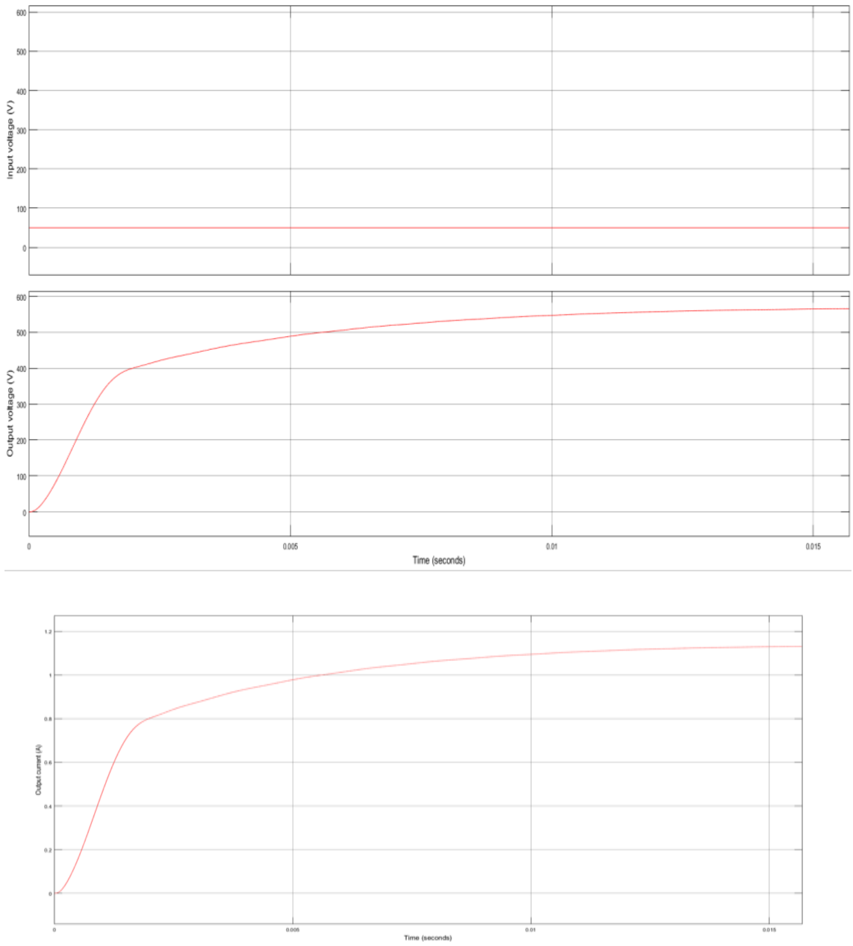

Fig 6. Input voltage, Output voltage and output current waveforms of the proposed converter

Table 1 shows the gain of the proposed converter realized with different values of turns ratio. Thus it can be seen that for a certain gain, there are more than one combination of winding turns to select from. Fig 7. indicates the influence of turns ratio n_{12} on the conversion gain and it can be found that converter gain can be increased by reducing the turns ratio n_{12}.

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Table1. Gain of the proposed converter realized with different turns ratios.

Gain M	$N_1:N_2:N_3$	$\frac{N_2+N_3}{N_1-N_2}$	$\frac{N_1+N_3}{N_1-N_2}$
$\frac{3}{1-D}$	(3:1:1), (4:1:2), (5:1:3), (5:2:1), (6:1:4)	1	2
$\frac{4}{1-D}$	(2:1:1), (3:1:3), (4:1:5), (5:1:7), (6:1:9)	2	3
$\frac{5}{1-D}$	(2:1:2), (3:1:5), (3:2:1), (4:1:8), (5:3:3), (5:2:7), (5:1:11)	3	4
$\frac{6}{1-D}$	(2:1:3), (3:1:7), (3:2:2), (4:1:11), (4:3:1), (5:1:15), (5:2:10), (5:3:5)	4	5
$\frac{7}{1-D}$	(2:1:4), (3:1:9), (3:2:3), (4:1:14), (4:3:2), (5:1:19), (5:2:13), (5:3:7)	5	6
$\frac{8}{1-D}$	(2:1:5), (3:1:11), (3:2:4), (4:1:17), (4:3:3), (5:1:23), (5:2:16), (5:3:9)	6	7
$\frac{9}{1-D}$	(2:1:6), (3:1:13), (3:2:5), (4:1:20), (4:3:4), (5:1:27), (5:2:19), (5:3:11)	7	8
$\frac{10}{1-D}$	(2:1:7), (3:1:15), (3:2:6), (4:1:23), (4:3:5), (5:1:31), (5:2:22), (5:3:13)	8	9

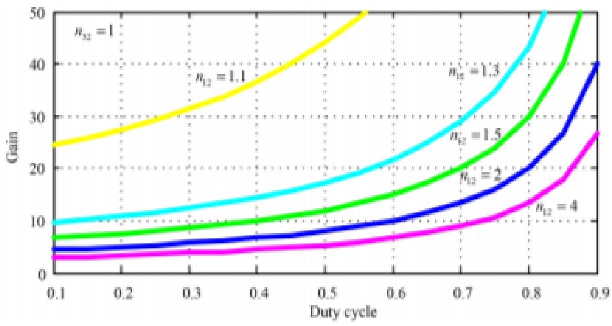

Fig 7. Influence of turns ratio n_{12} on conversion gain

VI. CONCLUSION

The proposed three winding coupled inductor inverse step up converter along with a voltage multiplier is simulated using MATLAB/SIMULINK. The output voltage is about 560 V, with good efficiency. It can be seen that the output voltage is insensitive to load condition with a proper closed loop control. One of the most remarkable aspect is that the smaller turns ratio is, the larger the gain is. In order to restrict the peak voltage of the switch and recycle the leakage energy to the load, diode-capacitor structure has been used.

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