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Comparative study of zeta converter and a novel zeta converter with coupled inductor

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***Abstract*-Recently, inductor manufacturers have begun to release off-the-shelf coupled inductors. Consisting of two separate inductors wound on the same core, coupled inductors typically come in a package with the same length and width as that of a single inductor of the same inductance value, only slightly taller. The price of a coupled inductor is also typically much less than the price of two single inductors. The windings of the coupled inductor can be connected in series, in parallel, or as a transformer. In this paper a zeta converter is presented with coupled inductor and a capacitor multiplier in the secondary of coupled inductor to achieve high voltage gain.Open loop simulations of conventional zeta converter and the novel zeta converter has been carried out using MATLAB/SIMULINK and compared the performance of the two converters.**

Keywords- zetaconverter, coupled inductor, capacitor multiplier .

1.INTRODUCTION

Electronic switch-mode DC to DC converters convert one DC voltage level to another, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. The storage may be in either magnetic field storage components (inductors, transformers) or electric field storage components (capacitors). This conversion method is more power efficient (often 75% to 98%) than linear voltage regulation (which dissipates unwanted power as heat). This efficiency is beneficial to increasing the running time of battery operated devices.

Linear regulators can only output at lower voltages from the input. They are very inefficient when the voltage drop is large and the current is high as they dissipate heat equal to the product of the output current and the voltage drop; consequently they are not normally used for large-drop high-current applications. The inefficiency wastes energy and requires higher-rated and consequently more expensive and larger components. The heat dissipated by high-power supplies is a problem in itself and it must be removed from the circuitry to prevent unacceptable temperature rises.That is why we go for switch mode dc-dc converters.

Energy storage method of dc-dc converters have mentioned above. When a current flows through an inductor, energy is stored temporarily in a magnetic field in the coil. That energy is fed to the load during each switching cycle. Now a days, concept of coupled inductor become more prevalence. That is, two separate inductors wound on the same core. This leads to many advantages like low cost,less size etc.

In this paper a zeta converter [2],[4],[5] and a novel zeta converter with coupled inductor[1] are compared. The performance of each convereter are analysed.

2.TOPOLOGICAL AND ELECTRICAL PROPERTIES OF THE CONVERTERS.

A.zeta converter

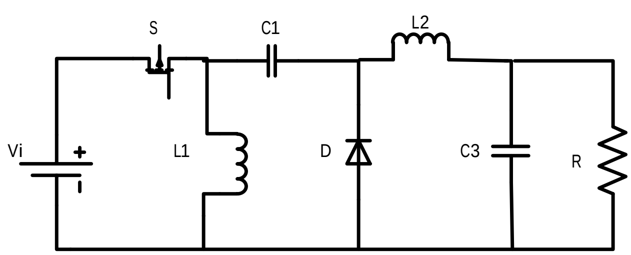

Figure 1.Zeta converter circuit

The zeta converter circuit is shown in Figure 1. It consists of IGBT transistor as a switch, Diode, two capacitors and , two inductors and load resistor . In the first mode of operation (switch is ON) the inductors L1 and L2 are in charging state.

During the second mode (switch is off)the inductors L1 and L2 are in the discharging state.L1 is discharging its stored energy into the capacitor , and the inductor L2 transform energy to output section.

The relation between input and output voltage of the zeta converter is given by,

$$Vo=\frac{D.Vi}{1-D}$$

B.Novel zeta converter with capacitor multiplier and coupled inductor.

The simplified circuit model of the proposed converter is shown in Figure 2. The coupled inductor T_1 includes a magnetizing inductor Lm, and an ideal transformer primary winding N_1 and secondary winding N_2. To simplify the circuit analysis of the proposed converter, the following assumptions are made.

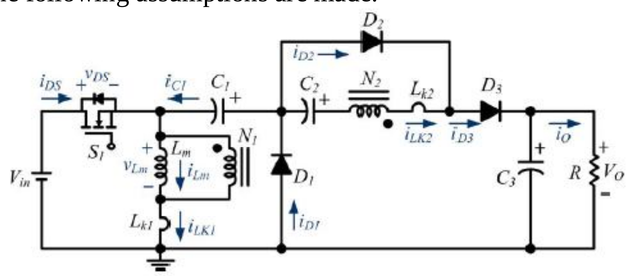

Figure 2.Novel zeta converter with coupled inductor

1) All components are ideal, except for the leakage inductance of coupled inductor T_1. The ON-state resistance$R_{DS(ON)}$ and all parasitic capacitances of the main switch S_1 are neglected, as are the forward voltage drops of the diodes $D_1 \sim D_3$.

2) The capacitors $C_1 \sim C_3$ are sufficiently large that the voltages across them are considered to be constant.

3) The ESR of capacitors $C_1 \sim C_3$ and the parasitic resistance of coupled-inductor T_1 are neglected.

4) The turns ratio n of the coupled inductor T_1 winding is equal to N_2/N_1.

A. Analysis of Operation Stages

For one switching cycle, the proposed circuit operations can be divided into five stages.

Stage 1[t0-t1]:

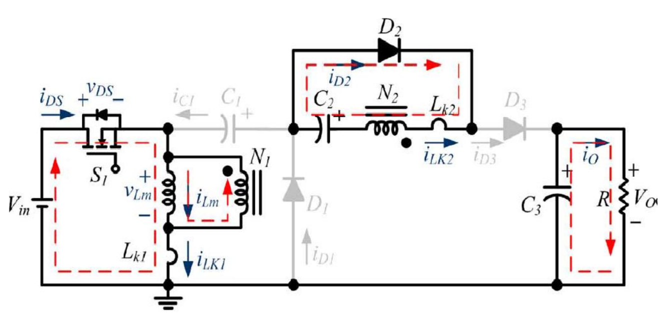

Figure 3.Mode I of Novel zeta converter with coupled inductor

In this transition interval, the secondary leakage inductor L_{k2} is continuously releasing its energy to capacitor C_2. The current flow path is shown in Figure.2; as shown, switch S_1 and diodes D_2 are conducting. The current i_{Lm} is descending because source voltage V_{in} is applied on magnetizing inductor L_m and primary leakage inductor L_{k1}; meanwhile, L_m is also releasing its energy to the secondary winding, as well as charging capacitor C_2 along with the decrease in energy, the charging current i_{D2} and i_{C2} are also decreasing. The secondary leakage inductor current i_{LK2} is declining according to i_{Lm}/n. Once the increasing i_{Lk1} equals the decreasing i_{Lm} at $t = t_1$, this mode ends.

Stage 2 [t1-t2]:

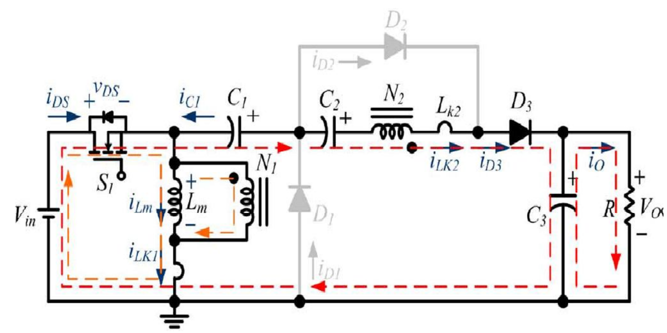

Figure 4.Mode II of Novel zeta converter with coupled inductor

During this interval, source energy V_{in} is series connected with C_1, C_2, secondary winding N_2, and L_{k2} to charge output capacitor C_3 and load R; meanwhile, magnetizing inductor L_m is also receiving energy from V_{in}. The current flow path is shown in Figure .3; as illustrated, switch S_1 remains on, and only diode D_3 is conducting. The i_{Lm}, i_{Lk1}, and i_{D3} are increasing because the V_{in} is crossing L_{k1}, L_m and primary winding N_1; L_m and L_{k1} are storing energy from V_{in}; meanwhile, V_{in} is also in series with N_2 of coupled inductor T_1, and capacitors C_1 and C_2 are discharging their energy to capacitor C_3 and load R, which leads to increases in i_{Lm}, i_{Lk1}, i_{DS}, and i_{D3}. This mode ends when switch S_1 is turned off at $t = t_2$.

Stage 3[t2-t3] :

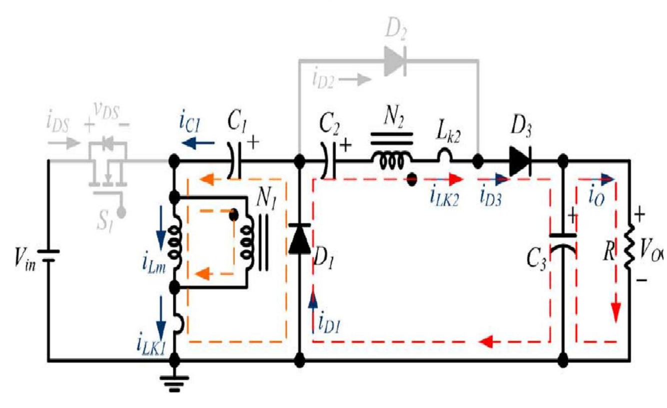

Figure 5.Mode III of Novel zeta converter with coupled inductor

During this transition interval, secondary leakage inductor L_{k2} keeps charging C_3 when switch S_1 is off. The current flow path is shown in Figure. 4, and only diodes D_1 and D_3 are conducting. The energy stored in leakage inductor L_{k1} flows through diode D_1 to charge capacitor C_1 instantly when S_1 turns off. Meanwhile, the L_{k2} keeps the same current direction as in the prior mode and is in series with C_2 to charge output capacitor C_3 and load R. The voltage across S_1 is the summation of V_{in}, V_{Lm}, and V_{Lk1}. Currents i_{Lk1} and i_{Lk2} are rapidly declining, but i_{Lm} is increasing because L_m is receiving energy from L_{k2}. Once current i_{Lk2} drops to zero, this mode ends at $t = t_3$.

Stage 4[t3-t4]:

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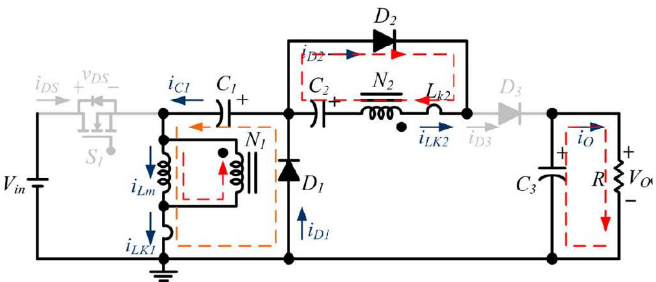

Figure 6.Mode IV of Novel zeta converter with coupled inductor

During this transition interval, the energy stored in magnetizing inductor L_m releases simultaneously to C_1 and C_2. The current flow path is shown in Figure. 5. Only diodes D_1 and D_2 are conducting. Currents i_{Lk1} and i_{D1} are persistently decreased because leakage energy still flows through diode D_1 and continues charging capacitor C_1. The L_m is delivering its energy through T_1 and D_2 to charge capacitor C_2. The energy stored in capacitors C_3 is constantly discharged to the load R. The voltage across S_1 is the same as previous mode. Currents i_{Lk1} and i_{Lm} are decreasing, but i_{D2} is increasing. This mode ends when current i_{Lk1} is zero at $t = t_4$.

Stage 5[t4-t5] :

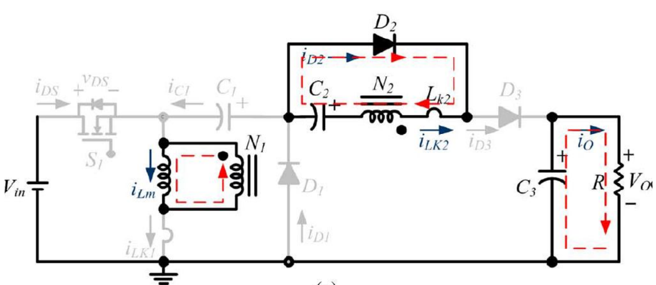

Figure 7.Mode V of Novel zeta converter with coupled inductor

During this interval, magnetizing inductor L_m is constantly transferring energy to C_2. The current flow path is shown in Figure. 6, and only diode D_2 is conducting. The i_{Lm} is decreasing due to the magnetizing inductor energy flowing continuously through the coupled inductor T_1 to secondary winding N_2 and D_2 to charge capacitor C_2. The energy stored in capacitors C_3 is constantly discharged to the load R. The voltage across S_1 is the summation of V_{in} and V_{Lm}. This mode ends when switch S_1 is turned on at the beginning of the next switching period.

3.DESIGN CONSIDERATION

A. *Duty Ratio and Turns Ratio*:

$$\frac{Vo}{Vin} = \frac{1+n}{1-D}$$

Duty ratio and turns ratio can be selected from the above equation.D>70% would result in greater conduction losses.Also $n \geq 4$ will result in small duty ratio.So selection should be made by compromise between these two.

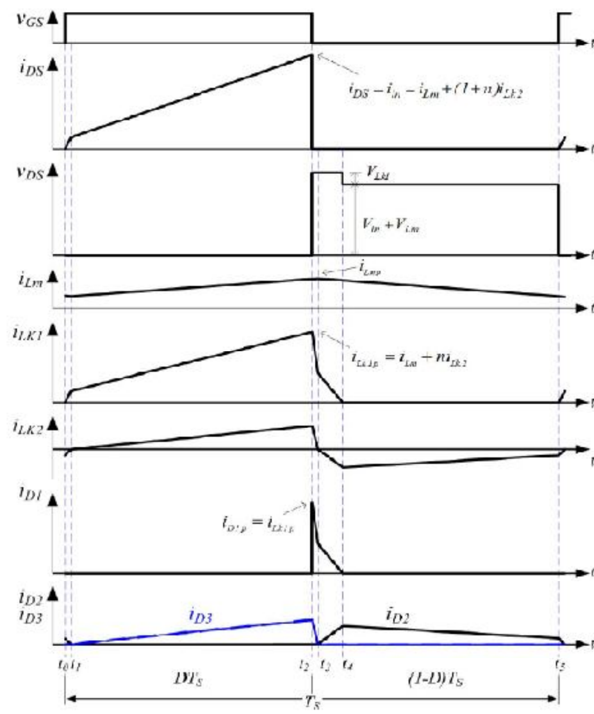

Figure 8.Typical waveforms of the novel converter.

B. *Magnetizing Inductor*

$$Lm = \frac{fs}{Rq} \cdot \frac{D^3 - 2D^2 + D}{2n^2 + 4n + 2}$$

C. *Active Switch and Diodes*:

The general voltage-rating active components obtained as follows

$$V_{DS} = V_{D1} = \frac{Vo}{1+n}$$

$$V_{D2} = \frac{nVo}{1+n}$$

$$V_{D3} = V_O$$

D. *Switched capacitors*

The energy transfers from the input through switched capacitors C_1 and C_2 to the output. Calculating the minimum capacitance of the switched capacitors depends on the maximum transferring power, the capacitor's voltage, and the operating frequency. The voltage of C_1 and C_2 can be obtained as follows

$$C1 \geq \frac{2.PMAX}{VC1^2.f_s}$$

$$C2 \geq \frac{2.PMAX}{VC2^2.f_s}$$

Where $V_{C1} = \frac{D\,Vin}{1-D}$ and

$$V_{C2} = \frac{nD}{1-D}\,Vin$$

4.SIMULATION RESULTS AND DISCUSSIONS

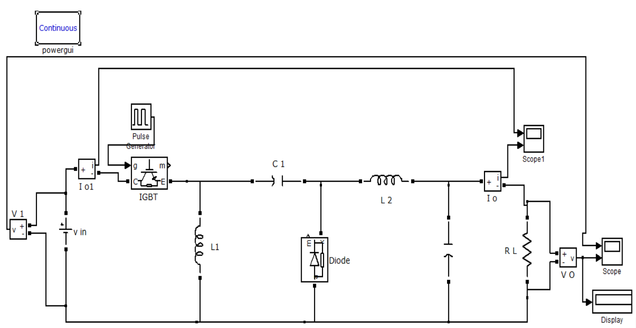

Figure 9.Simulink model of ZETA converter

The Figure. 8 shows the Simulink model for the conventional converter configuration. The circuit is built using MATLAB simulation package with an input voltage of 25v, a switching frequency of 50 kHz .

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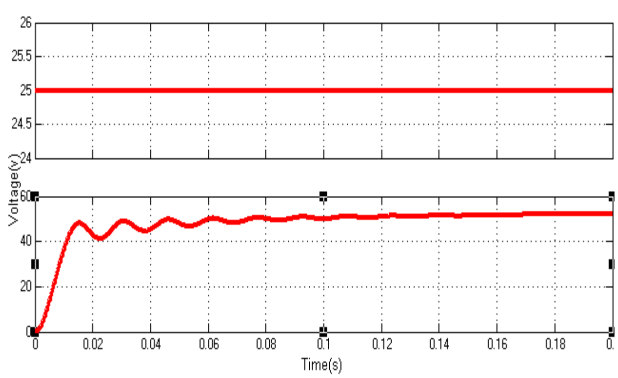

Figure 10.Input-output voltage waveforms of conventional ZETA converter.

From the waveforms,it is seen that input voltage is 25v dc and the output voltage is 50v dc with large amount of ripple.

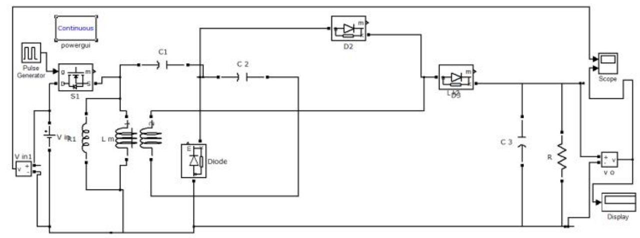

Figure 11.Simulink model novel zeta converter with capacitor multiplier and coupled inductor.

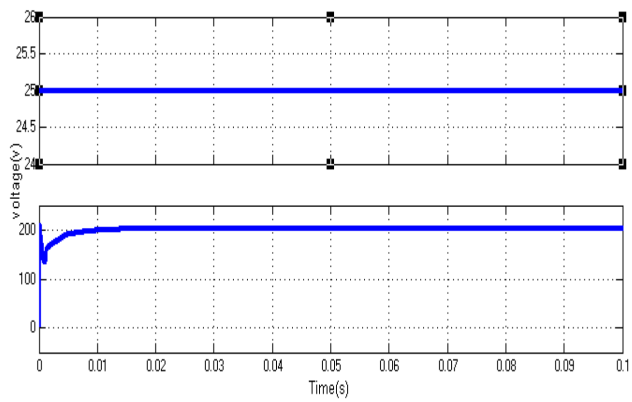

Figure 12.Input-output voltage waveform of novel zeta converter with capacitor multiplier and coupled inductor.

The Figure. 11 shows the Simulink model for the novel zeta converter configuration. The circuit is built using MATLAB simulation package with an input voltage of 25v, a switching frequency of 50 kHz .From the waveform it is seen that output voltage is 200v dc.The ripple content is less in the output voltage when compared to that of conventional converter.The settling time is reduced by 0.09s.

Table I

List of components of two converters.

Parameter	Zeta converter	Novel zeta converter
Input voltage,Vi	25 v	25 v
Output voltage,Vo	50 v	200v
Voltage gain,Vo/Vi	2	8
Capacitor,C1	150µF	47µF
Capacitor,C2	0	47µF
Capacitor,C3	600µF	10µF
Inductor ,L1	70µH	12.5µH
Inductor ,L2	50mH	500µH
Duty ratio,D	50%	50%
Switching frequency,fs	50kHz	50kHz
Output power,P out	250W	250W

The parameters of two converters are listed above.It was observed that the novel zeta converter is very much cost effective.The voltage gain of new converter is four times better than the conventional converter.

Plot between the voltage gain(Vo/Vi) and duty ratio(D) of the converters are shown below.The voltage gain is 8 for the new converter even at 50% duty cycle, that may help to reduce conduction losses.

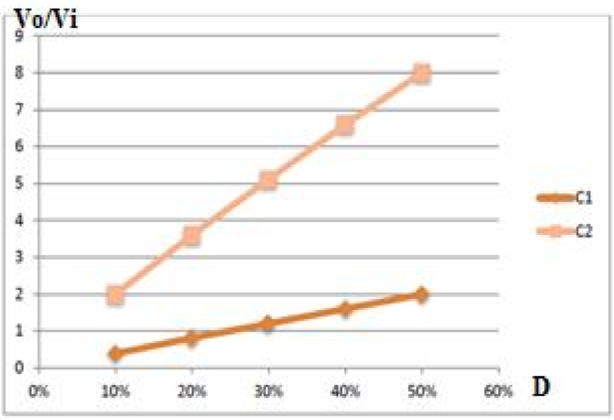

Figure 13.Voltage gain(Vo/Vi) as a function of duty ratio(D) for the proposed converter(C1) and zeta converter(C2).

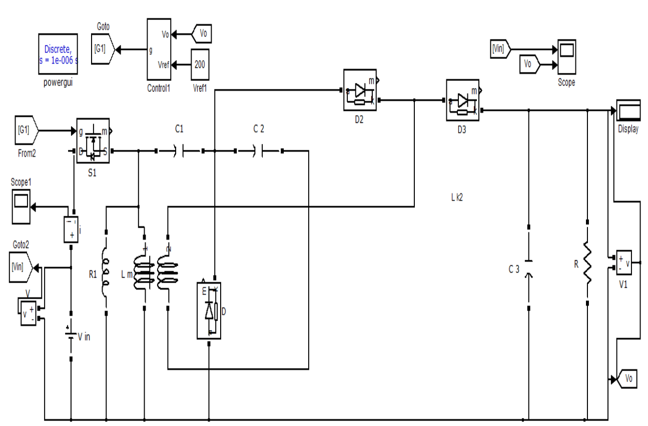

Figure 14.Simulink model novel zeta converter with capacitor multiplier and coupled inductor with PI controller.

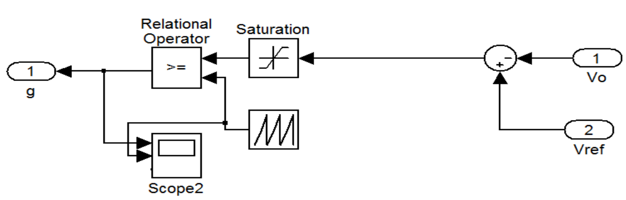

Figure 15.System for generating gate signal

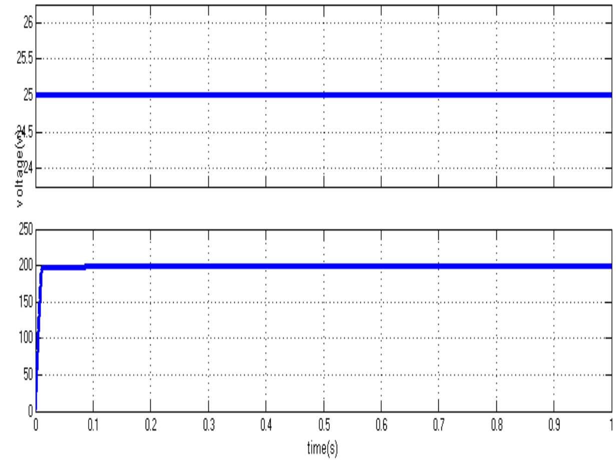

Figure 16.Input-output waveform of novel zeta converter with capacitor multiplier and coupled inductor with PI controller.

The output voltage is more regulated with PI controller.Smooth changes is observed.

5.CONCLUSION

The zeta converter is a fourth order dc-dc converter.To increase the voltage an extra capacitor and a coupled inductor is used.The coupled inductor replaces the two independent inductor,that leads to the reduced size and cost.The mutual induction in the coupled inductor also increase the voltage level.

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