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Simulation of DC- DC Boost Converter by Coupled Inductor Using PSIM

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Abstract **- The Conventional Boost Converters is not possible to obtain the high voltage gain. In this paper a DC-DC boost converter is proposed for achieving high voltage gain and to reduce the harmonic content in the output side. The circuit diagram of the proposed converter is consists of coupled inductor. Therefore the voltage stress on the active switch is reduced due to the presence of the inductor and the output voltage is high in the proposed converter and the response of various factors are analyzed using the simulation software PSIM.**

Keywords **– Boost converter, coupled inductor, high voltage gain, soft switching, and snubber**

I. INTRODUCTION

The conversion of the distributed energy sources like wind energy, fuel cell and photovoltaic's into the useful energy such as ac or dc power source increasing day by day in order to meet out the global energy requirement. In many applications, high-efficiency, high-voltage step-up dc–dc converters are required as an interface between the available low voltage sources and the output loads, which are operated at much higher voltages. The coupled-inductor boost converter can be a good solution to the previously discussed problems of the conventional boost converter. This is because the turn's ratio of the primary inductor ($L1$) to the secondary inductor ($L2$) of the coupled inductor can be effectively used to reduce the duty ratio and the voltage stress of the switch [1-8].

To reduce the voltage stress of the primary side active switches and secondary-side output rectifier diodes, a new voltage-multiplier circuit is integrated into the proposed interleaved four-phase current-fed boost topology. Based on the capacitor-divider concept, the main objectives of the new voltage-multiplier circuit in the converter are to 1) store energy in the output clamping capacitors 2) share voltage stresses both of active switches and rectifier diodes for improving the conversion efficiency and reducing the reverse-recovery problem of rectifier diodes. [9-12].

In the voltage multiplier module of the proposed converter, the turn's ratio of coupled inductors can be designed to extend voltage gain, and a voltage-lift capacitor offers an extra voltage conversion ratio. The advantages of the proposed converter are as follows:

1) The converter is characterized by a low input current ripple and low conduction losses, making it suitable for high power applications.
2) The converter achieves the high step-up voltage gain that renewable energy systems require;
3) Leakage energy is recycled and sent to the output terminal, and alleviates large voltage spikes on the main switch;
4) The main switch voltage stress of the converter is substantially lower than that of the output voltage;
5) Low cost and high efficiency are achieved by the low r_{DS}(on) and low voltage rating of the power switching device. Primary windings of the coupled inductors with Np turns are employed to decrease input current ripple, and secondary windings of the coupled inductors with Ns turns are connected in series to extend voltage gain. [1]

II. BASIC TOPOLOGY OF FLY-BACK CONVERTER

The input to the circuit may be unregulated dc voltage derived from the utility ac supply after rectification and some filtering. The ripple in dc voltage waveform is generally of low frequency and the overall ripple voltage waveform repeats at twice the ac mains frequency. The input voltage, in spite of being unregulated, may be considered to have a constant magnitude during any high frequency cycle. A fast switching device ('S'), like a MOSFET, is used with fast dynamic control over switch duty ratio to maintain the desired output voltage.

The transformer is used for voltage isolation as well as for better matching between input and output voltage and current requirements.

Primary and secondary windings of the transformer are wound to have good coupling so that they are linked by nearly same magnetic flux. As will be shown in the next section the primary and secondary windings of the fly-back transformer don't carry current simultaneously and in this sense fly-back transformer works differently from a normal transformer. In a normal transformer, under load, primary and secondary windings conduct simultaneously such that the ampere turns of primary winding is nearly balanced by the opposing ampere-turns of the secondary winding. Since primary and secondary windings of the fly-back transformer don't conduct simultaneously they are more like two magnetically coupled inductors and it may be more appropriate to call the fly-back transformer as inductor-transformer. Accordingly the magnetic circuit design of a fly-back transformer is done like that for an inductor. The output section of the fly-back transformer, which consists of voltage rectification and filtering, is considerably simpler than in most other switched mode power supply circuits. The secondary winding voltage is rectified and filtered using just a diode and a capacitor. Voltage across this filter capacitor is the SMPS output voltage.

A more practical circuit will have provisions for output voltage and current feedback and a controller for modulating the duty ratio of the switch. It is quite common to have multiple secondary windings for generating multiple isolated voltages. One of the secondary outputs may be dedicated for estimating the load voltage as well as for supplying the control power to the circuit. Further, as will be discussed later, a snubber circuit will be required to dissipate the energy stored in the leakage inductance of the primary winding when switch 'S' is turned off. [13]

III. Operation Of The Proposed Converter

The basic circuit of the proposed converter is as shown in Fig 1. The operation of the boost converter is explained following five modes.

MODE I: (t_0-t_1)

In this transition interval, switch S_1 is turned ON. Diodes D_1 and D_3 are conducted but diodes D_2 and D_4 are turned OFF. The path of the current flow is shown in Fig2. The energy of the dc source V_{in} is transferred to the input inductor *L*in through the diode D_1, and the voltage across the input inductor *L*in is *V*in; the input current i_{in} is equal to i_{D1} and is increased.

The capacitor C_1 delivers its energy to the magnetizing inductor L_m and the primary leakage inductor L_{k1}.

The voltage across the magnetizing inductor L_m and the primary leakage inductor L_{k1} is V_{C1}, but the magnetizing inductor L_m keeps on transferring its energy through the secondary leakage inductor L_{k2} to the charge capacitor $C_{0\,2}$ so that both currents i_{Lk2} and i_{Lm} decrease, until the increasing i_{Lk1}reaches and equals to decreasing i_{Lm}; in the meantime, the current i_{Lk2} is down to zero at $t = t_1$ this mode is ended.

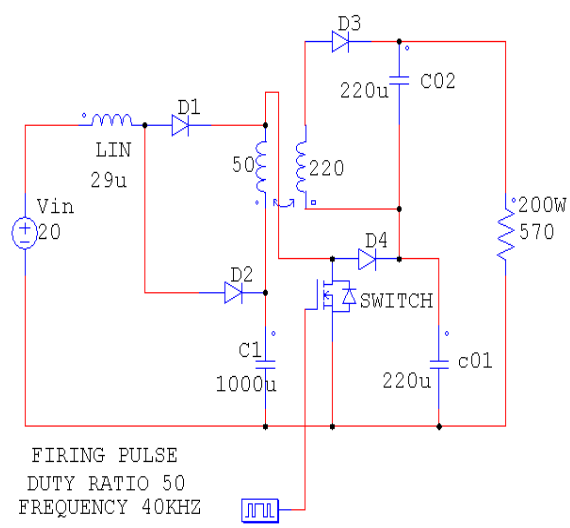

Fig 1. Circuit configuration of the proposed converter.

The energies stored in capacitorsC_{01} and C_{02} are constantly discharged to the load R.

MODE II :(t_1-t_2)

During this interval, the switch S_1 is remained ON. Only the diode D_1 is conducted and rest of other diodes D_2, D_3, and D_4 are turned OFF. The path of the current flow is shown in Fig3. The energy of the dc source in is still stored into the input inductor L_{in} through the diode D_1. The energy that has charged the capacitor C_1 is still delivered to the magnetizing inductor L_m and primary leakage inductor L_{k1}. The voltage across magnetizing inductor *Lm* and primary leakage inductor L_{k1} is V_{C1}.Thus, currents i_{in}, i_{D1}, i_{Lm}, and i_{Lk1} are increased. The energies stored in capacitors C_{01} and C_{02} are still discharged to the load *R*. This mode is ended when switch *S*1 is turned OFF at $t = t_2$.

MODE III :(t2-t_3)

During this interval, switch S_1 and diode D_1 are turned OFF; the diodes D_2, D_3, and D_4 are conducted. The path of the current flow is shown in Fig4. The dc source V_{in} and input inductor L_{in} are connected serially to the charge capacitor C_1 with their energies. Meanwhile, the primary leakage inductor L_{k1} is in series with capacitor C_1 as a voltage source V_{C1} through magnetizing inductor L_m then delivered their energies to the charge capacitor C_{01}.

The magnetizing inductor L_m also transferred the magnetizing energy through coupled inductor T_1 to secondary leakage inductor L_{k2} and to charge capacitor C_{02}. Thus, currents *i*in, i_{D2}, i_{D4}, i_{Lm}, and i_{Lk1} are decreased, but currents i_{C1} , i_{Lk2} , and i_{D3} are increased. The energies stored in capacitors C_{01} and C_{02} are discharged to the load *R*. This mode is ended when the current i_{C01} is dropped till zero at $t = t_3$.

MODE IV :(t_3-t_4)

During this transition interval, switch S_1 and diode D_1 are remained OFF; and diodes D_2, D_3, and D_4 are still conducted. The path of the current flow is shown in Fig5. Almost statuses are remained as Mode III except the condition of primary leakage inductor L_{k1} is in series with capacitorC_1 as a voltage source V_{C1} through magnetizing inductor L_m then discharged or released their energies to load. Thus, currents i_{in}, i_{D2}, i_{D4}, i_{Lm}, and i_{Lk1} are persistently decreased, but currents i_{C02}, i_{Lk2}, and i_{D3} are still increased. The energy stored in capacitors C_{01} and C_{02} is discharged to the load *R*. This mode is ended when current i_{Lk1} is decreased until zero at $t = t_4$.

MODE V :(t_4-t_0)

During this interval, switch S_1 and diode D_1 are remain OFF; diode D_4 is turned OFF and diodes D_2 and D_3 are keep conducted. The path of the current flow is shown in Fig6. The dc source V_{in} and input inductor *L*in are connected serially and still charged to capacitor C_1 with their energies. The magnetizing inductor L_m continuously transferred its own magnetizing energy through coupled inductor T_1 and diode D_3 to the secondary leakage inductor L_{k2} and to the charge capacitor C_{02}.

Thus, currents i_{in}, i_{D2}, i_{D3}, i_{Lk2}, and i_m are decreased. The energies stored in capacitors C_{01} and C_{02} are discharged to the load. This mode is end when switch S_1 is turned ON at the beginning of the next switching period.

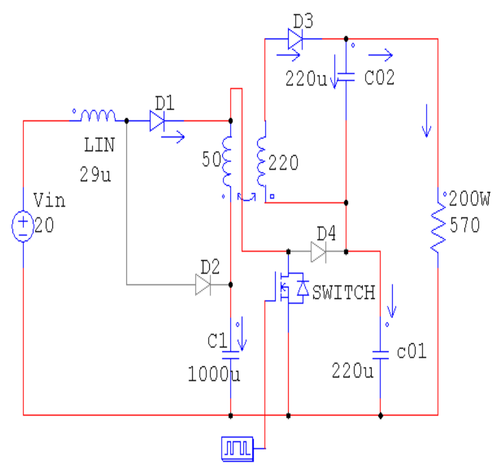

Fig2. The Mode 1 Circuit Diagram

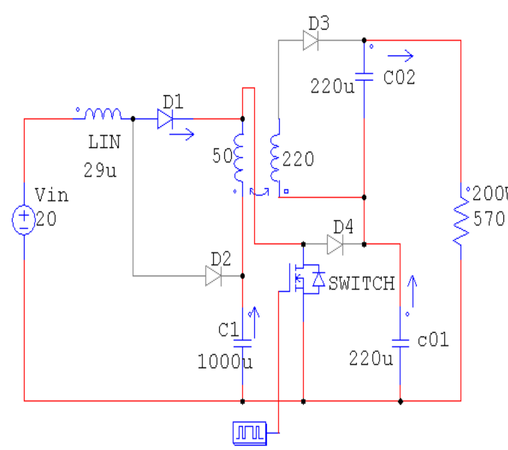

Fig3. The Mode 2 Circuit Diagram

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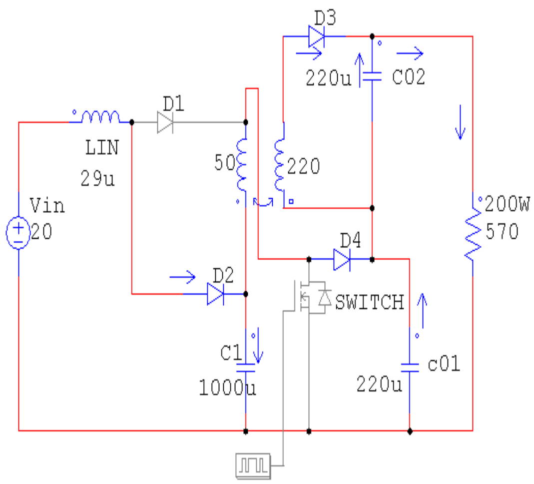

Fig 4. The Mode 3 Circuit Diagram

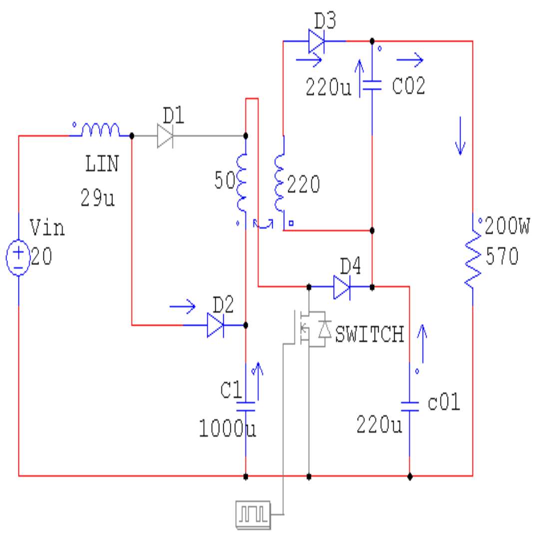

Fig 5. The Mode 4 Circuit Diagram

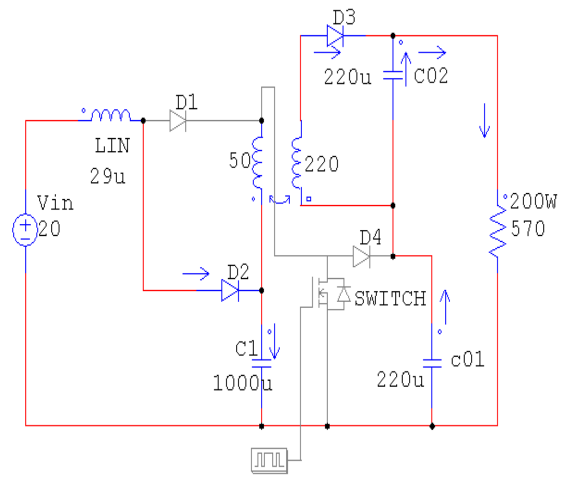

Fig 6. The Mode 5 Circuit Diagram

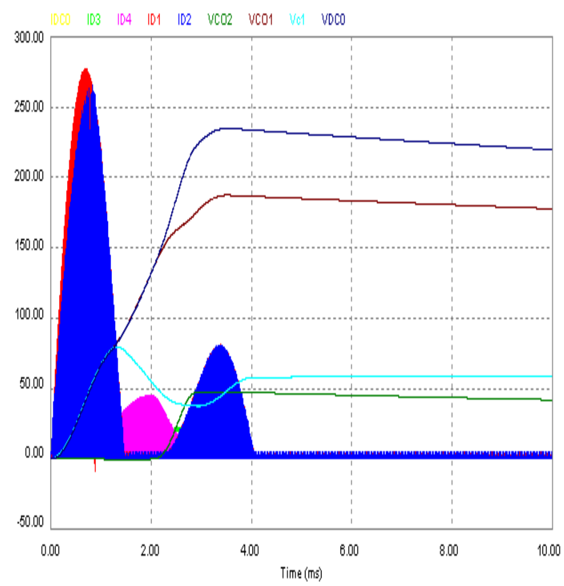

Fig 7. Output Waveforms

IV. STEADY-STATE ANALYSIS OF THE PROPOSED CONVERTER

During the time duration of Mode II, the main switch S_1 is conducted, and the coupling coefficient of the coupled inductor k is considered as $L_m / (L_m+L_{k1})$.

$$VL_{in} = V_{in} ------------- (1)$$

$$VL_m = \frac{Lm}{Lm + Lk1} Vc1 = kVc1 ---- (2)$$

$$VLk1 = Vc1 - VLm = (1-k)Vc1 ---- (3)$$

$$VLk2 = n.VLm ------------ (4)$$

During the period of Modes III and V that main switch S_1 is turned OFF, the following equations can be found as

$$VLin = Vin - Vc1 ------------ (5)$$

$$VLm = Vc1 - Vc01 - VLk1 -------- (6)$$

$$VLk2 = nVLm - Vc02 ---------- (7)$$

Where, the turn ratio of the coupled-inductor n is equal toN_2 / N_1.The voltage across inductor L_{in} by the volt-second balance principle is shown as

$$\int_0^{DTs} Vindt + \int_{DTs}^{Ts} (Vin - Vc1)dt = 0 --- (8)$$

$$Vc1 = \frac{Vin}{(1-D)} ------------- (9)$$

The voltage across the magnetising inductor Lm by the second volt principle is

$$\int_0^{DTs} kVc1dt + \int_{DTs}^{Ts} (Vc1 - Vc01 - VLk1)dt = 0 --- (10)$$

$$I_0 = \frac{V_0}{R} = \frac{V_{C01} + V_{C02}}{R} ---------- (11)$$

Substitute (9) into (10) and (11), and assume that L_{k2} is equal to nL_{k1}; thus V_{C01} and V_{C02} can be obtained from the following equations:

$$Vc01 = \frac{1 - D + kD}{(1-D)^2} Vin - VLk1 ----- (12)$$

$$Vc02 = \frac{nkD}{(1-D)} Vin - nVLk1 ------ (13)$$

The output voltage V_o express as

$$V_0 = V_{C01} + V_{C02} ------- (14)$$

The output current I_o is derived as

$$I_0 = \frac{V_0}{R} = \frac{V_{C01} + V_{C02}}{R} --------- (15)$$

V. CONCLUSION

This paper presents DC–DC Boost converters with coupled inductor. The proposed converter is simulated with various modes of operation and the working principle and the response is plotted in the Fig. 7. This converter is highly efficient because it recycles the energy stored in the leakage inductor of the coupled inductor. Moreover, the voltage across the switch is clamped at the lower voltage level, enabling the converter to use the low rating switch to improve efficiency. This high-efficiency converter topology provides for the various applications related to renewable energy, and it also can be extended easily to other power conversion systems for satisfying high-voltage demands.

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