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High Voltage Gain Boost Converter for Micro source Power Conversion system

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***Abstract*— In this paper, a new boost converter is introduced. In the proposed converter, a coupled inductor and voltage lift technique is used for raising the voltage gain .The designed converter especially for large voltage conversion ratio applications. By combining coupled inductor and voltage lift technique, the energy stored in the leakage inductor is recycled, therefore reduce the switch turn- off voltage and implement soft switching turn-on operation. The operating principles and steady-state analyses of continuous –conduction mode is discussed in detail. A 250W Converter Operating at 50KHZ with 25V input and 240V output simulation is presented to demonstrate the performance.**

***Index Terms*—Boost Converter, Coupled Inductor, Voltage Lift Technique, High Voltage Gain**

I. Introduction

In recent Years, renewable energy is becoming increasingly important in distribution System, which provide different choice to electricity consumers whether they receive power from the main electricity source or in forming a micro source not only to fulfill their own demand but alternatively to be a power producer supplying a microgrid.

A microgrid usually includes various microsources and loads . Microsource categories are comprised of diverse renewable energy applications, Such as solar cell modules and fuel cell stacks.Fig.1. Shows a regular schematic of a microgrid unit supplied by various microsources ; the boost converter is used to increase the output voltage of the microsource from 230-250V for the dc interface to the main electricity source through the dc-ac inverter [1],[2],[3].Both the single solar cell module and the fuel cell stacks are low-voltage sources, thus a high step-up voltage gain dc-dc converter is required to regulate the voltage of the dc - dc interface.

The conventional Boost converters cannot provide such a high dc voltage gain, even for an extreme duty cycle. It also may results in serious reverse –recovery problems and increases the rating of all devices. As a result ,the conversion efficiency is degraded and the electromagnetic interference (EMI) problem is severe under this situation [4].In order to increase the conversion efficiency and voltage gain ,many modified boost converter topologies have been investigated in the past decade[5]-[18].

Two winding coupled inductor is used and voltage gain is limited by turn ratio of transformer [5],[6].The Buck-Boost type converter operated in a duty ratio is higher than 0.5,high

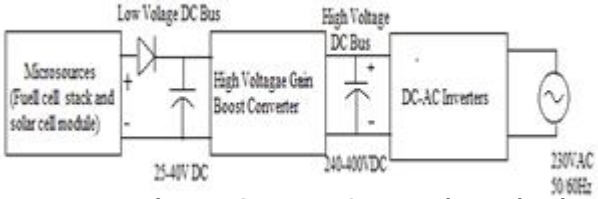

Figure 1. general Power Conversion System with a High Voltage Gain Boost Converter

voltage stresses on converter switches [7].The presented Converters in are used for fuel cell power conversion systems [8],[9],[10].The operation of the main switch is hard switching so turn on switching loss is high, this does not improve the efficiency sufficiently[8].In practical situation ,the maximum output voltage will be affected by parasitic effects, such as winding resistances of inductors, so the conversion ratio can be decreased[9].In [10],the active switch can suffer with very high current during the switch on period and this converter is suitable for low to middle power applications. A zero- voltage switching dc-dc converter with high voltage gain [11] consists of a ZVS boost converter stage and a ZVS half-bridge converter stage. The efficiency of the converter at light load is lower due to the additional conduction loss of the auxiliary circuit of the ZVS boost converter stage. In [12], the cascaded high step-up dc-dc converter with single switch is low efficiency converter is up to 92%at 30%full load. If low input voltage applied in dc-dc converter [13], it experiences extremely high input current at full load and high conduction loss during the switch turn-on period. The bidirectional zero voltage switching dc-dc converter [14], efficiency is improved at heavy load. The conduction loss due to auxiliary circuit causes the relatively low efficiency at light load. In [15] the converter is a fixed frequency ZVS current fed converter that uses a very simple auxiliary circuit to create ZVS over an extended range of load. However the main converter switches and active clamp switch have significant amount of conduction losses, since current flows either through the active clamp switch. The overlap of voltage and current in the bridge switches when they turn off creates considerable losses when the converter operating under heavy load conditions. The several conventional converters are presented with active clamp, snubber, voltage multiplier and coupled inductor [16], [17], [18].Soft Switching boost converter [16] is used to reduce current and voltage stress of the main switch. To achieve both soft switching features, more component count is usually required.

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This paper presents a high voltage gain Boost Converter, which uses the coupling inductor and voltage lift technique .The circuit diagram of proposed converter is shown if fig.2. and the features of this converter are as follows: 1) High Voltage gain 2)Duty ratio can be designed to 0.65 by adjusting the turns ratio of the coupled inductor. Thus the converter can be operated under Continuous conduction mode. 3) The energy stored in the leakage inductance of the transformer is recycled, thus increasing the efficiency. 4) The voltage is

clamped on the active switch, enabling the power switch to be selected with a low voltage rating and low conduction resistance rds. 5)The converter uses low –rating switch and diodes to minimize the cost.

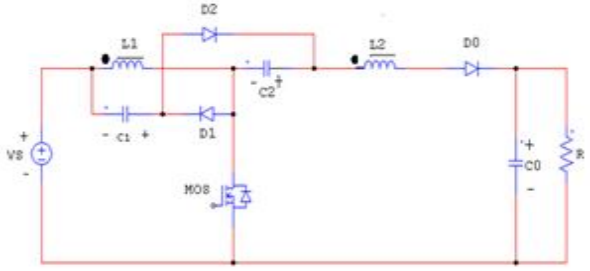


Figure 2. Circuit Diagram of High Voltage Gain Boost Converter

II. Proposed Converter And Operation Principle

Fig.3.Shows circuit configuration of the proposed converter, which is a boost converter with voltage lift technique and a coupled inductor. The equivalent model of the coupled inductor includes the magnetizing inductor Lm, leakage inductors LK1 and LK2 and an ideal transformer. This converter consists of a DC input voltage Vin, one power switch, one coupled inductor, three diodes and three capacitors. The boost converter is adopted to generate a stable voltage VC1 and to supply the energy for the load. Additionally, the diode D1 is turned on when switch S is in turned –off period, the voltage across switch S is clamped at a low voltage level, and the energy stored in the leakage inductance is recycled into C1.Since switch S has a low voltage rating and low conduction resistance rds(on) ,the proposed converter has high efficiency. The voltage –lift technique is applied to generate a constant voltage VC2 and provide the energy to output. Because the voltage across C2 is constant, the voltage gain can be enhanced. Furthermore, the turn ratio of the coupled inductor is adjusted to achieve a high step-up voltage gain.

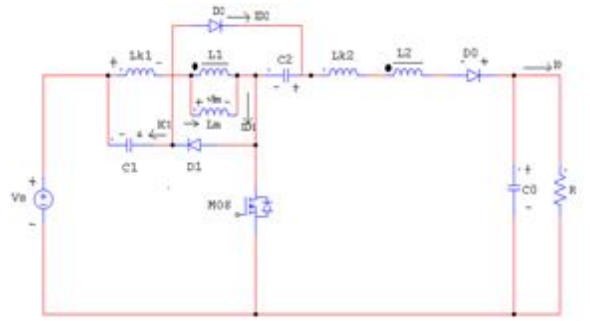


Figure 3. Circuit configuration of Proposed Converter

To simplify the circuit analysis, the following conditions are assumed:

1. Capacitors C1, C2 and Co are large enough that the V_{C1}, V_{C2}, and V0 are constant values in one switching period.
2. All semiconductor components are ideal.
3. Most of the energy is stored in the magnetizing inductance Lm, which is larger than the leakage inductance LKI and LK2.
4. Turns ratio of the coupled inductor n=N2/N1.

A. Continuous Conduction Mode

The Proposed converter operating in continuous conduction mode is analyzed. Fig.4. illustrates some typical waveforms under CCM operation in one switching period. The operating principle of CCM is divided into six modes during each switching period. The operating modes are described as follows:

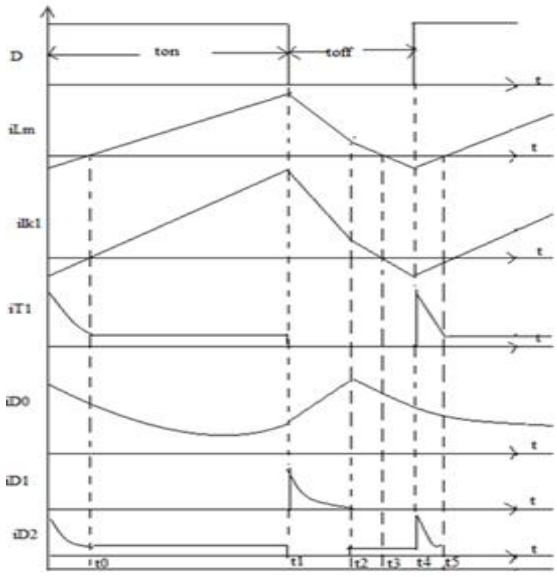
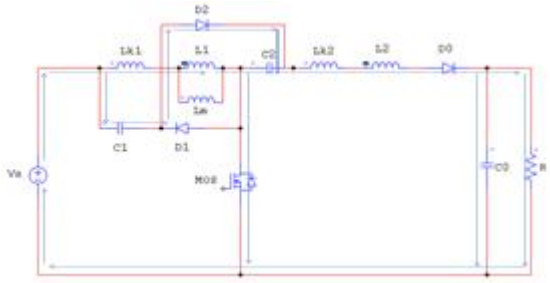
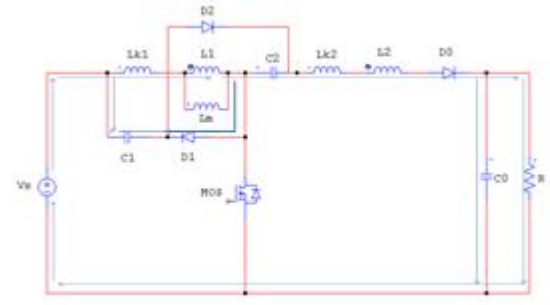


Figure 4. Some typical waveforms under CCM operation



(a) Mode 1 [t_0-t_1]



(b) Mode 2 [t_1-t_2]

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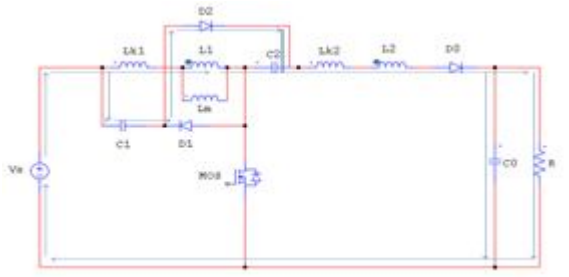
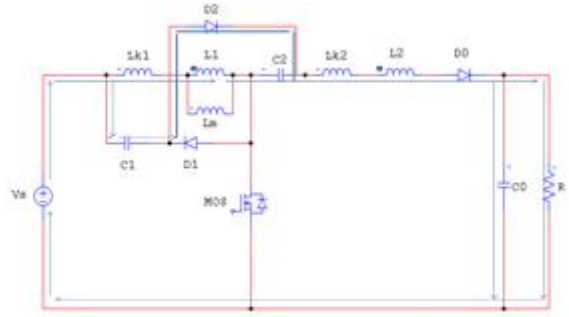
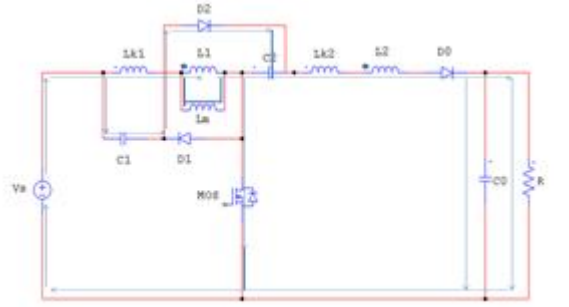


(c) Mode 3 [t_2-t_3]



(d) Mode 4 [t_3-t_4]



(e) Mode 5 [t_4-t_5]

Figure 5. Operating modes for CCM

(a). Mode 1 [t_0-t_1]

In this mode, the switch Q was turned on for a span. The magnetizing inductor (Lm) is charged by the input voltage source (V_s), the magnetizing current (il_m) increases gradually in an approximately linear way. The secondary voltage (V_{l2}) is charged the capacitor C_2 through the switch (Q). At $t=t_0$, the switch S is turned on, diodes D_2 and D_3 are turned on and D1 is turned off. Fig.5. (a) shows the equivalent circuit of the proposed converter in this mode.

(b). Mode 2 [t_1-t_2]

At $t=t_1$, switch Q is turned off, the voltage across the switch $V_{DS}=V_S+V_{C1}$.Switch Q and diode D_2 is turned off without reverse recovery current and diode D_1 is turned on. During this period, the energy stored in inductor released to the output terminal the current through the output diode D_o increased and current through the leakage inductor is reduced. The equivalent circuit of proposed converter of this mode is shown in Fig.5. (b).

(c). Mode 3 [t_2-t_3]

At $t=t_2$, S is still turned off. At this time interval, the current through the leakage inductor L_{k1} and L_m are decays to zero. Diode D_1 is turned off and Diode D_2 is turned on.Fig.5. (c) Shows the equivalent circuit of this mode. In this mode the circuit current flows is still directed to the output terminal, but the magnitudes of current decreases gradually.

(d). Mode 4 [t_3-t_4]

After releasing the leakage energy, the primary current (i_{L1}) and magnetizing current i_{lm} decays to zero at time $t=t_4$. Diode D_1 is conducting .Fig.5. (d) Shows the equivalent circuit of the proposed converter in this mode. The leakage inductor energy can be recycled, and the voltage stress of the switch can be limited.

(e). Mode 5 [t_4-t_5]

At $t=t_4$, the switch Q is turned on , and voltage across the switch V_{DS} reduces to zero. Diode D_2 is still conducting and Diode D_1 is turned off .The leakage inductor L_{K1} and Lm charged to input voltage (Vs) and current starts to increases as shown in Fig.5.(e).

B. Formula Derivation

When the switch (Q) is turned on, the voltage across the magnetizing inductor (L_m) and V_{L2} are written as

$$V_{lm} = V_S \tag{1}$$

$$V_{l2} = n\,V_{lm} = n\,V_S \tag{2}$$

When the switch (Q) is turned off, the voltage across the magnetizing inductor (L_m) and V_{L2} are written as

$$V_{Lm} = -\,V_{C1} \tag{3}$$

$$V_{l2} = n\,V_{lm} = -\,n\,V_{C1} = V_{C2}+V_{C1}+V_S-V_0 \tag{4}$$

$$V_{l2} = 2(V_{C1}+V_S)-V_O$$

Where the voltage across the capacitor (C_2) can be written as

$$V_{C2} = V_{C1}+V_S \tag{5}$$

By using voltage-second balance principle on N1 and N2 of the coupled inductor , the following Equations are written as

$$\int_0^{DT} Vs\,dt + \int_{DT}^{T} -Vc1\,dt = 0 \tag{6}$$

$$\int_T^{DT} nVs\,dt + \int_{DT}^{T} (2Vc1+Vs)-Vo]\,dt = 0 \tag{7}$$

From equation (6) and (7), VC1 and V0 are derived as

$$VC1 = \frac{D}{1-D}Vs \tag{8}$$

$$VO = \frac{(2+nD)}{1-D}Vs \tag{9}$$

As a result, the voltage gain of the step-up converter can be represented as

$$GV = \frac{VO}{Vs} = \frac{(2+nD)}{1-D} \tag{10}$$

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Equation (10) indicates that the converter accomplishes a high voltage gain by using voltage –lift technique and increasing the turn's ratio of the coupled inductor. Fig.6. Plots the ideal voltage gain against the duty ratio, under various turns ratios of the coupled Inductor.

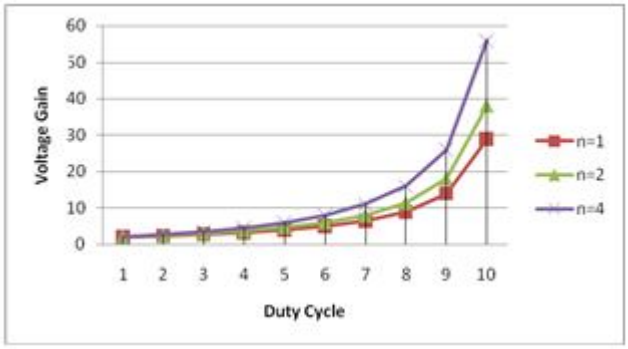

Figure 6. Voltage gain against duty ratio under various turns ratio of the coupled inductor

According to (8) and (9), the voltage stresses on the switch and the diodes are as follows

$$VDS = VC1 + Vs = \frac{1}{1-D}Vs \tag{11}$$

$$VD1 = VC2 = VC1 + VS = \frac{1}{1-D}Vs \tag{12}$$

$$VD2 = VC2 = VC1 + VS = \frac{1}{1-D}Vs \tag{13}$$

$$VD0 = nVS + VO - VC2 = \frac{n+1}{1-D}Vs \tag{14}$$

From (9) and (11), the voltage stress of the main switch is clamped at a low voltage, and less than output voltage.

III. Design Specifications Of The Proposed Converter

A proposed converter had the following specifications:

1. Input DC voltage = 25V
2. Output DC Voltage = 240V
3. Switching Frequency = 50KHZ
4. Output power = 250W
5. Duty cycle = 65%

The on state resistance of the power switch and the primary winding of coupled inductor result much conduction loss for the low input power source of the proposed converter. Therefore, the maximum operating duty ratio is selected as a reasonable duty ratio for the high current issue in this design. The maximum duty ratio is selected nearly 0.65.

Based on above circuit specifications, the circuit design consideration can be described as below

A. Designing of Coupled Inductor

Here coupled inductor is modeled as a ideal transformer, the magnetizing inductor (L_m) and a leakage inductor (L_{k1}) .The turns ratio (n) and the coupling coefficient (K) of this ideal transformer is defined as

$$n = \frac{n1}{n2} \tag{15}$$

$$K = \frac{Lm}{Lm + Lk} \tag{16}$$

Using above formula, "n" and "k" found to be 2 &0.98 respectively, so chosen value of k=1and using this values in the following equations

$$L1 = \frac{nD(1-D)R}{2f(2+nD)} \tag{17}$$

$$\frac{L1}{L2} = \frac{N2\text{^}2}{N1\text{^}2} \tag{18}$$

$$Lm = \frac{D(1-D)\text{^}2R}{2(n+2)(2+nD)f} \tag{19}$$

From equation (17), (18) and (19) select the values L1=79.28μH, L2=317μH, and Lm=13.87μH.

B. Designing of Capacitors

1. Capacitor C_1 &C_2

Using the following equations,

$$C1 = Is\frac{(1-D)}{fVs}$$

$$C2 = IO\frac{D(1-D)}{fVs}$$

Select the value of capacitor C1=2.6μF, C2=0.182μF

2. Filter Capacitor C_0

To find the value of filter capacitor "Co" for a desired output voltage ripple , we note that the capacitor resistor combination at the output of converter act as a low –pass filter for the current through the boost diode.

$$C0 = \frac{Io(1-D)[V0 - Vs(2+nD)}{2V0\,fVs}$$

Using this equation select Co is found to be $51.70e^{-9}$ F

3. Based on above design analysis, voltage across the power switches and diodes are determined from equation (11) to (14). Accordingly the power MOSFET and diodes D_1, D_2 and D_0 are selected respectively.

Fig.7. shows the Simulation diagram of proposed converter and Fig.8.Shows the simulation waveforms for P_O=250W and Vs=25 V. The proposed converter is operated at CCM. The simulated waveforms agree with the steady state analysis circuit design. From Fig .8. (a) ,V_{DS} is clamped at approximately 60V during the switch off period. The voltage stress of the switch is effectively clamped without any snubber circuit. Therefore, a low –voltage rating power switch with a low on stage resistance for the high efficiency conversion of the proposed converter is adopted .Fig.8. (b) Shows the conduction of diode D_1 and D_2.

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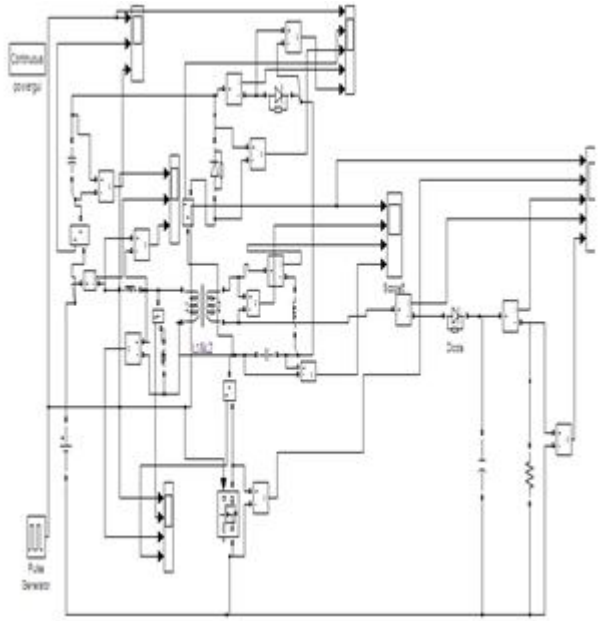
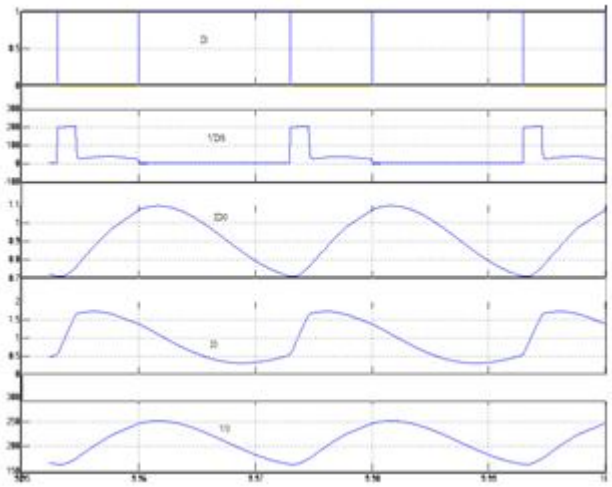
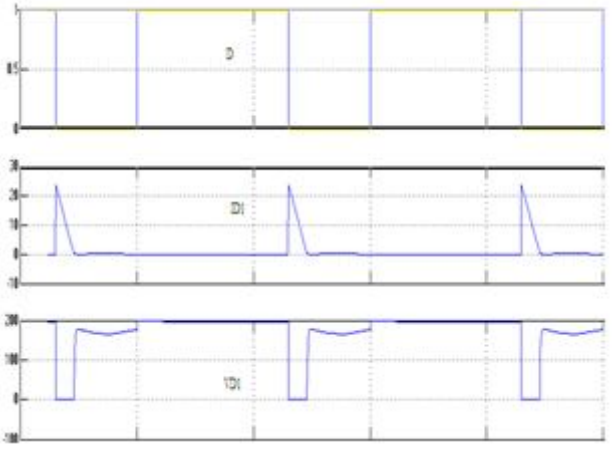


Figure 7. Simulation Diagram of Proposed Converter

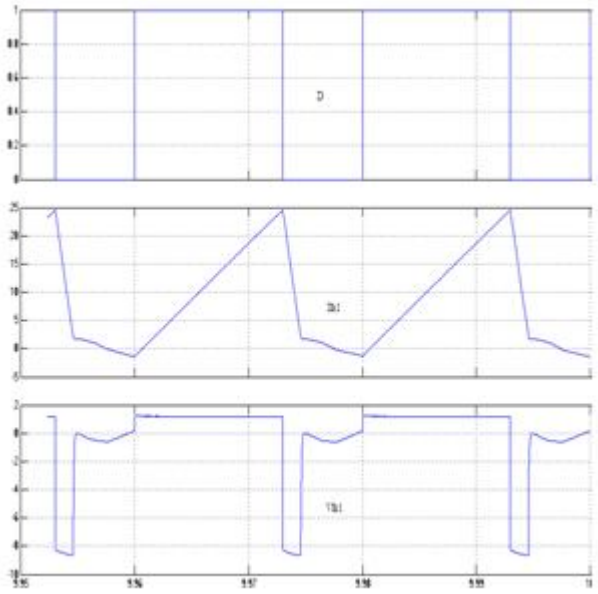


(a) proposed converter with V_O=250V and Po=250W



(b) Result of i_{D1} , $V_{D1,}$ i_{D2} and V_{D2} of proposed converter

Fig.9. shows the experimental conversion efficiency of the proposed converter at condition D=0.65, n= 2. The maximum efficiency was around 96.96 % at Po=240W and Vs=25V.The result verify that the proposed converter has



(c) i_{Lm} and V_{Lm} of proposed converter

Figure 8. Simulation results for proposed converter under CCM for n=2

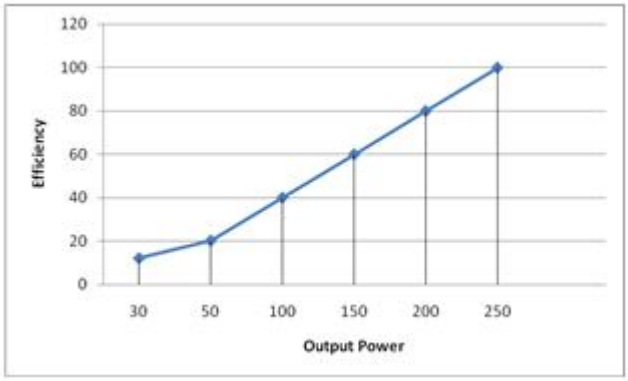


Figure 9. Conversion efficiency of the proposed converter at different output powers

high-efficiency conversion, which is higher than conventional converters. Since the low input is applied in this energy conversion system, the input of proposed converter should suffer very high current which result much conduction loss during the switch on period. Thus, it will result in lower conversion efficiency. Furthermore, the proposed converter uses only one active switch for the energy conversion, which also suffers very current during the switch on period. Thus the proposed converter is suitable for low-middle power applications. In order to reduce the switch conduction loss, the switches in parallel are usually adopted for this high current issue to improve efficiency. This approach can also be used for the proposed converter in high power applications.

Conclusion

This study has developed a high voltage gain Boost converter to achieve the High step-up voltage gain with voltage lift technique. The proposed converter has been highly efficient because it recycles the energy stored in leakage inductor of the coupled inductor while providing zero-voltage turn

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ON of the main switch. Since voltage across the switch is clamped, the low-voltage rating and low-on-resistance power switch can be selected to improve efficiency. The operating principle and steady state analysis have been described in detail. The simulation results have indicated that the full load efficiency was 96.96% at Vs=25V at Po=240W.Thus, the proposed converter is suitable for power conversion systems, such as fuel-cell-and solar-cell-based power conversion systems, high-intensity discharge lamps for automobiles head lamps etches authors can conclude on the topic discussed and proposed. Future enhancement can also be briefed here.

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