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A High Step-Up DC-DC Converter

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Abstract— Now a day increasing demand for clean and sustainable energy sources. A high step-up DC-DC converter with coupled inductor and switched capacitor for renewable energy applications was presented here. It consists of a coupled inductor and two voltage multiplier cells, in order to obtain high step-up voltage gain. Two capacitors are charged during the switch-off period, using the energy stored in the coupled inductor which increases the voltage transfer gain. The energy stored in the leakage inductance is recycled with the use of a passive clamp circuit. The voltage stress on the main power switch is also reduced in this topology. Simulation is done with 12V input voltage, 15W output power and 120V output voltage using MATLAB. Finally, a hardware prototype is implemented which converts the 12V input voltage into 120V output voltage.

Keywords—Dc-Dc converter, boost converter, high step-up, coupled inductor switched capacitor.

I. INTRODUCTION

Renewable energy sources has dramatically increased during the past few years with growing population and industrial development. Renewable energy is derived from natural processes. It derives directly from the sun, or from heat generated deep within the earth. The majority of renewable energy sources derive energy from solar radiation. Renewable energy sources are divided into three categories. Direct solar energy, Indirect solar energy and Non solar energy. Direct solar energy refers to solar thermal energy conversion and solar photovoltaic. Indirect solar energy includes wind power, wave power and bio-fuels. Non solar renewable are those that do not depend on solar radiation. There are two source of non solar renewable energy, tidal and geothermal. For a long time,

fossil fuels have been used as the major source of electricity generation. Environmental consequences of these resources have made it necessary to benefit from clean energy sources such as wind and solar.

Conventional boost converter steps up voltage from its input to its output. It is a class of switched-mode power supply (SMPS) containing at least two semiconductors and at least one storage element or the two combination. Power from the boost converter can come from any suitable DC sources such as batteries, solar panels, rectifiers and DC generators.

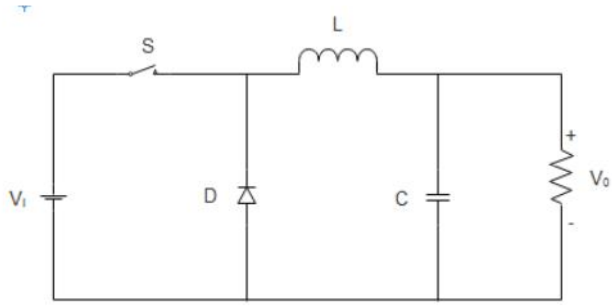

Figure 1: Conventional boost converter

The conventional boost converters are not suitable for the high step-up conversion applications because the duty cycle of the boost converter with high step-up conversion is large, which results in narrow turn off time. The extremely narrow turn-off time will bring large peak current and considerable conduction and switching losses. Conventional boost converter is shown in fig 1. However extreme duty ratio will result in serious reverse recovery problems and electromagnetic interferences. Impact of silicon carbide (SiC) MOSFETS on converter switching and conduction losses are reduced even though fast switching is done. Si diodes have ideal, but still SiC devices processes large amount of ringing current at turn off relatively to other devices.

Forward converter, push-pull converter and fly back converters are transformer based converters (isolated converters) and can achieve high voltage

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gain by adjusting the turns ratio of the transformer. But it has the disadvantages of voltage spike across the main switch, power dissipation due to leakage inductance of the transformer and safety standard needs. In [2] a single switch high step-up converter is proposed. The coupled inductor in that topology can act as both forward and fly back converter, thus it can charge two capacitors in parallel and discharge in series.

A high gain transformer less converter is presented in [3]. It consisting of a hybrid combination of two-level DC-DC converters . Thus it has large number of components and it will increase the cost. Switched capacitor techniques have been used widely in order to improve high voltage gain. But here high charging current will be flowing through main switch and increase the conduction loss.

Converters with charge pump will provide voltage gain in proportion to the number of stages of capacitors, but its drawback includes fixed voltage gain and large device area. In [4] diode capacitor techniques are implemented. It can also achieve high voltage gain in proportional to the number of stages, which is able to be extended by adding capacitors and diodes. But it may result in the larger voltage drop due to cut in voltage of the diodes in series.

Different converter technologies with tapped inductor technology is explained in [5]. Coupled inductor based converters also achieve high voltage gain by adjusting the turns ratio. However the stored energy in the leakage inductor causes a voltage spike on the main switch and deteriorates the conversion efficiency. To overcome this problem, coupled inductor based converter with active clamping circuits are presented [6]. It compare with this converter and conventional boost converter with coupled inductor only and active clamp circuit only. High step-up converter with two switch [7] and one switch [8] are explained. As no of switches increased losses will increased. However the conversion ratio is not large enough.

This paper presents, the converter structure consists of a coupled inductor and two voltage multiplier cells in order to obtain high-step-up voltage gain. In addition, a capacitor is charged during the switch-off period using the energy stored in the coupled inductor, which increases the voltage transfer gain. The energy stored in the leakage inductance is recycled with the use of a passive clamp circuit. The voltage stress on the main power switch is also reduced in this topology. Therefore, a main power switch with low resistance RDS(ON) can be used to reduce the conduction losses .New topology of this converter is a solution for the above mentioned problems.

II. CIRCUIT CONFIGURATION

A. Operation of the converter

The circuit configuration of the high gain boost converter with coupled inductor and switched capacitor topology is shown in Fig. 2 It comprises a dc input voltage (V_{in}), active power switch (S), coupled inductor, four diodes, and four capacitors. Capacitor C_1 and diode D_1 are employed as clamp circuit, and capacitor C_3 is employed as the capacitor of the extended voltage multiplier cell. The capacitor C_2 and diode D_2 are the circuit elements of the voltage multiplier which increases the voltage of clamping capacitor C_1 . The coupled inductor is modeled as an ideal transformer with turn ratio N (N_P /N_S), a magnetizing inductance L_m and leakage inductance L_k .

Assumptions are as follows:

1. All Capacitors are sufficiently large; therefore V_{C1} , V_{C2} , V_{C3} , and V_0 are considered to be constant during one switching period.

2. All components are ideal but the leakage inductance of the coupled inductor is considered. According to the aforementioned assumptions, the continuous conduction mode (CCM) operation of this converter includes five stages in one switching period. Conducting elements in each stages are shown in the corresponding explanation.

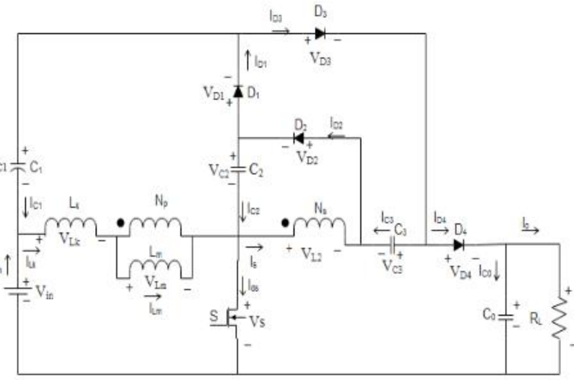

Fig 2. Circuit diagram of the presented high step-up converter

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Modes of operation

1) Stage 1: [Fig. 3.1]: In this stage, switch S is turned on. Also, diodes D_2 and D_4 are conducting and diodes D_1, D_3 are off. The DC source (V_{in}) magnetizes Lm through S. The secondary-side of the coupled inductor is in parallel with capacitor C_2 using diode D_2. As the current of the leakage inductor L_k increases linearly, the secondary-side current of the coupled inductor (i_S) decreases linearly. The required energy of load (R_L) is supplied by the output capacitor C_O. This interval ends when the secondary-side current of the coupled inductor becomes zero.

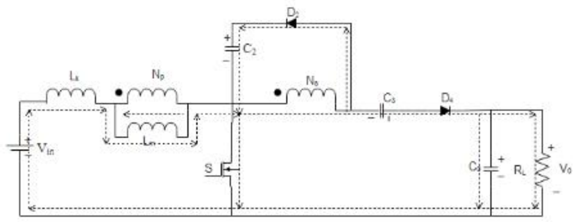

Figure 3.1: Stage 1

2) Stage 2 [Fig. 3.2]: In this stage, switch S on and diode D_3 is conducting and diodes D_1, D_2 and D_4 are off. The DC source V_{in} magnetizes L_m through switch S. So, the current of the leakage inductor L_k and magnetizing inductor Lm increase linearly. The capacitor C_3 is charged by dc source V_{in}, clamp capacitor C_1 and the secondary-side of the coupled inductor. Output capacitor C_O supplies the demanded energy of the load

R_L. This interval ends when switch (S) is turned off.

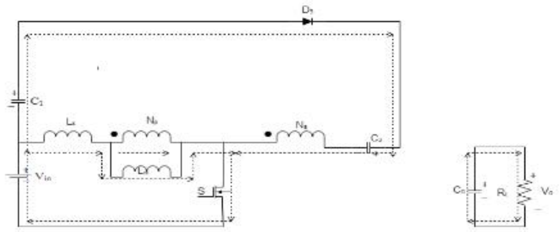

Figure 3.2: Stage 2

3) Stage 3 [Fig. 3.3]: In this stage, switch S is turned off. Diodes D_1 and D_3 are conducting and diodes D_2 and D_4 are off. The clamp capacitor C_1 is charged by the stored energy in capacitor C_2 and the energies of leakage inductor L_k and magnetizing inductor L_m. The currents of the secondary-side of the coupled inductor (i_S) and the leakage inductor are increased and decreased respectively. The capacitor C_3 is still charged through D_3. Output capacitor C_O supplies the energy to load R_L. This interval ends when i_{Lk} is equal to i_{Lm}.

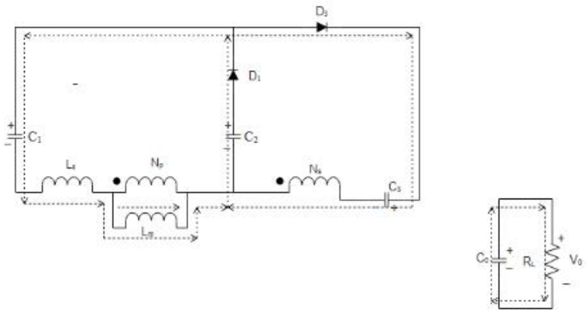

Figure 3.3: Stage 3

4) Stage 4 [Fig. 3.4]: In this stage, S is off. Diodes D_1 and D_4 are conducting and diodes D_2 and D_3 are off. The clamp capacitor C_1 is charged by the capacitor C_2 and the energies of leakage inductor L_k and magnetizing inductor L_m. The currents of the leakage inductor L_k and magnetizing inductor Lm decrease linearly. Also, a part of the energy stored in Lm is transferred to the secondary side of the coupled inductor. The dc source V_{in}, capacitor C_3 and both sides of the coupled inductor charge output capacitor and provide energy to the load R_L. This interval ends when diode D_1 is turned off.

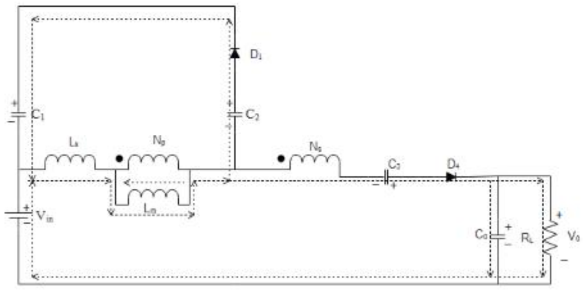

Figure 3.4: Stage 4

5) Stage 5 [Fig. 3.5]: In this stage, S is off. Diodes D_2 and D_4 are conducting and diodes D_1 and D_3 are off. The currents of the leakage inductor L_k and magnetizing inductor L_m decrease linearly. A part of stored energy in Lm is transferred to the secondary side of the coupled inductor in order to charge the capacitor C_2 through diode D_2. In this interval the DC input voltage V_{in} and stored energy in the capacitor C_3 and inductances of both sides of the

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Volume 6, Issue 7
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coupled inductor charge the output capacitor C_O and provide the energy demanded by the load R_L. This interval ends when switch S is turned on.

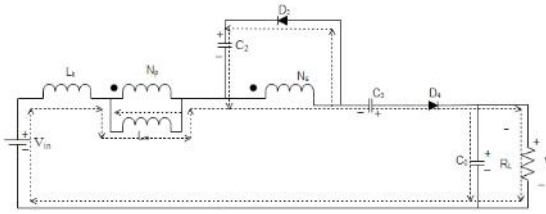

Figure 3.5: Stage 5

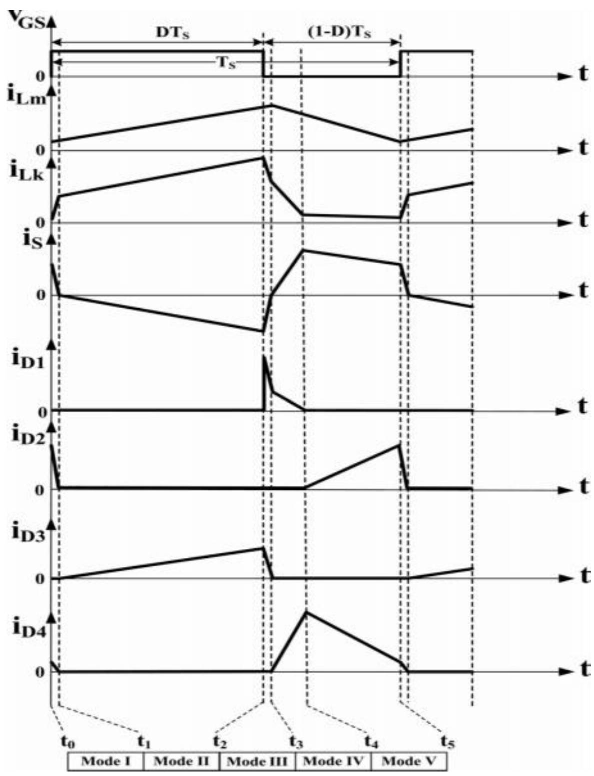

Fig. 4. Some typical waveforms of the converter at CCM operation.

III. STEADY-STATE ANALYSIS OF THE CONVERTE

CCM Operation

To simplify the steady-state analysis, only stages 2, 4, and 5 are considered since these stages are sufficiently large in comparison with stages 1 and 3. During stage 2, L_k and L_m are charged by dc source V_{in} . Therefore, the following equation can be written according to Fig. 2.2:

$$V_{Lm} = k\,V_{in} \qquad (1)$$

where k is the coupling coefficient of coupled inductor, which equals to $L_m/(L_m + L_k)$. Capacitor C_3 is charged by clamp capacitor C_1 , dc source V_{in}, and the secondary-side of the coupled inductor. The voltage across the capacitor C_3 can be expressed by

$$V_{C3} = V_{C1} + (kn + 1)V_{in} \qquad (2)$$

where n is the turn ratio of coupled inductor which is equal to N_S / N_P . As shown in Fig. 2.4, during stage 4, L_k and L_m demagnetize to the clamp capacitor C_1 with the help of capacitor C_2 . Hence the voltage across L_m can be written as

$$V_{Lm} = k\,(V_{C2} - V_{C1}) \qquad (3)$$

Also, the output voltage can be formulated based on Fig. 2.4

$$V_O = V_{in} + V_{C3} + (kn + 1)(V_{C1} - V_{C2}) \qquad (4)$$

According to Fig. 2.5, in the time interval of stage5, the voltage across L_m can be expressed by

$$V_{Lm} = -V_{C2}/n \qquad (5)$$

Moreover, the output voltage is derived as

$$V_O = V_{in} + V_{C3} + ((1/kn) + 1)V_{C2} \qquad (6)$$

According to aforementioned assumption, the output capacitor voltage is constant during one switching period. Therefore, by equalization of (4) and (6), the following equation is derived as:

$$Vc1 = \frac{k\ +1}{k} Vc2 \qquad (7)$$

Using the volt-second balance principle on L_m and equations

(1), (3), (5) and (7), the voltages across capacitors C_1 and C_2 is

obtained as

$$Vc1 = \frac{(k\ +1)D}{1-D}\ Vin \qquad (8)$$

$$Vc2 = \frac{k}{1-D}\ Vin \qquad (9)$$

Substituting (8) into (2), yields

$$Vc3 = \frac{k\ +1}{1-D}\ Vin \qquad (10)$$

Substituting (9) and (10) into (6), the voltage gain is achieved

As

$$V_0 = \frac{2+k\ +k}{1-D}\ Vin \qquad (11)$$

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IV. SIMULATION RESULTS

The simulation of the high step-up DC-DC converter with coupled inductor and switched capacitor techniques has been carried out.. An input voltage of 12V and switching frequency of 60 kHz is chosen and an output of 120V is obtained. Specifications of the converter are shown in table 1.

Table 1.specifications

PARAMETER	VALUE
Input dc voltage	12 V
Output voltage	120 V
Switching frequency	60 kHz
Coupled inductor	Lk = 1µH, Lm = 300µH
Capacitors C_1, C_2, C_3, C_O	47 µF ,47 µF ,100 µF,220 µF
Load	1000Ω

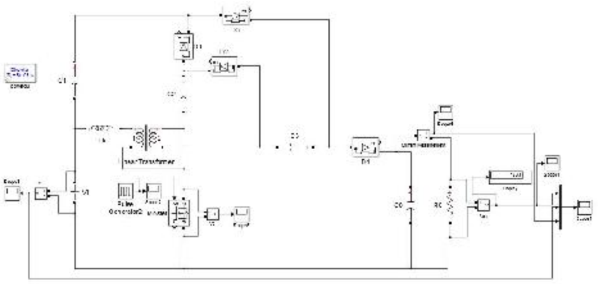

Fig. 5. open loop simulation diagram

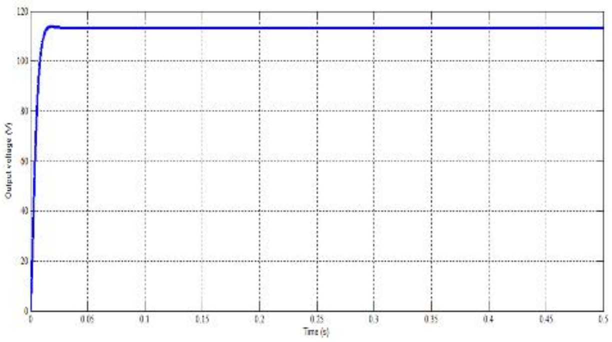

Fig.6.waveform of open loop output voltage

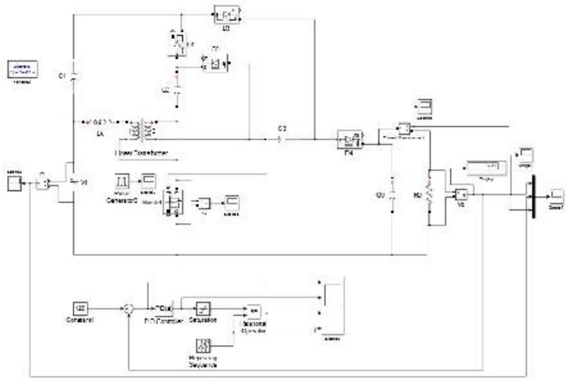

Fig. 7. closed loop simulation diagram

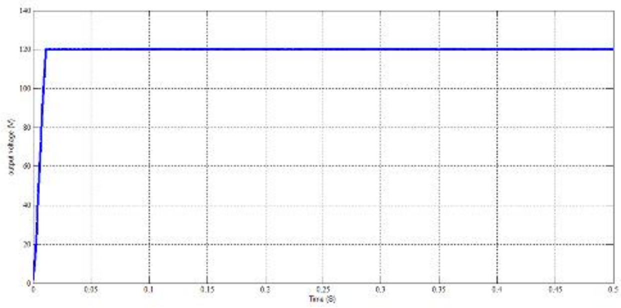

Fig.8.waveform of closed loop output voltage

V. HARDWARE IMPLIMENTATION

A prototype circuit is implemented in the laboratory. The specifications are as follows

1. Input DC voltage V_{in} : 12V
2. Output DC voltage V_0 : 120V
3. Maximum output power P_0 : 15W
4. Switching frequency f : 60kHz
5. MOSFET (S) : IRFP260
6. Diodes :MUR1540
7. Coupled inductor : E25 core, N_P : N_S = 1 : 2; L_m = 300µH; L_k = 1µH

8.Capacitors:C_1=47µf/160V;C_2=47µf/160V;C_3= 100µf/250V;

C_O = 220µf/250V

The converter is operated in CCM under the full-load condition.

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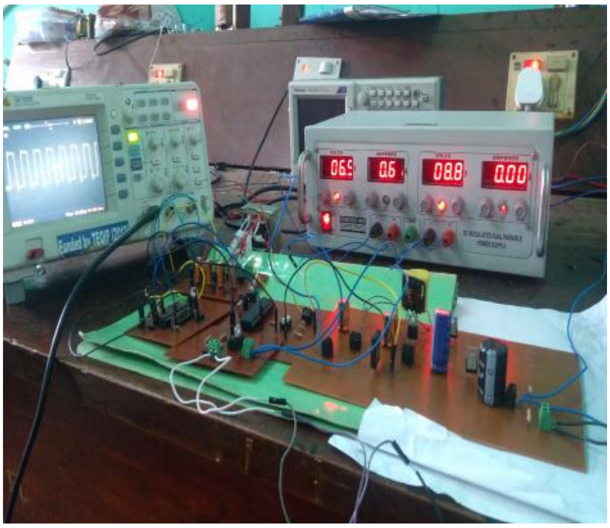

Fig.9. Hardware Setup of the converter

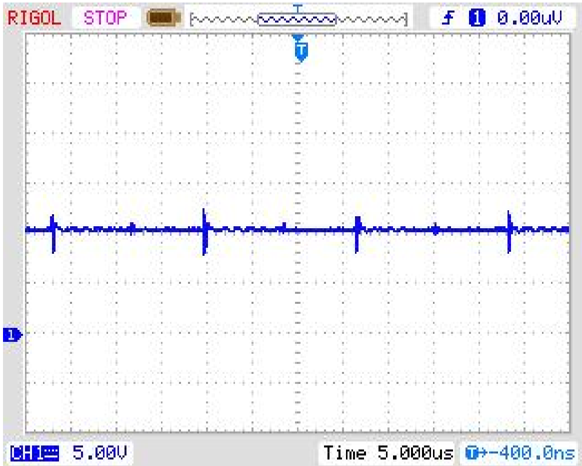

Fig.10. input voltage

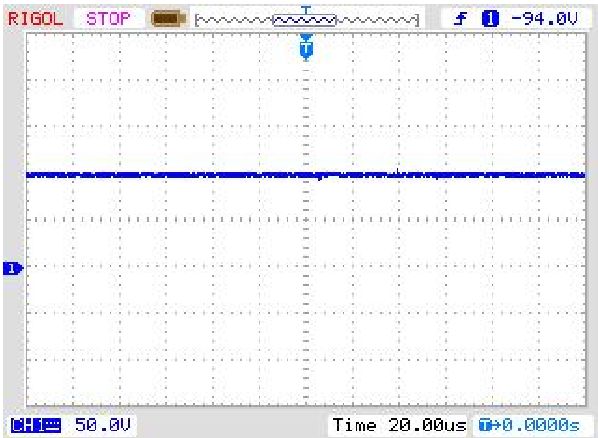

Fig.11. output voltage

VI. CONCLUSION

A high step-up DC-DC converter integrating coupled inductor and switched capacitor are presented for renewable energy applications. This converter is also suitable for Distributed Generation systems based on renewable energy sources, which require high-step-up voltage transfer gain. The energy stored in the leakage inductance is recycled to improve the performance of the presented converter. Furthermore, voltage stress on the main power switch is reduced. Therefore, a switch with a low on-state resistance can be chosen. The steady-state operation of the converter has been analyzed in detail. The simulation of the converter with 12V input voltage, 15W power and 120V/.125A has been carried out using MATLAB software. Finally, a hardware prototype is implemented which converts the 12V input voltage into 120V output voltage. The converter is capable of operating at 60kHz. The results prove the feasibility of the presented converter.

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