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A High Gain Dc-Dc Converter with Coupled Inductor and Charge Pump

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Abstract: **The Green Energy sources such as Photovoltaic cell and Fuel cell are more popular nowadays because of environment pollution and energy shortage. However, the output of these green energy sources seems to be very lowcompared to the dc bus voltage. Thus, a high step-up voltage gain dc-dc converter with high efficiency should be introduced to boost the voltage, and then this green energy can be connected to the grid. In order to obtain a high voltage gain, high efficiency converter, this paper proposes a dual switchdc-dc converter with three-winding-coupled inductor and charge pump. This converter provides a high step up voltage gain with low voltage/current stress on the power switches. It also can achieve a high gain with a small duty cycle, which is helpful to reduce the peak current through the power device and helps to improve the efficiency. A comparisonbetween performance of the proposed converter and previous high step up converters was conducted. Simulation results verify the correctness of the analysis.**

***Index Terms*—Charge pump, coupled inductor, zero current shutting off (ZCS), coupled inductor, Below resonance frequency mode (BRF).**

I. INTRODUCTION

Because of environment pollution and energy shortage, we have todepend more on Green energy sources such as Photovoltaic cell, Fuel celletc. However the output of these Green energy sources seems to be very low(lower than 50 V DC) compared to the dc bus voltage (200 or 400 V DC).Thus, a high step-up voltage gain dc-dc converter with high efficiency shouldbe introduced to boost the voltage, so that these green energy can be connectedto the grid. Among the non isolated dc-dc converters, the boost converter is usually used for voltage step up. However, the duty cycle will approach to unity whenthe output voltage is much higher than the input voltage. Thus, the currentripple of the inductor and current stress of the power device are large, whichresults in large conduction loss, switching loss, and low efficiency [6].

The common high step-up voltage gain dc-dc converter can be classified into four species: the cascade Boost topology, the switched-cell Boosttopology, the coupled-inductor Boost topology, and the mixture of thesethree. By cascading another boost converter, a high voltage gain can be easily obtained, but too many components are required, results in high cost andlow overall efficiency [2]. With the series and parallel connectionof the switched cell, we can achieve a high voltage gain, however, the voltage-conversion ratio is difficult and the pulsating voltage or pulsating current will result in more electromagnetic interference.

In order to overcome the drawbacks mentioned in the previous literatures this paper proposes a dual switch dc-dc converter with three winding coupled inductor and charge pump to boost the voltage. The proposed converter, when compared to the boost converter can provide a higher voltage gain with a lower voltage/current stress of the switches. The magnetic components can be integrated into one magnetic core, which is helpful to simplify the structure. Taking the advantages of the leakage inductor, all the diodes can achieve the Zero Current Shutting off (ZCS) to reduce the loss.

II. PRINCIPLE OF OPERATION OF PROPOSED CONVERTER

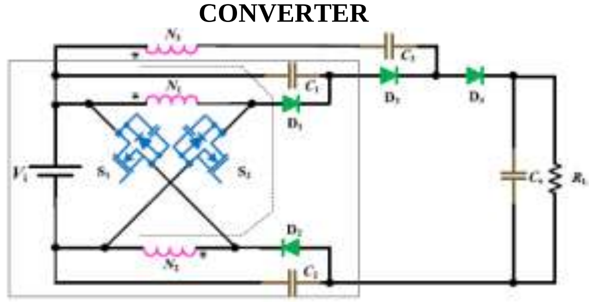

Fig.1 Proposed dual switch converter

Fig.1 shows the circuit diagram of the proposed converter.Vi is the input voltage.S1 and S2 are the dual

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switches which operate under same gate signal. The capacitors $C1$ and $C2$ are used to absorb the energy of leakage inductor and clamp the voltage across $S1$ and $S2$. $C3$ is the capacitor of charge pump, which is used to add the voltage conversion ratio.$N1$,$N2$, and $N3$ are the windings of the three-winding-coupled inductor. The turns ratio of N1, N2 and N3 is 1:1:n.C0 is the output filter capacitor.

In order to simplify the analysis we have to assume that The dual switches structure shares the same gate signal 2) The capacitance of $C1$, $C2$, and Co are largely enough, that the voltage Vc1 , Vc2 , and Vo could be treated as a constant.

A resonance loop is formed by the leakage inductor Lk and the charge pump C3 . According to the relationship between the resonance period and the on state period (DTs), the proposed converter can operates in two modes: If$\pi\sqrt{L_k C_3}$>D$T_s$the converter operates in the below resonance frequency mode (BRF mode), If $\pi\sqrt{L_k C_3}$ <DT_s ,the converter operates in over resonance frequency mode(ORF mode).

III. MODES OF OPERATION

Here each mode is explained on the basis that the converter operates in below resonance frequency (brf) mode.

A) MODE1

During this mode the switches S1 and S2 start to conduct. The equivalence circuit is shown in fig.2. The voltage across the switches decreases to zero. With the help of leakage inductor Lk, the current through the turns$N1$ and$N2$ increase from zero, which is helpful to reduce the switching loss. The diodes$D1$,$D2$, and$D3$ are reverse-biased, while$D4$ is conducting. The leakage inductor $Lk$and charge pump$C3$ begins toresonate. Since this time interval is too short that the leakage inductor current i_{Lk} drops almost at a constant slope.

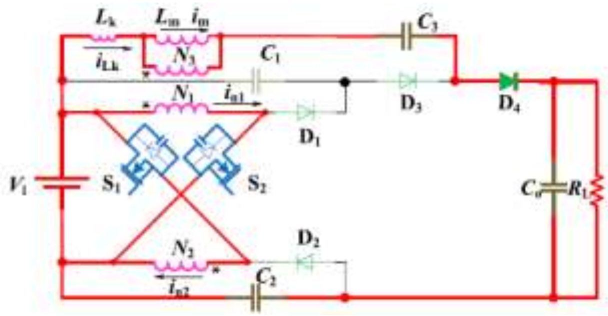

Fig.2 Operation Of Proposed Converter In Mode1

B) MODE2

During this stage, S1 and S2 remains in conduction, the equivalencecircuit is shown in Fig. 3. At the time of t_1 , the leakage inductor currenti_{Lk} decreases to zero, D4 turns OFF with ZCS, and then,i_{Lk}keeps falling,D3 turns ON, Lk and C3 are still in resonance state.

The state equations of resonant circuit from t1 to t2 can be written as follows:

$$L_k \frac{di_{Lk}}{dt} = V_{c3} - nVi - Vc1 \quad (1)$$

$$C_3 \frac{dV_{c3}}{dt} = -i_{Lk} \quad (2)$$

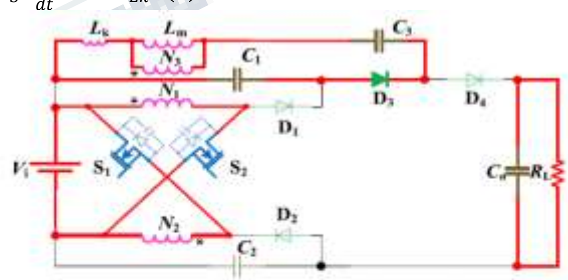

Fig.3 Operation Of Proposed Converter In Mode2

C) MODE 3

The equivalent circuit is shown in Fig. 4.At the time of t2 , S1and S2 are turned OFF. N1 and N2 transfer energy to the parasitic capacitors of S1 and S2 , the parasitic capacitors keep charging until D1 and D2 begins to conduct.

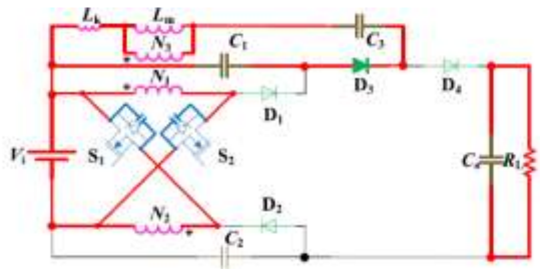

Fig.4 operation of proposed converter in mode 3

D) MODE 4

The equivalent circuit is shown in Fig.5. At the time of t3 , N1 and N2 transfer energy to the clamping capacitors C1 and C2 . C3 charges the leakage inductor Lk in a resonance way, considering this time interval is extremely short, the leakage inductor current i_{Lk} rises almost at a constant slope.

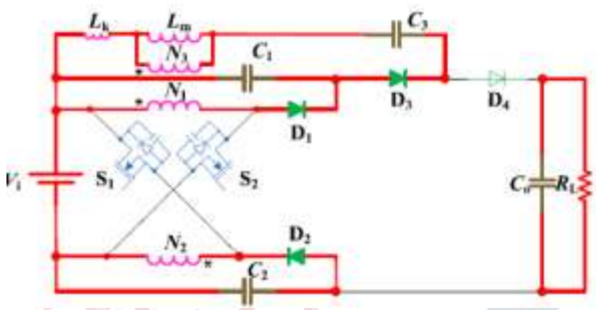

Fig.5 Operation of proposed converter in mode 4

E) Mode 5

The equivalent circuit is shown in Fig. 6. At the time of t4,the leakage inductor current iLk rise to zero, D3 turns OFF with ZCS, theniLk keeps rising and turns to positive, N1 and N2 keeps transferring energyto the clamping capacitors C1 and C2.Lk and C3 are still in resonance state, the state equations of resonantcircuit can be written as follows:

$$L_k \frac{di_{Lk}}{dt} = nV_{c1} + Vi + Vc2 + V_{c3} - Vo \ (3)$$

$$C_3 \frac{dV_{c3}}{dt} = -i_{Lk} \ (4)$$

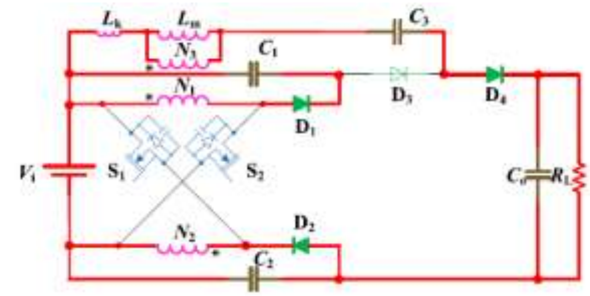

Fig.6 Operation of proposed converter in mode 5

F) Mode 6

The equivalence circuit is shown in Fig. 7. At the time of t5, the current through N1 and N2 decrease to zero, D1 and D2 turn OFF withZero current shutting off.

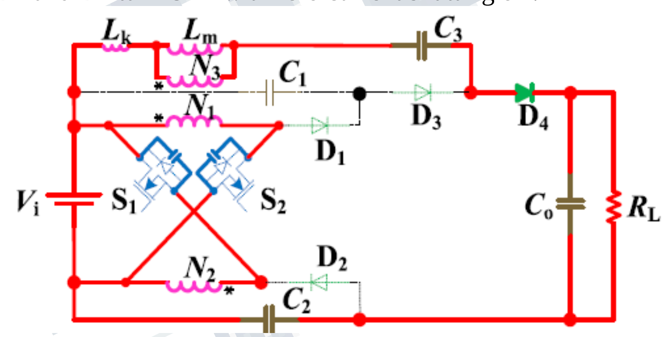

Fig.7 Operation of proposed converter in mode 6

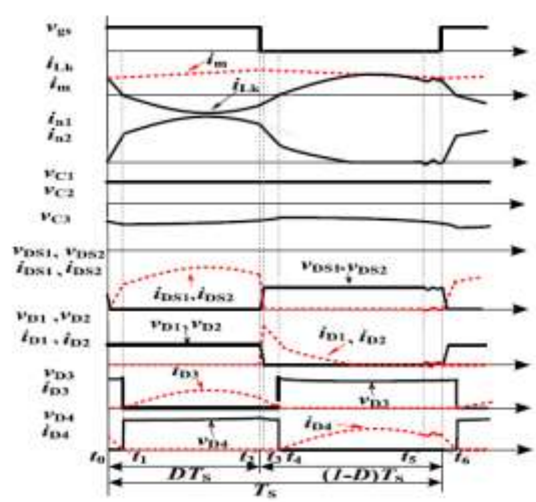

Fig.8 Operation waveforms of the proposed converter

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IV. ANALYSIS OF THE CIRCUIT

To simplify the analysis, the leakage inductances of the coupled inductor are neglected in the steady-state analysis. The operation modes can be simplified in to two modes.

When S1 and S2 turns ON, the magnetising inductor is charged, the voltage across the magnetizing inductor could be expressed as:

$V_{Lm} = nV_i$(5)

The turns N2 , the power switch S1 , the diode D2 , and the clamping capacitor C2 forms a Buck-Boost converter; the turns N1, the powerswitch S2 , the diode D1 , the clamping capacitor C1 , and the capacitor Coforms a Boost converter.

$$V_{c1} = \frac{1}{(1-D)}Vi - Vi = \frac{D}{(1-D)}\text{Vi} \qquad (6)$$
$$V_{c2} = \frac{D}{(1-D)}Vi \qquad (7)$$

The voltage across the charge pump C3 is
$$V_{c3} = \frac{D}{(1-D)}Vi + nVi \qquad (8)$$

While during the OFF state, the magnetizing inductor is discharged, the voltage across the magnetizing inductor is

$$V_{Lm}=\text{Vi}+V_{c2} + V_{c3} - Vo = \frac{1+D}{1-D}Vi + nVi - Vo \quad (9)$$

Using the inductor volt-second balance principle to the magnetizing inductor Lm, the following equations can be expressed as:

$$\int_0^{DTs} nVi\text{dt} + \int_{DTs}^{Ts}(Vi + V_{c2} + V_{c3} - Vo)dt = 0 \quad (10)$$

Substituting the expressions for Vc2 and Vc3 in above equation andsolving for Vo,

$$\text{Vo}=\text{Vi}\frac{(1+n+D)}{(1-D)} \qquad (11)$$

V SIMULATION RESULTS

The simulation is done in mat lab stimulant and a comparison of the voltage gain of the proposed converter with previous integrated boost fly back converter has been done. The specification and ratings of the components used in simulation are listed below.

COMPONENTS	SPECIFICATION
INPUT VOLTAGE	30 V
SWITCHING FREQUENCY	50 KHZ
MAGNETIZING INDUCTOR,LM	1530MH
LEAKAGE INDUCTOR,LK	25MH
CLAMPING CAPACITOR C1,C2	4.7MF
CHARGE PUMP,C3	3MF
FILTER CAPACITOR,CO	470MF
LOAD RESISTOR	320Ω

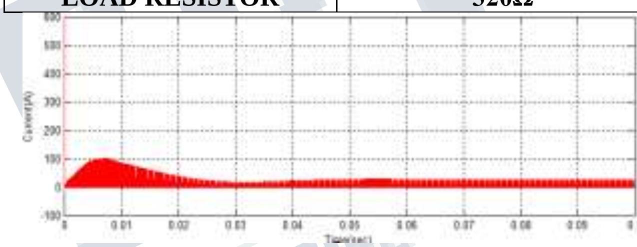

Fig.9 input current waveform of proposed converter
Fig. 9 shows the input current waveform of proposed converter.

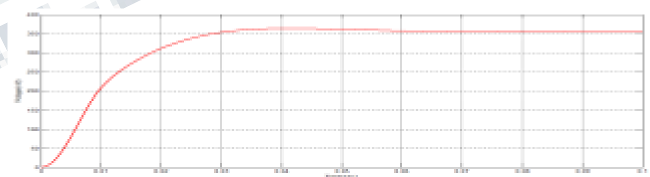

Fig.10 Output Voltage Waveform Of Proposed Converter

Fig.10 shows the output voltage waveform of proposed converter.The steady state value of output voltage is 354.6 V for an input voltageof 30 V, providing a high voltage gain.

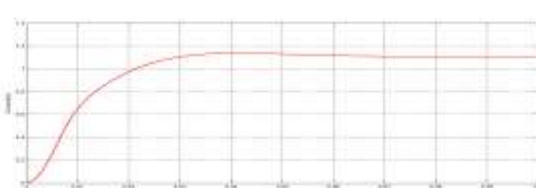

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Fig.11 Output Current Waveform Of Proposed Converter.

Fig.11 shows the output current waveform of proposed converter..Thesteady state value of output current is 1.108 A.

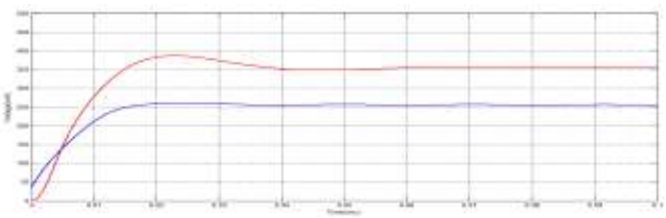

Fig.12comparison of Output Voltages of Proposed Converter and IBFC

Fig 12 shows the comparison of output voltages of proposed converter and Integrated Boost Fly back converter. The steady state value of output voltages of proposed converter and IBFC are 354 V and 252 V respectively for an input voltage of 30 V and duty ratio 0.65.

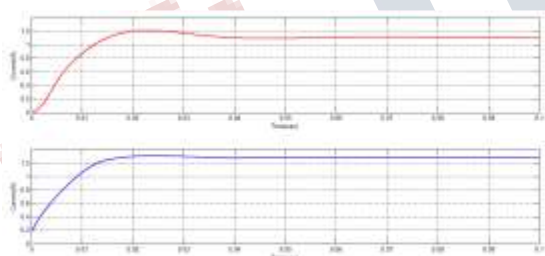

Fig. 13comparison of output currents of proposed converter and IBFC

Fig.13 shows the Output currents of Integrated Boost Fly back converter and proposed converter. The steady state value of output currents of proposed converter and IBFC are 1.15 A and 1.3 A respectively.

Table2. Comparison of voltage gain

Topology	Output voltage equation	Output voltage simulation value	Voltage gain
Integrated boost flyback converter	$Vo=V_{in}\frac{1+D\frac{N2}{N1}}{1-D}$	255 V	8.5
Proposed converter	$Vo=V_{in}\frac{(1+n+D)}{(1-D)}$	355V	11.83

VI CONCLUSION

For the application in Green energy sources such as Photovoltaic cell and fuel cell a high voltage gain converter is introduced in this paper, which consists of a dual switches structure with coupled inductor and charge pump. This converter can achieve a high gain with a smallduty cycle which helps to reduce the peak current through the device. The dual switches structure reduces the voltage/current stress of the power switches. The reverse recovery problem of the diode is reduced by the leakage inductance. So MOSFET with low on state resistance RDS ON can be used.Thecharge pump is used to add the voltage conversion ratio. So the proposed converter can provide high voltage gain with reduced voltage/current stress of the switches compared with conventional Integrated Boost Fly back Converter. The simulation results prove the same.

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