# A Dual Switch Dc-Dc Converter with Coupled Inductor and Charge Pump for High Step up Voltage Gain

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***Abstract*—This paper proposes a dual switch dc-dc converter with high step up voltage gain for solar application. The main features of this converter are the dual switch structure, three winding coupled inductor and charge pump. The proposed converter can provide a high voltage gain with small duty cycle which is helpful to reduce the peak current through the power device. The dual switch structure reduces the voltage\current stress of the power switches. The charge pump is used to add the voltage conversion ratio. All the diodes are achieving Zero Current Shutting off. We can use this converter to boost the voltage of Green Energy sources such as Photovoltaic cell and Fuel cell. Simulation is done in MATLAB/SIMULINK for the proposed converter and a comparison of the voltage gain of proposed converter with previous high step up converter was also done in this paper.**

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

## I. INTRODUCTION

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 low(lower than 50 V DC) compared to the dc bus voltage (200 or 400 V DC).So we need a high step-up voltage gain dc-dc converter with high efficiency 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 pulsatingvoltage 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 boostconverter can provide a higher voltage gain with a lower voltage/currentstress of the switches.The magnetic components can be integrated into one magnetic core, which ishelpful 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

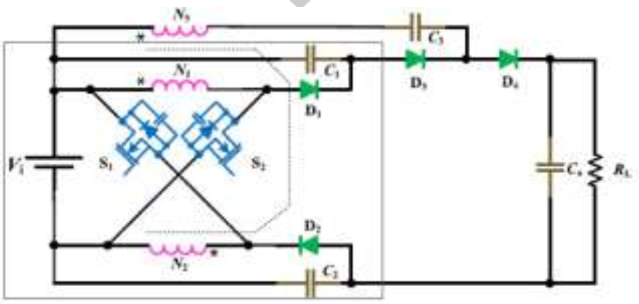

Fig.1 Proposed dual switch converter

Fig.1 shows the circuit diagram of the proposed converter.Vi is the input voltage.$S_1$ and $S_2$ are the dual switches which operate under same gate signal. The capacitors $C_1$ and $C_2$ are used to absorb the energy of leakage inductor and clamp the voltage across $S_1$ and $S_2$. $C_3$ is the capacitor of charge pump, which is used to add the voltage conversion ratio.$N_1$, $N_2$, and $N_3$ are the windings of the three-winding-coupled inductor. The turns ratio of $N_1$, $N_2$ and $N_3$ is 1:1:n.$C_o$ is the output filter capacitor.
In order to simplify the analysis we have to assume that,

1) The dual switches structure shares the same gate signal

2)The capacitance of $C_1$,$C_2$, and $C_o$ are largely enough, that the voltage $V_{c1}$ , $V_{c2}$ , and $V_o$ could be treated as a constant.

A resonance loop is formed by the leakage inductor $L_k$ and the charge pump $C_3$ . According to the relationship between the resonance period and the on state period (DTs ), the proposed converter can operates in two modes: If $\pi\sqrt{L_k C_3}$>$DT_s$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).

## IIIMODES 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 $S_1$ and $S_2$ 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 $L_k$, the current through the turns $N_1$ and $N_2$ increase from zero, which is helpful to reduce the switching loss. The diodes$D_1$ ,$D_2$ , and$D_3$ are reverse-biased, while$D_4$ is conducting. The leakage inductor $L_k$and charge pump $C_3$ begins to resonate. Since this time interval is too short that the leakage inductor current $i_{Lk}$ drops almost at a constant slope.

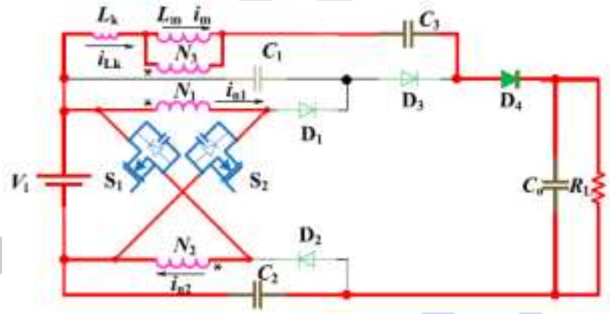


Fig.2 Operation of proposed converter in mode1

B) Mode2

During this stage, $S_1$ and $S_2$ remains in conduction, the equivalence circuit is shown in Fig. 3. At the time of $t_1$ , the leakage inductor current $i_{Lk}$ decreases to zero, $D_4$ turns OFF with ZCS, and then,$i_{Lk}$ keeps falling, $D_3$ turns ON, $L_k$ and $C_3$ are still in resonance state.

The state equations of resonant circuit from $t_1$ to $t_2$ can be written as follows:

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

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

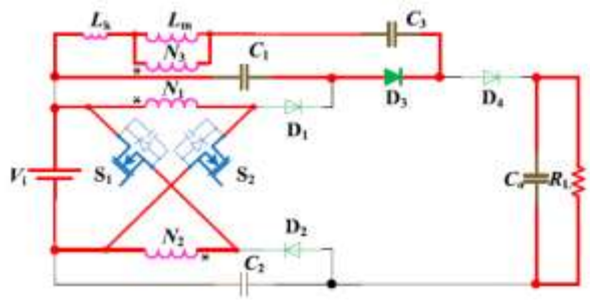


Fig.3 Operation of proposed converter in mode2

C) Mode 3

The equivalent circuit is shown in Fig. 4.At the time of $t_2$ , $S_1$ and $S_2$ are turned OFF. $N_1$ and $N_2$ transfer energy to the parasitic capacitors of $S_1$ and $S_2$ , the parasitic capacitors keep charging until $D_1$ and $D_2$ begins to conduct.

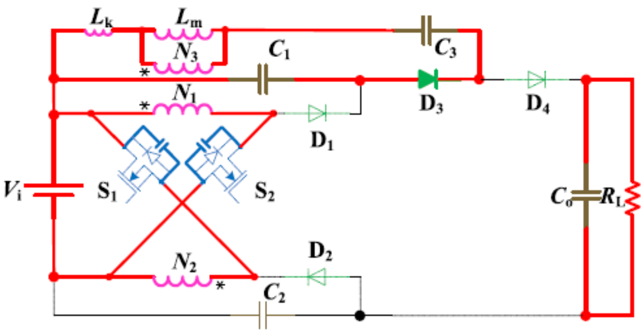


Fig.4 operation of proposed converter in mode 3

D) Mode 4

The equivalent circuit is shown in Fig.5. At the time of $t_3$ , $N_1$ and $N_2$ transfer energy to the clamping capacitors $C_1$ and $C_2$ . $C_3$ charges the leakage inductor $L_k$ in a resonance way, considering this time interval is extremely short, the leakage inductor current $i_{Lk}$ rises almost at a constant slope.

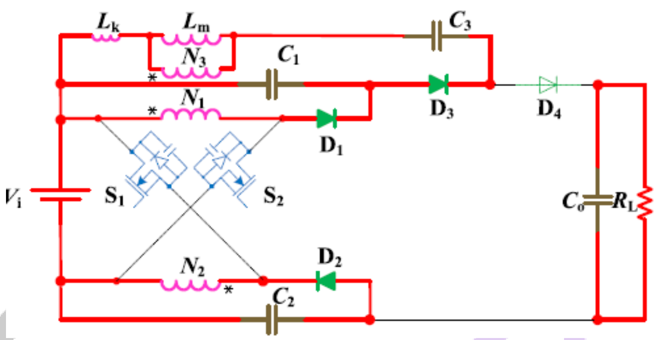


Fig.5 Operation of proposed converter in mode 4

E) Mode 5

The equivalent circuit is shown in Fig. 6. At the time of $t_4$,the leakage inductor current $i_{Lk}$ rise to zero, $D_3$ turns OFF with ZCS, then $i_{Lk}$ keeps rising and turns to positive, $N_1$ and $N_2$ keeps transferring energy to the clamping capacitors$C_1$ and $C_2$.$L_k$ and $C_3$ are still in resonance state, the state equations of resonantcircuit can be written as follows:

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

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

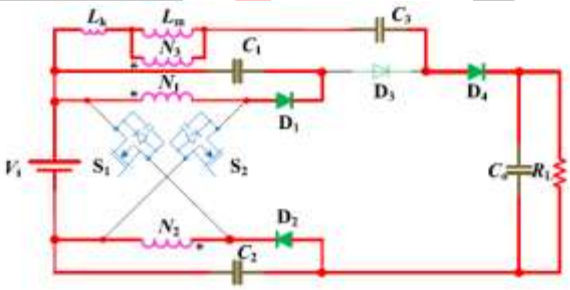


Fig.6 Operation of proposed converter in mode 5

A) Mode 6

The equivalence circuit is shown in Fig. 7. At the time of $t_5$, the current through $N_1$ and $N_2$ decrease to zero, $D_1$ and $D_2$ turn OFF withZero current shutting off.

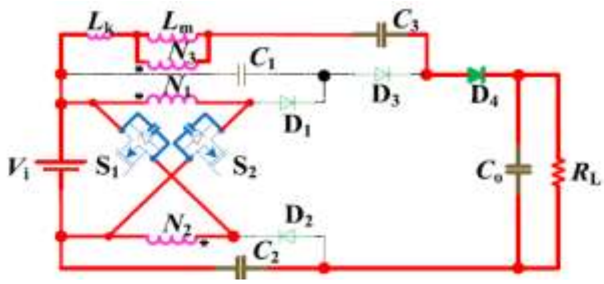


Fig.7 Operation of proposed converter in mode 6

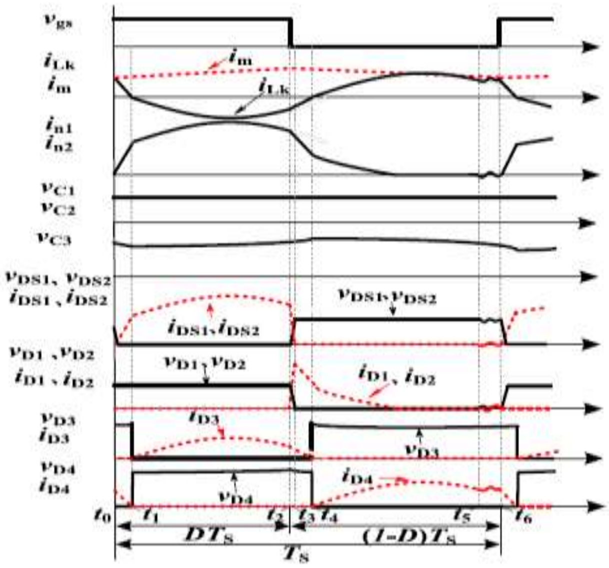


Fig.8 Operation waveforms of the proposed converter

## IV ANALYSIS OF THE CIRCUIT

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

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

$$V_{Lm} = nV_i \qquad (5)$$

The turns N2 , the power switch S1 , the diode D2 , and theclamping 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

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

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

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

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

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

## IV SIMULATION RESULTS

The simulation is done in MATLAB Simulink and a comparison of the voltage gain of the proposed converter with previous Integrated Boost Flyback converter has been done. The specification and ratings of the components used in simulation are listed below.

Table1:Parameters specification

| Components | Specification |
|---|---|
| Input voltage | 30 V |
| Switching frequency | 50 kHz |
| Magnetizing inductor, Lm | 1530µH |
| Leakage inductor ,Lk | 25µH |
| Clamping capacitor C1,C2 | 4.7µF |
| Charge pump,C3 | 3µF |
| Filter capacitor, Co | 470µF |
| Load resistor | 320Ω |

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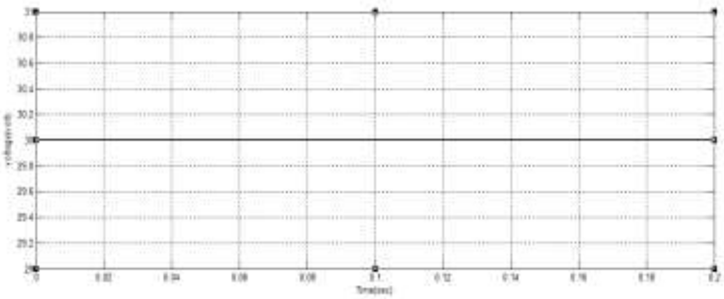

Fig.9 Input voltage waveform of proposed converter

Fig. 9 shows the input voltage waveform of proposed converter. Input voltage is 30V dc.

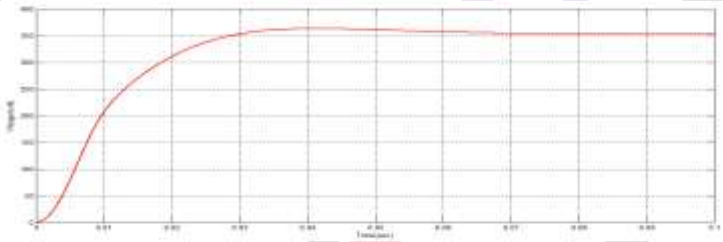

Fig.10 Output voltage waveform of proposed converter

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 and duty ratio 0.65, providing a high voltage gain.

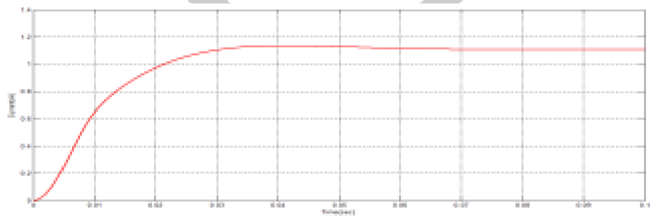

Fig.11 Output current waveform of proposed converter.

Fig.11 shows the output current waveform of proposed converter.The steady state value of output current is 1.108 A for an input voltage of 30V and duty ratio 0.65.

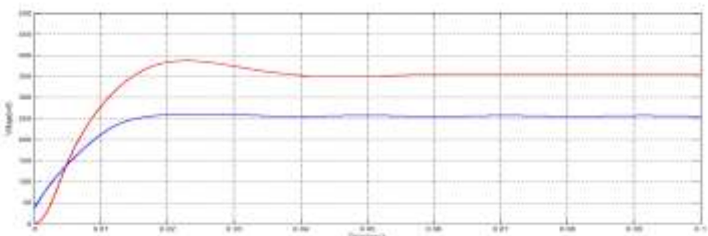

Fig.12 Comparison of output voltages of proposed converter and IBFC

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

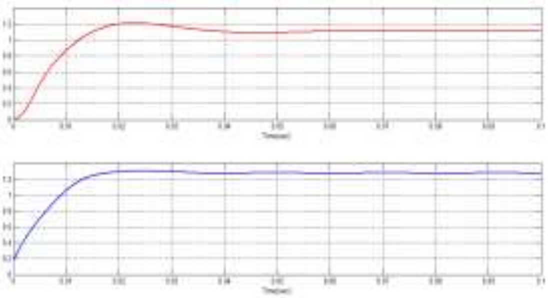

Fig. 13 Comparison of output currents of proposed converter and IBFC

Fig.13 shows the Output currents of Integrated Boost Flyback converter and proposed converter. The steady state value of output currentsof 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 | $Vo = V_{in}\frac{(1+n+}{(1-D)}$ | 355V | 11.83 |

## V CONCLUSION

For the application in Green energy sources such as Photovoltaiccell and fuel cell a high voltage gain converter is introducedin 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 dualswitches 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 ofthe switches compared with conventional Integrated Boost Flyback Converter. The simulation results prove the same.

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