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High Step-Up Interleaved Forward-Flyback Boost Converter for Green Energy Sources

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***Abstract*- A novel high step-up interleaved converter for high-voltage applications is proposed in this paper. High step-up conversion with high efficiency is obtained through three-winding coupled inductors. The proposed converter decreases the conduction losses and reduces the current stress on switches. In addition, due to the lossless passive clamp performance, leakage energy is recycled to the output terminal. Hence, large voltage spikes across the main switches are suppressed and the efficiency is improved. Finally MATLAB/ Simulink implementation of the proposed converter is developed for an output voltage of 380V with minimum ripple <2%.**

Keywords- High step-up, interleaved boost converter, renewable energy system.

I. INTRODUCTION

Nowadays renewable energy sources are valued and using worldwide for energy shortage and environmental contamination [1]–[8]. The renewable energy sources, such as fuel cells and photovoltaic cells, generate variable low-voltage energy. To connect to grid the DC voltage is converted in to AC with voltage equal to distribution grid voltage. In this process a dc/dc converter is required to maintain the output voltage constant and to step up the input low voltage. Thus, high step-up dc/dc converters have been widely employed in such renewable energy systems [9]–[13]. To convert low voltage from renewable sources into high voltage via a step-up conversion, and transform energy into DC-microgrid or utility through an inverter. Hence, the high step-up converter with high efficiency is seen as an important stage in such systems.

Theoretically, the conventional step-up converters, such as the boost converter and flyback converter, cannot achieve a high step-up conversion with high efficiency by extreme duty cycle or high turns ratio because of the resistances of elements or leakage inductance, also the voltage spike and stress on semiconductor devices are large.

The proposed boost/forward/flyback converter not only utilizes the switched capacitors, but also integrates three-winding characteristics well into coupled inductors, which achieves more flexible step-up regulation and voltage stress adjustment. Thus, the proposed converter is suitable as an excellent solution for high step-up conversion with high power and high efficiency. The advantages of the proposed converter are as follows:

1) The characteristics of low-input current ripple and low conduction losses, increase life-time of renewable energy sources and make it suitable for high-power applications;

2) The high step-up gain that renewable energy systems require is easily obtained;

3) Leakage energy is recycled to the output terminal, hence, large voltage spikes across the main switches are alleviated and the efficiency is improved;

II. PROPOSED CONVERTER

The proposed high step-up interleaved converter with three winding coupled inductors is shown in Fig. 1, where L_{m1} and L_{m2} are the magnetizing inductors; L_{k1} and L_{k2} represent the leakage inductors; S_1 and S_2 denote the power switches; C_{s1} and C_{s2} are the switched capacitors; and C_{o1}, C_{o2}, and C_{o3} are the output capacitors.

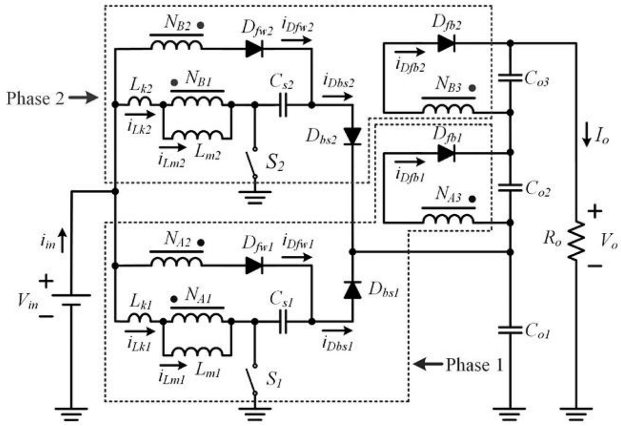

Fig. 1 Proposed Converter Configuration

D_{bs1} and D_{bs2} are the diodes for boost operation; and D_{fw1} and D_{fw2} are the diodes for forward operation; and D_{fb1} and D_{fb2} are the diodes for flyback operation. When the switches turn OFF by turn, the phase whose switch is off-state operates as a flyback mode, and the other phase whose switch is on-state operates as a forward mode. The primary windings of the coupled inductors with N_1 turns are employed to decrease input current ripple, and the secondary windings with N_2 turns are utilized to operate forward mode, as well as the third windings with N_3 turns are utilized to operate flyback mode. The turns ratios of the both coupled inductors are the same.

The duty cycles of the power switches are interleaved with a 180°phase shift, and the key waveform of the proposed converter operating in continuous conduction mode (CCM) is depicted in Fig. 2. Fig. 3 shows the corresponding topological mode of the circuit. Due to the completely

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symmetrical interleaved structure, the operating modes I to V and VI to X are mutually symmetrical. In order to simplify the analysis of operating principle of the proposed converter, only the operating modes I to V are described.

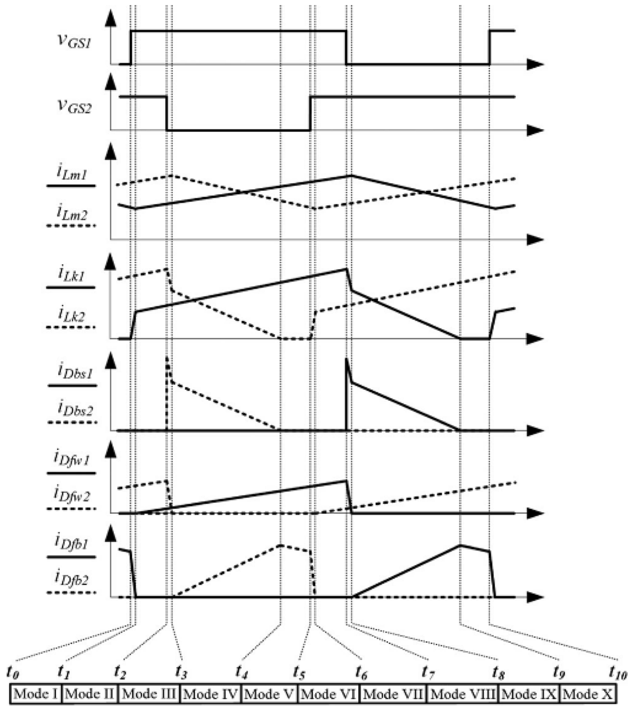


Fig. 2 Waveforms in Continuous Current Mode

Mode I [t_0,t_1]: At t=t_0, the power switchS1begins turning on to forward mode. The energy stored in magnetizing inductor L_{m1} is still transferred to third winding. The switched capacitor C_{s2}, leakage inductor L_{k2}, and magnetizing inductor L_{m2} are in charging state as shown in Fig. 3(a). The currents through leakage inductor L_{k1} given by the equations

$$i_{Lk1}(t_0) = i_{Lm1}(t_0) - K_{A31} i_{Dfb1}(t_0) \tag{1}$$

Mode II [t_1,t_2]: At t=t_1, both power switches S_1 and S_2 are in on-state, and both phases are in forward mode. The switched capacitors C_{s1} and C_{s2}, leakage inductors L_{k1} and L_{k2} and magnetizing inductors L_{m1} and L_{m2} are in charging state. The currents through leakage inductor L_{k1} given in equation

$$i_{Lk1}(t_1) = i_{Lm1}(t_1) + K_{A21} i_{Dfw1}(t_1) \tag{2}$$

Mode III [t_2,t_3]: At t=t_2, the phase 1 remains forward mode, but the power switches S_2 begins turning off to flyback mode. The magnetizing inductor L_{m2} still stores energy, and the energy stored in leakage inductor L_{k2} is naturally recycled to output capacitor C_{o1}. The currents through leakage inductor L_{k1} given by

$$i_{Lk1}(t_2) = i_{Lm1}(t_2) + K_{A21} i_{Dfw1}(t_2) \tag{3}$$

Mode IV [t_3,t_4]: At t=t_3, the phase 1 remains forward mode, and the power switches S_2 remains off-state. The energies stored in switched capacitor C_{s2}, magnetizing inductor L_{m2}, and leakage inductor L_{k2} are transferred to output terminal.

$$i_{Lk1}(t_3) = i_{Lm1}(t_3) + K_{A21} i_{Dfw1}(t_3) \tag{4}$$

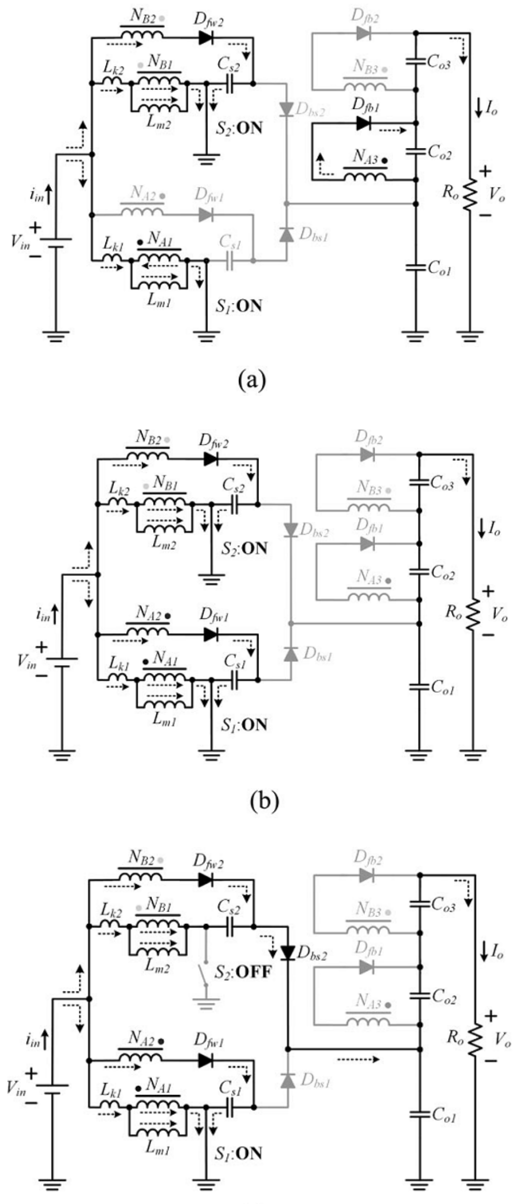
Mode V [t_4,t_5]: At t=t_4, the phase 1 remains forward mode, and the power switches S_2 remains off-state. The energy stored in leakage inductor L_{k2} is totally released, and energy stored in magnetizing inductor L_{m2} is still transferred to third winding.

$$i_{Lk1}(t_4) = i_{Lm1}(t_4) + K_{A21} i_{Dfw1}(t_4) \tag{5}$$

$$i_{Lk1}(t_4) = 0 \tag{6}$$

Where K represents the ratio of number of turns of secondary to primary.

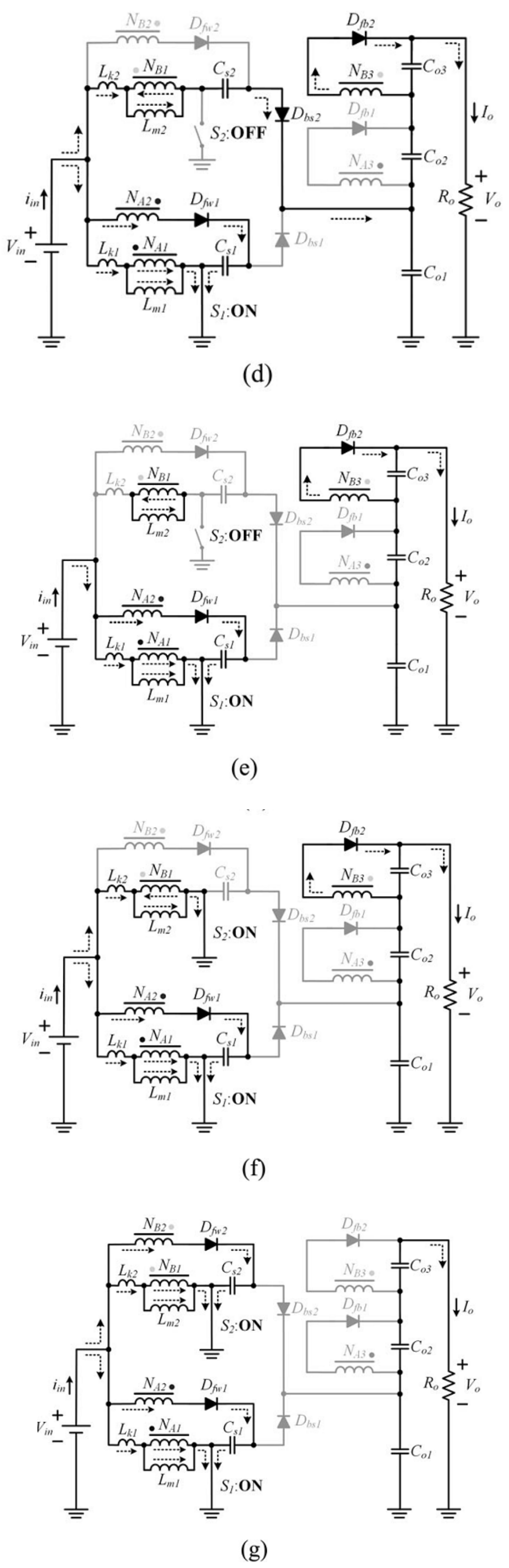
$$K_{A21} = \frac{N_{A2}}{N_{A1}} \tag{7}$$



(a)

(b)

(c)



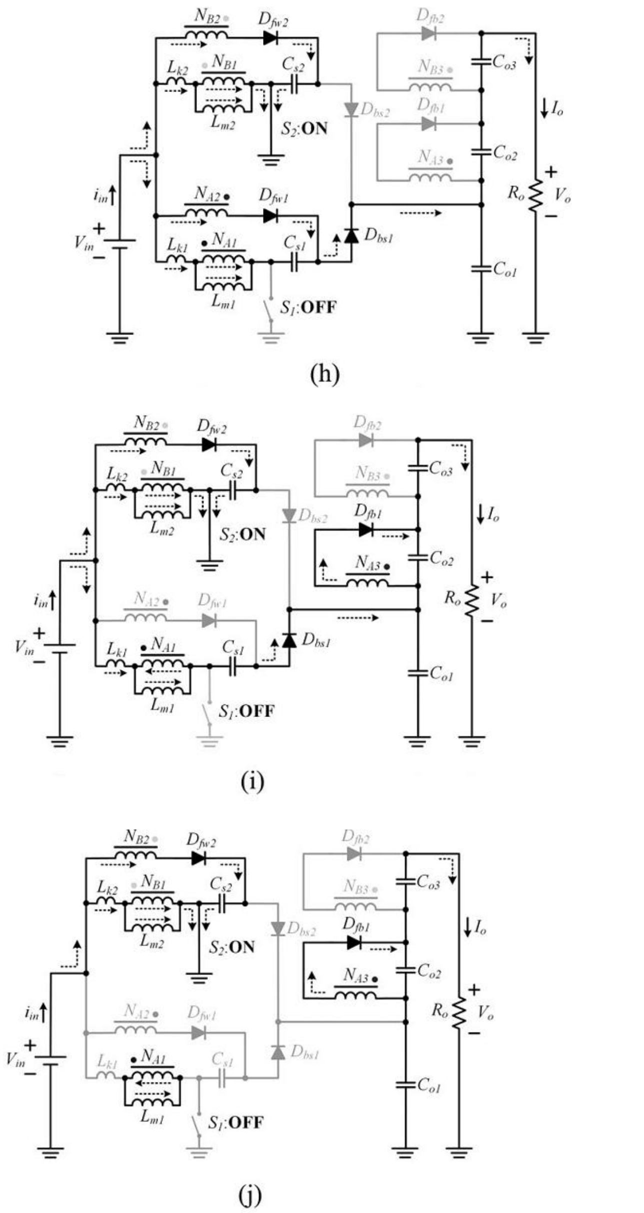


Fig. 3 Operating Modes
(a) Mode I (b) Mode II (c) Mode III (d) Mode IV (e) Mode V (f) Mode VI (g) Mode VII (h) Mode VIII (i) Mode IX (j) Mode X.

III . SIMULINK IMPLIMENTATION

The proposed converter is designed in MATLAB/ Simulnk with the specifications give in the Table. 1. The input voltage of the converter is 48V and the output voltage is 380V.

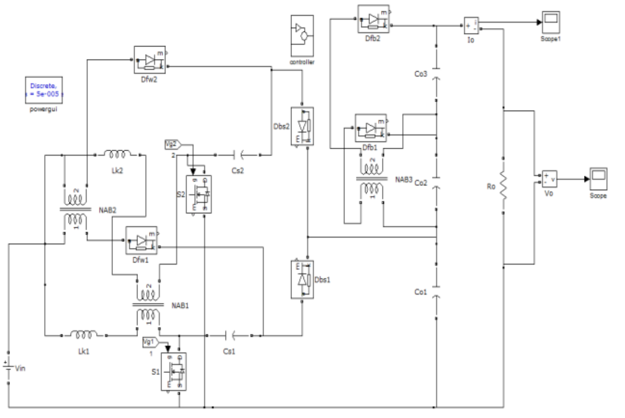


Fig. 4 Simulink Implementation of the Proposed Converter

Fig. 4 shows the simulink implementation of the proposed converter with three coupled inductors.

Table.1 Parameters of the proposed converter

Input Voltage	48V
Output Voltage	380V
Capacitors	120µF
Turns Ratio	1000:1000:1000
Leakage inductance	1.4mH
Switching Frequency	50Hz

IV. SIMULATION RESULTS

Input voltage to the converter is 48V DC supply. It is shown in the Fig. 5. The converter is supplied by pulses generated by PWM generator with Duty cycle of 0.6. It is seen that the output voltage of the converter is raised to a constant value 380V as shown in Fig. 6.

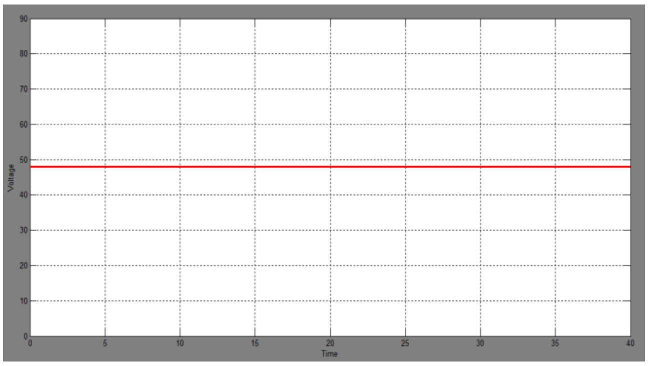


Fig.5 Input DC voltage to Converter

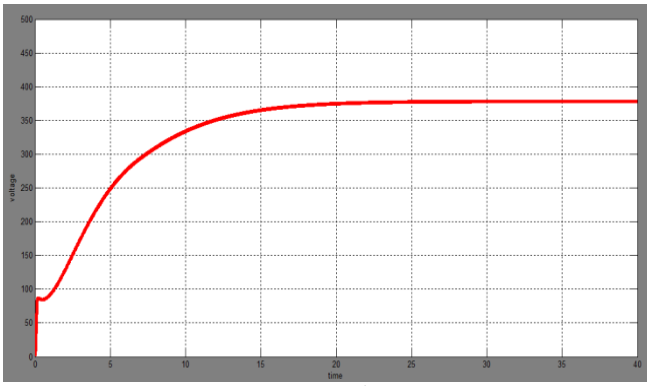


Fig. 6 Output Voltage of the Converter

The voltage across the switches is increased up to 180V that is nearly half of the output voltage. From this it is evident that the stress on the switches is reduced. Fig. 7 & 8 shows the voltage across the switches.

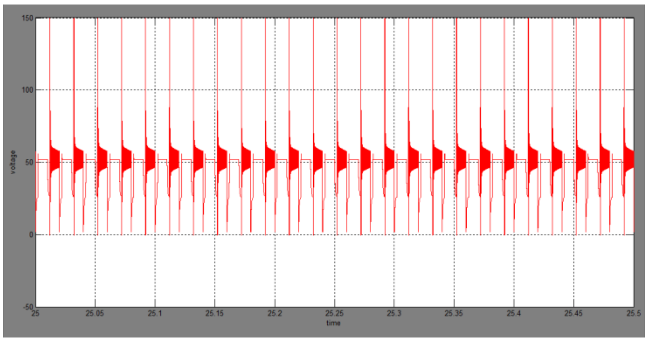


Fig. 7 Voltage across the switch S_1

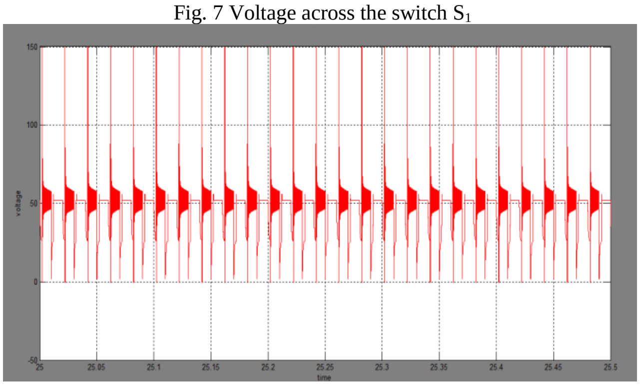


Fig. 8 Voltage across the Switch S_2

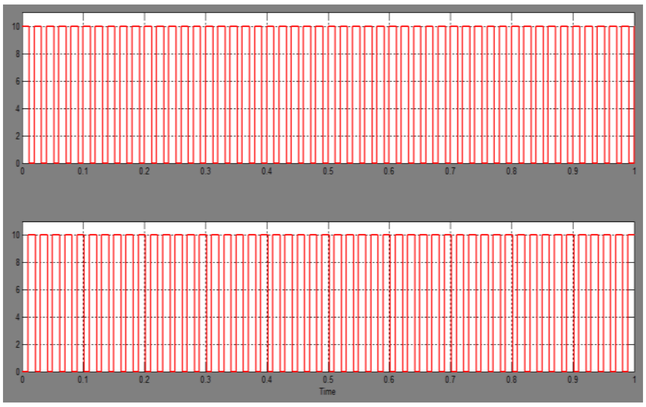


Fig. 9 Switching pulses to Switches S_1 and S_2

The converter has minimum peaks in the output voltage <5% so it is used to connect directly to DC Microgrid without any extra circuit. The power loss across the switches is also less.

V. CONCLUSION

This High Step-up Interleaved Forward-Flyback Converter is having high voltage gain ratio. The disturbance in the output voltage is minimum. The voltage stress on the switches is reduced by a great extent. The power loss in the switches is very less and this converter is highly efficient for high voltage DC conversions..

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