High Step-Up Interleaved Forward-Flyback Boost Converter for RES

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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 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 into 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 stepup 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 threewinding 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](image-url)
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 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.

**Mode I $[t_0,t_1]$:** At $t=t_0$, the power switch $S_1$ begins 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

$$i_{L_k1}(t_0) = i_{L_m1}(t_0) - K_{A21} i_{D_{fly1}}(t_0)$$

**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 equations

$$i_{L_k1}(t_2) = i_{L_m1}(t_2) + K_{A21} i_{D_{fly1}}(t_2)$$

**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

$$i_{L_k1}(t_3) = i_{L_m1}(t_3) + K_{A21} i_{D_{fly1}}(t_3)$$

**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.

**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.

$$i_{L_k1}(t_4) = i_{L_m1}(t_4) + K_{A21} i_{D_{fly1}}(t_4)$$

$$i_{L_k1}(t_4) = 0$$

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

$$K = \frac{N_{A2}}{N_{A1}}$$

![Fig. 2 Waveforms in continuous current mode](image_url)
III. SIMULINK IMPLEMENTATION

The proposed converter is designed in MATLAB simulink with the specifications given in Table 1.

![Simulink implementation of the proposed converter](image)

Table 1: Parameters of the proposed converter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>48V</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>380V</td>
</tr>
<tr>
<td>Capacitors</td>
<td>120µF</td>
</tr>
<tr>
<td>Turns Ratio</td>
<td>1000:1000:1000</td>
</tr>
<tr>
<td>Leakage inductance</td>
<td>1.4mH</td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>50Hz</td>
</tr>
</tbody>
</table>

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.

![Input DC voltage to converter](image)

![Output Voltage of the converter](image)

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.

![Voltage across the switch S1](image)

![Voltage across the switch S2](image)
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.

VI. ACKNOWLEDGEMENT
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REFERENCES