High Voltage Gain DC-DC Converter with a Three Winding Coupled Inductor

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Abstract

This project presents a DC-DC boost converter topology for low input and high output voltage applications. This configuration consists of a closed loop three winding coupled inductor, a single switch, and two hybrid voltage multiplier cells. The proposed converter has the following advantages they are the two secondary windings of the coupled inductor are increasing the voltage gain, improve the function rate of magnetic core and power density, and reduces the stress of power components to provide a stable constant dc output voltage, the two-hybrid multiplier cells reduces the current stress of the diode by absorbing the energy of stray inductance, and alleviate the spike voltage of the main switch, which improves the efficiency.

I. Introduction

The development of high gain dc-dc converters is important in many applications. Such as in uninterrupted power supplies (UPS), the voltage of acid battery (48V) is low, however the inverter bus dc converter is required to boost the low voltage of the car battery (12V) to much higher voltage (100V). Other important applications, Renewable energy sources such as photovoltaic arrays and the fuel cells sources are more and more widely used to provide electric energy. However, the photovoltaic arrays sources and the fuel cells are low voltage sources, needing step up dc-dc converter as an integral interface the available low voltage sources at high voltage and the output loads, which will be operated gain. An obvious solution would be transformer-based converters such as fly-back, full-bridge, half-bridge and push-pull to achieve a high step up voltage gain without operating at extremely high duty cycles[1]-[4].These converters usually require large transformer turns ratio to achieve high voltage gain, which increases the voltage and current stress on the primary elements. Active-clamp circuits or RCD snubbers can be used to address this issue [5]-[6], but these clamp circuits are complex and costly. In order to achieve high boost conversion ratio with high efficiency, some converters employ the switched-capacitor techniques [7], [8] and the switched-inductor techniques [9], [10]. However, the voltage stress of the switch in these converters is still high, causing serious conduction losses. The diode-capacitor voltage multiplier can be inserted into the conventional boost, sepic, and zeta converters to serve as the built-in voltage gain extension cell [11]-[14]. However, several multiplier stages are required to reach a very high voltage gain at the expense of increasing system size and cost, and further, the circuit would be more complex. Recently, some coupled-inductor-based converters have been published in literatures to offer another design freedom rather than the switch duty cycle to satisfy the stringently high step-up voltage gain requirements [15]-[22]. The leakage inductance of the coupled inductor may not only cause high voltage spikes on the power device when it turns off, but also induce large energy losses. In general, RCD snubbers, which are small networks composed of a resistor, a capacitor and a diode, can control the rate of change of voltage or current and clamp voltage overshoot. So the RCD snubbers are often used to suppress the voltage spike of the switch, but the leakage energy is dissipated. Thus, the converters based on the coupled-inductor technique with an active clamp circuit have also been proposed [19], [20], However, the number of driven switches increases, resulting in the complexity of the circuit. A passive regenerative snubber has been investigated in reference [21]. The voltage gain of the converter is higher than most converters based on coupled-inductor, and the voltage stresses on all power devices are relatively lower than the output voltage. A single switch high gain converter using a three winding coupled inductor was proposed [22]. The converter extends the voltage conversion ratio and overcomes the reverse-recovery problem of the output diode, and the leakage energy of coupled inductor can be recycled. This paper proposed a dc-dc boost converter topology based on three-winding coupled-inductor and diode-capacitor technology for high step-up, high power density and high efficiency conversion, which adopts a single switch and two series hybrid voltage multiplier cells. Moreover, two identical passive regenerative snubbers are used for absorbing the energy of stray inductance, clamping the voltage spike of the main switch. Besides, the regenerative snubbers have important role in supplying extra voltage conversion ratio.

II. PRINCIPLE OF THE PROPOSED CONVERTER

The equivalent circuit of the proposed converter topology is shown in Fig.1, in which a three winding coupled inductor (T) can be modeled by a magnetizing inductor L_m, a leakage inductance L_k, and an ideal transformer with primary winding N_1 and two secondary windings N_2 and N_3.

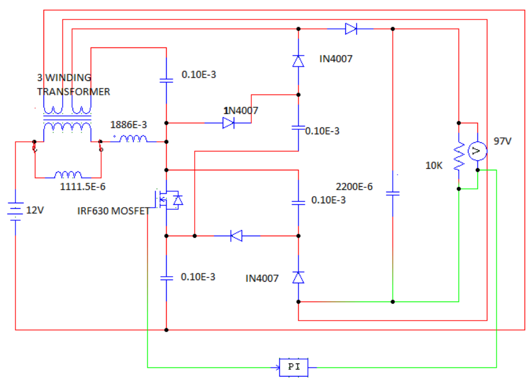

Fig.1. Circuit configuration of the proposed converter.

The two parallel passive regenerative snubbers are composed of the diode D_1 and capacitor C_3, the diode D_3 and capacitorC_1, through which the energy stored in the leakage inductor can be recycled effectively. Also, the voltage across the main switch S is clamped to a lower level. Thus, the efficiency can be improved greatly. In addition, two hybrid voltage multiplier cells are respectively composed of secondary side windings N_2 and C_2, N_3 and C_4. When the main switch is on, the magnetizing inductor and two capacitors in voltage multiplier cells are charged, and the capacitor C_o provides energy to the load. When the main switch is off, the primary side and secondary sides of the coupled inductor, two capacitorsC_2 and C_4, and input dc source are connected in series for transferring energy to the load. Therefore, the proposed converter can achieve high-voltage gain in appropriate duty cycles and low turns ratios.

III. KEY PARAMETER DESIGN

A. Turns ratio:

In the proposed converter, the coupled inductor is operated as both flyback and forward converters, Therefore, the coupled inductor should be designed as a flyback transformer. The turns ratio of the coupled inductor has an influence on the switch duty cycle, the voltage gain, and the voltage stress of power devices. The turns ratio can be depicted by

$$n = \frac{Vo}{Vin}(1-D) - \frac{3}{2}$$

The input voltage and the output voltage are determined by the specific application. Hence, if the duty cycle is chosen, the turns ratio of the coupled inductor can be carried out easily, and then the voltage stress of power devices can be calculated. Generally, the duty cycle is less than 0.7 in order to decrease conduction loss. On the contrary, if the duty cycle is too small, the volume of the coupled inductor will be larger due to the bigger turns ratio. As a result, a compromise should be made considering the duty cycle and the turns ratio under given voltage gain.

B. Voltage gain:

If the leakage inductor of the coupled inductor is not considered, that is to say, *k* is equal to 1, the ideal voltage gain is written as:

$$Vo = \frac{2n+3}{1-D}$$

By using the experimental results we obtain the output as 8 times of the input voltage.

IV. Simulation result

Simulation results of the proposed DC-DC boost converter topologies with three winding coupled inductor are presented

Table 1

Name of the parameter	Symbol	Value
Input voltage	V_s	12V
Output voltage	V_o	96V
Load resistance	R	10K
Frequnecy	F_s	40Khz
Capacitor	C_1,C_3	100μF
Capacitor	C_2,C_4	220 μF

V. Experimental result

A prototype in the laboratory is built to verify the performance of the proposed converter. The electric specifications and circuit components are selected as V_{in}=12V, V_o=96V, fs=40 KHz, N_1:N_2:N_3=1:1:1, C_1=C_3=100μF, C_2=C_4=220μF, MOSFET IRF630 is selected for switch S, the diodes are 1N4007.

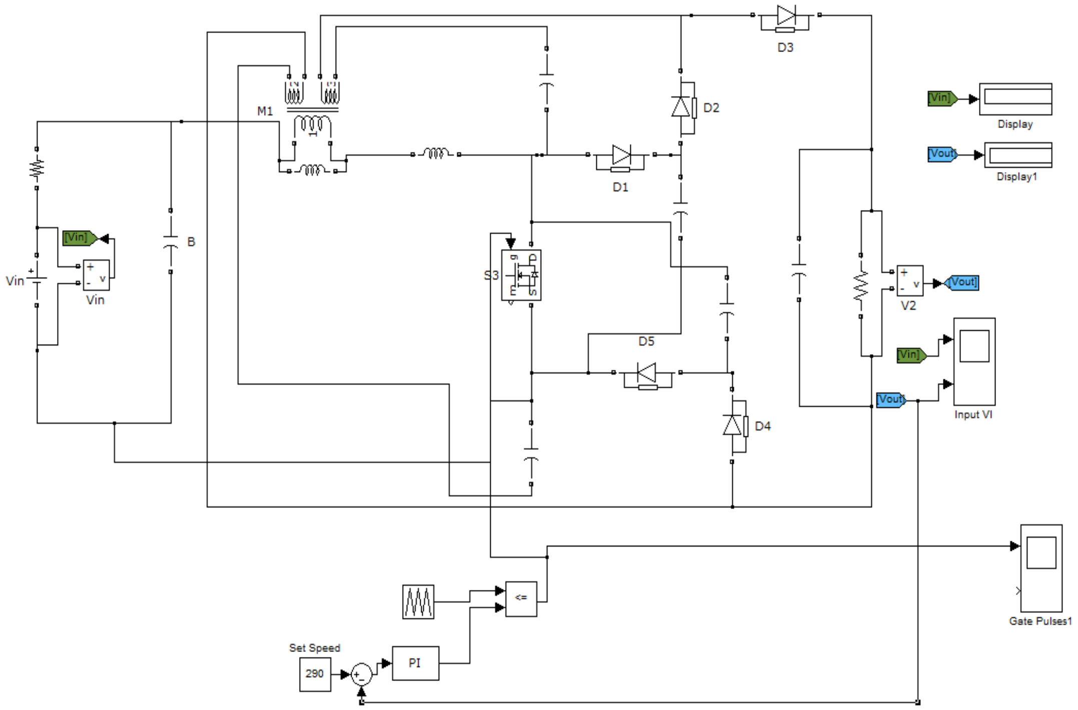

Fig.2.Simulation Circuit

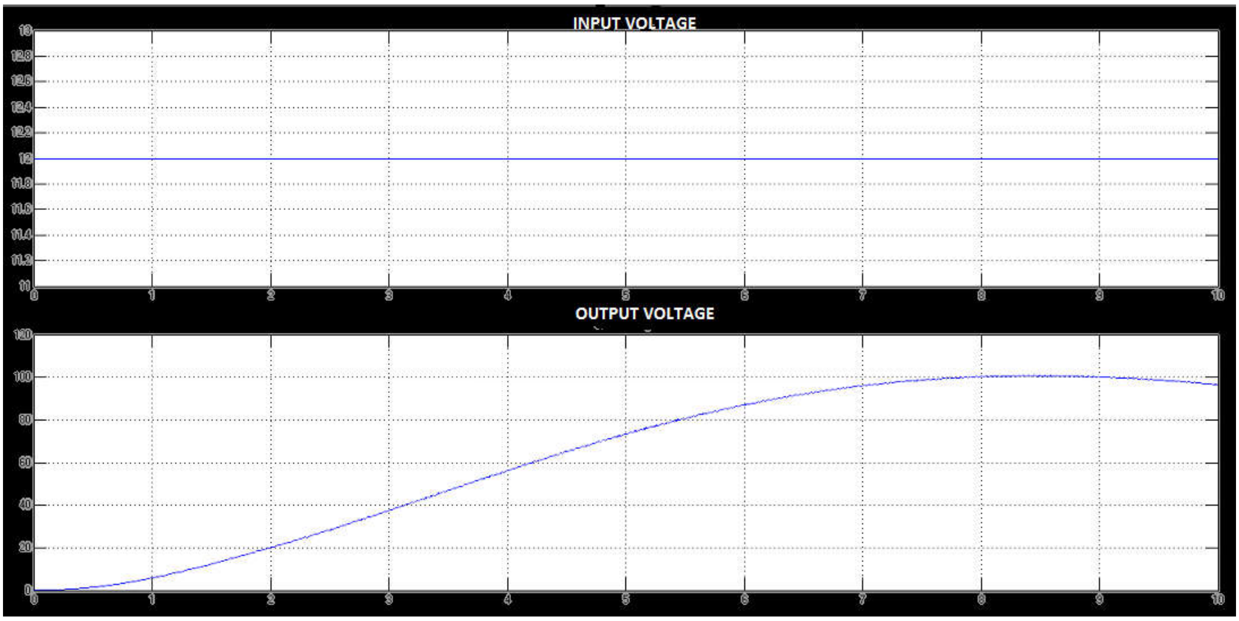

Fig.3.Simulation Result

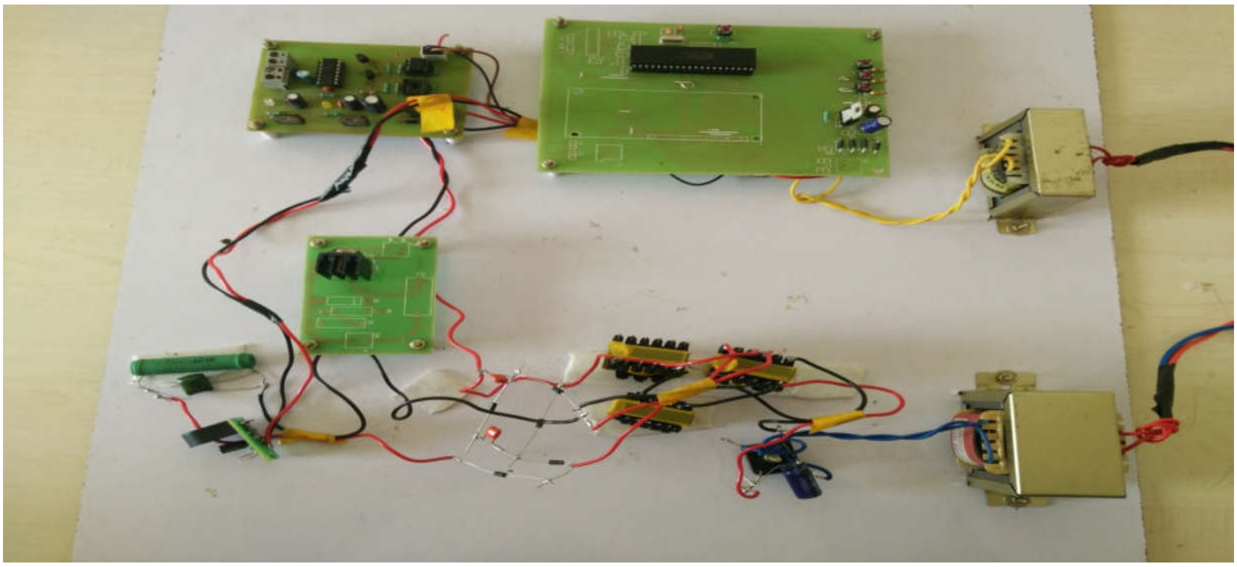

Fig.4 Experimental setup of the proposed system.

Fig.5 Experimental result for the proposed system

VI. Conclusion

Thus, the presented topology can provide very high voltage gain under appropriate duty cycle and turns ratio. Meantime, the operation analysis and design for the converter becomes quite simple since the two multiple voltage units are identical. Moreover, the voltage stress of the main switch S is clamped at a level far less than the output voltage, so the power switch is with low R can be selected to improve the efficiency. The steady-state analysis of the converter is discussed in detail. The simulated and experimental results verify the good performance of the proposed converter. The accuracy, reliability and the disturbances occurring from the external sources have been overcome by the automatic control system.

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