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ANALYSIS OF A DUAL COUPLED INDUCTORS FOR A HIGH GAIN INPUT-PARALLEL OUTPUT-SERIES DC/DC CONVERTER

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***Abstract*—**High voltage gain DC-DC converters are required in many industrial applications such as PV and fuel cell energy systems, high intensity discharge lamp(HID), DC back-up energy systems and electric vehicles. This paper presents a novel input-parallel output-series boost converter with dual coupled-inductors and a voltage multiplier module. On the one hand, the primary windings of two coupled-inductors are connected in parallel to share the input current and reduce the current ripple at the input. On the other hand, the proposed converter inherits the merits of interleaved series-connected output capacitors for high voltage gain, low output voltage ripple and low switch voltage stress**.** On the other hand, the proposed converter inherits the merits of interleaved series-connected output capacitors for high voltage gain, lowoutput voltage ripple, and lowswitch voltage stress. Moreover,the secondary sides of two coupled inductors are connected in series to a regenerative capacitor by a diode for extending the voltage gain and balancing the primary-parallel currents. In addition, the active switches are turned on at zero current and the reverse recovery problem of diodes is alleviated by

1. INTRODUCTION

owadays high voltage gain DC-DC converters are required in many industrial applications[1]For example, photovoltaic (PV) energy conversion systems and fuel-cell systems usually need high step-up and large input current dc-dc converters to boost low voltage (18–56V) to high voltage (200–400V) for the grid-connected inverters. High-intensity discharge lamp ballasts for automobile headlamps call for high voltage gain dc-dc converters to raise a battery voltage of 12V up to 100V at steady operation. Also, the low battery voltage of 48V needs to be converted to 380V in the front-end stage in some uninterruptible power supplies (UPS) and telecommunication systems by high step-up converters.Theoretically, a basic boost converter can provide infinite voltage gain with extremely high duty ratio. In practice, the voltage gain is limited by the parasitic elements of the power devices, inductor and capacitor. Moreover, the extremely high duty cycle operation may induce serious reverse-recovery problem of the rectifier diode and large current ripples which increase the conduction losses. On the other hand, the input current is usually large in high output voltage and high power conversion, but low-voltage-rated power devices with small on-resistances may not be selected since the voltage stress of the main switch and diode is respectively equivalent to the output voltage in the conventional boost converter.

Many single switch topologies based on conventional boost converter had been presented for high step-up voltage gain. The cascaded boost converter is also capable of providing high voltage gain without the penalty of extreme duty-cycle. However, the voltage stress of the main switch is equal to the output voltage. In references several switching-capacitor/switching inductor structures are proposed, and transformerless hybrid dc-dc converters with high voltage gain are derived by the use of structures integrated with classical single switch non-isolated PWM converters. They present the following

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advantage: the energy in the magnetic elements is low, which leads to weight, size and cost saving for the inductor, and less conduction losses. Another method for achieving high step-up gain is the use of the voltage-lift technique showing the advantage that the voltage stress across the switch is low. However, several diode-capacitor stages are required when the conversion ratio is very large, which makes the circuit complex. In addition, the single switch may suffer high current for high power applications, which risks reducing its efficiency.

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2. TOPOLOGY AND OPERATION PRINCIPLE OF THE PRESENTED CONVERTER

The derivation procedure for the proposed topology is shown in Fig. 1. This circuit can be divided as two parts. These two segments are named a modified interleaved boost converter and a voltage doubler module using capacitor-diode and coupled inductor technologies. The basic boost converter topology is shown in Fig. 1(a) and Fig.1 (b) is another boost version with the same function in which the output diode is placed on the negative dc-link rail. Fig.1(c) is called a modified interleaved boost converter, which is an input-parallel and output-series configuration derived from two basic boost types. Therefore, this part based on interleaved control has several main functions: 1) it can obtain double voltage gain of conventional interleaved boost; 2) low output voltage ripple due to the interleaved series-connected capacitors; 3) low switch voltage stresses. Then the double independent inductors in the modified interleaved boost converter are separately replaced by the primary windings of coupled inductors which are employed as energy storage and filtering as shown in Fig.1 (d). The secondary windings of two coupled inductors are connected in series for a voltage multiplier module, which is stacked on the output of the modified converter to get higher voltage gain. Fortunately, this connection is also helpful to balance the currents of two primary sides. The coupling references of the inductors are denoted by the marks "∗ " and "·". The equivalent circuit of the presented converter is demonstrated in Fig. 2, where L_{m1}, L_{m2} magnetizing inductances L_{k1}, L_{k2} leakage

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inductances $C1$, $C2$, $C3$ output and clamp capacitors $S1$, $S2$ main switches $D1$, $D2$ clamp diodes Dr, Cr regenerative diode and capacitor $D3$ output diode N turns ratio of Ns /Np $VN1$, $VN2$ the voltage on the primary sides of coupled inductors

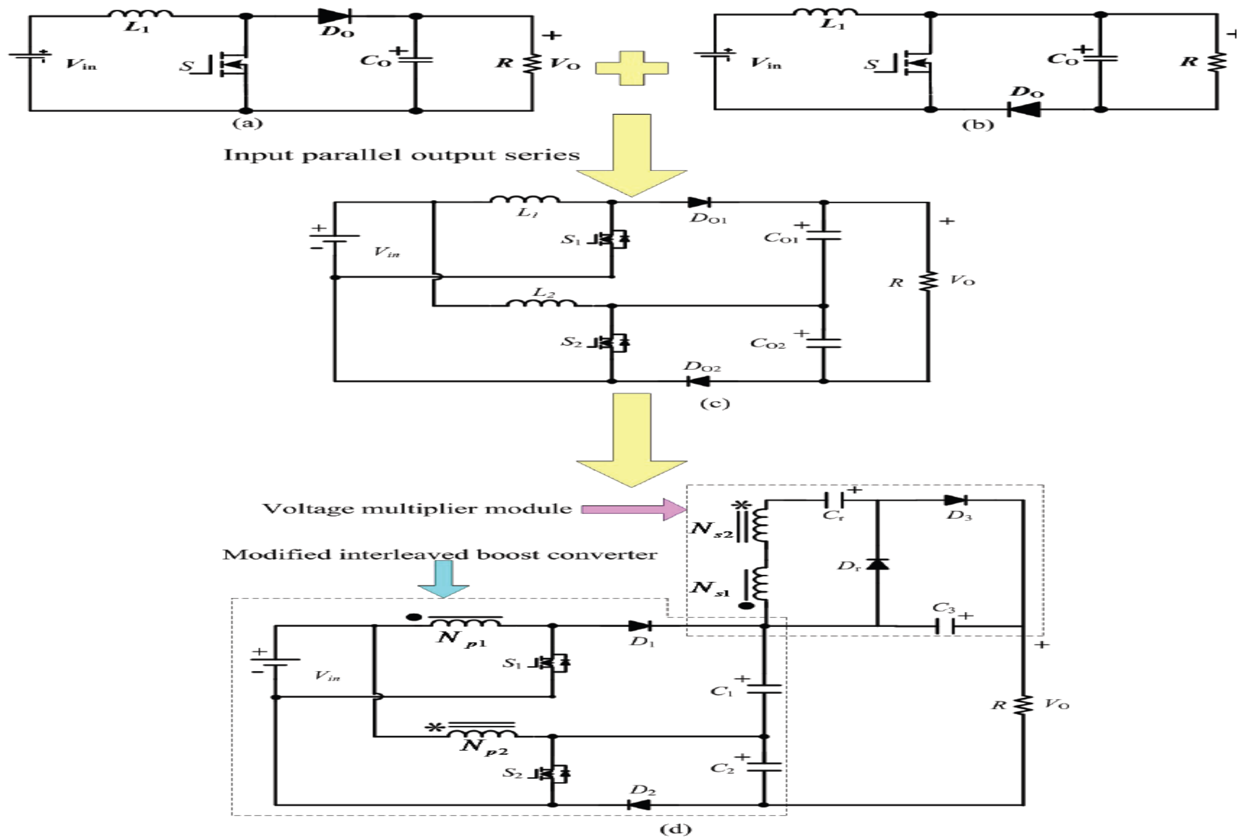

Fig. 1.The procedure to obtain the proposed converter with high voltage gain.(a) Conventional boost converter. (b) Other structure of boost converter. (c) The modified interleaved boost. (d) A high gain input-parallel output-series DC/DC converter with dual coupled-inductors.

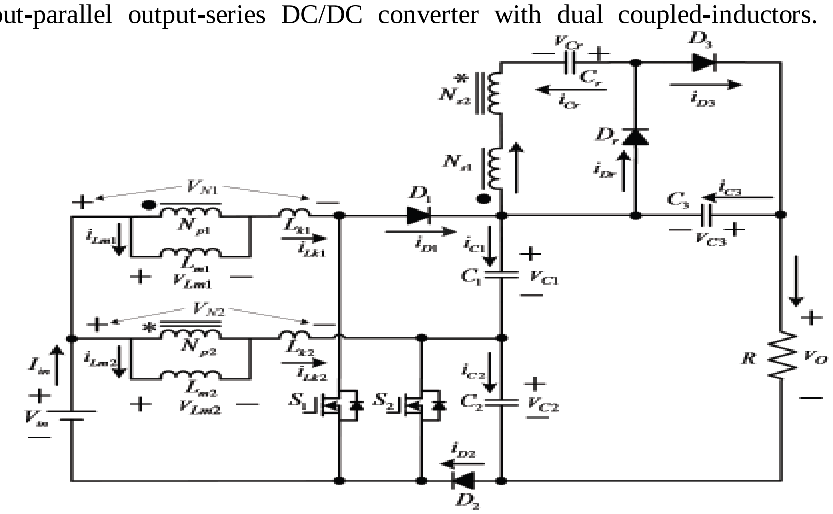

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Fig. 2 The equivalent circuit of the presented converter

Fig. 3 shows the theoretical waveforms when the converter is operated in continuous conduction mode (CCM). The duty cycles of the power switches are interleaved with 180°phase shift, and the duty cycles are greater than 0.5. That is to say, the two switches can only be in one of three states (S1: on, S2: on; S1: on, S2: off; S1: off, S2: on;), which ensures the normal transmission of energy from the coupled inductor's primary side to the secondary one. The operating stages can be found in Fig.4.

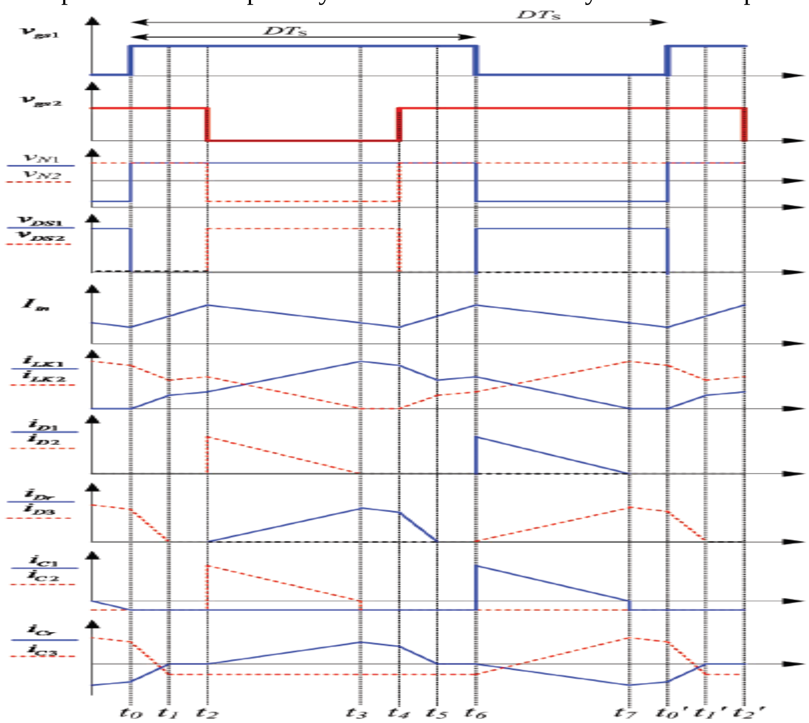

Fig. 3 Key theoretical waveforms

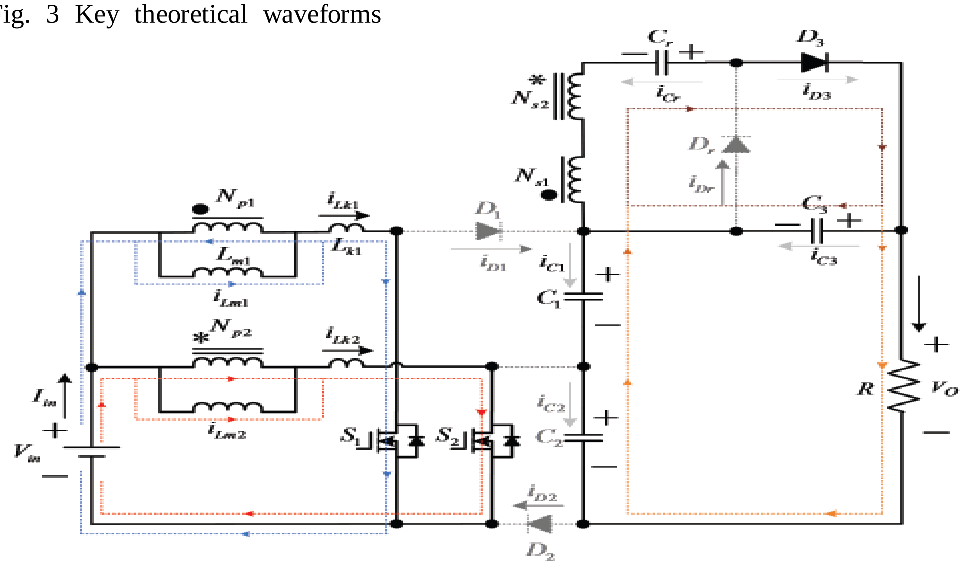

Fig. 4 First stage

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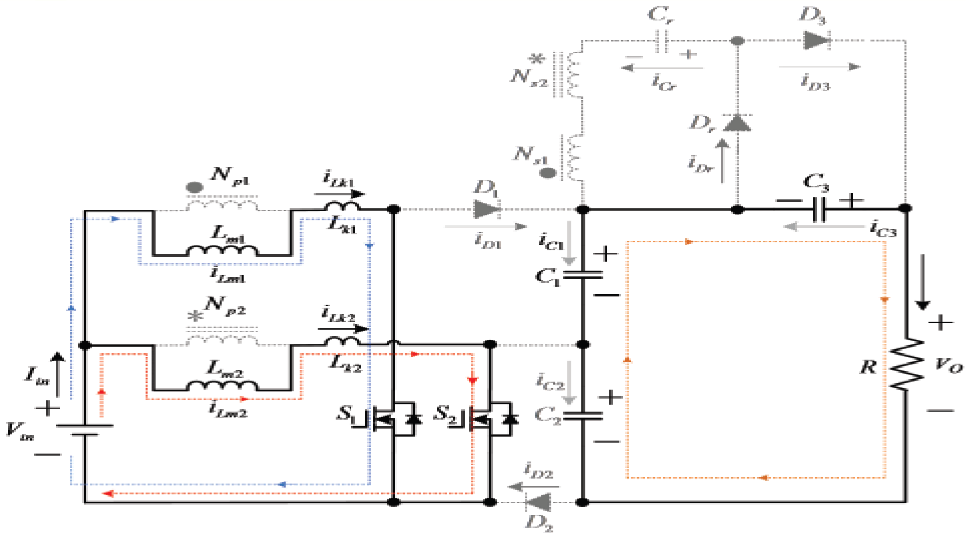

Fig. 5 Second stage

1) First stage [*t*0-*t*1]: At *t* = t0, the power switch *S*1 is turned on with zero current switching (ZCS) due to the leakage inductance *L*k1, while *S*2 remains turned on, as shown in Fig. 4. Diodes *D*1, *D*2 and *D*r are turned off, and only output diode *D*3 is conducting. The current falling rate through the output diode *D*3 is controlled by the leak-age inductances *L*k1 and *L*k2, which alleviates the diodes' reverse recovery problem. This stage ends when the current through the diode *D*3 decreases to zero.

2) Second stage [*t*1-*t*2]: During this interval, both the power switches *S*1 and *S*2 are maintained turned on, as shown in Fig.5 All of the diodes are reversed-biased. The magnetizing inductances *L*m1 and *L*m2 as well as leakage inductances *L*k1 and *L*k2 are linearly charged by the input voltage source *V*in.

CONCLUSION

For low input-voltage and high step up power conversion, this paper has successfully developed a high-voltage gain dc–dc converter by input-parallel output-series and inductor techniques. The key theoretical waveforms, steady-state operational principle, and the main circuit performance are discussed to explore the advantages of the proposed converter. Performance of the converter is simulated using MATLAB/SIMULINK software. From simulation circuit, we can see that the converter can achieve a much higher voltage gain and avoid operating at extreme duty cycle and numerous turn ratios. The main switches can be turned ON at ZCS so that the main switching losses are reduced. The current falling rates of the diodes are controlled by the leakage inductance so that the diode reverse-recovery problem is alleviated.

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