A Novel Input-Parallel Output-Series DC-DC Converter with Dual Coupled Inductors

YEMJALA KUMAR1, G. BHASKAR RAO2, JADAPALLI SREEDHAR3
1PG Scholar, Dept of EEE(EPS), Annamacharya Institute of Technology and Sciences, Hyderabad, TS, India, E-mail: yemjalakumar@gmail.com.
2Associate Professor, Dept of EEE, Annamacharya Institute of Technology and Sciences, Hyderabad, TS, India, Email: bhaskar.bhaskarg@gmail.com.
3Associate Professor, Dept of EEE, Annamacharya Institute of Technology and Sciences, Hyderabad, TS, India. Email: sreedharmtech@gmail.com.

Abstract: This project, along with the voltage multiplier chain with dual coil output to the boost converter provides a novel parallel input. On the one hand, and to take part in the input current and to reduce input current ripple in the two coils in parallel with the primary windings connected. On the other hand, it is proposed to change, and a series of interleaved output capacitors profit profitable high voltage, low output voltage ripple, low pressure switch is connected with trying gets. In addition, the two sides increase connected to the secondary coil of the two primary currents parallel to increase the voltage balance between the productive diode and capacitor is coupled in series. In addition, activation key to the current zero level are being driven and connected inductors reasonable inductance leakage diodes to reduce the problem of reverse recovery.

Keywords: DC–DC Converter, Dual Coupled Inductors, High Gain, Input-Parallel Output-Series.

I. INTRODUCTION

Nowadays high voltage gain dc–dc converters are required in many industrial applications [1]–[7]. For example, photovoltaic energy conversion systems and fuel–cell systems usually need high step up and large input current dc–dc converters to boost low voltage (18–56 V) to high voltage (200–400 V) 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 12 V up to 100 V at steady operation [8], [9]. Also, the low battery voltage of 48 V needs to be converted to 380 V in the front-end stage in some uninterruptible power supplies and telecommunication systems by high step-up converters [10], [11]. 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 the conventional boost converter had been presented for high step-up voltage gain [11]–[15]. The cascaded boost converter is also capable of providing high voltage gain without the penalty of extreme duty cycle [16]. However, the voltage stress of the main switch is equal to the output voltage. In [17] and [18], several switchingcapacitor/ 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 nonisolated PWMconverters. They present the following 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 [19], 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.

Another alternative single switch converters including forward, fly-back and tapped-inductor boost can achieve high conversion ratio by adjusting the turns ratio of the transformer [20]–[22], but these converters require large transformer turns ratio to achieve high voltage gain. In [23], an integrated boostflyback converter is proposed to achieve high voltage gain, and the energy of a leakage inductor is recycled into the output during the switch-off period. Unfortunately, the input current is pulsed from the experimental results. In addition, it should be noticed that the low-level input voltages usually cause large input currents and current ripples to flow through the single switch for high
step up and high power dc–dc conversion, which also leads to increasing conduction losses. Therefore, the single-switch topologies are not perfect candidates for high step up dc–dc conversion. In order to handle high input currents and reduce current ripples, the three-state switching cell based on interleaved control is introduced in boost converters [24]. However, the voltage gain of the conventional three-state switching boost converter is only determined by the duty ratio [18]–[25]. Moreover, the voltage stresses of the power devices are still equivalent to output voltage. Thus, the large duty ratios, high switch voltage stresses, and serious output diode reverse recovery problem are still major challenges for high step up and high power conversion with satisfactory efficiency. To solve aforementioned drawbacks, some three-state switching converters with high static gain employing diode–capacitor cells were presented [25].

However, several diode–capacitor cells are required to meet a very high step-up gain. Thus, other topologies using three-state switching cell and coupled inductors are investigated in [26]–[31]. The authors in [27] proposed an interleaved boost converter with coupled inductors and a voltage doubler rectifier in order to satisfy the high step-up applications and low input current ripple, in which the secondary sides of two coupled inductors are connected in series. The winding-cross-coupled inductors and output diode reverse-recovery alleviation techniques are also introduced in an interleaved three-state switching—dc–dc converters [32], [33], which can get a considerably high voltage conversion ratio and improve the performance of the converter. In [34], an interleaved fly-back converter based on three-state switching cell for high step up and high power conversion is proposed. Although the converter can eliminate the main limitations of the standard fly back, this circuit is a little complex and the input current ripples are large from the experimental results. This paper proposes an input-parallel output-series boost converter with dual coupled inductors for high step up and high power applications. This configuration inherits the merits of high voltage gain, low output voltage ripple, and low voltage stress across the power switches. Moreover, the presented converter is able to turn ON the active switches at zero current and alleviate the reverse recovery problem of diodes by reasonable leakage inductances of the coupled inductors.

II. 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 shown in Fig. 1(a) and (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 the conventional interleaved boost; 2) low output voltage ripple due to the interleaved seriesconnected capacitors; and 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 that 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:

1) \( L_{m1}, \) \( L_{m2} \): magnetizing inductances;
2) \( L_{k1}, L_{k2} \): leakage inductances;
3) \( C_1, C_2, C_3 \): output and clamp capacitors;
4) \( S_1, S_2 \): main switches;
5) \( D_1, D_2 \): clamp diodes;
6) \( D_r, C_r \): regenerative diode and capacitor;
7) \( D_3 \): output diode;
8) \( N \): turns ratio of \( N_0/N_{p'} \);
9) \( V_{N1}, V_{N2} \): the voltage on the primary sides of coupled inductors.

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 \((S1 : \text{ON}, S2 : \text{ON}; S1 : \text{ON}, S2 : \text{OFF}; S1 : \text{OFF}, S2 : \text{ON})\), 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 Figs. 4–11.

First stage \([t_0-t_1]\): At \( t = t_0 \), 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. 3. Diodes \( D_1, D_2 \), and \( D_3 \) 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 leakage 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.

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. 4 All of the diodes are reversedbiased. 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 \( V_{IN} \). This period ends at the instant \( t_2 \), when the switch \( S_2 \) is turned OFF.

Third stage \([t_2-t_3]\): At \( t = t_2 \), the switch \( S_2 \) is turned OFF, which makes the diodes \( D2 \) and \( D_r \) turned ON. The current flow path is shown in Fig. 6. The energy that magnetizing inductance \( L_{m2} \) has stored is transferred to the secondary side charging the capacitor \( C_r \) by the diode \( D_r \), and the current through the diode \( D_1 \) and the capacitor \( C_r \) is determined by the leakage inductances \( L_{k1} \) and \( L_{k2} \). The input voltage source,
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Fourth stage [\(t_3-t_4\)]: At \(t = t_3\), diode \(D_2\) automatically switches OFF because the total energy of leakage inductance stress of \(L_{k2}\) is the voltage on \(C_2\). The voltage stress of \(D_3\) is equivalent to the voltage on \(C_1\), and the voltage stress of \(D_3\) is the output voltage minus the voltages on \(C_1\) and \(C_2\) and \(C_r\).

Seventh stage \([t_6-t_7]\): The power switch \(S_1\) is turned OFF at \(t = t_6\), which turns ON \(D_1\) and \(D_3\), and the switch \(S_2\) remains in conducting state. The current-flow path of this stage is shown in Fig 9. The input voltage source \(V_{in}\), magnetizing inductance \(L_{m1}\) and leakage inductance \(L_{k1}\) release their energy to the capacitor \(C_1\) via the switch \(S_2\). Simultaneously, the energy stored in magnetizing inductor \(L_{m1}\) is transferred to the secondary side of coupled inductor and \(D_4\) until \(t_9\) series flows to the capacitor \(C_3\) and load through the diode \(D_3\).

Eighth stage \([t_7-t_9]\): At \(t = t_7\), since the total energy of leakage inductance \(L_{k1}\) has been completely released to the Capacitor \(C_1\), diode \(D_1\) automatically switches OFF. The current of the magnetizing inductance \(L_{m1}\) is directly transferred to the output through the secondary side of coupled inductor and \(D_4\) until \(t_9\) series flows to the capacitor \(C_3\) and load through the diode \(D_3\).
Advantages:
- It can achieve a much higher voltage gain and avoid operating at extreme duty cycle and numerous turn ratios.
- The voltage stresses of the main switches are very low, which are one fourth of the output voltage under $N = 1$.
- The input current can be automatically shared by each phase and low ripple currents are obtained at input.
- 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.

Applications:
- Photovoltaic energy conversion systems
- Fuel-cell systems
- Lamp ballasts for automobile headlamps

III. RELATED WORK

A. Voltage and Current Stress Analysis

Part attempt to simplify the analysis of stress, leak inductance inductor and capacitors and voltage ripples ignored pressure-voltage power key $S_1$ and $S_2$ from $V_{S1\text{-stress}} = V_{S2\text{-stress}} = V_{in}$

$$1 - D = \frac{V_{O2}(1 + N)}{}$$

In the equation above with at least RDS- low-voltage semiconductor field effect transistors oxide- metal classified plug and costs of the proposal to limit the damage that can be adopted for converting confirm that. The relationship
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between stress and the common voltage switch turns ratio of the coil are plotted.

B. Current Sharing Performance
Analysis of the performance of current sharing to ease, all phases II, III has been considered the sixth and seventh. The switch $S_1$, the average current diode $D_1$ is equal to zero. However, $D_2$, which passes the current average, $S_1$ key stop running as a power is equal to the average LK1 stream.

C. Key Performance Comparison
The proposed changes Tool Show, the first table is an increase in the voltage, and reveals a number of essential elements, and semiconductor stress transfer proposal and other similar converters common voltages. This communication is a high-step process of change and high energy will be a candidate. One is forced to change, to see all that, and they are effective transition feet, lower key than the voltage of the voltage can increase. The proposed change in the amount of diodes used and is lower than on the secondary windings.

<table>
<thead>
<tr>
<th>Components</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage $V_{in}$</td>
<td>18–36 V</td>
</tr>
<tr>
<td>Output voltage $V_O$</td>
<td>200 V</td>
</tr>
<tr>
<td>Maximum output power $P$</td>
<td>500 W</td>
</tr>
<tr>
<td>Switching frequency $f_s$</td>
<td>40 kHz</td>
</tr>
<tr>
<td>Turns ratio $N_r/N_p$</td>
<td>19/18</td>
</tr>
<tr>
<td>Magnetizing inductor $L_m$</td>
<td>120 uH</td>
</tr>
<tr>
<td>Leakage inductor $L_{k1}$</td>
<td>2.1 uH</td>
</tr>
<tr>
<td>Power switches $S_1, S_2$</td>
<td>F1RFP150N</td>
</tr>
<tr>
<td>Diodes $D_1, D_2$ and $D_3$</td>
<td>DSSK20-015A</td>
</tr>
<tr>
<td>Diode $D_2$</td>
<td>DSSK28-01AS</td>
</tr>
<tr>
<td>Capacitors $C_1$ and $C_2$</td>
<td>220 uF/100 V</td>
</tr>
<tr>
<td>Capacitor $C_3$</td>
<td>470 uF/100 V</td>
</tr>
</tbody>
</table>

Fig 3 shows the voltage stress waveforms of main switches and diodes when turns ratio $N$ is 1. From Fig. 3(a), it is seen that the voltage stresses $V_{ds1}$ and $V_{ds2}$ on the main switches are only a quarter of the output voltage during the steady-state period, which is about 50 V. Thus, low voltage ratings and low on-state resistance levels active switches can be selected for high efficiency. Fig. 3(b) and (c) shows that the voltage stresses on the diodes $D_1, D_2, D_3$, and $D_4$. One can see that the voltage stresses of the diodes $D_1, D_3$, and $D_4$ are approximately 100 V, which are equal to half of the output voltage in the steady-state period. The voltage stress of the diode $D_2$ is only a quarter of the output voltage, approximately 50 V. Therefore, low-voltage rated Schottky diodes with high performance can be adopted for the presented converter.

IV. SIMULATION RESULTS

Fig 11. Simulink Model.

Fig 12. Output Voltage.

Fig 13. S1, S2 Switching Pulses.

V. 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.

VI. REFERENCES


