Step-Up DC-DC Converter with High Voltage Gain Using Switched-Inductor Technique

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Abstract- A simple dc-dc boost converter are unable to provide high step-up voltage gains due to the effect of power switches, rectifier diodes, and the equivalent series resistance of inductor and capacitors. In this paper proposes new dc-dc converter to achieve high voltage gain without an extremely high duty ratio. In the proposed converters, two inductors with the same level of inductance are charged in parallel during the switch–on period and are discharged in series during the switch-off period. In this converter mainly proposed converter. That is used for PV system and DG systems.

Keywords — dc-dc boost converter, high step-up voltage gain, power stage, without an extremely high duty ratio.

I. INTRODUCTION

DC–DC converter with a high step-up voltage gain is used for many applications, such as high intensity discharge lamp ballasts for automobile headlamps, fuel-cell energy conversion systems, solar-cell energy conversion systems, and battery backup systems for uninterruptible power supplies. Theoretically, a dc–dc boost converter can achieve a high step-up voltage gain with an extremely high duty ratio [5]–[6]. However, in practice, the step-up voltage gain is limited due to the effect of power switches, rectifier diodes, and the equivalent series resistance (ESR) of inductors and capacitors. Moreover, the extremely high duty-ratio operation will result in a serious reverse-recovery problem. Many topologies have been presented to provide a high step-up voltage gain without an extremely high duty ratio [8,9].

However, these types are all complex and have a higher cost. The modified boost type with switched-inductor technique is shown in Fig. 1 [13]. The structure of this converter is very simple. Only one power stage is used in this converter. However, this converter has two issues: 1) Three power devices exist in the current-flow path during the switch-on period, and two power devices exist in the current flow path during the switch-off period, and 2) the voltage stress on the active switch is equal to the output voltage. A new dc–dc high step-up converter is proposed in this paper, as shown in Fig. 2(a). Compared with the converter in [13], the proposed converter I has the following merits:

1) Two power devices exist in the current-flow path during the switch-on period, and one power device exists in the current flow path during the switch-off period; 2) the voltage stresses on the active switches are less than the output voltage; and 3) Under the same operating conditions, including input voltage, output voltage, and output power, the current stress on the active Switch during the switch-on period is equal to the half of the current stress on the active switch of the converter in [13]. For getting higher step-up voltage gain, the other dc–dc converters are also presented in this paper, as shown in Fig. 2(b) and (c). These three proposed dc–dc converters utilize the switched inductor technique, in which two inductors with same level of inductance are charged in parallel during the switch-on period and are discharged in series during the switch-off period, to achieve high step-up voltage gain without the extremely high duty ratio. The operating principles and steady-state analysis are discussed in the following sections. To analyse the steady state characteristics of the proposed converters, some conditions are assumed as follows: 1) All components are ideal—the ON-state resistance $R_{DS(ON)}$ of the active switches, the forward voltage drop of the diodes, and the ESRs of the inductors and capacitors are ignored—and 2) all capacitors are sufficiently large, and the voltages across the capacitors can be treated as constant.

II. IMPROVEMENT OF BOOST CONVERTER

This topology is similar to the basic one except for adding two voltage lift circuits, shows this improved topology Figure (2). In fact, this converter uses two inductors of the same inductance level, and the two switches being simultaneously. Similarly to the other converter circuits, the operation of such a converter is subdivided into two modes; The CCM and the DCM. Typical waveforms of these modes are depicted in Figure (3). The following subsections address the performance and steady state analysis of this converter [14].
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**The Continuous Conduction Mode (CCM)**
This mode of operation can be further divided into two stages:

**STAGE 1:** This stage extends from $t_0$ to $t_1$. In this interval, switches $S_1$ and $S_2$ are both turned on as shown in figure (3-a). During this stage, inductors $L_1$ and $L_2$ are charged in parallel from the DC source whereas the capacitor $C_0$ releases its energy to the load. Moreover, capacitors $C_1$ and $C_2$ are charged from the DC source\[14\].

The voltages across $L_1$, $L_2$, $C_1$ and $C_2$ are given by:

$$ V_{L1} = V_{L2} = V_{in} = V_{L2} = V_{c2} \ldots \ldots \ldots (1) $$

**STAGE 2:** which extends from $t_1$ to $t_2$ shown in figure (3-a). During this time interval, $S_1$ and $S_2$ switched off as shown in the equivalent circuit shown in Figure 2. Besides, $L_1$, $L_2$, $C_1$ and $C_2$ are connected in series to the DC source in order to transfer the stored energy to $C_0$ and the load. So, the voltages across $L_1$ and $L_2$ are derived as:

$$ V_{L1} = V_{L2} = \frac{V_{in} + V_{C1} + V_{C2} - V_0}{2} = \frac{3V_{in} - V_0}{2} \ldots \ldots \ldots (2) $$

The two inductors are equal in values and have the same current implies the condition in (2). doing the integration in (2). The voltage gain can be evaluated as in (3);

$$ \int_0^{DTs} V_{in} \, dt + \int_0^{Ts} \frac{3V_{in} - V_0}{2} \, dt = 0 \ldots \ldots \ldots (3) $$

The voltage gain is thus derived by (3) rearranging

$$ \frac{V_0}{V_{in}} = \frac{3 + 2D}{1 - D} \ldots \ldots \ldots (4) $$

The voltage gain in (6) is plotted versus duty cycle (D) in Figure 4.

**The Discontinuous Conduction Mode (DCM)**
The DCM is also subdivided into three distinct stages:

**STAGE 1:** This takes place between $t_0$ and $t_1$ shown in fig.(3-b). The status of the converter is the same as that of stage 1 in the CCM. During this stage the converter will have the equivalent circuit shown in figure (2).

The peak currents of inductors $L_1$ and $L_2$ can be found as,

$$ I_{L1p} = I_{L2p} = \frac{V_{in}}{L_s} DTs \ldots \ldots \ldots (7) $$

**STAGE 2:** This extends from $t_1$ to $t_2$ shown in fig.(3-b). In this time interval, the switches $S_1$ and $S_2$ are turned off, the inductors $L_1$ and $L_2$ and capacitors $C_1$ and $C_2$ are series connected with the DC source in order to transfer the stored energy to the capacitor $C_0$ and the load.[14]

The inductor currents $I_{L1p}$ and $I_{L2p}$ start decreasing to zero at $t=t_2$. Another expression for $IL1p$ and $IL2p$ is that of (8).

$$ I_{L1p} = I_{L2p} = \frac{V_0 - V_{in} - V_{C1} - V_{C2}}{2L_s} D2Ts \ldots \ldots \ldots (8) $$
\[ I_{L1p} = I_{L2p} = \frac{V_0 - 3V_{in}}{2L} D2T_s \] (9)

**STAGE 3:** Which occurs between \( t_2 \) and \( t_3 \) shown in fig.(3-b). During this time interval, \( S_1 \) and \( S_2 \) are still turned off, on the capacitor \( C_0 \) charges the \( R \)-load since the energy in \( L_1 \) and \( L_2 \) is zero [14].

Rearranging (9) and substituting (8), one can write:

\[ D_2 = \frac{2DV_{in}}{V_0 - 3V_{in}} \] (10)

Observing the waveform of \( I_{C0} \) in fig(3-b), the average value of the capacitor output current during the whole period is found as follows:

\[ I_{C0} = \frac{1}{T_s} \int_{t_2}^{t_3} i_{C0}(t) dt = \frac{1}{2} D_2 I_L I_p - I_0 \] (11)

Substituting (10) and (11) in (12), the result is:

\[ I_{C0} = \frac{D^2 V_{in}^2 T_s}{L(V_0 - 3V_{in})} - \frac{V_0}{R} \] (12)

The capacitor output current equal zero, so:

\[ I_{C0} = \frac{D^2 V_{in}^2 T_s}{L(V_0 - 3V_{in})} = 0 \] (13)

Or equivalently:

\[ \frac{D^2 V_{in}^2 T_s}{L(V_0 - 3V_{in})} = \frac{V_0}{R} \] (14)

The voltage gain in this stage is given by:

\[ \frac{V_0}{V_{in}} = \frac{3}{2} + \frac{9}{4} \frac{D^2}{T_s} \] (15)

Based on (15), Figure (5) shows a plot of the voltage gain versus duty cycle in the discontinuous mode.

**III. SIMULATION RESULT**

**IV. COMPARISON WITH DIFFERENT DUTY CYCLE OF PROPOSED CONVERTER**

<table>
<thead>
<tr>
<th>Duty cycle</th>
<th>Vin</th>
<th>Lin</th>
<th>Vout</th>
<th>Iout</th>
<th>Pin</th>
<th>Pout</th>
<th>Efficiency(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>12</td>
<td>1.21</td>
<td>37.89</td>
<td>0.155</td>
<td>14.5</td>
<td>5.87</td>
<td>40.54</td>
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<td>0.2</td>
<td>12</td>
<td>1.16</td>
<td>41.2</td>
<td>0.172</td>
<td>16.35</td>
<td>7.09</td>
<td>43.38</td>
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<tr>
<td>0.3</td>
<td>12</td>
<td>1.18</td>
<td>45.33</td>
<td>0.18</td>
<td>16.5</td>
<td>8.16</td>
<td>48.98</td>
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<tr>
<td>0.4</td>
<td>12</td>
<td>1.39</td>
<td>50.9</td>
<td>0.21</td>
<td>16.66</td>
<td>10.89</td>
<td>64.8</td>
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<tr>
<td>0.5</td>
<td>12</td>
<td>1.6</td>
<td>58.93</td>
<td>0.24</td>
<td>19.23</td>
<td>14.14</td>
<td>73.5</td>
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<tr>
<td>0.6</td>
<td>12</td>
<td>1.95</td>
<td>70.43</td>
<td>0.29</td>
<td>23.4</td>
<td>20.42</td>
<td>87.9</td>
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<tr>
<td>0.7</td>
<td>12</td>
<td>3.04</td>
<td>91.32</td>
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<td>0.8</td>
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<td>0.55</td>
<td>77.4</td>
<td>71.99</td>
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<tr>
<td>0.9</td>
<td>12</td>
<td>21.1</td>
<td>251.33</td>
<td>0.99</td>
<td>255.7</td>
<td>248.8</td>
<td>97.3</td>
</tr>
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V. CONCLUSION

This paper has studied novel dc–dc converters with high step-up voltage gain. The structures of the proposed converters are very simple. Since the voltage stresses on the active switches are low, active switches with low voltage ratings and low ON-state resistance levels RDS (ON) can be selected. In this paper we can analyse different duty with efficiency and voltage gain. The simulation results confirm that high step-up voltage gain can be achieved.

REFERENCES

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