A Novel Immense Configurations of Boost Converter for Renewable Energy Application

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Abstract

A three immense configurations of boost converter for renewable energy application is presented in the paper. The Voltage Lift Switched Inductor (VLSI) structure is pledge to extra high voltage conversion. The proposed work represent the modified high voltage conversion boost converter (MBC) and its three configuration with VLSI module namely, Modified Boost Converter with XL Configuration (MBC-VLSI-XL), Modified Boost Converter with LY configuration (MBC-VLSI-LY) and Modified Boost Converter with XY configuration (MBC-VLSI-XY). The advantage of proposed converter configurations are-(i) immense voltage conversion ratio for high voltage and low current renewable energy applications, (ii) single switch topologies, (iii) input inductor to avoid reverse current flow from load to source. The detail mathematical analysis of proposed configurations are done with and without considering the internal voltage drop across the circuit components. The comparative investigation is carried out with existed high voltage conversion ratio topologies. The Matlab simulation results validates the working of proposed MBC configurations.

1 Introduction

Now a days, industrial, transportation and home appliances are utilizing renewable energy sources such as solar, wind instead of conventional energy sources due to various limitation of them [1,2]. Among the renewable energy sources, photovoltaic is getting more attraction due to its advantages features. A DC-DC converter is a key intermediate stage between energy conversion process from solar PV (low voltage) to grid or electric vehicle or DC electrical appliances [3].

In last decade, various DC-DC converters are introduced which are having high voltage conversion ratio capability. The high voltage at output is achieved either by utilizing transformer, coupled inductor, voltage multiple unit or voltage boosting technique. An isolated high voltage conversion ratio boost converter presented in [4] which achieve high gain by adopting the transformer in the circuit. The drawback of isolated converter is bulky transformer which increases the circuit size and affects the overall efficiency of the converter. In [5,6], a non-isolated high gain DC-DC boost converters are presented which achieves required high voltage by adopting coupled inductor and switched capacitor techniques. The advantage of presented topology is single switch which achieve zero current switching to reduce the conduction losses. A new high gain boost converter is proposed in [7] which shows reduced output voltage ripple content, high voltage conversion ratio and reduced voltage stress across boost switch accomplish by utilizing clamping circuit. A voltage conversion ratio of conventional boost converter is increased by adopting multistage switched inductor technique (SIBC) [8]. One stage of stack, increases overall voltage conversion ratio by addition of D/(1-D). In [9], a transformer less high gain DC-DC converter is presented. A Quadratic Boost Converter (QBC) is combination of two boost converter connected in series to attain high voltage conversion ratio [10]. By considering advantage of QBC over conventional boost converter, voltage conversion ratio of QBC is increase by

![Modified boost converter with voltage lift switched inductor module](image-url)
implementing feature of voltage multiplier unit and voltage lift technique. A QBC with voltage multiplier unit at output side and coupled inductor at input side is added to achieve high gain and to reduce the ripple content of input current respectively [11,12].

A Switched Inductor (SI) module is adopted in QBC to achieve high gain [13]. One stage of SI module increase overall voltage conversion ratio by addition of D/(1-D). By applying concept of QBC, a Modified SEPIC Converter (MSC) is derived by cascading of boost and SEPIC converter with single controlled switch [14]. The voltage conversion ratio of MSC is improve by implementing SI module [15]. VThe above discussed topologies are having high voltage conversion ratio but with high voltage stress across controlled switch which decreases the overall efficiency. In [16], a modified SEPIC boost converter with voltage multiplier unit is presented. The presented converter have high voltage conversion ratio with voltage stress across switch is one third of output voltage. By considering advantage and disadvantage of discussed high voltage gain converter, a new family of high voltage conversion ratio is presented in next section.

2 Modified Boost Converter with VLSI Module

The proposed converter configurations are an extension work of Modified Boost Converter (MBC) and Modified Boost Converter with SI module (MBCSI). The MBC is a combination of two conventional boost converter. The MBCSI is derived by replacing inductor of MBC by SI module which increase the overall gain by (1+D) times of conventional boost converter in each configurations. The MBCVLSI is derived by replacing inductor of MBC by VLSI module as shown in Fig. 1 which increase the overall voltage conversion ratio by four times of conventional boost converter in MBCVLSI-XY configuration. One VLSI module increase the overall voltage conversion ratio by addition of (1/1-D) in each boost converter. According to the position of VLSI module on the place of inductor L_X and L_Y, the MBC is classified into three configuration as MBCVLSI-XL by replacing inductor L_X, MBCVLSI-LY by replacing inductor L_Y and MBCVLSI-XY by replacing both inductors L_X and L_Y by VLSI modules as shown in Fig. 2 (a)-(c). The advantage of proposed configurations of MBC are, 1) single switch topology, 2) extremely high voltage conversion ratio with minimum number of active and passive components, 3) input inductor to avoid reverse current flow from load to source side. The number of active and passive components required for each configuration is articulated in Table 1.

The working of proposed converter is same as MBC except VLSI module. In VLSI module, both inductor and capacitor are charges equal to V_{in} through diodes during conducting state of switch. Two inductors and capacitor are discharge in series with input supply in non-conducting state of switch to boost the output voltage. The working operation of three configuration is nearly same except the at the VLSI module position. For simplicity, working of MBCVLSI-XY configuration is explained.

### 2.1 Working of MBCVLSI-XY configuration

The operation of MBCVLSI-XY configuration is separated into two part as switch ON mode and switch OFF mode as discuss in detail in following sub section.

1) **Switch ON mode**

During ON state of switch S, two inductors (L_X1 and L_X2) are energies up to input supply V_{in} with help of diodes D_X1 and D_X2 respectively and along with diode D_2 and switch S. Similarly, capacitor C_X is charges from V_{in} via diodes D_X1, D_X2, D_2 and switch S as shown in Fig. 3(a). In the same way, two inductors (L_Y1 and L_Y2) are energies up to capacitor C_Y via diodes D_Y1 and D_Y2 respectively along with switch S. Capacitor C_Y is charges up to V_{out} via diodes D_Y1 and D_Y2 respectively along with switch S. Diode D_2 is in reverse bias due capacitor C_2. During switch ON mode, output is equals to voltage across capacitor C_2.

2) **Switch OFF mode**
During OFF state of switch S, charged inductors $L_{X1}$, $L_{X2}$ and capacitor $C_X$ transfer the energy to capacitor $C_1$ along with input supply $V_{in}$ via diode $D_1$, as shown in Fig. 3(b). Similarly, capacitor $C_2$ is charges from inductors $L_{Y1}$, $L_{Y2}$ and capacitor $C_Y$ along with input supply $V_{in}$, inductors $L_{X1}$, $L_{X2}$ and capacitor $C_X$ via diode $D_3$. In OFF mode, diode $D_2$ is in reverse bias state.

Here $V_d(L)$ is voltage drop across each inductor due to its internal resistance. Similarly, $V_d(D)$ and $V_d(S)$ are voltage drop across uncontrolled diode and controlled switch respectively.

To simplify mathematical analysis, the voltage drop across all device are considered as equal

$$V_d(L) = V_d(D) = V_d(S) = V_d$$ (3)

$$V_{LX1} = V_{LX2} = V_{in} - 4V_d$$

$$V_{CX} = V_{in} - 4V_d$$

$$V_{LY} = V_{Cl} - 2V_d$$

$$V_{LX1} + V_{LX2} = V_{in} + V_{CX} - V_{Cl} - 3V_d$$

$$V_{LX} = \frac{2V_{in} - V_{Cl} - 7V_d}{2}$$

$$V_{LY} = V_{Cl} - V_0 - 2V_d$$

By volt second balance law for inductor $L_X$

$$\int_0^{T_s} (V_{in} - 4V_d)dt + \int_0^{T_s} (2V_{in} - V_{Cl} - 7V_d)dt = 0$$ (6)

$$V_{Cl} = \left(\frac{2}{1 - D}\right)V_{in} - \left(\frac{7 + D}{1 - D}\right)V_d$$ (7)

For inductor $L_Y$

$$\int_0^{T_s} (V_{Cl} - 2V_d)dt + \int_0^{T_s} (V_{Cl} - V_0 - 2V_d)dt = 0$$ (8)

$$V_0 = \frac{V_{Cl} - 2V_d}{1 - D}$$ (9)

By (7)

$$V_0 = \left(\frac{2}{(1 - D)^2}\right)V_{in} - \left(\frac{9 - D}{(1 - D)^2}\right)V_d$$ (10)

If internal voltage drop is neglected then voltage conversion ratio is

$$V_0 = \left(\frac{2}{(1 - D)^2}\right)V_{in}$$ (11)

3) $MBC_{VLSI}$-LY Configuration

Steady state equations of circuit during CCM are

$$V_{LX} = V_{in} - 3V_d$$

$$V_{LY} = V_{Cl} - 3V_d$$

$$V_{CX} = V_{in} - 3V_d$$

$$V_{LY1} = V_{LY2} = V_{Cl} - 3V_d$$

ON state

$$V_{LY} = V_{Cl} - 3V_d$$

Fig. 3 Working of $MBC_{VLSI}$-XY configuration in (a) switch ON mode and (b) switch OFF mode

3 Analysis of Voltage Conversion Ratio of Proposed $MBC$ Configurations with VLSI Module

This section deals with detail analysis of voltage conversion ratio of $MBC_{VLSI}$-XL, LY and XY configuration in continuous conduction mode. The analysis is done with and without considering the internal voltage drop of circuit components.

1) $MBC_{VLSI}$-LL Configuration

The voltage conversion ratio of $MBC_{VLSI}$-LL configuration is expressed as [13],

$$V_0 = \frac{1}{(1 - D)^2} V_{in}$$ (1)

2) $MBC_{VLSI}$-XL Configuration

Steady state equations of circuit during CCM are

$$V_{LX1} = V_{LX2} = V_{in} - 2V_d(L) - V_d(D) - V_d(S)$$

$$V_{CX} = V_{in} - 2V_d(L) - V_d(D) - V_d(S)$$

$$V_{LY} = V_{Cl} - V_d(L) - V_d(S)$$

(2)
\[ V_{LX} = V_{in} - V_{C1} - 2V_d \]
\[ V_{LY} = \frac{2(V_{C1} - V_0 - 6V_d)}{2} \quad \text{OFF state} \]

### Table 2: Simulation parameter and value

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>10 V</td>
</tr>
<tr>
<td>Output power</td>
<td>250 W</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>50 KHz</td>
</tr>
<tr>
<td>Duty ratio</td>
<td>70%</td>
</tr>
</tbody>
</table>

By volt second balance law for inductor \( L_X \)
\[
\frac{1}{D_T} \int_0^1 (V_{in} - 3V_d) dt + \frac{T_s}{D_T} (V_{in} - V_{C1} - 2V_d) dt = 0
\] (14)

\[ V_{C1} = \left( \frac{1}{1 - D} \right) V_{in} - \left( \frac{2 + D}{1 - D} \right) V_d \] (15)

for inductor \( L_Y \)
\[
\frac{1}{D_T} \int_0^1 (V_{C1} - 3V_d) dt - \frac{T_s}{D_T} \left( \frac{2(V_{C1} - V_0 - 6V_d)}{2} \right) dt = 0
\] (16)

\[ V_0 = \left( \frac{2}{1 - D} \right) V_{C1} - \left( \frac{2}{1 - D} \right) V_d \] (17)

From (15)
\[ V_0 = \frac{2V_{in}}{(1 - D)^2} - \frac{6V_d}{(1 - D)^2} \] (18)

If internal voltage drop is neglected then voltage conversion ratio is
\[ V_0 = \frac{2V_{in}}{(1 - D)^2} \] (19)

4) MBC_{VLSI-XY} Configuration

Steady state equations of circuit during CCM are
\[ V_{LX1} = V_{LX2} = V_{in} - 4V_d \]
\[ V_{CX} = V_{in} - 4V_d \]
\[ V_{LY1} = V_{LY2} = V_{C1} - 3V_d \]
\[ V_{CY} = V_{C1} - 3V_d \]
\[ V_{LX} = \frac{2V_{in} - V_{C1} - 7V_d}{2} \quad \text{ON state} \]
\[ V_{LY} = \frac{2V_{C1} - V_0 - 6V_d}{2} \quad \text{OFF state} \]

By volt second balance law for inductor \( L_X \)
\[
\frac{1}{D_T} \int_0^1 (V_{in} - 4V_d) dt + \frac{T_s}{D_T} \left( \frac{2V_{in} - V_{C1} - 7V_d}{2} \right) dt = 0
\] (21)

From (23)
\[ V_0 = \frac{4V_{in}}{(1 - D)^2} - \frac{10 - 4D}{(1 - D)^2} \] (26)

If internal voltage drop is neglected then voltage conversion ratio is
\[ V_0 = \frac{4V_{in}}{(1 - D)^2} \] (27)

### 4 Result and Discussion

To validates the working operation of proposed three configurations of MBC (MBC_{VLSI-XL}, MBC_{VLSI-LY}, and MBC_{VLSI-XY}), these converter are simulated in Matlab R2016a with resistive load. All three configurations are simulated at high switching frequency to reduce the components size and output waveform ripple content. The simulation parameters and their value for three configurations are tabulated in Table. 2

1) MBC_{VLSI-XL} Configuration

The proposed configuration is simulated with resistive load (197.53 Ω). Proposed converter is two stage converter which give intermediate stage voltage of 66.4 V with fluctuation of 0.45% as presented in Fig. 4(a). Proposed converter provides 221 V at the output with fluctuation of 0.09% as shown in Fig. 4(b). Fig. 4(c) shows the output current waveform with resultant amplitude of 1.112 A with fluctuation of 1.17%. From Figs. 4(b) and (c), proposed configuration work with 245.97 W power and shows efficiency of 98.38%.

2) MBC_{VLSI-LY} Configuration

The proposed configuration is simulated with resistive load (197.53 Ω). The intermediate stage voltage of proposed configuration is 33.1 V with fluctuation of 1.2% as presented in Fig. 5(a). Proposed converter gives 221.6 V at the output with fluctuation of 0.09% as shown in Fig. 5(b). The output current waveform is shown in Fig. 5(c) which shows the resultant current is 1.114 A with fluctuation of 1.5%. From Figs. 5(b) and (c), proposed configuration work with 247.41 W power and shows efficiency of 98.96%.

3) MBC_{VLSI-XY} Configuration

The proposed configuration is simulated with resistive load (788.5 Ω). The intermediate stage voltage of proposed configuration is 65.5 V with fluctuation of 0.6% as presented in Fig. 6(a). Proposed converter gives 443 V at the output with fluctuation of 0.04% as shown in Fig. 6(b). The output
current waveform is shown in Fig. 6(c) which shows the resultant current is 0.555 A with fluctuation of 0.36%. From Figs. 6(b) and (c), proposed configuration work with 245.86 W power and shows efficiency of 98.34%. Fig. 7 shows the comparative graph of voltage conversion ratio of three configuration of MBC with VLSI module and cascaded boost converter, conventional boost converter, multistage switched inductor boost converter and MBC with SI module. It shows that, MBC<sub>VLSI</sub>-XY configuration is having highest voltage conversion ratio among the MBC family, conventional and cascaded boost converter. If internal voltage drop is neglected then, MBC<sub>VLSI</sub>-XL and MBC<sub>VLSI</sub>-LY configuration have same voltage conversion ratio.

5 Conclusion

In this paper, the modified boost converter and its three configuration using VLSI module is discussed. The detail comparative analysis of proposed three converter configurations are done with existed high voltage conversion ratio. The detail mathematical analysis of proposed
configurations are carried out with and without considering the internal voltage drop. The MBC\textsubscript{VLSI-XY} configuration is having highest voltage conversion ratio as well as lower efficiency in among the other two configurations. The MBC\textsubscript{VLSI-XL} and MBC\textsubscript{VLSI-LY} configurations have same voltage conversion ratio in ideal condition and MBC\textsubscript{VLSI-XL} configurations is having lower efficiency as compared to MBC\textsubscript{VLSI-LY} configurations. The detail comparative analysis of three configurations are done with respective their voltage conversion ratio and number of components.

**References**


