Dual Output Quadratic Buck Boost Converter with Continuous Input And Output Port Current

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Abstract- This paper presents a dual output quadratic buck boost converter with continuous input and output port current. Voltage conversion ratio of the quadratic converter has a quadratic relationship in terms of the duty cycle. The input and the output port current of the traditional quadratic buck-boost converter are discontinuous, which is possible to result in increased input and output current ripples and complicate the design of the input and output filters. Hence these problems can be solved by using a quadratic buck boost converter with continuous input and output port current. Compared with the traditional buck-boost converter, the modified converter can obtain a wider range of the voltage conversion ratio with the same duty cycle. It provides two outputs for a single input both in buck and boost operation. The modified converter can provide current sharing between the loads. The input current and its output current ripple is extremely low. The simulation is done using MATLAB/Simulink R2017a software. The switching pulses for the control circuit is generated using PIC16F877A microcontroller. The prototype of dual output quadratic buck boost converter is implemented and also observed dual output voltage of 10.3V and 10.6V with a input voltage of 20V in buck mode.

IndexTerms- Quadratic buck boost Converter, Dual output, Ripple

I. Introduction

Nowadays, renewable energy systems such as fuel cell stacks and photovoltaic power systems are becoming one of the most attractive and promising sources of providing electrical energy compared to the conventional fossil-fuel energy generating sources. These renewable energy sources or systems have relatively low voltage output characteristics and demand for high step-up DC-DC converter, for any potential practical application. Power electronics circuits are usually required to convert their output power to match the load demand. In these cases, a buck-boost DC/DC converter with wide gain is required.

The buck boost converter is a DC-DC converter. The output voltage of buck boost converter is greater than or less than the input voltage. For the quadratic buck boost converter, the voltage conversion ratio M (M=Vo/Vi, where Vo is the output voltage and Vi is the input voltage) of the PWM DC-DC converters is defined as a function of the duty cycle of the switch. Traditional buck boost converter is formed by cascading two traditional buck-boost converters [8].

High step up/step down voltage gain can be obtained by using a transformer less buck boost converter [4]. Even though its construction is simple, it produces naturally discontinuous input and output current. Two synchronously operating switches are responsible for their discontinuous in input and output waveforms.

The soft switching can be obtained by introducing two resonant networks [6]. The switches used are not subjected to high switch voltage or current stresses and, consequently, present low conduction losses. But it consists of more number of components than other configurations. So these limitation is solved by using single switch quadratic buck boost converter [1]. As the name suggests, it consists of only one switch and control circuit is simpler one.

For many applications, well-regulated power supplies with multiple outputs are needed [7]. In the modern world fields such as industries, telecommunication, LED drivers, dc based nano grid etc. require multiple output because of the auxiliary circuits present in those system other than main circuit. So that the researches on single...
input multiple output DC-DC converters are going on in order to get a less bulky system, more reliable control strategy and less cross regulation etc. [3].

In this paper, dual output quadratic buck boost converter with continuous input and output port current is proposed. It uses only one switch. The ripples present in output current and output voltage are lower than the proposed structures in existing literature. The modified converter has wide range of voltage conversion ratio with same duty cycle.

II. QUADRATIC BUCK BOOST CONVERTER

The circuit diagram of quadratic buck boost converter is shown in fig.1. The boost converter consists of input source \( V_g \), diodes \( D_1 \) and \( D_2 \), inductor \( L_1 \), capacitor \( C_1 \), and switch \( S \). The buckboost converter consists of capacitors \( C_1 \) and \( C_2 \), inductor \( L_2 \), diode \( D_3 \), and switch \( S \). The buck converter consists of capacitors \( C_2 \), \( C_3 \) and \( C_4 \), diodes \( D_4 \), \( D_5 \), \( D_6 \) and \( D_7 \), inductor \( L_3 \), switch \( S \), and load \( R \). It can be seen that the output capacitor of the boost converter is the input source of the buck-boost converter while the output of the buck-boost converter is the input source of the buck converter.

![Figure 1. Proposed dual output quadratic buck boost converter](image)

III. OPERATING PRINCIPLE

When the duty ratio is below 50%, the converter act as buck and when the duty ratio is above 50%, the converter act as boost converter. The working of the circuit can be explained by two modes of operation.

![Figure 2. Theoretical waveforms of the Converter.](image)

Mode 1: In this mode switch \( S \) is conducting, diodes \( D_3 \), \( D_5 \), and \( D_7 \) are in ON state, and diodes \( D_1 \), \( D_4 \), and \( D_6 \) are reverse-biased by \( V_{C1} \), \( V_{C1} + V_{C2} \), and \( V_{C2} \) respectively. The input source \( V_g \) delivers power to the inductor \( L_1 \) through the diode \( D_1 \) and the switch \( S \), meantime, the energy stored in capacitors \( C_1 \) and \( C_2 \) is being released to inductors \( L_2 \) and \( L_3 \), respectively. Therefore, the currents flow through inductors \( L_1 \), \( L_2 \), and \( L_3 \), i.e., \( i_{L1} \), \( i_{L2} \), and \( i_{L3} \) are increasing.
Mode 2: In this mode, the switch S is turned OFF, diodes D₁, D₃, D₅, D₆, and D₇ are in ON state, and diodes D₂ and D₄ are reverse-biased by VₓC₂ and VₓC₁, respectively, in this operating mode. The energy stored in the inductor L₁ as well as the input source is delivered to the capacitor C₁, and the capacitor C₁ starts to store energy. The inductor L₂ discharges energy to the capacitor C₂ through the diode D₃. At the same time, the inductor L₃ discharges energy to the capacitor C₃, C₄ and load R. Therefore, iₓL₁, iₓL₂, and iₓL₃ are decreasing.

IV. DESIGN OF COMPONENTS

In this converter an input voltage of 20V and output voltage of 45V are used. The switching frequency is 40kHz. Duty ratio of 60% is chosen. Two load resistances are used, in which each having value of 100 Ω.

The current ripples of the inductors, namely, ΔiₓL₁=3A, ΔiₓL₂=1.875A, and ΔiₓL₃=0.25A. Therefore, the inductance of the inductors L₁, L₂, and L₃ can be obtained as

\[
L₁ = \frac{(1-D)^2 V₀}{D \Delta iₓL₁ F} = 100 \ \mu H
\]  
(1)

\[
L₂ = \frac{(1-D) V₀}{D \Delta iₓL₂ F} = 400 \ \mu H
\]  
(2)

\[
L₃ = \frac{(1-D) V₀}{D \Delta iₓL₃ F} = 3 mH
\]  
(3)

The voltage ripples of the capacitors of the converter, namely, ΔVₓC₁=3.5V, ΔVₓC₂=2.5V, and ΔVₓC₃=0.008V. The capacitors are designed to control the voltage ripples of the capacitors, which can affect the stability of the converter, to an acceptable extent.
\[ C_1 = \frac{D^2 I_0}{(1-D) \Delta V_{C_1} F_S} = 47 \mu F \]  
\[ C_2 = \frac{D I_0}{\Delta V_{C_2} F_S} = 47 \mu F \]  
\[ C_3, C_4 = \frac{(1-D) I_0}{\Delta V_{C_3} F_S} = 220 \mu F \]

V. SIMULATION PARAMETERS

The simulation parameters used for the modified dual output quadratic buck boost converter are shown in the following table:

<table>
<thead>
<tr>
<th>Components</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>20V</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>64V (boost)</td>
</tr>
<tr>
<td>Load Resistance</td>
<td>100 ( \Omega )</td>
</tr>
<tr>
<td>Inductors</td>
<td>( L_1 = 100 \mu H )</td>
</tr>
<tr>
<td></td>
<td>( L_2 = 400 \mu H )</td>
</tr>
<tr>
<td></td>
<td>( L_3 = 3 ) mH</td>
</tr>
<tr>
<td>Capacitors</td>
<td>( C_1 = 47 \mu F )</td>
</tr>
<tr>
<td></td>
<td>( C_2 = 47 \mu F )</td>
</tr>
<tr>
<td></td>
<td>( C_3 = C_4 = 220 \mu F )</td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>40KHz</td>
</tr>
</tbody>
</table>

VI. SIMULATION RESULTS

The modified converter is simulated in MATLAB/SIMULINK R2014 with an input of 20V.

\[ V_{gs} \]

\[ V_{ds}(V) \]

**Figure 5.** (a) Gate Pulse (b) Voltage Stress across switch in boost mode

The voltage stress across switch is shown in fig.5. The maximum switching stress across the switch is 157V for an input voltage of 20V in boost mode of operation.
**Figure 6.** Current through inductor (a) $L_1$ (b) $L_2$ (c) $L_3$ Voltage across capacitor (d) $C_1$ (e) $C_2$ (f) $C_3$ in boost mode

Fig. 6 shows current through inductors. The current flow through the switch is approximately equal to the sum of the three inductor currents when the switch is turned ON.

**Figure 7.** (a)Input voltage (b) and(c) Output voltages in boost mode

Fig. 7 shows output voltages of quadratic buck boost converter. The output voltage is 64.01V for an input voltage of 20V. The ripple in the output voltage is less than 1% that is ripple is very small in output voltage.

**Figure 8.** (a) Input current (b) and(c) Output current in boost mode

Fig. 8 shows the input and output current in the boost mode of operation. The output current obtained is 0.64A.
The drain-source voltage of the switch is approximately equal to the sum of the voltages across the capacitors $C_1$ and $C_2$. Fig. 9 shows drain source voltage of the switch is 90.8V.

Fig. 10 shows current through inductors. The current flow through the switch is approximately equal to the sum of the three inductor currents when the switch is turned ON.

Fig. 11 shows output voltage of quadratic buck boost converter. The output voltage is 16.51V for an input voltage of 20V. The ripple obtained in the output voltage is less than 1%.

Fig. 12 shows the input and output current in the buck mode. The output current obtained is 0.165A.
VII. PERFORMANCE ANALYSIS

For analysis of the converter, it is assumed that all the components are ideal and the system is under steady state.

![Figure 13. Efficiency versus duty ratio](image)

**Figure 13. Efficiency versus duty ratio**

Fig.13 gives the plot showing variation of efficiency versus duty ratio for an input voltage of 20V with a load of 100 ohm. It is observed that better efficiency is obtained for duty ratio in the range of 35% to 65%.

![Figure 14. Gain versus duty ratio and voltage stress versus duty ratio](image)

**Figure 14. (a)Gain versus duty ratio (b) voltage stress versus duty ratio**

Fig.14 gives the plot showing variation of gain versus duty ratio and voltage stress across switch versus duty ratio. The modified converter has wide range of voltage conversion ratio with same duty cycle. The voltage across switch is increases with increases in duty ratio.

VIII. EXPERIMENTAL SETUP AND RESULTS

For the purpose of hardware implementation, a prototype is designed and the hardware is implemented with an input of 20V, output 12V and frequency of 10 kHz.

<table>
<thead>
<tr>
<th>TABLE II: COMPONENTS USED FOR PROTOTYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Components</strong></td>
</tr>
</tbody>
</table>
| Inductors | L<sub>1</sub> = 620 µH  
L<sub>2</sub> = 2.2mH  
L<sub>3</sub> = 2mH |
| Capacitor | C<sub>1</sub> = 22µF  
C<sub>2</sub> = 8.2µF  
C<sub>3</sub> = C<sub>4</sub> = 5.6µF |
| Diode | IN5819 |
| Controller | PIC16F877A |
| MOSFET | IRF540 |
| Driver IC | TLP250 |
The power supply consists of a step down transformer, full bridge diode rectifier, filter capacitor and a regulator IC (7812). IRF540 MOSFET is used as the switches. TLP250 driver is used to drive the MOSFET. To generate the switching signal PIC16F8771A was programmed in the laboratory and necessary waveforms were obtained. The switches are working in 10kHz frequency and have duty ratio of 39%.

Figure 14. Experimental setup

Figure 15. Switching pulses

Figure 16. Output Voltage (a) V1=10.3V (b) V2=10.6V
IX. Conclusion

Dual output quadratic buck boost converter offers a wide range of conversion ratio, low switch voltage stress, and uniform current sharing. The modified converter can operate more efficiently in step-up mode than in step-down mode. The efficiency of the modified quadratic buck boost converter increases with increase in duty cycle. Also ripples present in the output voltage is less than 1%. The best operating duty ratio for the converter is 35% - 65%. The modified converter is capable of delivering continuous output port current. The prototype of dual output quadratic buck boost converter with input voltage of 20V is built. The dual output voltages are obtained as 10.3V and 10.6V in buck mode. The proposed converter finds its application in battery chargers.

REFERENCES


