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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 theswitch. 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.

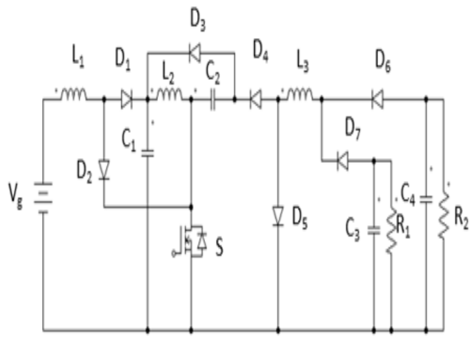

Figure 1. Proposed dual output quadratic buck boost converter

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.

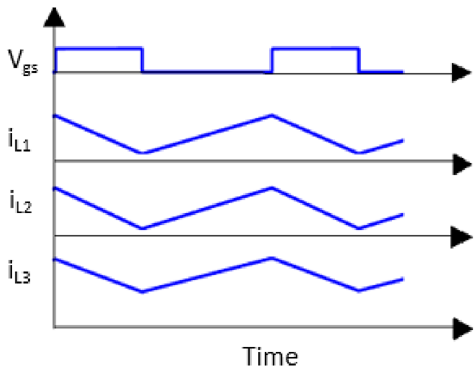

Figure 2. Theoretical waveforms of the Converter.

Mode 1: In this mode switch S is conducting, diodes D_2, D_4, D_6, and D_7 are in ON state, and diodes D_1, D_3, and D_5 are reverse-biased by V_{C1}, V_{C1} + V_{C2}, and V_{C2} respectively. The input source Vg 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.

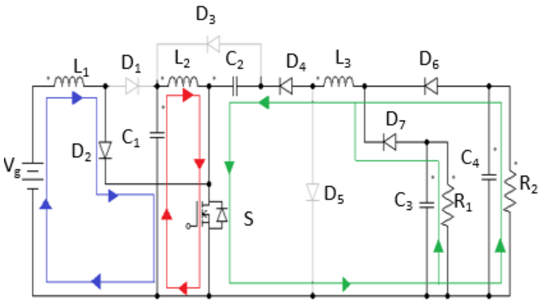

Figure 3. Mode 1 Operation

Mode 2: In this mode, the switch S is turned OFF,diodes D_1, D_3, D_5, D_6, and D_7 are in ON state, and diodes D_2 and D_4 are reverse-biased by V_{C2} and V_{C1}, respectively, in this operating mode. The energy stored in the inductor L_1 as well as the input source is delivered to the capacitor C_1, and the capacitor C_1 starts to store energy. The inductor L_2 discharges energy to the capacitor C_2 through the diode D_3. At the same time, the inductor L_3 discharges energy to the capacitor $C_{3,}$ C_4 and load R. Therefore, i_{L1}, i_{L2}, and i_{L3} are decreasing.

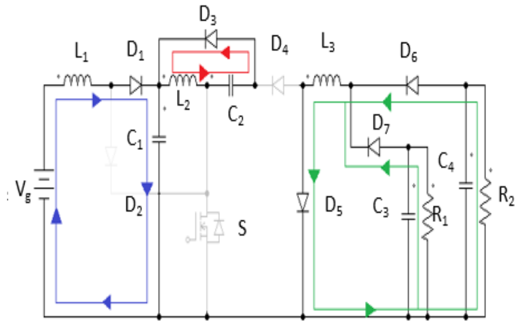

Figure 4. Mode 2 Operation

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, Δi_{L1}=3A, Δi_{L2}=1.875A,and Δi_{L3}=0.25A.Therefore, the inductance of the inductorsL_1,L_2andL_3 can be obtained as

$$L_1 = \frac{(1-D)^2 * V_O}{D * \Delta i_{L1} * F_S} = 100\ \mu H \qquad (1)$$

$$L_2 = \frac{(1-D) * V_O}{D * \Delta i_{L2} * F_S} = 400\ \mu H \qquad (2)$$

$$L_3 = \frac{(1-D) * V_O}{D * \Delta i_{L3} * F_S} = 3mH \qquad (3)$$

The voltage ripples of the capacitors of the converter, namely, Δv_{C1}=3.5V, Δv_{C2}=2.5V, andΔv_{C3}=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.

$$C_1 = \frac{D^2 * I_O}{(1-D) * \Delta V_{C1} * F_S} = 47\ \mu F \qquad (4)$$

$$C_2 = \frac{D * I_O}{\Delta V_{C2} * F_S} = 47\ \mu F \qquad (5)$$

$$C_3, C_4 = \frac{(1-D) * V_O}{8 * L_3 * \Delta V_{C3} * F_S} = 220\ \mu F \qquad (6)$$

V. SIMULATION PARAMETERS

Thesimulation parameters used for the modified dual output quadratic buck boost converter are shown in

TABLEI:SIMULATION PARAMETERS

Components	Rating
Input Voltage	20V
Output Voltage	64V(boost)
	16V(buck)
Load Resistance	100 Ω
Inductors	L_1=100µH
	L_2=400 µH
	L_3=3mH
Capacitors	C_1=47µF
	C_2=47µF
	C_3= C_4=220 µF
Switching Frequency	40KHz

VI. SIMULATION RESULTS

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

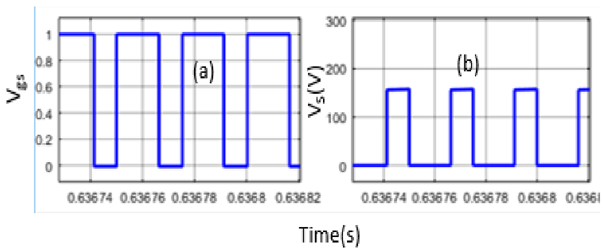

Figure 5. (a) Gate Pulse (b) Voltage Stress across switchin boost mode

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.

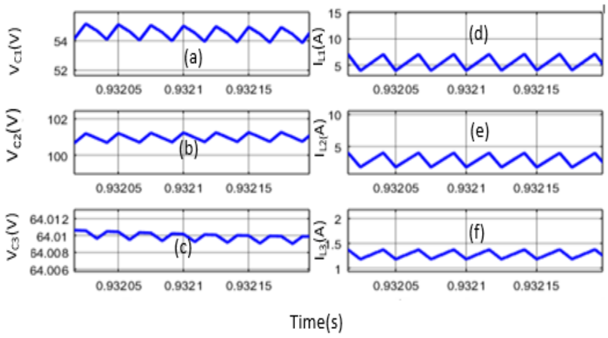

Figure 6. Current through inductor (a) L_1 (b) L_2 (c) L_3Voltage across capacitor (d) C_1 (e) C_2 (f) C_3 in boost mode

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.

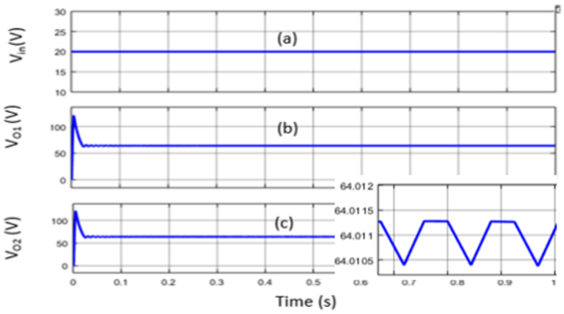

Figure 7. (a)Input voltage (b) and(c) Output voltages in boost mode

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.

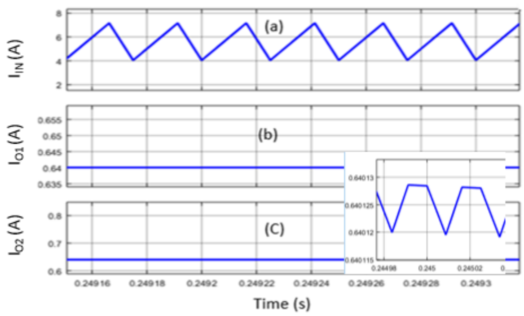

Figure 8. (a) Input current (b) and(c) Output current in boost mode

Fig. 8 shows the input and output current in the boost mode of operation. The output current obtained is 0.64A.

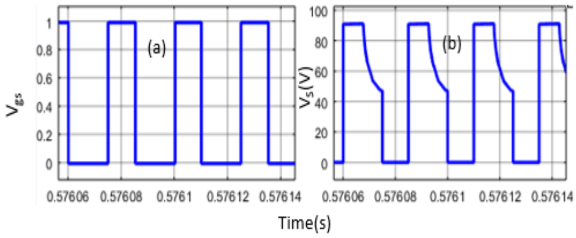

Figure 9. (a)Gate Pulse (b) Voltage Stress across switch in buck mode

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.

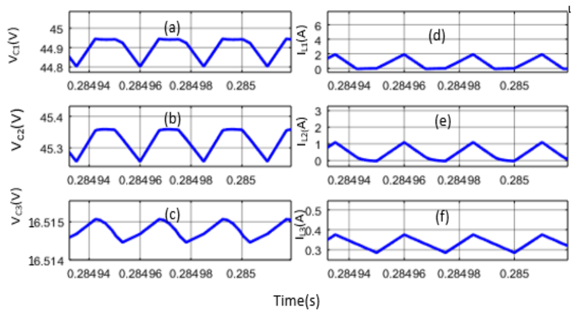

Figure 10. Current through inductor(a) L_1 (b) L_2 (c) L_3 Voltage across capacitor (d) C_1 (e) C_2 (f) C_3 in buck mode

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.

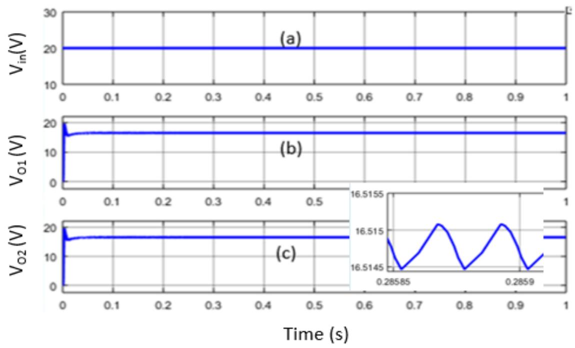

Figure 11. (a) Input voltage(b) and(c) Output voltage in buck mode

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%.

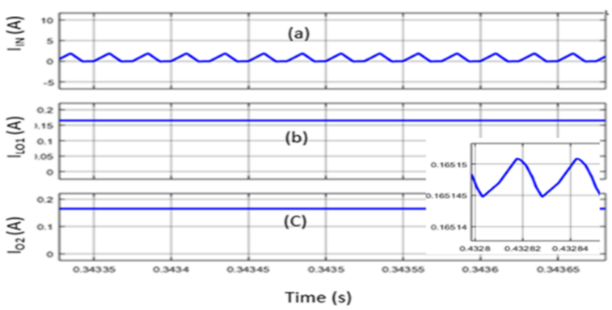

Figure 12. (a) Input current (b) and(c) Output current in buck mode

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.

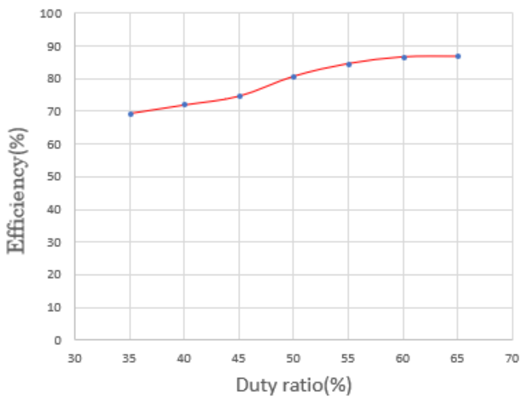

Figure 13. Efficiency versus duty ratio

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%.

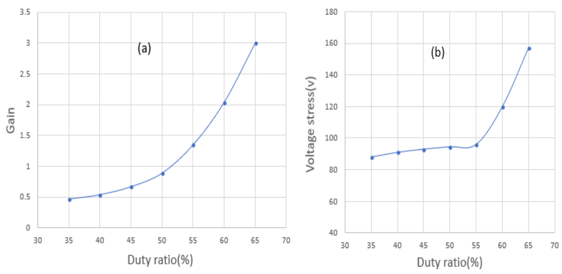

Figure 13. (a)Gain versus duty ratio (b) voltage stress versus duty ratio

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 II:COMPONENTS USED FOR PROTOTYPE

Components	Rating
Inductors	L_1= 620 µH L_2= 2.2mH L_3=2mH
Capacitor	C_1 =22µF C_2 =8.2µF C_3=C_4=5.6µF
Diode	IN5819
Controller	PIC16F877A
MOSFET	IRF540
Driver IC	TLP250

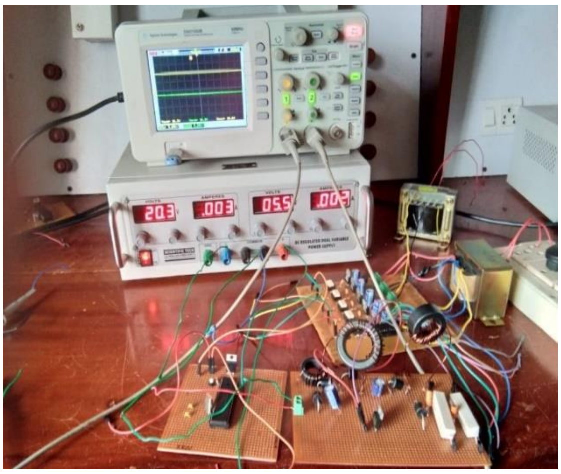

Figure 14. Experimental setup

The power supply consists of a step down transformer, full bridge diode rectifier, filtercapacitor 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. TheSwitchesareworkingin10kHzfrequencyandhave adutyratioof 39%.

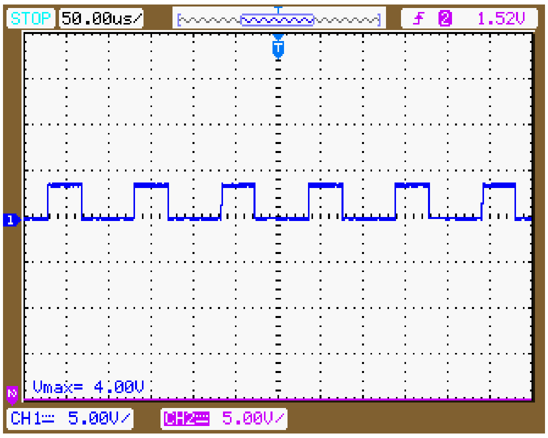

Figure 15. Switching pulses

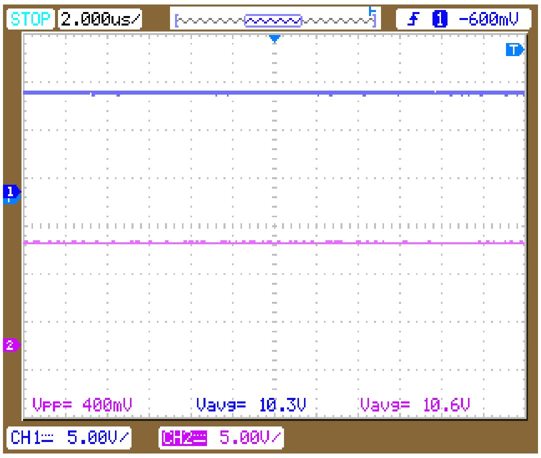

Figure 16. Output Voltage(a) V_1=10.3V (b)V_2=10.6V

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 themodified quadratic buck boost converter is 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.

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