A SINGLE SWITCH QUADRATIC BUCK-BOOST CONVERTER WITH WIDE-RANGE OF VOLTAGE CONVERSION

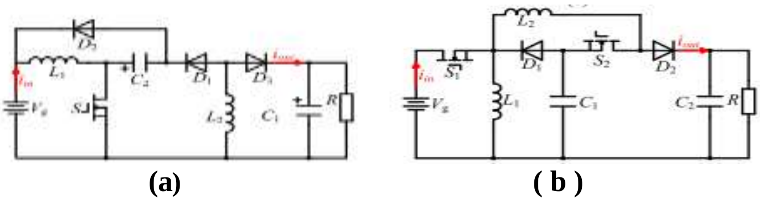
NOORAIN SABHA, MAHADEVI S.N
M.Tech Student, Professor
PDA College of Engineering, Kalaburagi 585102

Abstract—In this paper, a new type of quadratic buck boost converter is proposed with wide range of voltage conversion ratio. It is the combination of the traditional boost, buck and buck-boost converter with single switch. It also operates at continuous input and output port currents and results in reduction o size of input and output filters and also reduction of cost. Due to its continuous nature of output current, it can be used in several industrial applications. A performance comparison study is made with different types of controllers such as PI for closed loop analysis.

Key words—**continuous current, quadratic buck-boost converter, high voltage conversion ratio, linear controllers**

I. INTRODUCTION

Renewable sources of Energy such as solar, wind power generation, etc., are extensively used to increase efficiency, depletion of conventional energy sources and reducing manufacturing cost. As the input voltage of the sources will vary according to the weather changes, dc-dc converters along with control circuits are used to maintain the output voltage. As the i/p voltage variation can be larger range, we need to vary the duty ratio accordingly. The quadratic converters have wide range of voltage conversion as slight variation in duty ratio causes large variation in the output voltage. Several topologies of the quadratic converters are introduced. A cascaded quadratic buck-boost converter is designed by cascading two conventional buck-boost converter. As the input current is equal to the inductor current which operates under discontinuous conduction modes same as output current due to switching operation. Hence the filter design is expensive and large in size due to higher ripple currents. A transformer-less quadratic buck-boost converter is proposed which consists of two switches and still operating on discontinuous mode. The dc-dc converters are mainly used to process the input voltage to generate the required output voltage. Also it is used for bus regulation, noise isolation, etc., The switched mode dc –dc converters are used to convert the dc voltage levels simply by switching pulses. The output voltage level can be maintained as per the reference given with varying input voltage levels. Voltage control loop and current control loop with P, PI and PID controllers are the most commonly used control circuits. The main advantage of these controllers is that they can be tuned to get enough performance over steady state and transient conditions. PI controller based nonlinear control circuit was designed to eliminate the steady state error. As the PI controllers are slow to adapt the transient changes, other types of controllers such as PID, fuzzy or neural network control algorithms can be used to increase the performance of the controllers.



(a) (b)

Fig. 1 Quadratic Buck-Boost converter topologies

This paper proposes a new quadratic converter for buck-boost operations, which constitutes of one conventional boost converter, one buck converter, and buck–boost converter with only single switch. It has a larger voltage conversion ratio compared to the conventional buck–boost converter. The proposed converter operates with continuous output port current and also continuous input port current, which leads to the simplicity of the design of output and input filters. Also a voltage control loop based on PI controller is designed and the performance of the controller is compared.

II. PROPOSED SINGLE SWITCH QUADRATIC BUCK-BOOST CONVERTER

The circuit diagram for the proposed converter is provided below:

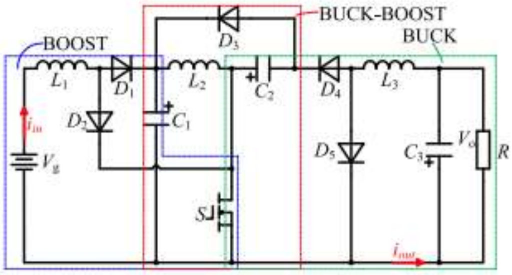


Fig. 2 Proposed Quadratic Buck-Boost converter

In the converter shown in above circuit, a combination of buck converter, buck-boost converter and boost converter with only single switch, which resulted in relatively simple circuit structure. The buck converter comprises of C2 and C3, D4 and D5, L3, S, and a load. The boost converter is a combination of input voltage source, inductor, two diodes, capacitor, and a switch. The buck-boost converter is provided by the combination of C1 and C2, L2, D3, and S. The input of the buck converter is from the output of the buck-boost converter whereas the input of the buck-boost converter is from the output of the boost converter whose input is from the voltage source. An inductor is coupled to the input port and an inductor is coupled to the output port of the converter, which can provide input and output port current as continuous which is shown below:

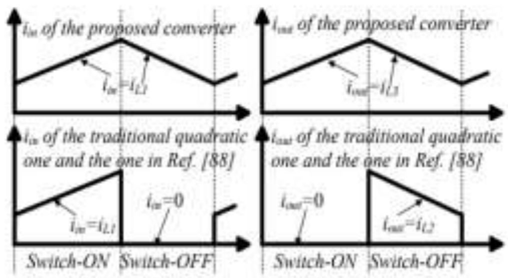


Fig. 3 Input and output port current waveforms for conventional and proposed quadratic converters

The following assumptions are made to reduce any complexity in analyzing the operation of the proposed converter, which is provided as follows, 1) All components used are ideal components; 2) All capacitor's voltage is assumed to be constant for one switching cycle. The proposed converter works in both discontinuous current mode and continuous current mode. But the continuous current mode is preferred in several industrial applications to minimize the ripple current and operates in continuous output and input current which is an advantage to the proposed converter, the continuous current mode is studied in this paper. As per the assumptions made, the converter operates in two modes, i.e., when S is turned ON (mode 1) and when S is turned OFF (mode 2), for each single switching cycle.

The operation of the proposed converter is provided in the key waveforms which aregiven below:

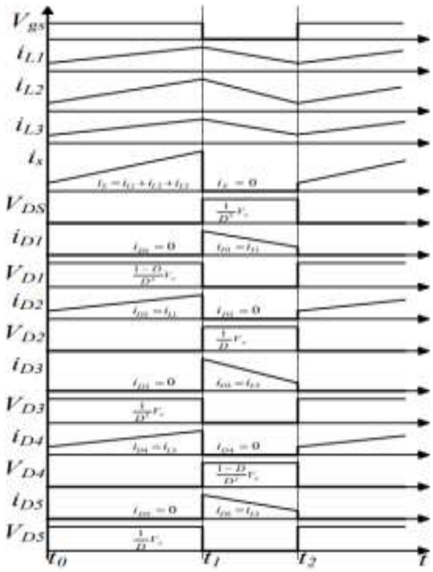


Fig. 4 Key waveforms for the proposed Quadratic Buck-Boost converter.

Mode 1:

In mode1, the switch S is ON, diodes D_2 and D_4 are conducting, and diodes D_1, D_3, and D_5 are in reverse bias. The voltage source charges the inductor L1and the inductor current passes through diode D1 and switch S, and at the same time, the capacitors C1 and C2 is discharged to energize the inductors L2 and L3.

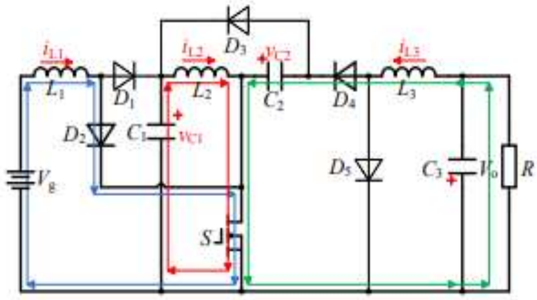


Fig. 5. Equivalent circuit of proposed converter for Mode 1

Mode 2:

In Mode 2, the switch S is OFF, diodes D1, D3 and D5 are conducting and diodes D2 and D4 are in reverse bias. The inductor L1 is discharged along with input voltage source and charges the capacitor C1. The inductor L2 discharges to charge the capacitor C2 through diode D3. In the meantime, the inductor L3 discharges and provide power supply to the capacitor C3 and load R.

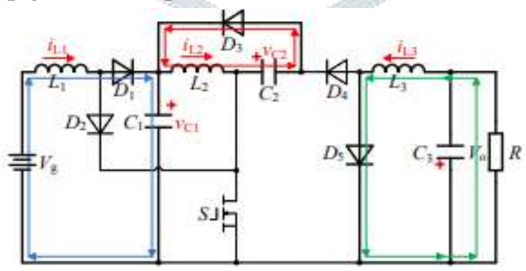


Fig.6. Equivalent circuit of proposed converter for Mode 2

III. FORMULATION OF CLOSED LOOP CONTROL

For open loop, we have provided constant duty ratio and if the input voltage is varied, the load voltage also get varied. To prevent this the closed loop control circuits are designed in which we can regulate the load voltage.

The widely used controller for the closed loop was PI controller in which we can tune the Proportional and Integral gains to get required output voltage.

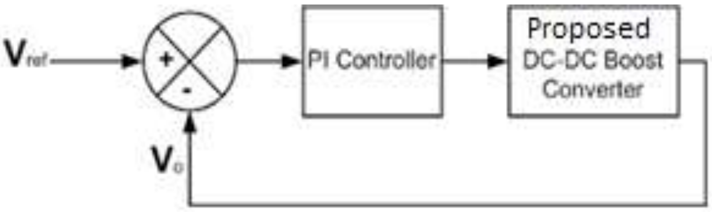


Fig.7. PI control based closed loop circuit

According to the above circuit, the reference voltage gets compared with measured load voltage and the generated error is provided to PI controller which generates duty ratio accordingly to minimize the error.

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IV. DESIGN AND ANALYSIS OF THE PROPOSED CONVERTER

The equation for duty ratio, D is given below:

$$\frac{D}{1-D} = \sqrt{\frac{V_O}{V_{IN}}}$$

The inductor values can be calculated with the following equations:

$$L_1 = \frac{(1-D)^4 * R_L}{2 * D^3 * F_S}$$

$$L_2 = \frac{(1-D)^2 * R_L}{2 * D^2 * F_S}$$

$$L_3 = \frac{(1-D) * R_L}{2 * F_S}$$

The capacitor voltages can be calculated by the following equations:

$$V_{c1} = \frac{1}{1-D} * V_g$$

$$V_{c2} = \frac{D}{(1-D)^2} * V_g$$

$$V_{c3} = V_o$$

The capacitor values can be calculated with the following equation:

$$C_1 = \frac{I_o * D^2}{(1-D) * \Delta V_{c1} * F_S}$$

$$C_2 = \frac{I_o * D}{\Delta V_{c2} * F_S}$$

$$C_3 = \frac{V_o * (1-D)}{8 * L_3 * \Delta V_{c3} * {F_S}^2}$$

V. SIMULATION RESULTS AND DISCUSSION

The parameters used in the design of simulation circuit are given in the following table:

Table 1: Simulation parameters of the proposed converter

Parameters	Values
Input voltage	20V
Resistive load	96Ω
Load voltage	41V
Switching Frequency	40kHz

The simulation circuit is drawn in the MATLAB/Simulink model for open loop and closed loop of the proposed converter. The Simulink model proposed converter is shown in fig 8.

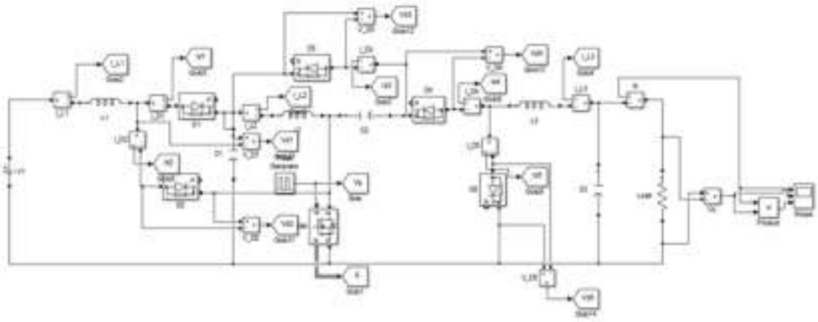

Fig.8. Simulink circuit diagram for proposed converter

The key waveforms of the proposed converter are given in the following graphs:

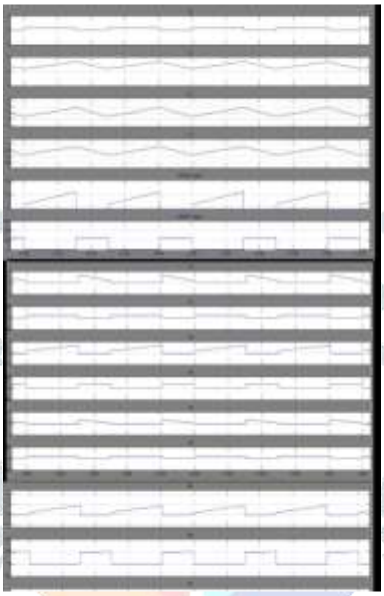

Fig.9. Key waveforms of the proposed converter

The load voltage and current waveforms for proposed converter is shown in fig.10.

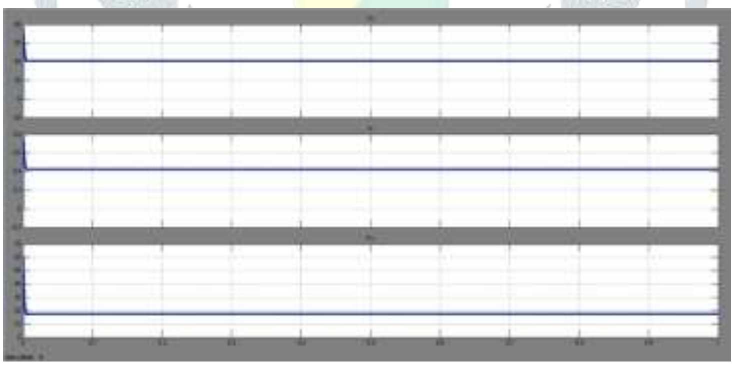

Fig.10. Load voltage and current for proposed converter

The proposed converter simulation circuit with PI controller based closed loop is shown in fig.11.

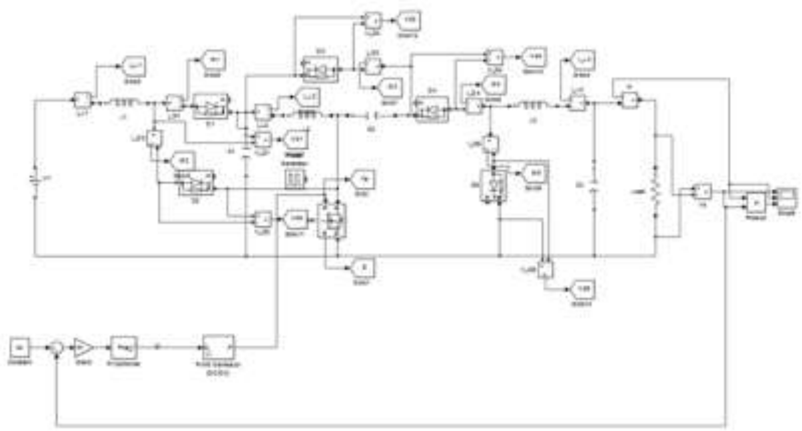

Fig.11. Proposed converter with PI control technique

The load voltage and current waveforms for proposed converter with PI controller is shown in fig.12.

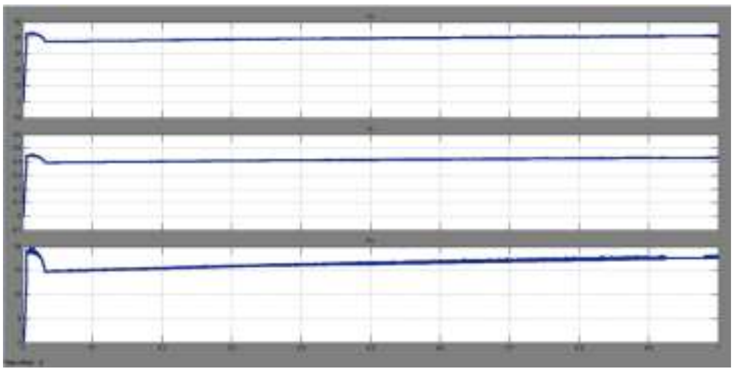

Fig. 12. Load voltage and current for proposed converter with PI control technique

The parameters used in the design of simulation circuit are given in the following table:

Table 1: Simulation parameters of the proposed converter

Parameters	Values
Input voltage	12V
Resistive load	5kΩ
Load voltage	48V
Switching Frequency	37kHz

The input voltage is 12V, switching frequency of 37KHz and R load of 5kΩ we get the load voltage as 48V.

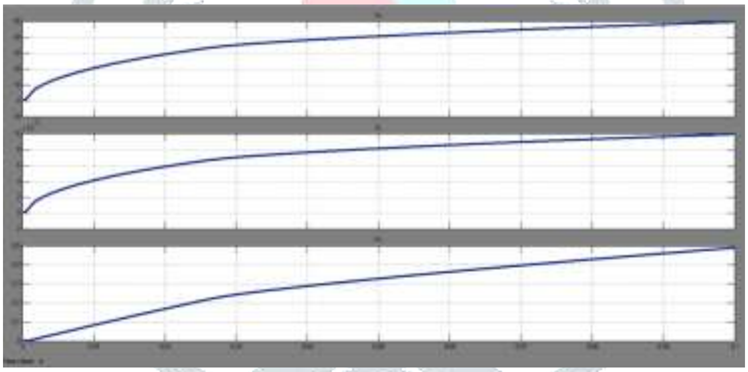

Fig.14.Load voltage and current for proposed converter.

VI. HARDWARE SETUP AND RESULTS

The hardware circuit arrangement is provided below in the following figure:

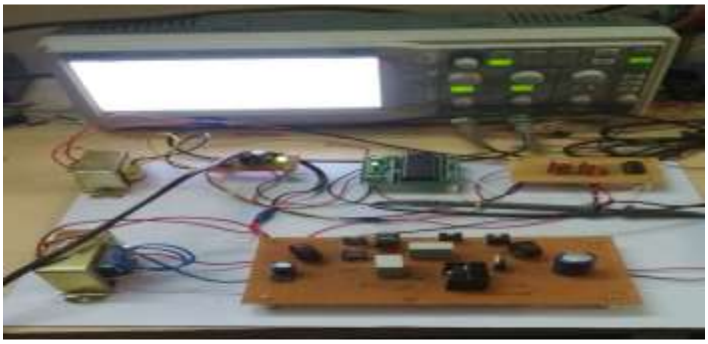

Fig.13. Hardware circuit setup

The input voltage is 12V, switching frequency of 37kHz, IRF250N is used as switch and Diodes U1560 used as diodes respectively.

The pulses are generated from PIC16F877A microcontroller which is given in fig.13.

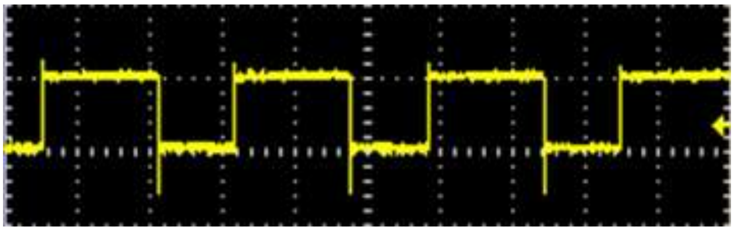

Fig 13. Gate Pulses Generated from PIC16F877A microcontroller

The load voltage of the proposed single switch quadratic converter is as follows:

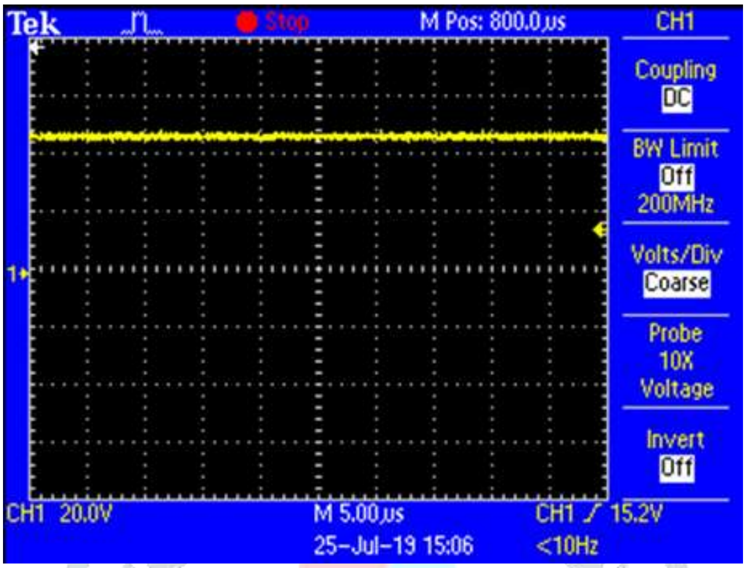

Fig .14. Load voltage

The load voltage for the input voltage of 12V is 44V.

VII. CONCLUSIONS

A new type of quadratic buck boost converter is proposed with wide range of voltage conversion ratio. It also operated at continuous input and output port currents and the size of input and output filters is minimized and also cost is reduced. In this, a closed loop with PI controller is introduced in order to maintain constant load voltage under the varying input conditions. The design of the proposed converter is simulated under open loop and closed loop conditions and the results are obtained and compared with conventional system design.

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